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(6) ASSESSMENT OF SELECTED LIGHTER-THAN-AIR VEHICLES FOR MISSION TASKS OF THE U.S. COAST GUARD.

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BY

(10) RALPH E. BEATTY, JR. STUDY DIRECTOR

RICHARD D. LINNEL

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DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD

MAILING ADDRESS:
U.S. COAST GUARD (G-DSA-3/TP44)
WASHINGTON, D.C. 20590
PHONE: 202-426-1050

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1. This report is forwarded to the technical community in the interest of providing further information on:

a. flight vehicles which achieve some or all their sustention from buoyant lift, and

b. the utility of those vehicles for Coast Guard missions.

2. Readers and, in particular, users of the data and conclusions contained herein are advised that the U.S. Coast Guard does not concur with numerous elements of this analysis. Consequently, no endorsement or acceptance of the authors' conclusions concerning the applicability of lighter-than-air type vehicles for Coast Guard missions should be implied. Enclosure (1) addresses items which form the basis for nonconcurrence.

3. The contents of this report reflect the views of the Center-for-Naval Analyses, University of Rochester, Arlington, Virginia, who are responsible for the facts and accuracy of the data presented herein. The report's contents do not reflect official views or policies of the Coast Guard. This report does not constitute a standard, a specification, or a regulation.

4. This study effort was performed for the U.S. Coast Guard Office of Research and Development, Safety and Advanced Technology Division, under a grant from the Department of Transportation, Office of Assistant Secretary for Systems Development and Technology.

J. S. GRACEY
Chief of Staff

Encl: (1) Coast Guard Review - CNA Study 1078

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Subject: Comments on CNA Study 1078

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Coast Guard Review of CNA Study 1078

I. Introduction: During the course of this study the Coast Guard provided general and specific comments on areas of concern. Not all areas of concern were resolved. The purpose of this review is to identify these concerns, provide the rationale, and forward the information to the technical community.

II. Summary: The subject study should not be used to judge the worth of LTA vehicles for Coast Guard missions because of the following: (1) discrepancies in cost accounting between vehicles: (2) over-estimation of LTA vehicle maintenance costs; (3) under-estimation of the costs of the hydrofoil and possibly other vehicles; (4) use of a task rather than a mission profile approach; and (5) comparison on a per-vehicle basis rather than a mission effectiveness basis.

III. General Review Comments:

(A) By employing a single task approach rather than using scenarios or equivalent missions, the relative ranking of the various vehicles is rendered highly questionable. The optimization criteria for non-rigid ellipsoidal LTA vehicles used by the authors (single task mission, landing gear/tail fin configuration) do not assure that their recommended designs are optimum for Coast Guard - type missions.

(B) The authors rely heavily on data which is considered not applicable to LTA vehicles of modern design. A primary source of cost data used by the authors is an extended U.S. Navy operation in the late 1950's. Serious relevancy problems exist in employing that data.

ENCLOSURE(1)

The vehicles employed had reciprocating engines, complex and unreliable transmissions and shafting, cotton envelopes and vacuum tube electronics. That situation differs considerably from the reliability and serviceability aspects of currently available avionics, propulsion equipment, and structural materials.

(c) The, operating crew, maintenance personnel, and spare parts costs do not appear to be consistent in computation or allowance among the vehicles.

(d) Although required as a primary part of this effort, the authors did not include hybrid vehicles in the study. Whether or not hybrid craft have utility for Coast Guard missions remains unresolved.

(e) The conclusions of the subject study and the 1976 CNA Annual Report are not considered consistent with the data and statements contained in the report.

IV. Specific Review Comments:

The rationale for the General Review Comments is prescribed below.

A. Analytical Techniques

(1) The various vehicle concepts were compared for a series of independent tasks instead of for typical mission profiles. This makes it impossible to draw firm conclusions about relative mission effectiveness unless one vehicle demonstrates a clear superiority in all tasks, which was not the case and the conceptual LTA vehicle designs to be optimized to criteria other than the proper one, namely, total mission cost effectiveness.

(2) For a mission that consists of a single task, the authors technique is acceptable. Accounting for transit costs, as is done in Section V of the report, is equivalent to determining the backup factor for on-station platforms. However, when missions are not comprised of a single task, the relative cost-effectiveness of the various platforms will change. There is no analysis of mixed task missions in the cost-effectiveness sections of the report.

(3) Mixed task missions require scenario definition to identify the types of tasks and their duration. Based on the results presented in the report, any scenario with a mixed task requirement should show the LTA vehicle as the most cost-effective platform. To test this assumption an arbitrary scenario was selected for a brief analysis. For this analysis a mixed mission was chosen in which a specified area is searched, and, upon detection, the target is trailed for 5 hours. The mean time for detection, was calculated, and 5 hours for trail was added to it to determine the total time of operation. These times were multiplied by the authors' hourly rate to obtain the total mission cost. Zero range-to-station for the search phase was assumed. It was also assumed that the target had a medium radar cross section. Search areas of 10,000 square nautical miles and 40,000 square nautical miles were used. These correspond to a 100 by 100 nmi and 200 by 200 nmi areas, respectively. Transit time was not considered. When multiple platforms are required there is a transit cost involved which would increase the effective cost of using more than one platform. Table I gives the results of this hypothetical mixed mission analysis for three platforms; the

TABLE I MIXED TASK MISSION

SEARCH FOR MEAN DETECTION TIME

TRAIL 5 HRS – 0 RANGE TO STATION – MEDIUM TARGET

	TOTAL HRS OF OPERATION		TOTAL COST ($)	
	10,000 NMI^2	40,000 NMI^2	10,000 NMI^2	40,000 NMI^2
LTA1 (8)	6.52	11.06	4662	7908
MRS	5.87*	8.48*	6938	10023
FLAGSTAFF II	10.79	29.15*	5976	16322

* Require more than 1 craft, transit cost of extra vehicle not included

LTA1(8), the MRS aircraft, and the Flagstaff II hydrofoil. The LTA1 (8) has the lowest cost of the three platforms in performing both of these missions. The difference in operating cost of the Flagstaff II for patrol tasks and trail tasks has been accounted for. It should be noted that for both missions more than one MRS is required, and for the 40,000 nmi^2 mission more than one Flagstaff II would be required. A more complete analysis would include those transit costs as well. While this is an arbitrary scenario similar results should be obtained for other mixed task scenarios.

(4) The method of vehicle evaluation had the effect of ignoring the airship's greatest natural attribute for surveillance and patrol missions - i.e., its ability to provide in a single vehicle both a high speed dash capability compared to surface ships and long endurance at low speeds compared to airplanes. This is the result of the relatively low penalties involved with designing for a high speed capability, provided the high speed is used sparingly. Thus, although LTA vehicles cannot compete equally with airplanes in high speed tasks nor with surface ships for stationkeeping operations, it appears that LTA vehicles of modern design are strong competitors in missions which require combinations of these attributes. Whether or not such combinations are desirable for Coast Guard applications remains to be established.

(5) The LTA vehicle role is best suited for long-endurance missions compared to helicopters and fixed wing aircraft while airplanes are superior in the speed-dominated patrol tasks. In trail/observation tasks, however, LTA vehicles can fill an important gap. Comparing data for a 60 knot/2000 n.m./14 crew member LTA vehicles (page J-75), as

one example against the primary competition in Trial tasks, namely the Flagstaff and WMEC-210, the following is apparent from Tables V-8 and V-9: For ranges less than 200 nautical miles, the Flagstaff is more cost effective when endurance from 36 to 51 hours is sufficient. For endurance of 2 to 4 days, an LTA vehicle is probably the most cost-effective (slightly better than WMEC). For endurance greater than 4 days, the ships and LTA vehicles are competitive.

For ranges greater than 2000 nautical miles, the cross-over for Hours/$1000 occurs at approximately 350 n.m. between the LTA and Flagstaff; however LTA vehicle endurance is 3 to 6 time greater. Beyond 350 n.m., LTA vehicles are clearly superior to other candidates for endurance up to 5 or 6 days and possibly longer. Flagstaff has virtually no capability beyond 473 n.m. (hullborne mode means slow response, reduced effectiveness, and limited time on station).

Several general observations are as follows: a mission crew of 14 can probably be substantially reduced for LTA vehicles for trail tasks which would result in a greatly improved cost-effectiveness; LTA vehicles should be optimized for station-keeping, not speed-dominated patrol tasks, and should be compared primarily with hydrofoils and small surface craft, not fixed wing aircraft (LTA should compliment fixed wing, not compete for the same roles); and with increase in coastal jurisdiction activities, long range surveillance/search/recovery capabilities implies station radii in excess of 200 n.m. are of interest.

(6) Analysis was done to optimize the fuel utilization to maximize the fraction of time on station to the total mission time. This analysis

ignores the fact as the fuel utilization is improved, the endurance of a mission increases, thereby forcing an increase in crew and size of the LTA vehicle required to fulfill the mission. The cost-effectiveness in performing the tasks is thereby decreased. A better approach is to look at the total cost-effectiveness including crew size factors. If the optimal fraction of time-on-station is calculated within the constraint that the mission cannot exceed the endurance of the specified crew size, the overall cost effectiveness would be improved. If the analysis of the LTA vehicles considered the endurance factors in both the initial design of the family of LTA vehicles and in the analysis of the optimal utilization of the LTA vehicles, the cost-effectiveness of the LTA vehicles would increase.

(7) The rationale for selecting sustained speed equal to endurance speed (Vol. I, page II-15, paragraph 2) is not explained. LTA vehicles maximize their time on station by loitering at slow speeds (30 knot range); however, they operate at cruise or dash speeds to reach station as the mission demands. No previously designed LTA vehicles have loitered at their dash speed, nor does this feature appear to offer any advantages.

(8) There is concern about the algorithms used to derive and size the LTA vehicles used in this study. Table 3 on page 35 of Vol. III attempts to compare fixed wing aircraft with LTA vehicles, both a non-rigid and a rigid. While these types of air vehicles cannot be compared on an equal basis due to their speed and endurance mismatch, the data presented causes concern. The CNA LTA vehicle design model computes an LTA vehicle with a gross weight of 1,870,000 pounds and

TABLE II. Rigid Airship Comparison

	CNA "Dirigible"	MM-836[1]	GAC-11.2[2]
Speed (kt)	100	80	100
Range (n.m.)	5000	14,400	12,000
Altitude (ft)	4000	10,000	10,000
Crew	3	35[3]	36[3]
Passengers	374	533[4]	363[4]
Takeoff Weight (lb.)	1,870,000	414,251	482,100
Volume (cu. ft.)	24,400,000	9,320,000	11,200,000
Length (ft.)	1,061	783	832
Diamenter (ft.)	212	164	160
Power (h.p.)	22,660	5,140	13,017
Fuel (weight (lb.))	514,000	102,200	147,000[5]
Empty Weight (lb.)	625,000	179,400	269,060

1/ This vehicle was designed for the ANVCE Project (1977)

2/ This vehicle was designed for the LTA Project Office (NADC, Code 6096) (1977)

3/ The majority of this compliment are sensor and weapons operators.

4/ Military payload capacity divided by 200 lbs/passenger.

5/ Includes oil and consumables.

The MM-836 is 62 percent smaller than the CNA "Dirigible", can carry 43 percent more passengers, and transport them nearly three times farther.

volume of 24,400,000 cubic feet to transport the same number of passengers as a Boeing 747. Table II presents specifications for this CNA "Dirigible" compared with two recent rigid LTA vehicle point designs prepared for the Navy. Note that the CNA model produces an LTA vehicle 2-3 times larger.

(9) Specification of the LTA buoyant lift-to-total lift ratio (β) was based on landing gear/tailfin geometry. This is an important design parameter affecting overall transport efficiency and mission parameters including vehicle size and cruise speed. Since landing gear design is relatively unimportant, β should be selected on the basis of mission effectiveness and not constrained by an arbitrary landing gear design. Recent LTA vehicle studies for NASA and the Navy address thrust vectoring for landing, takeoff and hovering operations. The impact of this capability on LTA vehicle design and cost for Coast Guard applications was not addressed.

(b) <u>Data</u>

(1) Performance, cost and powerplant data appear to be extrapolations from 1940's and 50's. While historical problems such as ground handling are mentioned, no recommendations or assumptions for technology improvements are examined. In this particular instance, a precision hover capability seems well worth exploring. All NASA and Navy LTA studies have assumed that a hover capability is required.

(2) The capability for boarding is within the state-of-the-art, but this was not considered by the authors.

(3) Too much reliance was placed on the use of Kevlar as an envelope

material. The impression is given that if Kevlar cannot be used, the prospects for efficient LTA vehicle designs are very slim. Recent experience suggests that this material needs further development to be an acceptable material for LTA vehicle use. However, the weight and cost penalties for using polyester instead of Kevlar as stated in the report are not consistent with Navy and NASA studies.

(4) The authors discuss using existing, occupied, original LTA facilities for servicing and constructing new LTA vehicles. However, about half of the conceptual LTA vehicle designs presented in the report should be compatible with many of the facilities which are currently used to service and construct jumbo jets. LTA vehicles of configurations other than ellipsoidal could be compatible with the very numerous facilities designed for smaller aircraft.

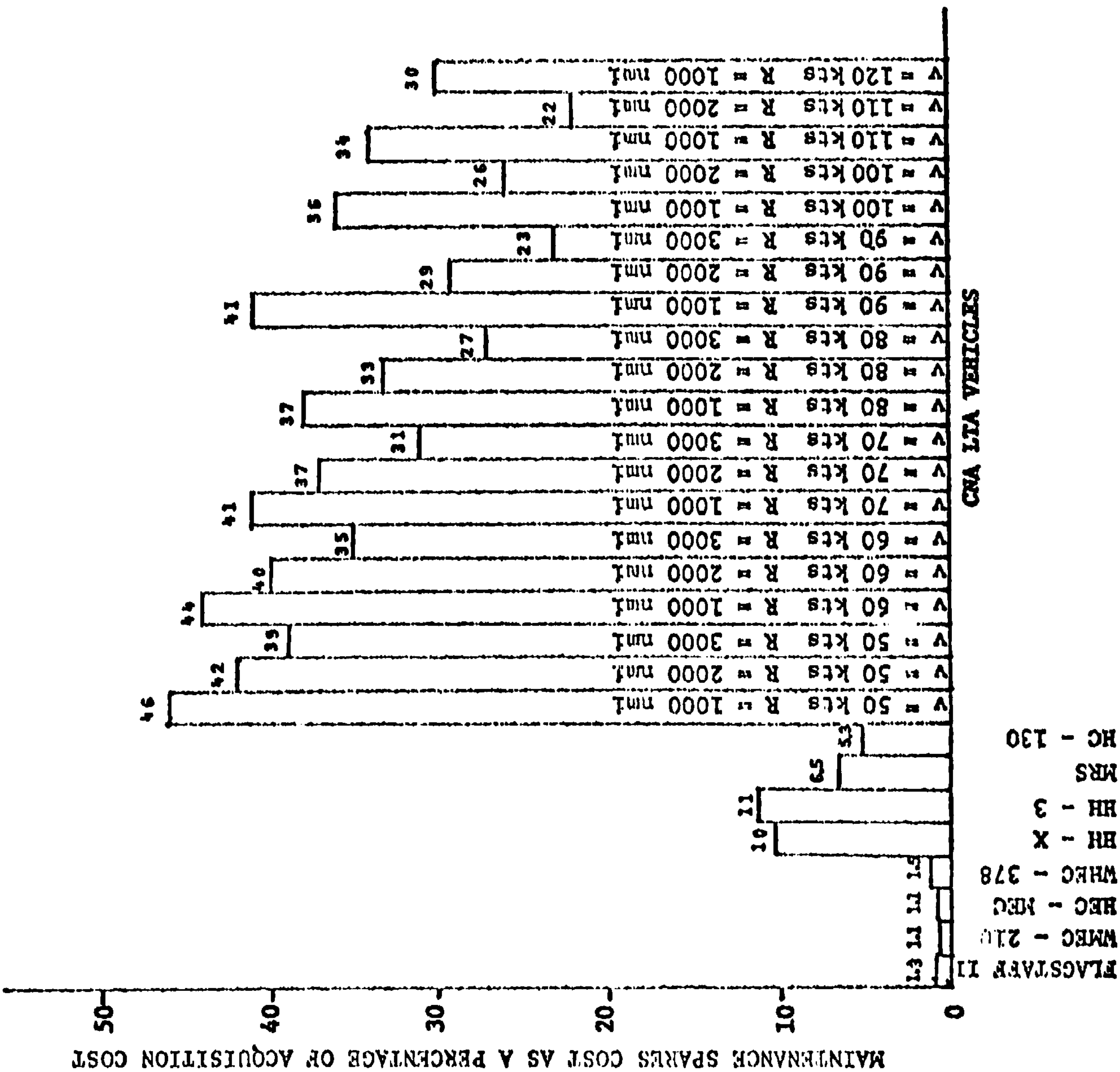
(5) The analysis of LTA vehicle cost was heavily dependent on Goodyear data. The LTA vehicle design computer program presented synthesizes a size from the performance parameters, using the calculated weight to define all engineering and most vehicle costs on the basis of a linear cost/weight relationships. Historically, this has been the commonly used approach for various items including Aircraft, Avionics and Engines. This approach is far too simplistic since state-of-art, size (scale) relationships and other performance-related parameters are not considered. However, as a first cut approach, especially at top level, the results obtained are generally adequate. A summary of this approach with the resulting cost figures is presented on Page II-5 of Vol. I. These are stated as:

$70/# incremental cost of the prototype
$200/# for engineering
$170/# for the 1st unit cost
for quantity analysis, an 85% learning curve was assumed.

As stated previously, this approach appears reasonable at a high level. However, this relationship cannot be linear for all sizes and weights; the cost per unit of weight would tend to decrease for increasingly higher weights. The authors apparently assumed only one prototype; thus, no method is provided to establish the cost of additional prototypes. Additionally, a factor of $200/pound for engineering cost is low. However, the report is not clear on the total content of the engineering effort. If that item contains only the design/drafting/analysis manpower for engineering, some additional funding will be required for documentation, ILS analysis, etc., which are a part of all similar programs.

(C) Costs

(1) The maintenance costs for the LTA vehicles are dramatically higher than they are for any other vehicle on an hourly basis than are those of any other vehicle, including the airplanes. For example, in round numbers the maintenance costs used in the study for the C-130, the hydrofoil, and the LTA vehicle design considered previously are $500/hr, $70/hr, and $675/hr. The data sources for LTA vehicle maintenance costs are stated to be U.S. Navy blimp operations in 1957-1959 for routine maintenance spare parts and Navy operations and Goodyear commercial blimp operations for maintenance labor. Use of this data should be questioned for two reasons. First, it gives costs which are much higher than has been experienced in similar operations.


MAINTENANCE SPARES COST AS A PERCENTAGE OF ACQUISITION COST
0
10
20
30
40
50
FLAGSTAFF II
WMEC - 210
HEC - MEC
WHEC - 378
HH - X
HH - 3
MRS
HC - 130
CNA LTA VEHICLES
V = 50 kts R = 1000 nmi
V = 50 kts R = 2000 nmi
V = 50 kts R = 3000 nmi
V = 60 kts R = 1000 nmi
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46
42
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44
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35
41
37
31
37
33
27
41
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36
26
34
22
30

Figure 1

Second, it is based on out-moded state-of-the-art in propulsion, avionics, and other systems; there have been dramatic improvements in the maintenance requirements of such systems since the 1950's. The Goodyear commerical operation data is particularly inappropriate for this study because it pertains to highly specialized operations which are not related to Coast Guard or Navy missions.

(2) The cost of maintenance spares is based on a single data point relevant to 1957 technology. The 1957 cost for maintenance spares of $150/hr was increased to $350 to reflect inflation factors up to 1976. This approach ignores the improved reliability of modern equipment. Vacuum tubes have been replaced with solid state electronics and reciprocating engines replaced with turbine engines. A more realistic approach is to estimate maintenance spares based on the component parts, e.g., engine, power train, avionics and airframe. Most of this equipment, or equivalent equipment, exists on other modern vehicles. A comparison of maintenance spares cost with the acquisition cost gives a strong indication that the authors' costs are out of line. Figure 1 shows the percentage of the acquisition cost associated with the yearly maintenance spares costs for the LTA vehicles and the other platforms analyzed in the study. For the LTA vehicles presented, the maintenance spares cost is from 22 to 46 percent of the acquisition cost. This is equivalent to the purchase cost of a new LTA vehicle every two to four years, and does not include the maintenance labor cost. For the competing vehicles the highest percentage is 11.4, associated with the H-3 helicopter, which is considered to have a severe operating environment, with a

TABLE 11 MAINTENANCE MANHOURS PER FLIGHT HOUR

		UTILIZATION RATE					
		1500 HR/YR			3000 HR/YR		
SPEED (KTS)	RANGE (NMI)	VEHICLE MMH/FLTH	PAYLOAD MMH/FLTH	TOTAL MMH/FLTH	VEHICLE MMH/FLTH	PAYLOAD MMH/FLTH	TOTAL MMH/FL
50	1000	7	6	13	5.0	4.5	9.5
50	2000	9	6	15	6.5	4.5	11.0
50	3000	10	6	16	7.5	4.5	12.0
60	1000	7	6	13	5.5	4.5	10.0
60	2000	9	6	15	7.0	4.5	11.5
60	3000	10	6	16	9.0	4.5	13.5
70	1000	7	6	13	5.5	4.5	10.0
70	2000	10	6	16	7.5	4.5	12.0
70	3000	14	6	20	10.5	4.5	15.0
80	1000	8	6	14	6.0	4.5	10.5
80	2000	11	6	17	8.5	4.5	13.0
80	3000	17	6	23	12.5	4.5	17.0
90	1000	7	6	13	5.0	4.5	9.5
90	2000	13	6	19	10.0	4.5	14.5
90	3000	20	6	26	15.0	4.5	19.5
100	1000	7	6	13	5.5	4.5	10.0
100	2000	25	6	31	11.5	4.5	16.0
110	1000	8	6	14	6.0	4.5	10.5
110	2000	18	6	24	13.5	4.5	18.0
120	1000	8	6	14	6.0	4.5	10.5

subsequent high demand for maintenance spares. The cost of spare parts for the hydrofoil vehicle, FLAGSTAFF II, is only $46,000 per year, or a factor of 50 lower than for the LTA vehicle. This difference is unreasonable since hydrofoils are relatively complex mechanically and are considered to be high-maintenance vehicles. Goodyear currently spends a total of $225,000 per year on maintenance spares for four advertising blimps or $56,000 per LTA vehicle. Compared to the CNA estimate of $562,000 per year for maintenance spares cost per 319,000 cubic foot LTA vehicle, Goodyear's actual expenditure is 1/10 the CNA estimate. Although the Goodyear airships have a much less sophisticated payload, the CNA figures appear unrealistic.

(3) Maintenance personnel costs are also questionable. Based on a 1500 hour man-year, Table II shows that it takes from 5-25 maintenance man-hours per flight hour for vehicle maintenance, and another 4 1/2 - 6 maintenance man-hours per flight hour for payload maintenance. Based on Navy maintenance statistics it takes about 6 maintenance man-hours per flight hour to maintain the SH-3A helicopter. This includes engine, radar and airframe maintenance. Again, comparison with equivalent equipment on other vehicles would give a more realistic estimate of manpower requirements. Maintenance requirements for the payload of the airship should be equivalent to those of other aircraft.

(4) There is an inconsistency in determining the size of the operating crew for the various vehicles. In sizing the crew for the LTA vehicles it is assumed that one air crew is required for missions of 12 hours or less endurance, 1 1/2 crews are required for missions of 12 to 36 hours endurance and 2 crews for missions of greater than 36

hours. In costing the Flagstaff II (hydrofoil) a total crew (operating and maintenance) of 14 is specified for operations of 23 hours endurance. This is a rather low personnel estimate for 1 1/2 crews. For trail and presence missions where the Flagstaff II is assumed to have a 61 and 125 hour endurance, respectively, no change is made in personnel costs, i.e., the crew size is not increased. It is also not indicated if the Flagstaff II is designed to have the housekeeping capacity for an expanded crew. The study states that the Flagstaff II is the most cost effective platform for the endurance tasks. Increases in the crew requirements would reduce its cost-effectiveness.

(5) Using standard, accepted comparative cost accounting procedures, the primary economic figure of merit is vehicle direct operating cost (DOC) per hour of operation. However, a rather unconventional cost accounting for DOC was used by the authors. This leads to an erroneous assessment of the relative magnitudes of the cost elements and causes serious errors when comparing costs between different vehicles. The DOC cost accounting as used in the study is as follows for the 100 knot, 2000 mile range design at a utilization of 3000 hrs/yr, based on Table III-II of the report:

Investment		$200		
Personnel (54 people)		500		
Air Crew (22)			250	
Flight Crew (12)				150
Payload Maintenance (10)				100
Ground (32)		250		
Vehicle Maintenance (23)			175	
Payload Maintenance (9)			75	
Maintenance	500			
Routine Materials		450		
Overhaul, Labor, Materials				
Fuel	150			
	$1350/hr			

This cost breakdown implies that cost are dominated by personnel and maintenance costs. This conclusion, however, is erroneous and is a consequence of the cost allocation. Contrary to the procedure used by the authors, it is standard practice to put vehicle maintenance labor costs under the maintenance element and to omit payload-related maintenance costs from DOC. This is done because it is presumed that payload-related costs are the same for all vehicles and hence do not enter into a vehicle comparative analysis. By definition, DOC consists of all costs which are vehicle-related and only such costs. Thus, a more conventional and informative allocation of DOC is as follows for the same LTA vehicle conceptual design:

Investment	200	
Personnel (flight crew)	150	
Maintenance	675	
Routine Materials		450
Overhaul, Labor, Materials		50
Fuel	150	
	$1175/hr	

It would, of course, be satisfactory to include payload-related costs provided they were included for all vehicles on a consistent, equivalent basis. However, there are indications that this was not done. For example, personnel costs for the FLAGSTAFF II are given as $150/hr in Table III-20 which cannot possibly include "flight" crew, onboard and ashore payload maintenance personnel, and vehicle maintenance personnel.

(6) The revised cost breakdown presented in the last item makes it clear that the LTA vehicle DOC's as estimated in the subject study are dominated by maintenance costs, particularly routine maintenance. In most cases, maintenance costs are well over 50% of the total. The maintenance costs estimated for LTA vehicles are considerably higher than for any other vehicle.

(7) The authors assigned one full maintenance crew to each LTA vehicle. However, in a fleet or squadron operation one maintenance crew should be able to service several vehicles.

(8) It is proposed, as an alternate method of costing maintenance spares and personnel requirements, that a value of 10% of the acquisition cost be used as the maintenance spares cost per year, and that the ground crew requirements be reduced by a factor of 3; in other words, one ground crew maintains three LTA vehicles. Revised hourly costs for the LTA vehicles, based on these assumptions, are given in Table III. Using these revised costs, Table IV compares the ratio of the cost effectiveness of the MRS aircraft and the Flagstaff II hydrofoil to the LTA vehicle LTA1 for the primary tasks investigated in the study.

TABLE III REVISED HOURLY COST FIGURES

MAINTENANCE SPARES COST 10% OF ACQUISITION COST

1 GROUND CREW FOR EVERY 3 LTA

SPEED (KTS)	RANGE (NMI)	PERSONNEL ($/HR)	MAINTENANCE ($/HR)	FUEL ($/HR)	INVESTMENT ($/HR)	TOTAL ($/HR)	OLD TOTAL ($/HR)
50	1000	274	41	9	41	365	634
50	2000	432	60	12	60	474	810
50	3000	348	78	15	78	519	909
60	1000	277	45	16	45	383	659
60	2000	287	66	21	66	440	777
60	3000	358	104	29	104	595	1030
70	1000	277	51	25	51	404	688
70	2000	290	83	36	83	492	860
70	3000	367	144	52	144	707	1201
80	1000	280	58	38	58	434	722
80	2000	296	106	59	106	567	971
80	3000	380	208	93	208	889	1454
90	1000	216	48	46	48	358	621
90	2000	306	142	94	142	684	1129
90	3000	338	305	161	305	1109	1741
100	1000	219	56	64	56	395	663
100	2000	316	197	152	197	862	1358
110	1000	222	66	88	66	442	715
110	2000	329	286	247	286	1148	1706
120	1000	222	79	120	79	500	784

TABLE IV TASK COST EFFECTIVENESS COMPARISONS

TASK	CNA EFFECTIVENESS PER UNIT COST		EFFECTIVENESS PER UNIT REVISED COST	
	MRS/LTA1	FLAGSTAFF II/LTA1	MRS/LTA1	FLAGSTAFF II/LTA1
TRANSIT	2.06	.54	1.21	.32
GROSS SURVEILLANCE				
MEDIUM TARGET	1.05	.31	.62	.19
SMALL TARGET	.83	.25	.49	.15
INVESTIGATE DISPERSED TARGETS				
NO INVESTIGATION DELAY	1.27	.53	.75	.31
INVESTIGATION DELAY LOW DENSITY	1.19	.53	.70	.31
INVESTIGATION DELAY HIGH DENSITY	.88	.65	.52	.38
TRAIL	.69	1.85	.40	1.07
PRESENCE	.69	1.60	.40	.93

In all cases the cost-effectiveness of the LTA vehicle improves, and in most cases it becomes significantly more cost effective than the other two platforms. This demonstrates that the overall sensitivity of the study's results to these cost is very significant.

(9) Helium costs and reprocessing may require less effort and expense than previously anticipated. Vast quantities of helium (tens of millions of cubic feet) are presently being discharged daily into the atmosphere. Thus, a low cost alternative to re-purification of lifting helium for LTA's might be treating the gas as a consumable and replacing it periodically.

(d) Operations

(1) In Appendix I, "Wind Effects and Statistical Data", the data presented here is clearly in great detail, yet there is no obvious evidence that this data was used at all in the remainder of the report. The authors are in error when they state in Appendix I that wind has little effect on surface vessel speed. The speed of advance and transport efficiency of all interface vehicles can be seriously degraded by interaction with wind - generated waves. Slamming, deck wetness, and broaching limits are frequently encountered prior to any serious habitability limits. What is important is the relative effect of the environment on the competing vehicles' performance capabilities. The authors penalized the operational effectiveness of the LTA vehicles in their analysis by imposing wind factors. The report does not show that similar enviromental penalties were applied to other vehicles.

(2) The presence task discussed in Vol. I, Page IV-3 could benefit from the size/altitude/unique identity characteristics of LTA vehicles. In presence or deterrence roles the Coast Guard craft must be seen and recognized. An LTA vehicle at 2000 feet would be recognizable visually to surface craft over perhaps ten times as many square miles when compared to a Coast Guard cutter. Another clarification to be made regarding this role of presence (as a deterrent) concerns the statement made in paragraph 3 on page IV-24 of Vol. I. It is stated that "For purposes of analysis, we assume (as did the Hydrofoil Study) that each vehicle exerts the same amount of deterrence".
It is more credible to account for the fact that a vehicle must be seen and recognized to be of deterrent value. The size of the vehicle should, therefore, be a factor for consideration.

(3) Also in the deterrence role cruise speed in lieu of endurance speed should be considered. The exposure of the "presence" vehicle would be higher for higher loiter speeds. An LTA vehicle at 30 to 40 knots would be more efficient than any of the other vehicles. The measure of effectiveness would be a function of cost per hour, cruise speed, and "visibility" area, or the cost to maintain a given area under surveillance. In reference to Table IV-8, "Cost Effectiveness of Vehicles Conducting Investigations of Dispersed Targets-Low Density" on page IV-16, another measure of effectiveness should be the number of targets/hours on station multiplied by the time on station.

(e) Energy

(1) The energy consumption analysis of Section VII suffer, from the

lack of a meaningful basis of comparison. The comparison is on a vehicle basis rather than on a mission effectiveness basis. The relevant parameter should be energy consumption to do a given job, regardless of the number or size of vehicles required. For example, helicopters are identified as the most energy efficient for several tasks, simply because of their small size. No account is made of the fact that the helicopter's payload capacity is several times less than that of some of the other vehicles.

(2) The energy analysis conflicts with the data from a previous CNA study "Hydrofoils for the Fisheries Law Enforcement Mission of the U.S. Coast Guard" Vol. I. Chap. 5. That study showed the FLAGSTAFF II consuming more fuel than the WMEC for equivalent patrol coverage. This conflict is apparently related to the difference in comparing single task missions to multitask missions.

(f) Conclusions

(1) While ellipsoidal vehicles (non-rigids) were considered to operate as much as 53 percent heavy, the first study objective (Vol. I, p. I1) to examine "hybrid vehicles of various characteristics", such as high aspect ratios (deltoids), was not met. On pages II-2, 5 and 6 of Vol. I, hybrid LTA vehicles are described and discounted on the basis that they "require considerable development, complicating comparison with other vehicles". NASA reports provide data on several specific hybrid designs.

(2) Even with the methods and assumptions which were employed in the study regarding LTA vehicle costs, the report shows that LTA vehicles

are competitive with other candidate vehicles for most tasks.

(3) The study does not make any strong recommendations about the future development of lighter-than-air vehicles for Coast Guard missions. It does imply, in the conclusions, that there are better platforms for the same operations that have less technological risk associated with their development. This conflicts with the statement on page II-6 Vol. I which states "blimp technology is developed to about the level of the technology of alternative Coast Guard vehicles". The CNA Annual Report, however, does make a much stronger negative statement about the use of the LTA vehicles for Coast Guard operations. The authors' rejection of LTA vehicles on the basis of technological risk is unfounded in the light of the low relative acquisition cost. Assuming that unanticipated technological difficulties can be overcome by additional research and development funding and that in overcoming those difficulties a cost overrun of 100%, occurs, the vehicle total hourly cost will be increased by less than 10% for most LTA vehicle designs. Therefore, while technological risk may exist, it should not impact nearly as significantly the cost-effectiveness of LTA vehicles compared to the other platforms.

V. Acknowledgement: The U.S. Coast Guard wishes to acknowledge the sizeable contributions to this review effort by the Lighter-than-air Project Office, Naval Air Development Center, and by Dr. Mark Ardema and Mr. Michael Harper of NASA's Ames Research Center's V/STOL Aircraft Technology Division and Mr. Norman Mayer of NASA Headquarters.

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16. Abstract

This study examines the role of lighter-than-air (LTA) vehicles in performing several United States Coast Guard missions including Enforcement of Laws and Treaties, Marine Environmental Protection, and Search and Rescue. Reconnaissance tasks required for surveillance of the 200-mile coastal economic zones are emphasized.

Before assessing how well LTA vehicles performed these missions, basic lighter-than-air craft needed to be designed. The study develops a conceptual design model to estimate the characteristics of a family of modern airships with varing range and speed. All the LTAs considered are semibuoyant hybrids that use aerodynamic lift to increase fuel capacity. The effect of different design features (such as envelope material, engine type, and design altitude) are also investigated.

The family of LTAs is compared with existing and proposed Coast Guard vehicles that were previously examined in the CNA study (no. 1061) of hydrofoils for the Fisheries Law Enforcement mission of the U.S. Coast Guard. The comparisons, based on cost and effectiveness in patrol tasks, are made by evaluating miles and square miles on station per dollar. For trail tasks, the measure used to compare vehicles is hours on station per dollar. Some comparison of how efficiently vehicles consumed fuel is also made.

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LIST OF FIGURES (Cont'd)

I. INTRODUCTION

This study examines the suitability and desirability of using lighter-than-air (LTA) vehicles for the performance of Coast Guard missions. A family of modern airships is designed, costed, and optimized. Cost/effectiveness comparisons are made with other vehicles on the basis of task and mission capabilities. Vehicles are also compared on an energy efficiency basis.

BACKGROUND

An LTA interagency workshop held at Monterey, California in fall 1974 is evidence of recent strong interest in the potential of lighter-than-air vehicles (reference 9). Under NASA-NAVY-DOT-FAA sponsorship, Goodyear Aerospace Corporation and Boeing Vertol Company conducted Phase I LTA technology studies, which were reported in references 7 and 1, respectively. Goodyear has conducted additional work on a Phase II study that has been reported in reference 8 and also in "Aviation Week" (21 June 1976). The U.S. Navy is continuing to investigate LTA concepts in a study of advanced naval vehicle concepts.

The increased interest in LTA vehicles was motivated largely by the energy crisis and by the possibility of using modern LTA transport vehicles to reduce fuel consumption. Another impetus was the interest in use of tethered or remotely piloted high altitude vehicles as surveillance or communications relay platforms. The availability of new polymer materials (such as Kevlar, used in tires) with high strength-to-weight ratios was also a factor in stimulating interest in the potential of new LTA vehicles.

Coast Guard interest in advanced vehicles has been increased by the impending need for surveillance of the contiguous fishing zone to 200 miles from U.S. shores.

In 1972 the Center for Naval Analyses performed a study (reference 3) for the Coast Guard on the application of high performance water craft in 3 different missions. That study found a large potential benefit (taking cost into account) in using hydrofoil vehicles for the fisheries law enforcement (ELT) mission. In 1974 the Center for Naval Analyses conducted a more intensive investigation (reference 4) of hydrofoils for the Coast Guard. A summary of that study, referred to as the "Hydrofoil Study," is presented in appendix B of this study.

STUDY OBJECTIVES

The work statement (reference 5) listed the following objectives:

- To compare lighter-than-air vehicles including hybrids of various characteristics with the Coast Guard's existing vehicles from the standpoint of cost and effectiveness for various employment concepts.

- To determine preferred characteristics for lighter-than-air vehicles for each of the various roles and missions to be analyzed.
- To compare the energy consumption of the hypothetical lighter-than-air vehicles with improved conventional craft.
- Where applicable, to include comparisons between lighter-than-air vehicles and other advanced platforms that CNA has previously studied, such as hydrofoils and air cushion vehicles.

STUDY CONTENT AND SCOPE

The study required effort in the following areas:

- Operations Analysis - Determining how and how well the various competing vehicles perform various functions. The missions analyzed included:
  - Enforcement of Laws and Treaties (ELT)
  - Marine Environmental Protection (MEP)
  - Search and Rescue (SAR)
  - Short-Range Aids to Navigation (AN)
- Technical Design - Determining gross characteristics of several lighter-than-air vehicles for Coast Guard applications in order to obtain desired operational characteristics and to make translating these characteristics to costs possible.
- Cost Analysis - Determining and comparing the investment and operating costs of the various existing and hypothetical vehicles.
- Energy Consumption Analysis - Determining the energy consumption efficiency of the various vehicles studied.

VEHICLES COMPARED

Vehicles compared with LTA vehicles include the conventional vehicles considered in the Hydrofoil Study and the Flagstaff II hydrofoil, which that study found to be most cost/effective:

- Hydrofoil
  Flagstaff II - This conceptual vehicle is based on a redesign of an operational U.S. Navy hydrofoil.
- Cutters
  WMEC-210 - A 210-foot cutter capable of a maximum speed of 18 knots.
- HEC-MEC - A conceptual cutter, approximately 275 feet long, with a maximum speed of 18 knots.

WHEC-378 - 378 foot cutter with a speed of 29 knots.

- Helicopters
  HH-3 - An operational helicopter with a speed of 126 knots.

  HH-X - A conceptual replacement for the HH-52 with a speed of 125 knots.

- Fixed-wing Aircraft
  HC-130 - An operational turboprop aircraft with a speed of 290 knots.

  MRS - A planned jet replacement for the HU-16E with a maximum speed of about 375 knots.

COAST GUARD MISSIONS

A summary of all the Coast Guard missions is presented in appendix A together with a discussion of potential applications of LTA vehicles. The missions were screened to select those that appear most promising and important. The following 4 missions were considered to merit additional study:

- Enforcement of Laws and Treaties (ELT) - While this mission is concerned with a wide variety of Coast Guard related national and international treaties, it principally involves the enforcement of fisheries laws. The scope of this mission will probably increase greatly in view of recent discussions concerning a 200 mile national contiguous fishing zone. The mission involves collecting census data on fishing fleets (by nationality and type of fishing activity) in various fishing areas, deterring violations, and detecting and seizing violators. Cutters are used to provide most of the close-in surveillance and to accomplish the boarding inspections and seizures. Aircraft are used to provide gross surveillance and target investigation (rigging) in large patrol areas.

- Search and Rescue (SAR) - This mission involves aiding persons and property in distress on the high seas and in waters under U.S. jurisdiction. The search phase of the SAR mission capitalizes on the transit speed and search rate of the vehicle. The rescue phase requires providing direct assistance, e.g., life saving equipment. Physically removing an ill or injured person may be required, and cannot be accomplished by fixed-wing aircraft. Towing a disabled vessel may be required; this can be done only by a surface vessel.

- Marine Environmental Protection (MEP) - The Coast Guard MEP program consists of four phases. Impact assessment involves investigating effects of pollutants and collecting pollutant data. Prevention and enforcement uses aircraft surveillance to detect oil on the water surface and determine its source. The Coast Guard has an Airborne Oil Surveillance System (AOSS) under development for this purpose. Response involves rapid clean-up of petroleum spills and in-house abatement. It used containment and oil recovery equipment that is designed to be air-transportable by HH-3 helicopters and HC-130 aircraft.

- Short-Range Aids to Navigation (AN) - The AN program involves all the ships, boats, and other vehicles, as well as bases and personnel, necessary to maintain necessary buoys, lights, and radio beacons. Primarily, buoy tenders are used. Aircraft are used to search for missing floating aids. Helicopters are used to reach places where boat landings are unsafe.

STUDY APPROACH

The study was conducted in several phases of increasing complexity.

The objective in the initial phase was to determine critical factors. A technical design model was used to estimate airship characteristics for a broad range of design parameters. Effectiveness was estimated by applying the methodology developed in the Hydrofoil Study to compare hydrofoils with conventional vehicles on a task basis. Costs were treated parametrically.

In later phases the technical design model was developed further and characteristics were determined for a family of 24 airships with speeds that varied from 50 to 120 knots and ranges of 1,000, 2,000, and 3,000 miles. Personnel and maintenance requirements were estimated as a function of airship size and endurance. Hourly costs were based on estimates of airship lifetime and annual utilization rate. Costs of vehicles other than airships were based on the Hydrofoil Study.

Cost effectiveness was determined for a series of tasks considered appropriate for airships. Each task was examined independently of the others. Aspects of particular geographic locations were not considered. The tasks considered were:

- Transit to station
- Gross surveillance
- Local surveillance
- Investigation of dispersed targets
- Trail/Observation
- Presence

Gross surveillance is measured by vehicle search rate in square miles per hour; it is a function of vehicle speed and sensor detection performance. Sensor performance is measured by sweepwidth (effective pathwidth) in miles.

Local surveillance is the task of searching a fixed area to achieve a prescribed detection probability of locating a ship or group of ships. Performance is measured by the time required to achieve that probability.

Investigation of dispersed targets is a task requiring close approach of randomly distributed targets. It is measured by track distance made good per hour on station.

The target investigation task was extended to include the effects of time delays during investigation. Two cases were considered (high and low density). In the low density case the average track distance between targets was assumed to be 200 miles and the delay time per investigation was assumed to be .1 hour. In the high target density case, the track distance was 2 miles and the delay time was assumed to be .01 hour.

The trail (or observation) task is an extension of the pursuit task considered in the Hydrofoil Study. The target under trail was assumed to move at an average speed of 15 knots. All vehicles considered in this study were assumed to be capable of trailing the assumed 15 knot target; hence, comparisons were made between vehicles on the basis of cost per hour to perform this task.

To take geography into account generally, the task analysis was extended to determine cost-effectiveness on station as a function of distance to station. Thus, this on-station task analysis combines the transit task with any of the other tasks. Transit speed was varied to maximize the fractional time on station. For patrol tasks involving search and investigation functions the effectiveness depends on the "effective speed," defined by the track miles on station per flight hour. (See chapter IV.)

The application of task analysis to mission requirements and mission capability is discussed for three of the four missions of special interest. Complete mission analyses are beyond the scope of this study. Such analysis would require consideration of the complex multi-task multi-vehicle nature of Coast Guard missions, including air station locations relative to mission operating areas.

For the Search and Rescue mission a simple model was developed to measure mission capability as a function of distance to datum. The contribution of airships in a secondary SAR role was also investigated.

Energy consumption analysis was performed to compare vehicles on the basis of energy efficiency, measured by miles, square miles, or hours on station per gallon, as a function of distance to station.

VOLUME I CONTENTS

Other chapters of this volume include:

Chapter 2 - Vehicle Characteristics

A general review of LTA vehicle types is followed by descriptions of the family of airships designed for this study, including construction features and operational considerations. Sensitivity of vehicle characteristics to changes in design parameters is discussed, and specific inputs to the technical design model are listed. Other vehicle characteristics are also listed.

Chapter 3 - Cost Analysis

Cost estimates in FY 1976 dollars are presented for the family of airships and other vehicles described in chapter 2. Sensitivity of cost factors to certain characteristics (utilization rates, investment, personnel, maintenance, and fuel costs) is discussed, and vehicles are compared on the basis of total hourly costs.

Chapter 4 - Task Analysis

Detection, investigation, and observation tasks are defined. A reduced set of 3 airships (LTA 1, LTA 2, and LTA 3) of varying range is compared with the other vehicles on a cost-effectiveness basis in patrol tasks.

Chapter 5 - On Station Task Analysis

The task analysis of chapter 4 is extended to include the effects of transit to station.

Chapter 6 - Search and Rescue Analysis

Use of an LTA in a secondary role in Search and Rescue missions is analyzed, using historical SAR cases.

Chapter 7 - Energy Consumption Analysis

Vehicles are compared on an energy efficiency basis.

Chapter 8 - Conclusions and Recommendations

II. VEHICLE CHARACTERISTICS

INTRODUCTION

A general description of LTA vehicle types is followed by a more detailed discussion of airship characteristics and operational considerations. The specifications used to generate the reference set of airships are listed and the principal characteristics are presented. Comparisons between some conceptual airships are presented to illustrate the influence of speed, range, and altitude. Variations of structural materials and power plant technology are also considered. The principal results are sizes of conceptual airships in terms of envelope volume and investment cost. A more detailed discussion of these subjects is presented in chapters 1 and 2 of volume III.

Except for the MRS aircraft, characteristics of vehicles other than airships are taken generally from the Hydrofoil Study. Speed and endurance estimates for the MRS were obtained from the Coast Guard Aviation Branch.

LTA VEHICLES

Lighter-than-air vehicles can be classified in several ways. A classification for use in this analysis is shown in table II-1. The broad categories are balloons, airships, and hybrid LTA vehicles.

Balloons

Balloons usually have a vertical axis of symmetry. They are intended for small speeds relative to atmospheric wind, or simply to drift with the winds. The shape of balloons is maintained by internal gas pressure slightly greater than the external atmospheric pressure.

Tethered balloons are currently used in heavy logging operations in the northwest United States to move felled trees from upper slopes to a valley floor. Logging balloons with volumes from 250,000 to 815,000 cubic feet are used to carry loads from 11,000 to 40,500 pounds.

Free balloons with very large volume capacities are used, in the physical sciences, to carry experimental equipment, usually measurement equipment, to high altitudes (above most of the atmospheric mass) for a few days.

Airships

Airships differ from balloons because they are intended to provide self-propelled airspeeds of, say, 30 knots or more. To reduce air drag, airships have a horizontal axis of symm try, with length-diameter ratios of about 4 to 8. The cross sections are approximately circular. Blimps and dirigibles are two basic types of airships.

TABLE II-1

LIGHTER-THAN-AIR VEHICLES

Type	Characteristics
Balloons	Vertical axis of symmetry Very low horizontal speed Shape/strength by internal pressure
Airships :	
Blimps	Horizontal axis of symmetry Moderate horizontal speed Shape/strength by internal pressure Moderate sizes (historical)
Dirigibles	Horizontal axis of symmetry Moderate horizontal speed Shape/strength by structural framework
Hybrid LTA vehicles	Semi-buoyant lifting body Shaped lifting body Independent rotor lift

Blimps are nonrigid structurally; their envelope shape is maintained by internal gas pressure. The envelope material of blimps is usually flexible, can deform temporarily under extreme and unexpected operational loads, and then return to its normal shape when the load is reduced. However, lack of gas cell compartmentation in blimps could make them more susceptible to serious damage when gas cell integrity is lost.

A 975,000-cubic foot 1955 U.S. Navy blimp is compared with a Coast Guard WHEC cutter in figure II-1.

Dirigibles are rigid airships, that is, airships whose envelope is supported by a structural framework. A sketch of a U.S. Navy dirigible of the 1930s is shown in figure II-2. Its volume was 7.4 million cubic feet.

Hybrid LTA Vehicles

Hybrid LTA vehicles use an integrated combination of static buoyancy lift and other methods for producing lift. These other lift methods include body aerodynamic lift, independent rotor lift, integral rotor, and shaped-body aerodynamic lift. Some representative examples of hybrid vehicles are shown in figure II-3.

Blimps were usually operated as STOL (short takeoff and landing) vehicles using body aerodynamic lift throughout their flight. Thus, they were hybrid LTA vehicles.

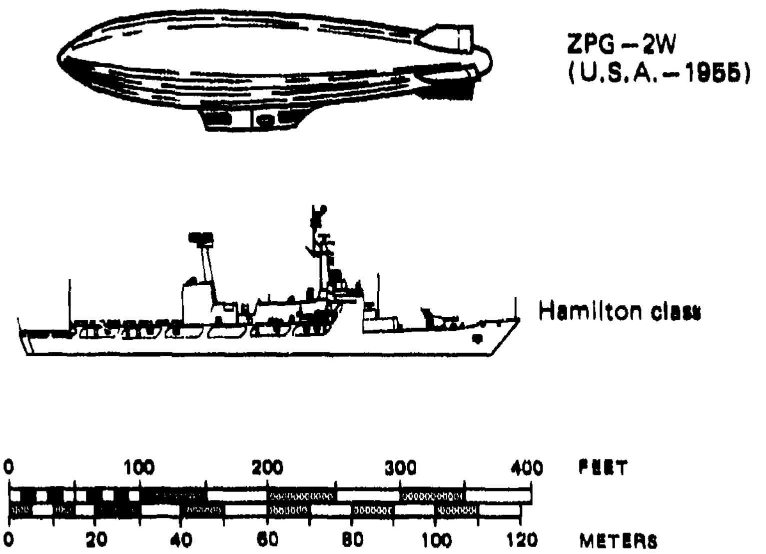


FIG. II-1: COMPARISON OF A 1955 BLIMP WITH A HAMILTON CLASS CUTTER

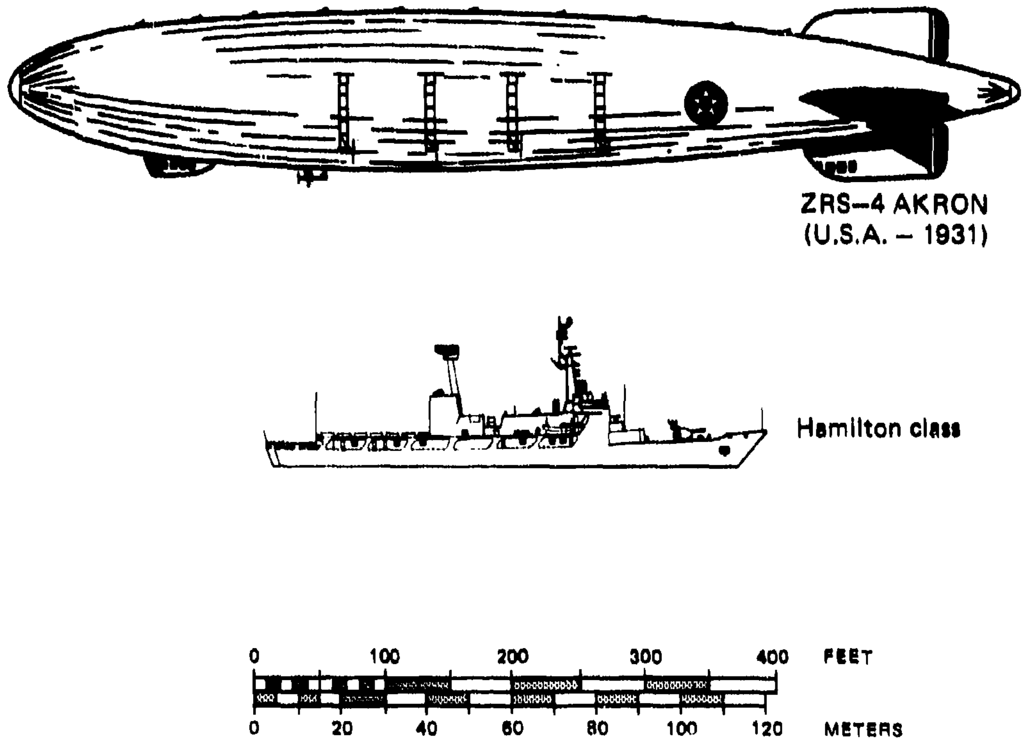


FIG. II-2: COMPARISON OF A 1931 DIRIGIBLE AND A HAMILTON CLASS CUTTER

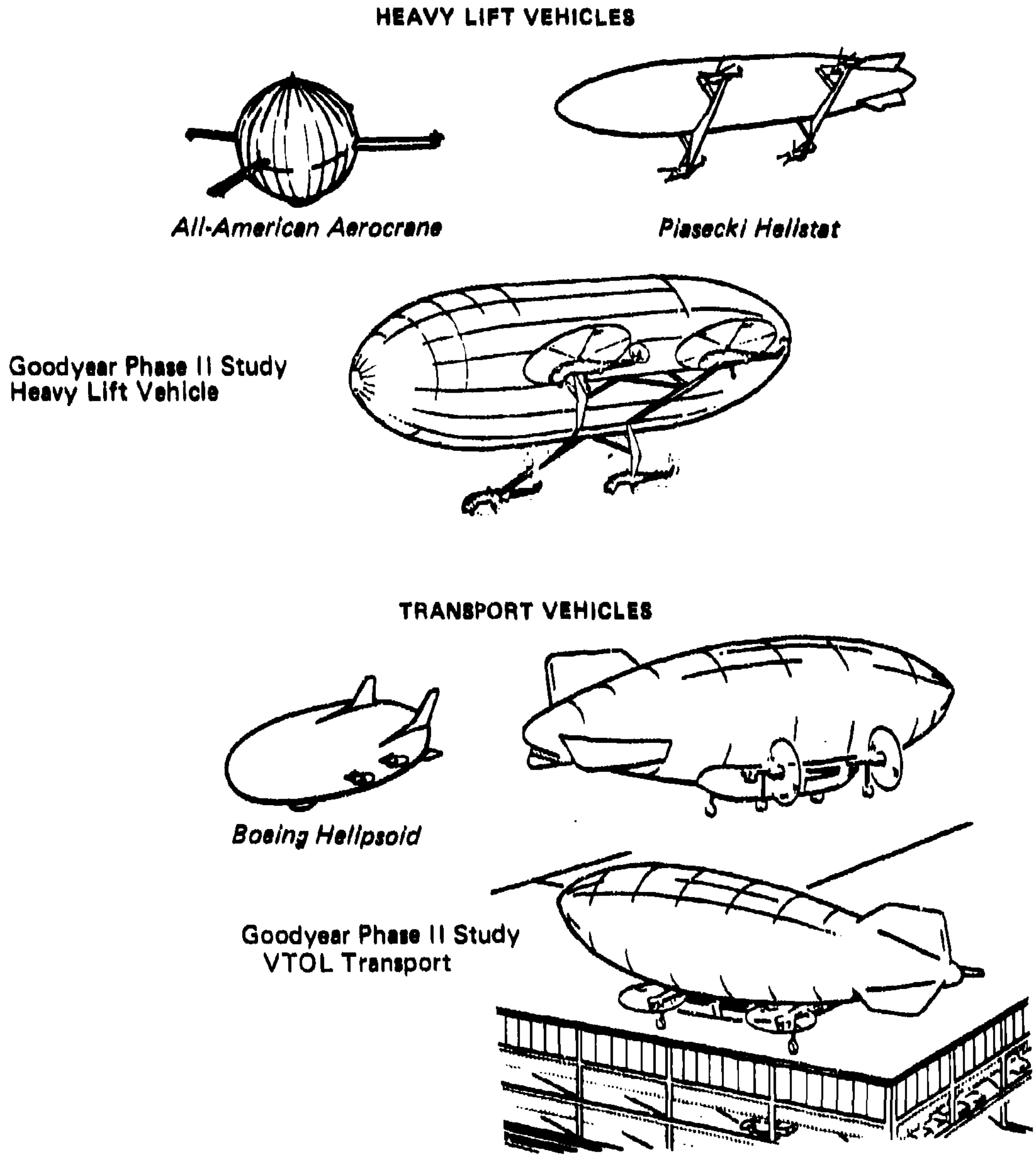


FIG. II-3: SOME HYBRID LTA CONCEPTS

Shaped lifting body hybrids would obtain aerodynamic lift at improved lift-drag ratios. This hybrid's body would be shaped as a thick narrow wing in contrast to the cylindrical body of airships. The Helipsoid proposed by Boeing Vertol in the Phase I study is an example of this type and is illustrated in figure II-3.

Hybrid LTA vehicles using a combination of static buoyancy and independent rotor lift have been proposed principally to achieve very large unit lift capability beyond that obtainable using a single helicopter. One proposal under investigation by the U.S. Navy is the Helistat (Piasecki, page 465, reference 9). The Helistat provides no-load lift by static buoyancy, and uses helicopter rotors to add the large unit load lift for short duration transportation periods. Additional analysis of this concept was conducted in the Goodyear Phase II study. See figure II-3.

An integral rotor lift hybrid, called the Aerocrane, has been proposed by the All American Engineering Company (Perkins and Doolittle, page 571, reference 9). Static buoyancy lift is provided by a balloon. The vertical axis of symmetry of the balloon is necessary because the entire balloon (and integral-rotor system) is rotated at low rates by tip-mounted reciprocating engines and propellers to develop lift on the rotor blades. Low horizontal speeds are adequate for transportation of large unit loads; therefore, a balloon form is not a disadvantage for this concept.

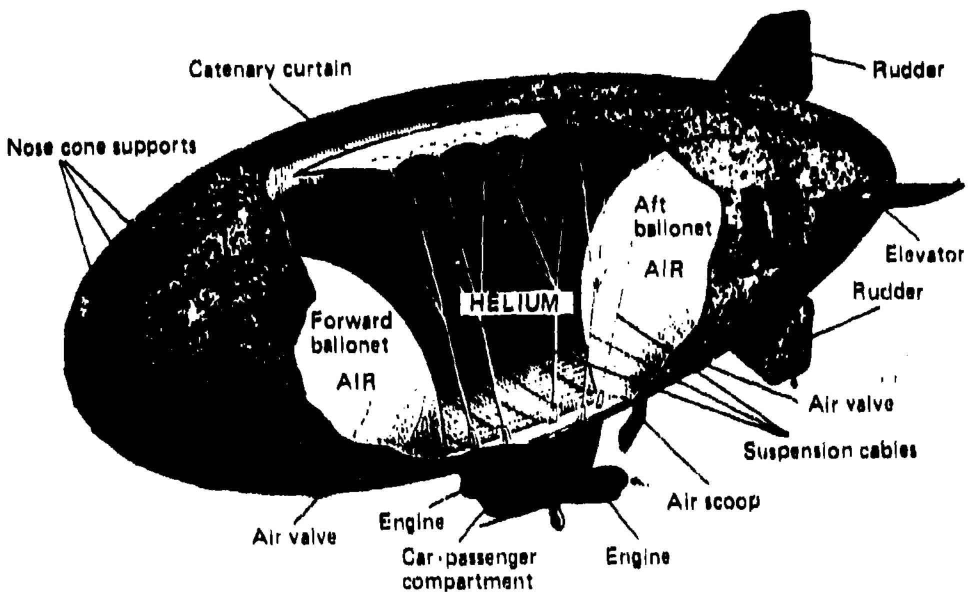
The 80-passenger Airport Feeder vehicle proposed by Goodyear in the Phase II study is a short range, moderate speed (more than 100 knots) transport using a high percentage of aerodynamic lift during flight. Takeoff requires tilting propellers, which also provide a vertical takeoff and landing capability. This hybrid combines 3 lifting processes - static, aerodynamic, and independent rotor thrust.

Only the blimp airship LTA is considered further in this study. Blimp technology is developed to about the level of the technology of alternative Coast Guard vehicles such as airplanes, helicopters, and hydrofoils. Shaped lifting bodies would require considerable development, complicating comparison with other vehicles. The Helistat and Aerocrane heavy lift capability does not appear to be needed by the Coast Guard.

BLIMP CONSTRUCTION FEATURES

A blimp consists of an envelope that encloses pressurized lifting gas; it has stabilizing and control surfaces on the tail, and a car and propulsion structure that are supported below the envelope (figure II-4).

The envelope is made of Dacron, or other material, and is covered on the outside with an aluminum pigment. As the blimp increases altitude, the lifting gas within the envelope expands due to the decreased external pressure. To permit this expansion, flexible air ballonets are installed within the envelope.



Source: Goodyear, NASA, Vol. III, 19, P. 6, reference 7.

FIG. II-4: TYPICAL BLIMP CONSTRUCTION

As the blimp ascends, the lifting gas is permitted to expand by deflation of the ballonets. When the ballonets are completely deflated, the envelope is 100 percent full of lifting gas and the blimp is at its gas, or pressure altitude.

The car structure and attached propulsion plants are supported by a combination of two suspension systems. The internal steel suspension cables distribute the concentrated load of the car to a pair of laterally symmetrical catenary curtains inside the top of the envelope. Another catenary system distributes pitching and yawing forces from the car to the envelope.

The car structure contains the flight controls and communications in a pilot compartment, support for outriggers for mounted engines, internal tanks for fuel, and the landing gear.

The air scoop and a blower system provide pressurized air to ballonets. The blimp envelope is a pressurized structure. The required pressure differential depends on the bending moment expected in flight. (The relation between pressurization and loads for a pressurized structure can be seen directly for a fabric building that is pressurized. If a snow load of about one foot is expected, the internal pressurization must be sufficient to support this vertical load.) The pressure differential for blimps has been about 3 inches of water (0.8 percent of atmospheric pressure). Larger pressure differentials increase the envelope weight.

Current Blimps

Several countries have constructed blimps, largely for military applications. Germany built many prior to and during World War I, and has recently designed and constructed new blimps. The United States has been the major user of blimps. The U.S. Navy used blimps between 1917 and 1962; the U.S. Army acquired blimps from 1921 to 1933. Commercial blimps have been built by Goodyear from 1919 through 1972.

Early U.S. blimps had volumes between 35,000 and 200,000 cubic feet. During the 1950s volumes were increased to about 1 million cubic feet; the largest U.S. Navy blimps in 1959-60 had a volume of 1.5 million cubic feet.

In 1976 there are 3 operational blimps in the United States: the Columbia II, the America, and the Europe, which are advertising blimps of the Goodyear Aerospace Corporation. There is also a development program, funded by the U.S. Navy, for a very high altitude (about 70,000 feet) unmanned station-keeping blimp called the High Altitude Superpressurized Powered Aerostat (HASPA) (Wessel and Patroni, page 595, reference 9; Korn, page 585, reference 9.) Coast Guard missions require low altitude operations, so high altitude airships are not considered in this study.

An unmanned tethered communication (TCOM) blimp is produced commercially by Sheldahl, Inc. of Minnesota (Mehke, page 613, reference 9). The dimensions of this airship are: length, 175 feet; diameter, 56.8 feet; full volume, 267,000 cubic feet. The structure of the airship is designed to withstand 90-knot winds at sea level and 100 knots at 10,000 feet. The airship has remained aloft for 5 days; its endurance is limited by onboard fuel to generate electrical power for the pressurizing blowers and the communications system. A 4-person crew recovers, services, and launches the balloon. With 4,000 pounds of payload at 10,000 feet altitude, the system provides line-of-sight communications to a radius of 120 miles. A prototype system began operating in summer 1973 on Grand Bahama Island to provide television coverage for the outer islands.

GROUND OPERATIONS

Hangaring

Although the military services currently have no blimps, a dozen airship hangars still exist in the United States. These were constructed for earlier blimp and dirigible programs and are currently in use, at least in part, for other purposes. Thus, hangar facilities costs for new airships would be the cost of alternative facilities for the present occupants of the airship hangars. Approximately 100 medium size (500,000 cubic feet) blimps could be accommodated in existing airship hangar facilities. (Piasecki, page 37, reference 10).

Hangar facilities are needed in all but the most benign climates (moderate temperature and low winds) for overhaul and damage repair of airships. Overhaul time was only a small fraction of the service life of earlier airships; therefore, for this purpose one hangar facility can serve several airships. In the 1950s, U.S. Navy blimps (1 to 1.5 million cubic feet) were on a schedule of an 8-months overhaul after each 48 months of service. In the 1970s, the Goodyear advertising blimps (200,000 cubic feet) spent 2 weeks in overhaul each year. Thus, the existing airship hangars could accommodate several hundred medium size blimps for overhaul purposes.

In most parts of the United States, it would be desirable to use hangars for routine shelter at least in some seasons. The large U.S. dirigibles of the 1930s were hangared almost continuously except when in flight.

In contrast, the U.S. Navy K-ships (about 400,000-cubic foot volume) of World War II were operated on coasts of the Atlantic Ocean in the tropics without any hangar facilities at all.

Ground Handling

During the 1950s, the U.S. Navy developed mechanized equipment and procedures for mooring and handling blimps on a field. Mobile masts could be moved by special mast and docking tractors. Ground handling mules were maneuverable tractors with a constant-tension winch capable of accepting line loads from any direction. These were capable of restraining the blimp and controlling the line loads. For larger blimps, additional mules were used in the operations of moving the blimp and mast to a mooring circle, hangaring, and moving to and from a takeoff position.

This equipment made it possible to operate the 1.5 million cubic foot ZPG-3W with relatively few ground crew. Hangaring and takeoff required about 12 people; landing and mooring operations required about 18.

Field Services

Several kinds of services for airships are required on the field when hangars are not used nor available. For example, fuel pipes or tank trucks are needed. Helium supplies and water for ballasting are requirements unique to airships. Helium trailers could be used. Electric power to maintain pressurization of blimps on the ground is required. These services could be easily provided.

Maintenance and Overhaul

Maintenance includes preflight checks and preflight correction of deficiencies. The helium gas must be monitored for quantity and purity for all airships. Special ladders called "sky hooks" were used for envelope inspection, patching, and painting. Retensioning (monthly in 1959) of the car-support cables required from 24 to 48 hours. However, new design criteria may eliminate, reduce, or at least minimize, this requirement.

Overhaul of U.S. Navy blimps in the 1950s was accomplished at one central location at Lakehurst, New Jersey. Every 48 months the Overhaul and Repair (O&R) unit performed specified overhauls that took 8 months.

Maintenance personnel requirements and costs are discussed in appendixes E and F of volume II;

FLIGHT OPERATIONS

Takeoff, landing, and flight operations for airships differ from those of airplanes.

Historically, airships did not hover well and were difficult to control at low speeds. Response to control forces was very slow and required the pilot to plan ahead.

Short takeoff and landing (STOL) operation of airships minimizes the time spent at low and relatively unstable speeds. U.S. Navy blimps in the 1950s generally used ground run for takeoff and landing.

Blimp Takeoff and Landing

The ground run distance for blimps when heavy is short with respect to the length of the blimp. The U.S. Navy ZPG-3W blimp, required a ground run for takeoff of 587 feet and a takeoff distance of 1,468 feet to clear a 50-foot obstacle.

For the ZPG-3W blimp, about 12 people and 2 mules were required for takeoff.

For landing, the ZPG-3W blimp used 18 people and equipment to restrain the blimp and move it back to its mooring mast or hangar. The Goodyear advertising blimps of 200,000-cubic foot volume use about 7 people and no equipment.

Influence of Flight Altitude

Selection of flight altitude is important for both airships and airplanes. Jet airplanes can fly high, without decreasing useful, loads to obtain greater speed and range by better engine efficiency. Airplanes with reciprocating engines also fly as high as the engine supercharging permits, to obtain greater speed and range.

In contrast, the useful load of airships decreases rapidly with increasing gas altitude. Either payload or fuel (and range), or both, must be decreased as gas altitude is increased.

Buoyancy and Trim

The weight of an airship decreases as propulsion fuels are used. For buoyant operations, compensating weight must be added if a constant altitude is to be maintained. Dirigible airships maintained static buoyancy by condensing water ballast from engine exhaust. The condensate was stored in empty fuel tanks. The condensing systems, however, added to the weight, complexity, and maintenance requirements of the airship.

U.S. Navy blimps using aerodynamic lift operated over coastal areas where they could descend to sea level, winch down a canvas bag water scoop, and obtain water to pump into empty fuel tanks. This method was simple and direct, but required operations at low altitudes over water.

The temperature and pressure of the lifting gas and local atmospheric air must be monitored. When the local air temperature is greater than the standard value, the air density and static lift are reduced. When gas temperature reaches equilibrium with the increased air temperature, the static lift is decreased about 1 percent for each 5 degrees Fahrenheit of air temperature increase.

Gas temperature is affected by direct solar radiation and airflow heat conduction on the envelope in flight. Excess gas temperature above air temperature is called superheat. This superheat reduces gas density and increases static lift (about 1 percent for each 4 degrees of superheat).

In flight, small percentage changes in static lift can be handled by dynamic lift; for ground operations such as takeoff and landing, it is more difficult to compensate for these effects.

Aerodynamic Lift and Ballasting

Aerodynamic lift was used by U.S. Navy blimps to provide good controllability; hence, the blimp was flown in the manner of an airplane.

The heaviness makes the blimp more manageable as it is moved out for takeoff. A short takeoff run then produces enough speed to develop an aerodynamic lift equal to the heaviness.

During climb, the aerodynamic lift is maintained and static lift is constant. Additional lift can be obtained (given sufficient structural strength) by increasing the angle of attack. As propulsion fuel is used, the heaviness (the required aerodynamic lift) decreases.

When heaviness has decreased, the blimp descends to sea level and obtains water ballast. Speeds of about 10 knots could be used without excessive angles of attack.

WEATHER OPERATIONS

Weather affects the operational effectiveness of all aircraft. Due to airships' relatively low speed capability, wind speed can be a significant weather deterrent to operational effectiveness. As with other aircraft, snow, icing, and lightning also lower effectiveness. Various types of weather storms also limit aircraft effectiveness.

Winds and Airships

Atmospheric winds are the most significant consideration for airships: wind effects are important near the ground during hangaring, masting, takeoff, and landing. Winds also affect flight operations. When operating at a cruise speed of 40 knots into a head wind of 30 knots, the ground speed is only 10 knots. Thus, the speed and direction of expected wind must be considered, together with the desired mission flight path.

Cumulative frequency of wind speeds in several U.S. coastal marine areas, is analyzed in volume II of this report. A typical result indicates that during 95 percent of the summer months, the wind speed at sea level is not greater than 10 knots. During 77 percent of the winter months, the wind speed is not greater than 10 knots. Thus, at a 40-knot blimp cruise speed, the influence of wind speed can be important. But, at a 100-knot cruise speed the influence would be much less.

At an altitude of about 2,000 feet the wind speeds are considerably greater than at sea level, particularly in winter. This is generally true for all U.S. coastal marine areas, and the wind speeds continue to increase as larger altitudes are considered.

Because of this, airships should be operated at low altitudes to reduce the influence of wind speed. With this restriction, airships could operate for much of the year in most U.S. coastal marine areas without drastic reductions of ground speeds due to head winds.

The influence of higher wind speeds can be reduced by selecting routes and altitudes to minimize head winds. In 1976, weather reporting and forecasting provided continuous radio weather information.

Snow and Icing

Snow accumulations on a flying blimp can be minimized by changing altitude, and by the effects of air flow on the envelope.

For moored blimps, heavy wet snowfall tends to stick rather than slide off. The weight of a moderate thickness of wet snow can exceed the design strength of the landing gear and that of the pressurized structure envelope, causing roll over or collapse of the envelope. In the 1960s, the U.S. Navy washed snow from moored blimps with a fire hose; helicopter downwash was also used to blow accumulated snow away and to heat the helium gas to reduce accumulation.

Icing is not a major problem, except when the airship is moored. In this case, the effect is analogous to the effect of snow.

Freezing rain occurs infrequently along the coastal areas, and does not occur 200-300 miles off shore due to the warming effect of the ocean. Freezing rain occurs only at altitudes of about 1,000 to 3,000 feet, so reduction of altitude can eliminate ice accumulation.

Severe Weather

Severe weather conditions, such as regions of strong frontal turbulence, thunderstorms, squall lines, and hurricanes, are avoided by all aircraft whenever possible. Predictions of probable turbulence regions are now made routinely and on-board radar can warn of the possibilities of such severe weather conditions.

Lightning has not been a hazard to airships in flight in the past. There has been some evidence of lightning strikes on blimp fins, cars, and radomes, but none that caused detectable damage to the envelope. There is also evidence that a lightning strike did ignite spilled fuel under a moored Navy blimp, leading to rapid burning of the envelope.

Long squall lines may present the most difficult weather problem for airships. It is not easy to fly around the long squall line at airship speeds, and the airship cannot rise to the height necessary to fly over the line.

Boarding and Recovery

Boarding is a requirement of the ELT mission. For an airship, it might be accomplished by use of a collar supported at the end of a cable of considerable length. Capabilities are limited by the atmospheric and wind conditions, the sea state, and above all, the cooperative or uncooperative attitude of the receiving surface vessel.

Direct boarding is a hazardous operation for an airship even under optimum conditions. Since the atmospheric and wind conditions cannot be controlled, and receiving vessels would probably not be cooperative in the ELT mission, direct transfer to a vessel is not considered to be an airship capability.

Recovery in SAR missions should be feasible for an airship, but would probably not be as advantageous as recovery by helicopter.

CONCEPTUAL AIRSHIPS FOR COAST GUARD MISSIONS

A set of conceptual airships is presented whose characteristics were estimated according to the conceptual airship model presented in volume III. These airships are compared later with other Coast Guard vehicles to determine if airships could provide improved mission performance.

A conceptual design model analyzes various new concepts possible; however, the model should be based on data on existing vehicles as well as physical principles. In the case of airships, however, the available data on airships are for vehicles at least 15 years old. In addition, the conceptual airships of most interest incorporate new technology, principally engines and structural materials, that has not previously been used in airship construction.

Conceptual design models for other vehicles provide weight and cost estimates within ±10 percent of detail-design results. The differences are often less than ±10 percent. However, because of the lack of current airship data and in view of the new technology, the accuracy of the conceptual airship model calculations may not be so good as ±10 percent.

The conceptual airship model is described at length in volume III, and includes the details of the estimating equations.

Specifications and Characteristics

This section describes a set of conceptual blimps used throughout the study. A preliminary screening of the cost effectiveness of airships showed that envelope volumes of about 0.5 million cubic feet are desirable for Coast Guard missions. For such sizes, blimps are usually preferable to dirigibles, depending on the technology assumed for each type. In addition, for missions over coastal ocean waters the ocean water ballast procedures developed for U.S. Navy blimps can be used. It is possible that dirigibles could use similar procedures, but they have not been developed. Finally, if dirigibles with 1976 technology were considered for these missions, the conceptual design model indicates that there would be only small changes compared with the set of blimps. Therefore, only the set of blimp-type airships is considered.

The set of 24 conceptual blimps was formed by varying sustained air speed, endurance air speed, and endurance range. Sustained speed and endurance speed were equal for each blimp. Eight speeds (50, 60, ..., 120 knots) were used. At each speed, endurance ranges of 1,000, 2,000, and 3,000 nautical miles were considered. The specifications used for the set are shown in table II-2.

The cruise altitude was specified as 2,000 feet. Officer and enlisted aircrew were specified according to the requirements discussed in appendix E of volume II. The ship duration in days was specified as (endurance range/endurance speed) divided by 24. This does not provide accommodations facilities and personnel stores for the longer ship durations that are possible at lower operating speeds and range combinations. The envelope length-diameter ratio and prismatic coefficient are about optimum (minimum size and cost) for this set of blimps. A lift gas purity of 94 percent and a design gust speed of 35 feet per second are often used in design calculations for airships.

A takeoff speed ratio of 60 percent gives a takeoff ground run approximately equal to 2.5 times the blimp length (see volume III). The takeoff angle of attack for carrying fuel by aerodynamic lift was specified to be the optimum. Optimum is defined in the model as the maximum takeoff angle of attack attainable without lengthening the landing gear beyond the length required for car and propeller clearance. A ratio of engine cruise power to maximum (takeoff) power of 0.80 is often used in design calculations for airships.

A design payload equipment weight of 3,500 pounds was assumed for the Coast Guard Airborne Oil Surveillance System (AOSS) and miscellaneous equipment. A deck area of 105 square feet was specified to provide space for this equipment. Separate payload equipment electric power (specification 31) was specified as 14 kilowatts. The number of engines for blimps is to be specified as two.

The investment cost was calculated in 1976 dollars for a production quantity of 20. A 1976 specific cost of $170 per pound of empty weight was used for the first production airship and a cumulative learning rate of 85 percent was used. These specifications lead to an average production cost of about $105 per pound in 1976 for the 20-airship buy. When engineering cost and production prototype increment cost are also included in these estimates, the specific cost rises to $119 per pound, including helium costs brings the total to about $125 per pound.

Other characteristics and features specified for the reference set of blimps include turboprop conceptual (rubber) engines, helium lift gas, and a new envelope material

TABLE II-2

SPECIFICATIONS FOR REFERENCE SET OF BLIMPS

Sustained speed	varied	Special payload (lb.)	3,500
Endurance speed	varied	Special deck (sq.ft.)	105
Endurance range	varied	Electric power (kw)	14
Cruise altitude (ft.)	2,000	Number of engines	2
Number of officers	(a)	Year dollars	1976
Number of enlisted	(a)	Production quantity	20
Ship duration, days	(b)	Specific cost[f] ($/lb.)	170
Length/Diameter	5	Learning rate (%)	85
Prismatic coefficent[c]	0.65	Engine type	turboprop
Gas Purity (%)	94	Lift gas	helium
Design gust (ft./sec.)	35	Envelope	Triaxial Kevlar
Takeoff speed ratio (%)[d]	60	Minimum ballast (%)	3
Takeoff angle	optimum	Reserve fuel (%)	10
Cruise power ratio[e]	0.8		

(a) From volume II, appendix E, table E-7, for each speed and endurance range.

(b) Equal to (endurance range/endurance speed) divided by 24.

(c) Ratio of envelope volume to volume of circumscribing cylinder.

(d) Ratio of takeoff speed to sustained speed

(e) Ratio of cruise (endurance) power to maximum (sustained speed) power.

(f) For first production unit.

called triaxial Kevlar film. The triaxial Kevlar film material has been used previously in balloons, but not in blimps. A minimum operating ballast of 3 percent of total weight and a fuel reserve of 10 percent of operating fuel were specified.

The principal characteristics of the reference set of blimps are shown in tables II-3 and II-4. The average cost does not include the cost of payload equipment and payload installation.

Hull length can be compared with the Hamilton class Coast Guard cutter, which is 350 feet at the waterline.

The total power rating of the two conceptual engines is also shown in table II-3. These power ratings indicate the size of engine required for the specified speed and range combinations.

Fuel rates are used to estimate operating costs. This rate is also of interest because of its relationship to potential fuel conservation.

The total lift shown in table II-4 equals the sum of the buoyant lift plus aerodynamic lift. Considerable aerodynamic lift is provided by the optimum takeoff angle of attack, especially at the larger flight speeds. The ratio of aerodynamic lift to buoyant lift shown in table II-4 increases from about 0.10 at 50 knots to 0.61 for a 1,000-mile range and 120 knots.

The ratio of aerodynamic lift to total fuel weight is the fraction of fuel that is carried aerodynamically. At 50 knots and a 1,000-mile range, 56 percent of the fuel is carried aerodynamically; the fraction decreases to 17 percent for a 3,000-mile range. In the first case, reballasting is required at least once; in the second case, at least five reballastings are required. When the fuel carried by aerodynamic lift has been used, it is possible for the airship to use buoyant low speed operations without burning "aerodynamic lift" fuel.

At 120 knots, 97 percent of the fuel is carried aerodynamically, so there is little opportunity to use low speed operations.

The lift-drag ratios (at half of aerodynamic lift) increase slowly with airship size and decrease rapidly with increasing flight speed. At 50 knots, the lift-drag ratios are above 20; at 120 knots, the ratio is down to 5.6 .

The takeoff angles of attack are shown in the last column of table II-4. They are around 6 degrees from the 2,000- and 3,000-mile range cases. For the 1,000-mile range cases, the takeoff angle of attack increases from 7.5 to 9.4 degrees as the speed increases.

TABLE II-3

CHARACTERISTICS OF REFERENCE SET OF CONCEPTUAL AIRSHIPS

Speed (knots)	Range (miles)	Envelope volume (1000 cu.ft.)	Average cost [a] (1976 $1000)	Hull length (ft.)	Engine [b] power (h.p.)	Fuel rate (gal./hr)
50	1000	319	1220	250	277	23
50	2000	514	1790	293	373	30
50	3000	727	2350	329	462	37
60	1000	347	1360	257	494	40
60	2000	569	1970	303	665	52
60	3000	980	3120	364	944	71
70	1000	377	1530	264	815	62
70	2000	709	2480	326	1196	88
70	3000	1360	4320	405	1821	129
80	1000	408	1730	271	1268	93
80	2000	903	3190	354	2058	144
80	3000	1958	6250	458	3402	227
90	1000	340	1440	255	1563	112
90	2000	1188	4270	387	3461	231
90	3000	2854	9140	519	6155	394
100	1000	374	1680	263	2266	157
100	2000	1623	5920	430	5767	372
110	1000	411	1980	273	3218	215
110	2000	2322	8570	484	9635	606
120	1000	465	2370	285	4506	293

a) Investment cost per airship, based on a 20-airship buy, including costs for engineering, development, and prototype.

b) Total for the two engines.

TABLE II-4

AERODYNAMIC RATIOS OF REFERENCE SET OF CONCEPTUAL AIRSHIPS

Speed (knots)	Range (miles)	Total lift (1,000 lb.)	Aero lift / Buoy. lift ratio	Aero lift / Total fuel ratio	Lift / Drag ratio	Takeoff Angle of attack (deg.)
50	1,000	21.6	.10	.56	20.0	7.5
	2,000	34.2	.07	.26	24.2	6.8
	3,000	47.9	.06	.17	28.0	6.3
60	1,000	24.5	.14	.61	14.7	7.8
	2,000	39.1	.11	.30	18.0	7.0
	3,000	65.6	.08	.18	22.1	6.3
70	1,000	27.8	.19	.68	11.5	8.1
	2,000	50.0	.14	.32	14.7	7.1
	3,000	92.4	.10	.20	18.6	6.2
80	1,000	31.7	.25	.74	9.5	8.4
	2,000	65.2	.16	.34	12.6	7.1
	3,000	134.6	.11	.21	16.5	6.0
90	1,000	28.8	.37	.84	7.6	9.0
	2,000	87.4	.19	.36	11.2	7.0
	3,000	197.8	.12	.21	15.2	5.9
100	1,000	33.5	.45	.89	6.7	9.2
	2,000	121.2	.20	.37	10.3	6.8
110	1,000	39.1	.53	.94	6.0	9.3
	2,000	174.5	.21	.37	9.9	6.6
120	1,000	46.5	.61	.97	5.6	9.4

The variation of the envelope volume and of basic investment cost of the reference set of blimps with speed are shown graphically in figures II-5 and II-6. Figure II-5 shows that at the 1,000-mile range, the volume changes slowly as speed increases from 50 to 100 knots. For a speed of 50 knots, the envelope volume approximately doubles when the range increases from 1,000 to 3,000 miles. At 100 knots, envelope volume increases fourfold when the range increases from 1,000 to 2,000 miles.

The average cost per airship for a production buy of 20 turboprop/polymer blimps of the basic reference set is shown in figure II-6. These curves have the same general form as the envelope volume curves in figure II-5.

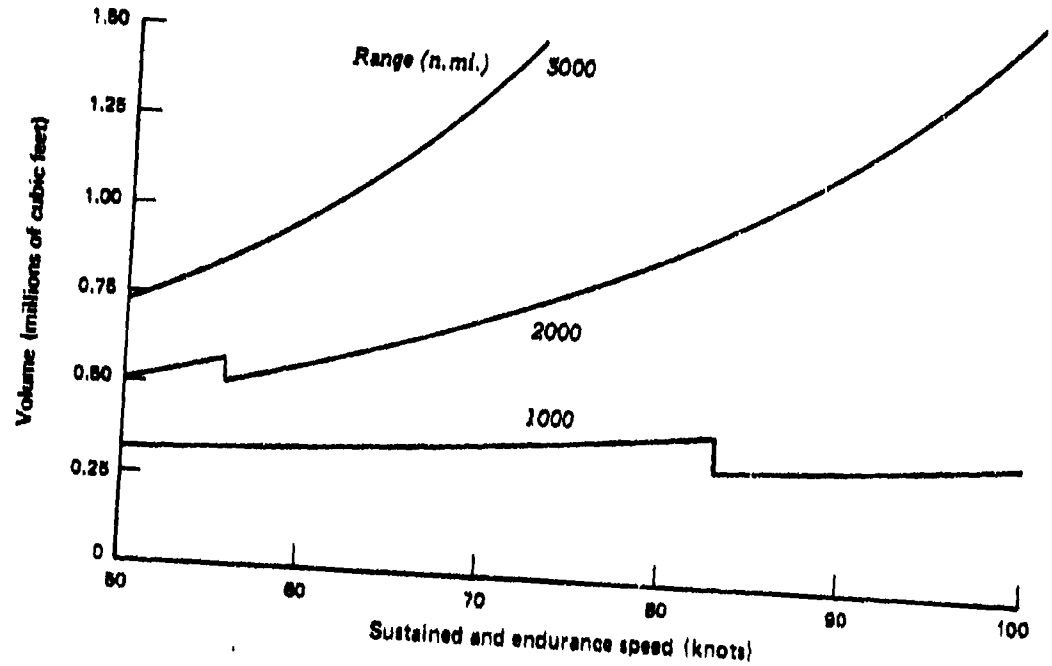


FIG. II-5: VOLUMES FOR TURBOPROP/POLYMER BLIMPS

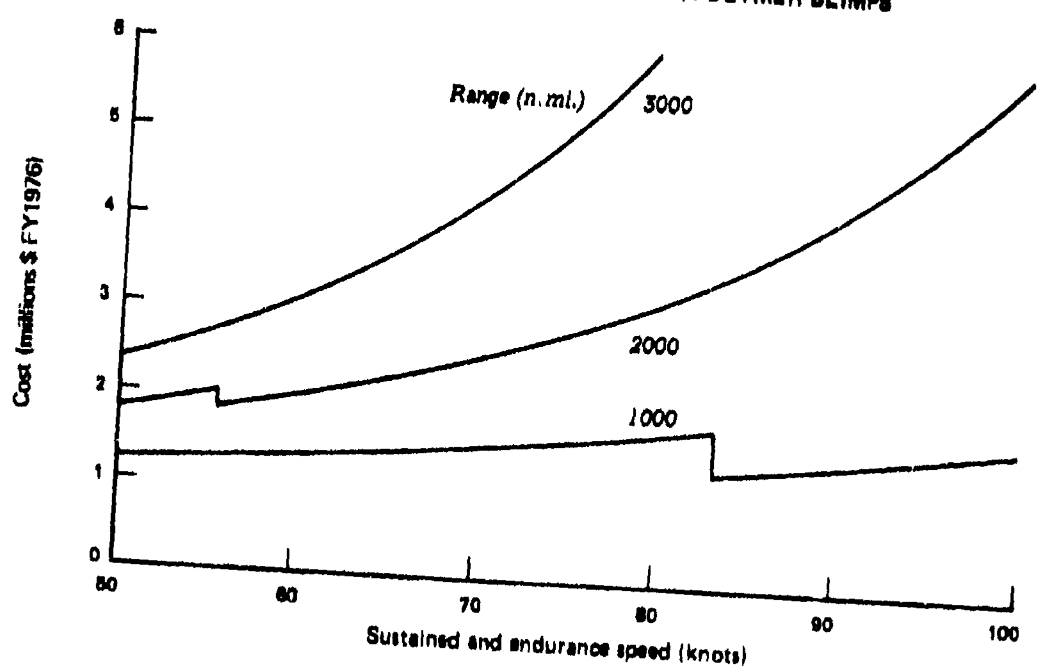


FIG. II-6: COST FOR TURBOPROP/POLYMER BLIMPS

Change of Engine Type and Envelope Material

This section examines the influence of using reciprocating engines and conventional neoprene-Dacron envelope material. Envelope volume and cost ratios (relative to the turboprop blimps) for a second set of blimps are shown in figures II-7 and II-8. This set differs from the reference set in that horizontal-opposed reciprocating engines were specified instead of turboprop engines. Generally, blimps with reciprocating engines required smaller volumes than the same case with turboprops. This result occurs because the estimated specific fuel consumption is lower for the reciprocating engines, even though the estimated engine weight per horsepower is larger. The decreases of envelope volume are greatest for low speed and long range cases.

The cost ratios, shown in figure II-8, are larger than the envelope volume ratios. Even though the volume ratio is less than unity for blimps with reciprocating engines and a range of 1,000 miles, the cost ratio is equal to or greater than unity. A significant cost reduction is found only for the blimps with ranges of 2,000 and 3,000 miles.

In chapter 6 of volume III it is shown that 1976 reciprocating engines are principally horizontal-opposed configurations up to about 450 horsepower. In contrast, turboprop engines are available in ratings from about 400 to 4,000 horsepower. Thus, turboprop engines are not available for the 50- and 60-knot turboprop blimps of table II-3; and recriprocating engines are not available for the 80-, 90-, and 100-knot blimps. At 70 knots, both types of engines are available. When engine sizes are not available, development costs would be required to provide the desired engine.

A preliminary screening of the cost effectiveness of blimps indicated that the speeds that require turboprop engines are desirable for Coast Guard missions. Therefore, the turboprop-polymer reference set was used in the cost effectiveness analysis.

The principal alternative to using 1976 polymer-film envelope material is 2-ply neoprene-Dacron, which was originally developed in the 1940s. Since then its strength and durability have been improved. Goodyear uses neoprene-Dacron in their advertising blimps. However, neoprene-Dacron material still has a greater weight for given strength than the 1976 polymer-film materials. The ratios of envelope volume and investment cost for blimps using neoprene-Dacron envelope material (relative to the reference set) are shown in figures II-9 and II-10. This set is 25 to 70 percent larger and costs 40 to 90 percent more than the reference set constructed with polymer-film materials.

Design Altitude and Off-Design Performance

Airship volume and investment cost increase when the design cruise altitude is increased. Use of optimum aerodynamic lift, and all other conditions except design altitude, were kept constant. The variation of the ratio of envelope volume to the volume for a

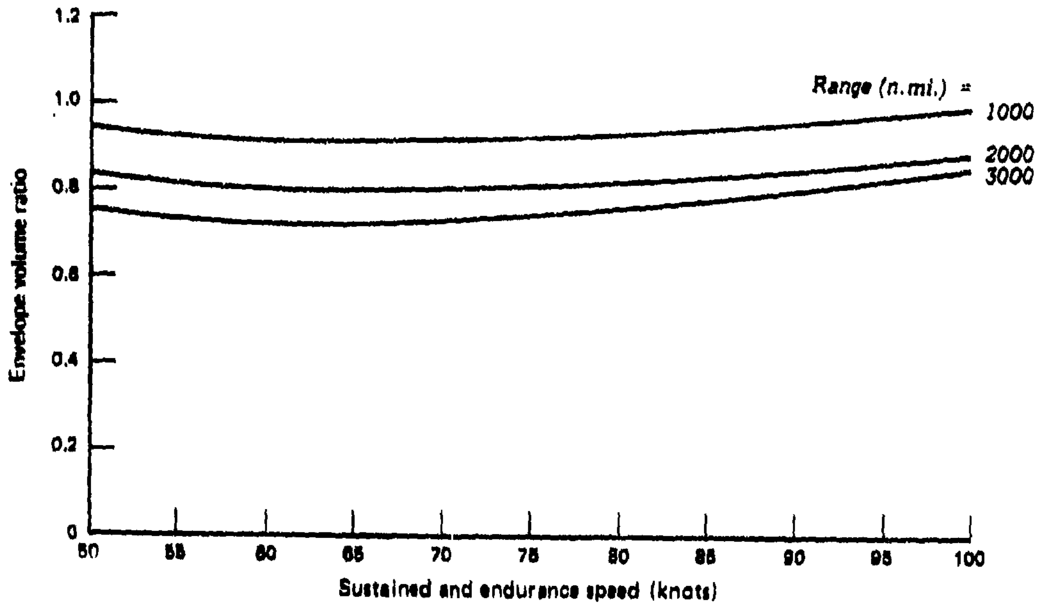


FIG. II-7: VOLUME RATIO FOR RECIPROCATING/POLYMER BLIMPS

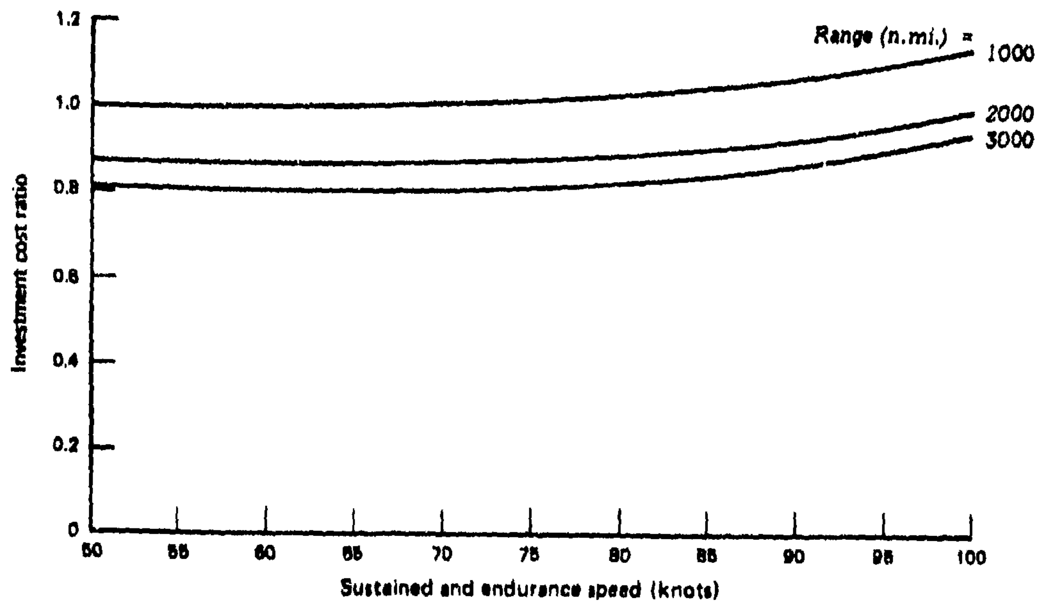


FIG. II-8: COST RATIO FOR RECIPROCATING/POLYMER BLIMPS

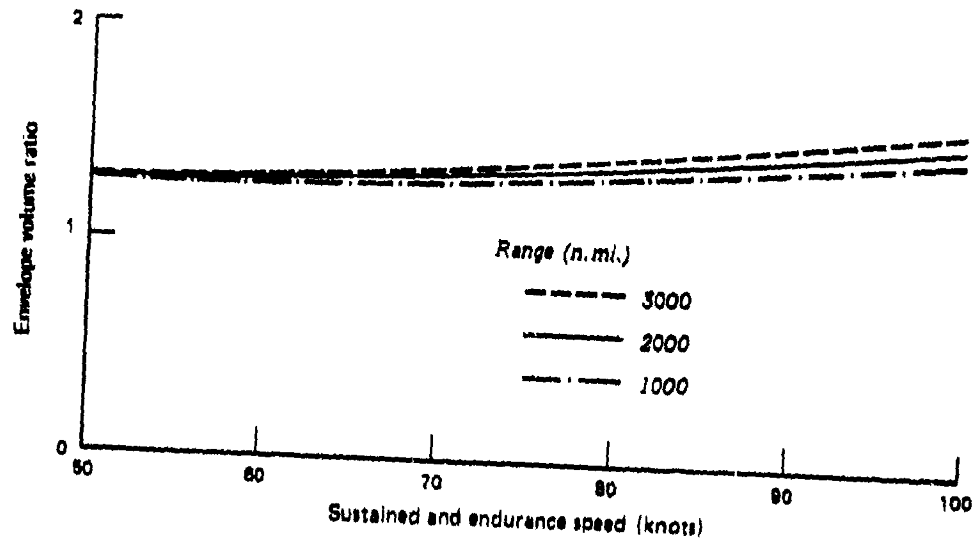


FIG. II-9: VOLUME RATIO FOR TURBOPROP/NEOPRENE BLIMPS

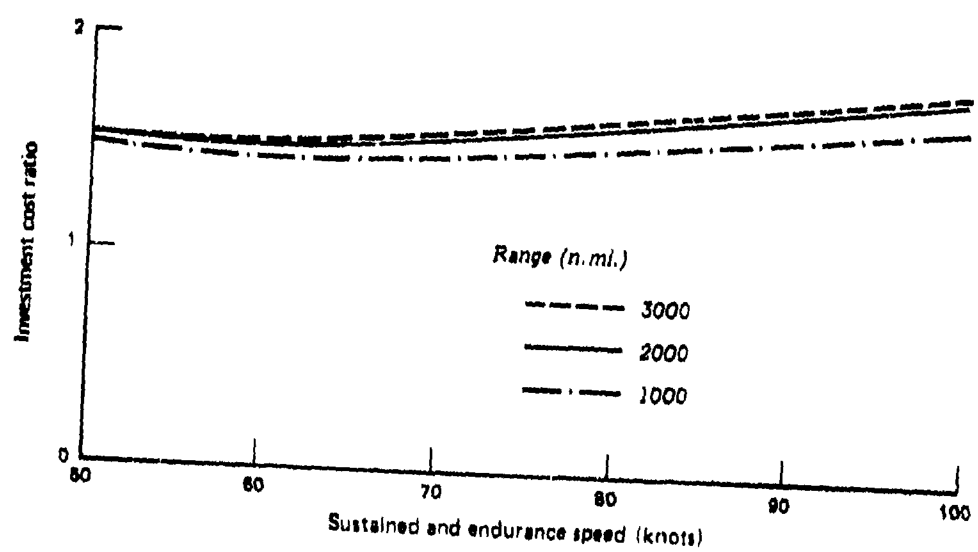


FIG. II-10: COST RATIO FOR TURBOPROP/NEOPRENE BLIMPS sea level design altitude is shown in figure II-11 as a function of design altitude for three speed and range combinations. The ratio of the basic construction cost for a sea level design for the same cases is shown in figure II-12. Blimps with a design cruise altitude of 10,000 feet are approximately 80 percent larger and cost about 60 percent more than similar blimps designed to cruise at sea level.

Historically, airships had sustained speeds of about 80 knots, but they normally operated at lower operating speeds in order to increase operating range and flight duration. The conceptual design model can take into account such specifications.

CHARACTERISTICS OF OTHER VEHICLES

Other Coast Guard vehicles considered in this study are listed in table II-5. The table includes operational, planned, and proposed resources. Resources not yet in the Coast Guard inventory are the MRS, HH-X, Flagstaff II, and HEC-MEC.

The MRS is the planned replacement for the medium range surveillance aircraft, the HU-16E. The MRS is a small jet-aircraft (Falcon 20G) similar in size (about 31,000 pounds gross weight) to a twin-engined executive airplane. The performance estimates in table II-5 were made by CNA based on data obtained from the Coast Guard Aviation Branch.

The HH-X is a possible replacement for the HH-52 helicopter. Although the design of the replacement helicopter is not firm at this time, the HH-X is assumed to be a twin-engine helicopter based on the Sikorsky S-76 design, weighing less than 10,000 pounds. The study assumed that the HH-X would be equipped with a radar and a navagational package, and would have a cruising speed of about 125 knots. Helicopter range and endurance in table II-5 are CNA estimates for the no-hover case.

Flagstaff II is a proposed version of the existing U.S. Navy PGH-1, FLAGSTAFF, built by the Grumman Aerospace Corporation. Flagstaff II is the smallest, and most cost-effective, of the 4 hydrofoils considered in the Hydrofoil Study. As proposed by the Grumman Aerospace Corporation, it is 87 feet long with a full load displacement of 83 tons. The design has been modified to provide longer struts than installed on the Flagstaff I, for greater capability in high sea states. Flagstaff II also has hullborne propeller propulsion for greater endurance, and a modern gas turbine engine. Range and endurance performance for mixed foilborne/hullborne operations was based on figure 6 of the Hydrofoil Study (volume I).

The HEC-MEC is a new cutter currently being designed by the Coast Guard. This ship would be larger than the current WMEC-210, but considerably smaller than the WHEC-378. The performance capabilities of the HEC-MEC would also be closer to those of the WMEC-210 than the WHEC-378. A maximum speed of 18-20 knots is

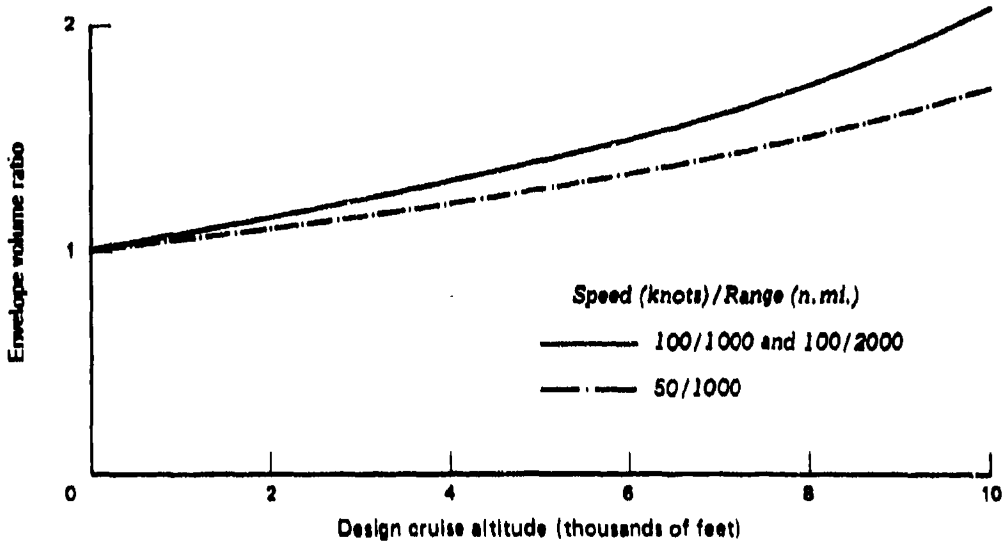


FIG. II-11: VOLUME RATIO vs. CRUISE ALTITUDE

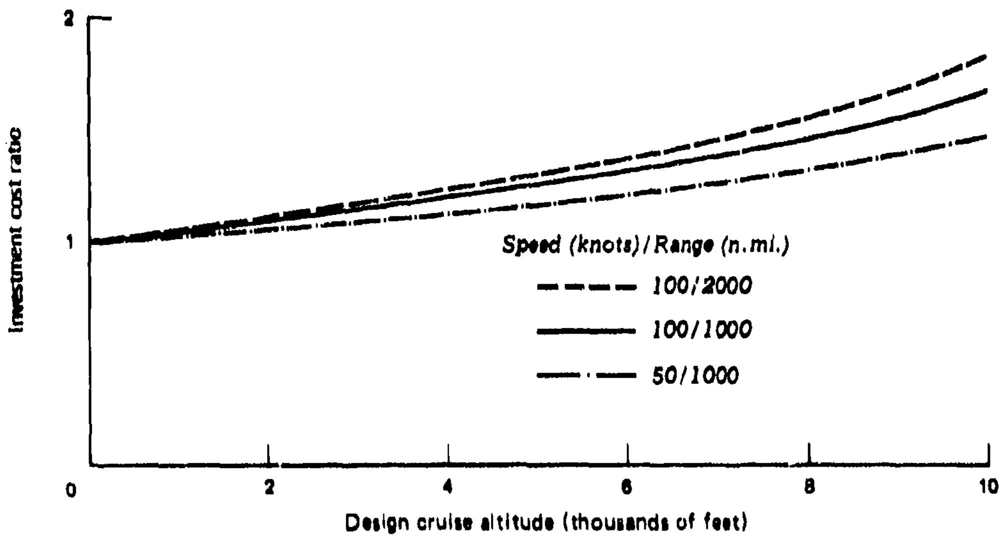


FIG. II-12: COST RATIO vs. CRUISE ALTITUDE currently planned, and the HEC-MEC would be capable of carrying a small helicopter, such as the HH-52 or HH-X.

TABLE II-5

CHARACTERISTICS OF OTHER VEHICLES

Vehicle	Speed (kts.)	Range (mi.)	Endurance (hrs.)
Fixed-wing aircraft			
MRS	375(230)[a]	1690	4.5
HC-130	290(210)[a]	3440	11.8
Helicopters			
HH-X	125	530	4.2
HH-3	126	720	5.7
Hydrofoil			
Flagstaff II	45(48)[b]	1035	23
Cutters			
WMEX-210	18	2700	150
HEC-MEC	18	3000	167
WHEC-378	29	3000	103(753)[c]

[a]Transit speed (low altitude search speed)

[b]Transit speed (search speed)

[c]Endurance at 19 knots

Fuel consumption rates for these vehicles are listed in table II-6; except for the MRS aircraft, they are based on tables 5 and 10 of the Hydrofoil Study (volume I). The MRS fuel rate is based on a Coast Guard estimate of 1,900 pounds per hour.

The sweepwidths (effective search pathwidths) assumed for vehicles performing surveillance in this study are given in table II-7 for two target sizes -- medium and small.

Except for the LTA, sweepwidths against medium targets are the same as those presented in table 6 of the Hydrofoil Study (volume I); they are assumed to be twice the detection range perpendicular to the search path. The detection ranges were estimates of current Coast Guard radar capabilities.

The cutter radars are surface search radars. A detection range of 18 miles against a 50-foot target was assumed. This performance assumption is typical for a good surface search radar.

TABLE II-6

FUEL CONSUMPTION RATES

Resource	Speed (kt.)	Fuel rate (gal./hr.)
MRS	230 (low alt.)-375 (high alt.)	285
HC-130	210 (3 engines, low alt.)	642
	290 (4 engines, high alt.)	556
HH-X	125	91
HH-3	126	186
Flagstaff II	10	40
	45	225
	48	262
WMEC-210	low (1 engine idle)	20
	14	108
	18	315
HEC-MEC	low (1 engine idle)	49
	14	172
	18	245
WHEC-378	low (1 engine idle)	97
	19	344
	29	2514

The radars presently aboard the HH-3 and HC-130 are basically for navigation purposes and were not designed for surface search. Aircraft navigation radars are generally sector scanners, and search a sector of 30-45 degrees to either side of the aircraft heading. Sector scanning reduces the perpendicular detection radius of the platform and therefore reduces the sweepwidth. Future Coast Guard radars are expected to be designed specifically for surface search activities. The detection ranges for medium targets given in table II-7 are estimates of current Coast Guard capabilities against targets of approximately 500 square meters, which is assumed to represent the radar return characteristics of a typical foreign trawler. No data were available from the Coast Guard to substantiate these assumptions.

TABLE II-7

SURVEILLANCE SWEEPWIDTHS

Resource	Medium targets: Detection range perpendicular to path (mi.)	Medium targets: Sweepwidth (mi.)	Small targets: Sweepwidth (mi.)
Airships			
LTA	30	60	38
Fixed-wing aircraft			
MRS	25	50	25
HC-130	25	50	25
Helicopters			
HH-X	20	40	20
HH-3	20	40	20
Hydrofoil			
Flagstaff II	18	36	18
Cutters			
WMEC-210	18	36	18
HEC-MEC	18	36	18
WHEC-378	18	36	18

Many targets of interest in the SAR, MEP and AN missions are smaller than the typical targets in the ELT mission. Small boats (20-30 feet), for example, have radar cross-sections of a few square meters.

One of the principal targets of interest in the MEP mission is oil on the water surface. One of the sensors of the Airborne Oil Surveillance System (AOSS) is a side-looking radar that can detect oil by the reduction in radar scattering caused by the oil-covered water surface.

Detection of small targets depends greatly on environmental factors (principally sea state) and sensor capability. Platform speed should also influence small-target detection. In view of the limited data available, it was necessary to make rough assumptions concerning sweepwidths for the case of small targets. Except for the LTA, it was assumed that the sweepwidth for small targets would be 1/2 the sweepwidth for medium targets. For the purpose of comparing LTA vehicles with other vehicles, it is the relative sweepwidth that is most important. The slow speed of the LTA vehicles permits relatively more looks at a target, and should result in larger sweepwidths compared to the higher speed fixed-wing aircraft. Comparative data is available in reference 6, which reports on the operation of ZPG-3W airships in the off-shore radar barrier in 1957 and 1958. Against aircraft targets, the airships were shown to be about 50 percent more effective than aircraft in detection. Both types of vehicles employed the APS-20 radar. While the significance of this difference in performance may be related more to vehicle altitude differences than speed differences, some advantage should be credited to slower search speed and increased opportunities for detection.

The LTA sweepwidths given in table II-7 are based on the assumptions that the LTA vehicles will have a 20 percent higher sweepwidth than fixed-wing aircraft against medium size targets, and 50 percent higher sweepwidth against small targets.

III. COST ANALYSIS

INTRODUCTION

This chapter presents cost estimates expressed in FY 1976 constant dollars for the family of airships and other vehicles described in chapter II. Airship costs are treated in more detail in appendix F, volume II. Airship investment costs are based on the production cost estimates made in chapter 8, volume III.

Costs are first computed on an annual basis and then reduced to an hourly basis; these consist of 2 major categories: investment costs and operating costs. These major components can be broken down into operating costs that include personnel, maintenance, and fuel, and annual investment cost that is the acquisition cost of the vehicle amortized over its expected lifetime. Thus, there are four cost components. This cost is for vehicles assigned to an operational squadron. It does not include investment costs for vehicles in major overhaul or pipeline status. Hourly costs (or the cost attributable to each hour of operation) are obtained by dividing the annual utilization rate into annual cost.

Costs for vehicles other than airships are based on FY 1975 costs presented in the Hydrofoil Study (reference 4). Major differences between the two studies are (1) translating costs to FY 1976 dollars, (2) using increased fuel costs per gallon, and (3) revising personnel costs according to the Coast Guard version of the Navy Billet Model.

Airships are compared to other vehicles on the basis of total costs per hour of operation. A sensitivity analysis shows the effects of changes in airship utilization rate and uncertainties in the 4 cost components that comprise total hourly cost: personnel, maintenance, fuel, and investment.

AIRSHIP COSTS

Costs of airships are related to vehicle size and weight, which in turn vary with speed and range. The cost determining characteristics - volume, empty weight, and fuel consumption rate - are presented in table III-1. Endurance is defined and calculated on the basis of maximum cruise speed rather than most economical speed.

We develop investment and operating costs for a utilization rate of 3,000 hours per year based on two aircrews per airship. Personnel and total costs are also presented for a utilization rate of 1,500 hours per year, corresponding to the case of a single aircrew per airship. Airship utilization rate is treated more fully in appendix D, volume II.

TABLE III-1

AIRSHIP CHARACTERISTICS

Speed (kts.)	Range (mi.)	Volume (cu. ft.)	Empty weight (lbs.)	Fuel consumption rate (gal./hr.)
50	1000	319,000	9,800	23
	2000	514,000	14,400	30
	3000	727,000	18,700	37
60	1000	347,000	11,100	40
	2000	569,000	15,900	52
	3000	980,000	24,900	71
70	1000	377,000	12,500	62
	2000	709,000	19,900	88
	3000	1,360,000	34,400	129
80	1000	408,000	14,200	93
	2000	903,000	25,700	144
	3000	1,958,000	49,800	227
90	1000	340,000	11,800	112
	2000	1,188,000	34,500	231
	3000	2,854,000	72,900	394
100	1000	374,000	13,800	157
	2000	1,623,000	47,900	372
110	1000	411,000	16,400	215
	2000	2,322,000	69,400	606
120	1000	465,000	19,700	293

Airship investment cost is based on the average cost per pound of empty weight for a buy of 20 airships, estimated in volume III. The annual investment cost is based on an expected lifetime of 10 years at the utilization rate of 3,000 hours per year. Airship lifetime and its relationship to utilization rate are examined in appendix D.

Personnel costs are based on the air and ground personnel requirements estimated in appendix E, together with unit personnel costs per year developed in appendix C.

Total maintenance cost includes routine maintenance and major overhaul costs. Routine maintenance cost is based on cost information for U.S. Navy blimp operations in 1957-1959.

Major overhaul costs were assumed to be a percentage of the investment cost and occur at specified intervals.

Fuel costs are obtained using the consumption rates shown in table II-6 together with a cost per gallon supplied by the Navy Fuel Supply Office in November 1975.

The estimated investment and operating costs do not include base and ground support equipment costs. The effect of these costs is not analyzed in the study.

Utilization Rate

Utilization rates achieved historically for blimps in World War II and the late 1950s provided a basis for extrapolation to future operations, using a model of scheduled flight operations.

In discussing utilization rates, it is important to distinguish between three categories of aircraft: assigned, possessed, and available. Assigned aircraft are those belonging to a particular squadron base or away from the base in overhaul. Possessed aircraft are those assigned to a squadron and either physically located at the squadron base or else flying. An available aircraft is one that is assigned to a squadron, located at the squadron base, and either currently flying or else ready to fly.

Historical Utilization Rate

During World War II the K-class blimps were most active in 1943. About 90 percent of the assigned blimps were available, or "on-the-line" in a flying condition. The average utilization rate for these blimps was 3,412 hours per year; the average number of aircrews was between two and three per blimp.

During the late 1950s Airship Airborne Early Warning Squadron One (ZW-1) conducted extensive operations with the larger ZPG-2W class of airships. Four aircrews flew an average of three possessed airships for a total of 5,118 operational hours (nontraining) in a 1-year period, achieving an average utilization rate of 1,706 hours per year per airship. When training flights are included the rate rises to 1,940 hours per year.

Average mission time was about 11.5 hours during World War II; mission time averaged 31.4 hours for the larger ZPG-2W blimp in 1957/1958.

Future Airship Utilization Rate

A model of scheduled airship operations was used in appendix D to estimate future utilization rate capability. Using rough estimates of failure and repair rates, an availability factor of about 84 percent was estimated for 12 hour missions scheduled 6 days per week. In this case the hours flown per week would be 60 hours. Allowing 50 weeks per year, an annual utilization rate of 3,000 hours is obtained.

An airship utilization rate of 3,000 hours per year exceeds the capability of a single air crew. Examination of historical air crew utilization rates indicates that an annual rate of 1,500 hours (monthly rate of 125 hours) per aircrew represents an upper limit for peacetime operations. On this basis, a requirement of 2 aircrews per airship is assumed.

When sorties are scheduled more frequently the model predicts that a theoretical rate per airship of about 4,400 hours per year is possible. Approximately three aircrews would be required to reach this maximum capability.

However, it was found that the cost of adding the third crew was disproportionately high compared to the advantage gained by the higher utilization rate. Therefore, the study assumed 2 aircrews and a 3,000-hour per year utilization rate.

The utilization rate model does provide useful indications of the effects of various parameters, such as mission time. It is shown in appendix D, for example, that utilization rate is very insensitive to an increase in mission time from 12 to 36 hours.

Lifetime

Historical data provide very little basis for estimating the lifetime of airships. For nonrigid airships the envelope lifetime is assumed to increase from the 4 to 5 year estimate for the 1950s to about 10 years in the future, based on the availability of greatly improved envelope materials. The remainder of the vehicle is assumed to have a typical aircraft lifetime of 10 to 20 years, depending on the utilization rate.

While aircraft lifetimes are typically expressed in years, such an approach fails to reflect the significance of differing utilization rates. For future airships we have assumed a total lifetime of 30,000 flight hours, and a 10-year lifetime for the envelope.

Thus, the lifetime is 10 years at the 3,000 hour per year utilization rate, and 20 years at the 1,500 hours per year rate.

Investment Costs

Prototype and production cost data for the 127 K-class blimps built during World War II and the 50 U.S. Navy blimps built during the 1950s were analyzed and updated to estimate specific cost factors in 1976 dollars per pound of empty weight.

The costs are divided into production costs and incremental prototype and engineering costs. The specific incremental costs are $70 per pound for the prototype and $200 per pound for engineering. The unit-one production cost is $170 per pound.

In table III-2 the average specific cost factors are shown for production quantities of 1, 10, 20, and 40 units. These costs are based on a unit-average learning rate of 85 percent. The first column lists the average production costs only; the second column includes the average engineering development, and prototype (increment) costs. These decrease rapidly as they are spread over a larger production quantity.

TABLE III - 2

AVERAGE SPECIFIC INVESTMENT COSTS (1976 dollar/lb.)

Quantity	Production Cost	Production and Incremental Cost
1	170	440
10	121	148
20	105	119
40	75	82

For this study a production quantity of 20 was assumed. Investment costs for the family of airships were calculated using the specific production and incremental cost of about $119 per pound. Helium costs were also added, bringing the total specific cost to about $125 per pound of empty weight.

The airship investment costs presented in table III-3 were obtained using the computer model described in volume III. For the 10-year lifetime the annual costs are one-tenth the indicated acquisition costs. The hourly costs are equal to the annual costs divided by the annual utilization rate of 3,000 hours per year.

Personnel Requirements

Airship personnel are divided into two categories - aircrew and ground personnel. The aircrew includes the flight crew and the payload crew; flight crew operate the airship and payload crew operate the equipment. The ground personnel include the people

TABLE III-3

AIRSHIP INVESTMENT COSTS
(1976 dollars)

Speed (kts.)	Range (mi.)	Acquisition cost ($1,000)	Hourly cost[a] ($/hr.)
50	1000	1,220	41
	2000	1,790	60
	3000	2,350	78
60	1000	1,360	45
	2000	1,970	66
	3000	3,120	104
70	1000	1,530	51
	2000	2,480	83
	3000	4,320	144
80	1000	1,730	58
	2000	3,190	106
	3000	6,250	208
90	1000	1,440	48
	2000	4,270	142
	3000	9,140	305
100	1000	1,680	56
	2000	5,920	197
110	1000	1,980	66
	2000	8,570	286
120	1000	2,370	79

[a]At a utilization rate of 3,000 hours per year.

required to maintain, service and handle the airship on the ground. Details of the analysis of personnel requirements are contained in appendix E.

Air crew

As a point of reference for size of air crews, the K-ships in World War II had crews of 8 to 10 people. Approximately half were assigned to operate the vehicle and half to operate payload equipment. The ZPG-2/2W class airships operated in the 1950s with a flight crew of 8 and payload crews of 6 and 13, respectively. Current fixed wing patrol aircraft, such as the Coast Guard HC-130 and the U.S. Navy P3 aircraft, have flight crews of about 9 to 12 personnel for mission times of approximately 10 to 12 hours.

Flight crews for future airships are estimated in appendix E and vary with mission endurance as shown in table III-4. Payload personnel were assumed to vary with endurance in a similar manner to permit a rotating watch with 2 equipment operators on duty throughout the flight. Total air crew requirements vary from 8 to 14 as shown below.

TABLE III-4

AIR CREW REQUIREMENTS
Total (Officer/Enlisted)

	Crew		
Endurance	Flight	Payload	Air
12 hrs or less	4(2/2)	4(0/4)	8(2/6)
Intermediate	6(3/3)	5(0/5)	11(3/8)
36 hrs or more	8(4/4)	6(0/6)	14(4/10)

The above requirements refer to a single aircrew, or the 1,500 hours per year utilization rate. For the higher utilization rate of 3,000 hours per year the aircrew requirements are doubled.

Ground Personnel

Requirements for ground personnel were based on a review of U.S. Navy operations in the 1950s and information obtained from Goodyear Aerospace Corp. regarding commercial blimp operations. For the one million cubic foot ZPG airship used by the Navy, vehicle maintenance personnel varied from 18 to 24 as utilization rate increased from 1,706 to 2,471 hours per year. See appendix F for further details.

However, fewer maintenance personnel will be required because of technological improvements. Therefore, for future airships, it was assumed that 12 maintenance personnel would be required for a utilization rate of 1,500 hours per year, and that doubling the utilization rate would increase this personnel requirement by 50 percent. Based on a comparison with the small (200,000 cubic feet) commercial blimps, the vehicle maintenance requirement was assumed vary as the square root of the airship volume.

Personnel requirements for payload maintenance were assumed to be 6 and 9 for the 1,500 and 3,000 hours per year rates, respectively.

TABLE III-5

TOTAL GROUND PERSONNEL

Airship volume (millions cu. ft.)	Utilization rate 1,500 hr./yr.	Utilization Rate 3,000 hr./yr.
0.2	11	17
0.5	14	21
1.0	18	27
1.5	21	31
3.0	27	40

The ground personnel requirements calculated as described above are listed in table III-5 for several volumes, from 0.2 to 3.0 million cubic feet.

The total ground personnel requirements are presented graphically in figure III-1 as a function of volume for the 2 utilization rates.

Total Air Crew and Ground Personnel

Air crew and ground personnel requirements for the family of airships are presented in table III-6. The air crew requirements are obtained from the airship endurance and the air crew sizes shown in table III-4. Ground personnel requirements are derived from the airship volumes listed in table III-1 and the requirements shown in figure III-1 as a function of volume. The total personnel requirements are divided into officer and enlisted personnel in appendix E.

The percentage of officers varies from 15 to 20 percent of the total personnel at the higher utilization rate. At the lower utilization rate, the officer percentage is slightly less.

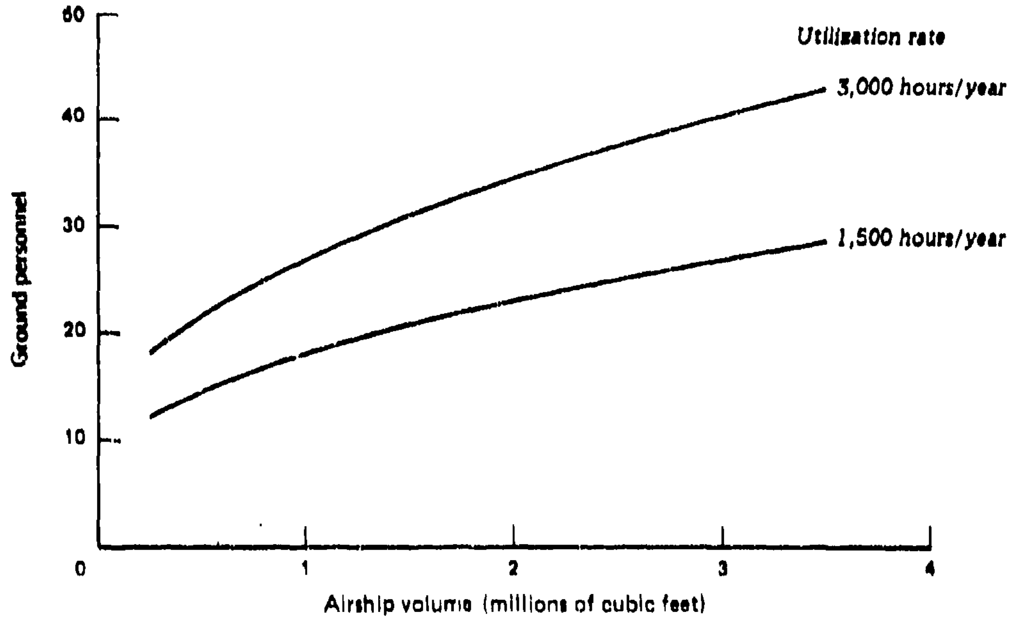


FIG. III-1: AIRSHIP GROUND PERSONNEL REQUIREMENTS

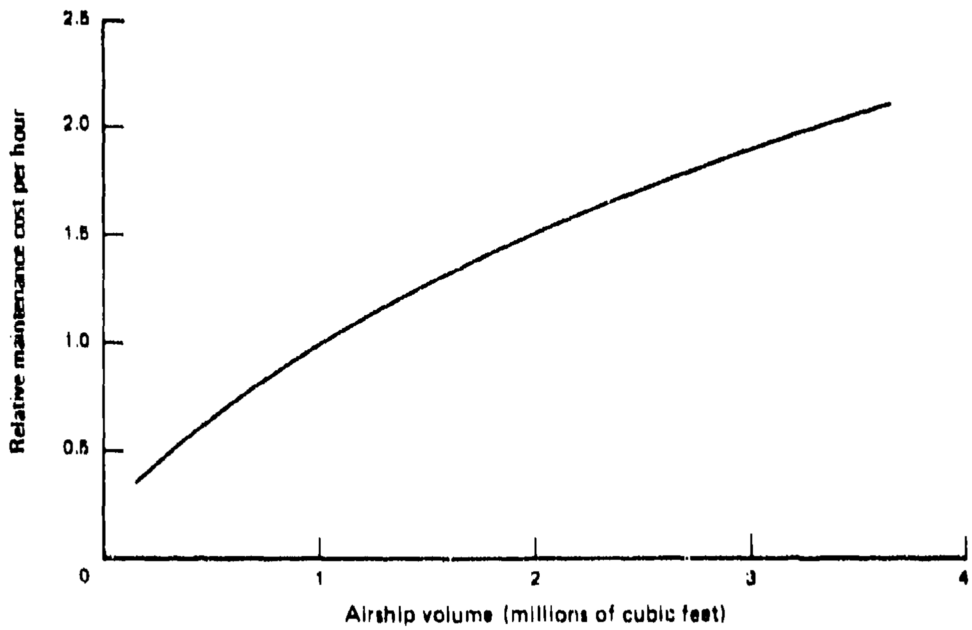


FIG. III-2: RELATIVE MAINTENANCE COST FACTOR

TABLE III-6

AIRSHIP PERSONNEL REQUIREMENTS

Speed (kts.)	Range (mi)	Utilization Rate 1,500 hr./yr. Air	Ground	Total	Utilization Rate 3,000 hr./yr. Air	Ground	Total
50	1000	11	13	24	22	19	41
	2000	14	15	29	28	22	50
	3000	14	16	30	28	24	52
60	1000	11	13	24	22	20	42
	2000	11	15	26	22	23	45
	3000	14	18	32	28	27	55
70	1000	11	13	24	22	20	42
	2000	11	16	27	22	24	46
	3000	14	20	34	28	30	58
80	1000	11	14	25	22	21	43
	2000	11	17	28	22	26	48
	3000	14	23	37	28	34	62
90	1000	8	13	21	16	19	35
	2000	11	19	30	22	29	51
	3000	11	26	37	22	39	61
100	1000	8	13	21	16	20	36
	2000	11	31	32	22	32	54
110	1000	8	14	22	16	21	37
	2000	11	24	35	22	36	58
120	1000	8	14	22	16	21	37

Personnel Costs

Officer and enlisted annual unit costs are presented in table III-7. These costs are based on the personnel costs estimated in appendix C using the Coast Guard Billet Model.

TABLE III-7

ANNUAL UNIT COSTS FOR AIRSHIP PERSONNEL

Billet	Unit Cost (FY 1976 dollars/yr.)
Officers	$59,613
Enlisted	$21,598

Because information was not available on the airship personnel rating requirements, average officer and enlisted costs were assumed to be the same as for the MRS and HU-16E aircraft shown in appendix C.

By comparing the personnel requirements with the annual unit personnel costs, we obtain the personnel costs for the family of airships shown in table III-8 at the 3,000 hours per year utilization rate.

Maintenance and Overhaul Costs

Total maintenance costs are divided into routine maintenance costs (material only) and major overhaul costs. Labor hours for maintenance are accounted for under personnel costs. Overhaul costs, however, include both labor and material, and are estimated as a percentage of investment cost.

Routine maintenance cost is assumed to be a function of airship volume and to vary directly with the utilization rate. Taking a volume of one million cubic feet as a reference, the relative maintenance cost factor varies as shown in figure III-2.

The reference value for one million cubic feet is based on operating costs experienced by airship squadron ZW-1 during a 21 month period in 1957-1959. Maintenance spare parts were found to cost approximately $150 per flight hour. In 1976 dollars this increases to 350 dollars per flight hour.

Major overhauls were assumed to be required every 3 1/3 years and cost 10 percent of investment cost. With a 10-year lifetime, 2 overhauls are required, costing 20 percent of the investment cost.

TABLE III-8

AIRSHIP PERSONNEL COSTS (FY 1976 dollars)
(Utilization rate, 3,000 hr./yr.)

Speed (kts.)	Range (mi.)	Annual Cost ($)	Hourly Cost ($/hr.)
50	1000	1,190,000	397
	2000	1,465,000	488
	3000	1,527,000	509
60	1000	1,201,000	400
	2000	1,277,000	426
	3000	1,590,000	530
70	1000	1,212,000	404
	2000	1,317,000	439
	3000	1,671,000	557
80	1000	1,224,000	408
	2000	1,366,000	455
	3000	1,777,000	592
90	1000	993,000	331
	2000	1,430,000	477
	3000	1,704,000	568
100	1000	1,006,000	335
	2000	1,514,000	505
110	1000	1,019,000	340
	2000	1,629,000	543
120	1000	1,038,000	346

At the lower utilization rate the lifetime increases to 20 years and additional overhauls are required. A special overhaul that costs one-third of the investment cost, is assumed to be required at 10 years to replace the envelope and recover the empennage. Total overhaul cost in this case adds up to 73 percent of the investment cost.

Total maintenance costs for the reference family of airships are presented in table III-9 for the 3,000 hours per year utilization rate. The major overhaul costs are a small fraction (4 to 8 percent) of this total. Appendix F includes more detailed information on maintenance costs by type and utilization rate.

Fuel Costs

A cost of 40.8 cents per gallon is assumed for JP-5 fuel. This price was supplied by the Navy Fuel Supply Office in November 1975.

Combining the cost per gallon with the fuel consumption rates shown in table III-1, we obtain the results shown in table III-10.

Total Costs

The component costs estimated above are combined in table III-11 to determine total hourly costs. Total operational costs for airship ranges of 1,000 and 2,000 miles are also presented graphically in figures III-3 and III-4, respectively. The fractional distribution of these hourly costs is shown in figures III-5 and III-6, respectively.

For the 1,000 and 2,000 mile airships the investment cost is only 6 to 17 percent of the total cost. The dominant costs are clearly those for personnel; these vary from 1/3 to 1/2 for the fast airships (20 knot speed) to about 60 percent for the small airships (50 knot speed). Maintenance costs are about 0.3 to 0.37 of the total cost, depending on size. Fuel costs are the smallest, varying from 2 to 16 percent as size and speed increase.

Airship Cost Sensitivity

The sensitivity of total hourly costs to changes in utilization rate and the component costs is discussed in this section.

The effect of utilization rate is indicated in table III-12. In all cases the cost is between 10 and 15 percent less at the higher utilization rate. As was shown above the reductions are smaller when the other cost components are included, because these costs are either constant or almost constant on an hourly basis.

The sensitivity of the total hourly cost to 50 percent changes in the component costs is illustrated in table III-13. Changes in personnel cost have the greatest effect, varying from 31 percent for the smallest airship to 17 percent for the largest. Changes in

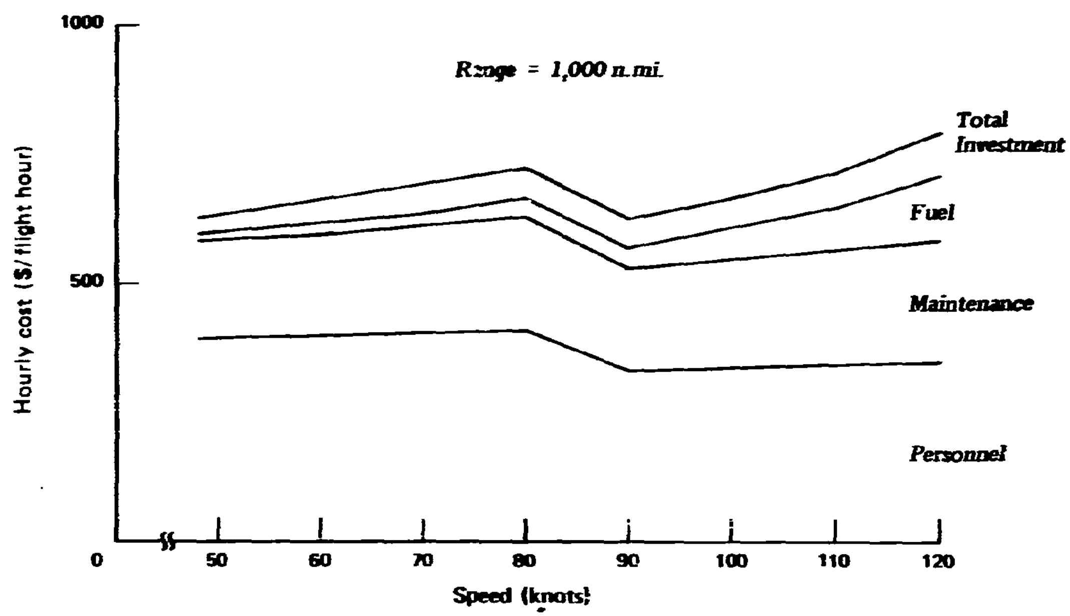


FIG. III-3: TOTAL AND COMPONENT HOURLY COSTS

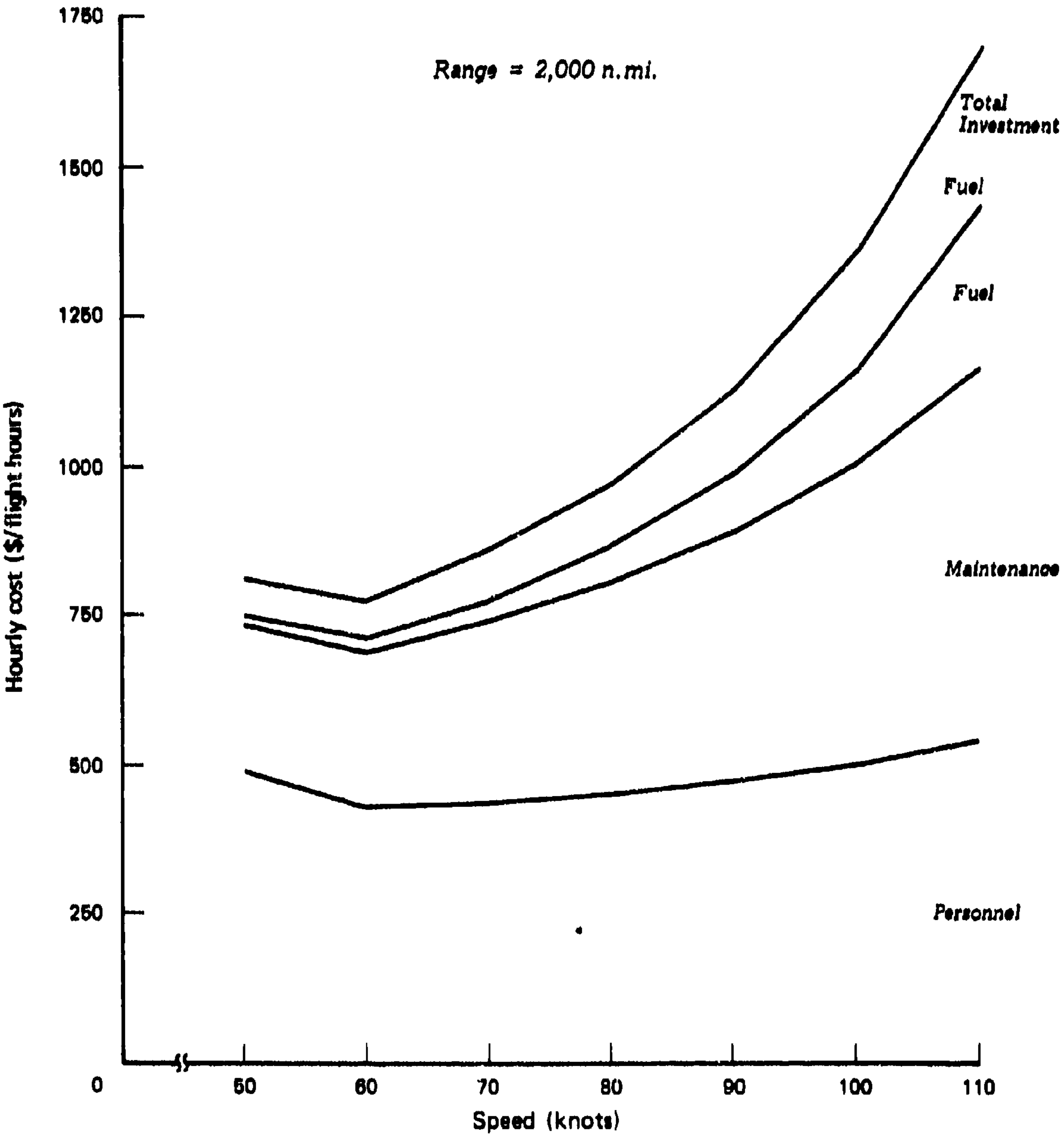


FIG. III-4: TOTAL AND COMPONENT HOURLY COSTS

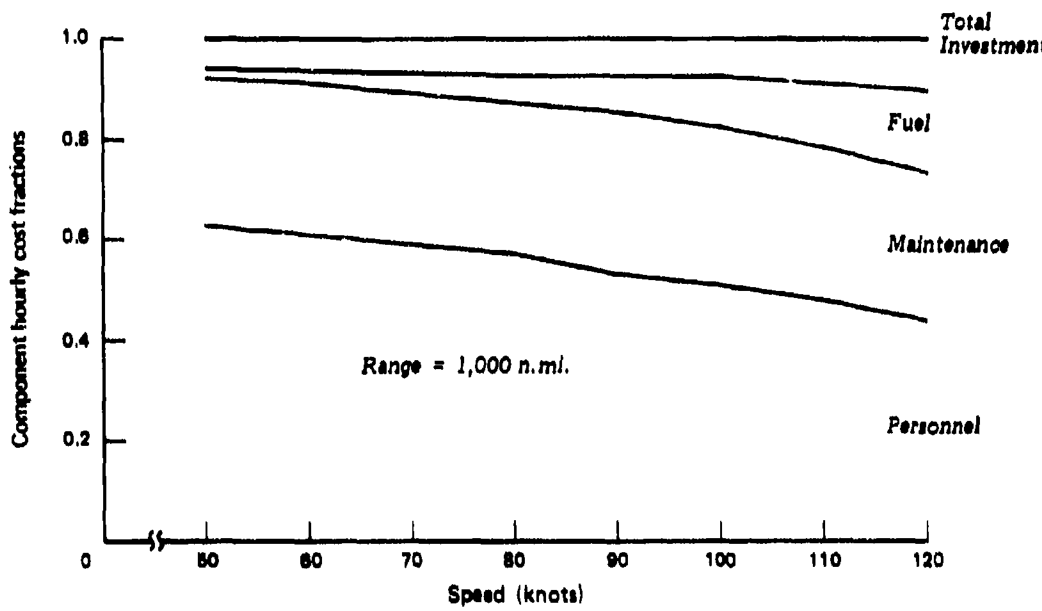


FIG. III-5: DISTRIBUTION OF HOURLY COSTS

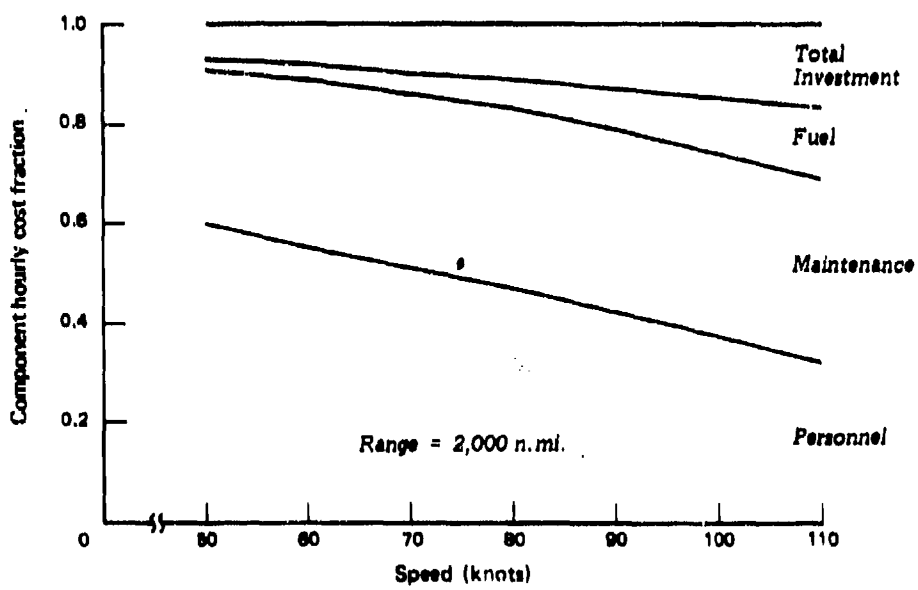


FIG. III-6: DISTRIBUTION OF HOURLY COSTS

TABLE III-9

AIRSHIP TOTAL MAINTENANCE COST (1976 dollars)

Speed (kts.)	Range (mi.)	Annual Cost ($)	Hourly Cost[a] ($/hr.)
50	1000	562,000	187
	2000	747,000	249
	3000	919,000	306
60	1000	592,000	197
	2000	794,000	265
	3000	1,100,000	367
70	1000	624,000	208
	2000	908,000	303
	3000	1,343,000	448
80	1000	656,000	219
	2000	1,053,000	351
	3000	1,680,000	560
90	1000	588,000	196
	2000	1,247,000	416
	3000	2,122,000	707
100	1000	624,000	208
	2000	1,513,000	504
110	1000	664,000	221
	2000	1,890,000	630
120	1000	718,000	239

TABLE III-10

AIRSHIP FUEL CONSUMPTION RATES AND COSTS (FY 1976 dollars)

Speed (kts.)	Range (mi.)	Fuel Consumption Rate (gal/hr.)	Hourly Cost ($/hr.)
50	1000	23	9
	2000	30	12
	3000	37	15
60	1000	40	16
	2000	52	21
	3000	71	29
70	1000	62	25
	2000	88	36
	3000	129	52
80	1000	93	38
	2000	144	59
	3000	227	93
90	1000	112	46
	2000	231	94
	3000	394	161
100	1000	157	64
	2000	372	152
110	1000	215	88
	2000	606	247
120	1000	293	120

TABLE III-11

AIRSHIP HOURLY COSTS (FY 1976 dollars)

(Utilization rate, 3,000 hr./yr.)

Speed (kts)	Range (mi)	Personnel ($/hr)	Maintenance ($/hr)	Fuel ($/hr)	Total Operating cost ($/hr)	Investment ($/hr)	Total Cost ($/hr)
50	1000	397	187	9	594	41	634
	2000	488	249	12	750	60	810
	3000	509	306	15	830	78	909
60	1000	400	197	16	614	45	659
	2000	426	265	21	712	66	777
	3000	530	367	29	926	104	1,030
70	1000	404	208	25	637	51	688
	2000	439	303	36	778	83	860
	3000	557	448	52	1,057	144	1,201
80	1000	408	219	38	665	58	722
	2000	455	351	59	865	106	971
	3000	592	560	93	1,245	208	1,454
90	1000	331	196	46	573	48	621
	2000	477	416	94	986	142	1,129
	3000	568	707	161	1,436	305	1,741
100	1000	335	208	64	607	56	663
	2000	505	504	152	1,161	197	1,358
110	1000	340	221	88	649	66	715
	2000	543	630	247	1,420	286	1,706
120	1000	346	239	120	705	79	784

TABLE III-12

AIRSHIP HOURLY COSTS VS. UTILIZATION RATE
(FY 1976 dollars)

Speed (kts.)	Range (mi.)	Utilization Rate 1,500 hr./yr.	Utilization Rate 3,000 hr./yr.
50	1000	710	634
	2000	903	810
	3000	1,019	909
60	1000	739	659
	2000	876	777
	3000	1,161	1,030
70	1000	772	688
	2000	972	860
	3000	1,362	1,201
80	1000	811	722
	2000	1,101	971
	3000	1,660	1,454
90	1000	701	621
	2000	1,285	1,129
	3000	2,013	1,741
100	1000	749	663
	2000	1,553	1,358
110	1000	808	715
	2000	1,960	1,706
120	1000	886	784

TABLE III-13

SENSITIVITY OF TOTAL HOURLY AIRSHIP COSTS TO 50 PERCENT CHANGES IN COMPONENT COSTS
(Utilization rate = 3,000 hrs./yr.)

Speed (kts.)	Range (mi.)	Hourly cost change (percent of total)			
		Personnel	Maintenance	Fuel	Investment
50	1000	31	15	1	3
	2000	30	15	1	4
	3000	28	17	0.5	4.5
60	1000	30	15	1	4
	2000	28	17	1	4
	3000	26	18	1	5
70	1000	29	15	2	4
	2000	25	18	2	5
	3000	23	19	2	6
80	1000	28	15	3	4
	2000	24	18	3	5
	3000	20	19	4	7
90	1000	26	16	4	4
	2000	21	19	4	6
	3000	17	20	4	9
100	1000	25	16	5	4
	2000	18	19	5	8
110	1000	24	15	6	5
	2000	16	19	7	8
120	1000	22	15	8	5

maintenance cost very from 15 to 20 percent as airship size increases. Fuel and investment cost changes are small, less than 8 and 12 percent, respectively, for all airships.

OTHER VEHICLE COSTS

The costs of vehicles other than airships are taken from the hydrofoil study with appropriate updating to 1976 dollars and changes reflecting revised investment and personnel costs and increased fuel costs.

Lifetime and Utilization Rate

Platform life and planned annual utilization of hydrofoils, conventional cutters, helicopters, and fixed wing aircraft are presented in volume I (table 7) of the hydrofoil study. Conventional cutters were assumed to have a 25 year life and a utilization rate of 3,000 hours per year. The corresponding figures for hydrofoils were 20 years and 2,000 hours per year, respectively. Aircraft life expectancies and utilization rates were provided by Coast Guard Headquarters. Table III-14 summarizes the data for the vehicles considered in this study.

Investment Costs

Acquisition costs for other vehicles, presented in table III-15, are obtained by applying cost inflation factors to the FY 1975 costs given in the hydrofoil study (table 7, volume I). For the hydrofoil and cutters, the inflation factor was 14.5 percent, based on the price index presented in volume III. Inflation factors of 12 and 6.9 percent were used for fixed wing and rotary wing aircraft, respectively, based on the wholesale price index for commercial aircraft. (June 1975 to June 1976.)

Dividing the acquisition costs by the lifetimes and utilization rates from table III-14, we obtain the annual and hourly costs shown in table III-15.

Ship Cost Uncertainty

Uncertainties in the hydrofoil and cutter acquisition costs are discussed in the hydrofoil study. It was pointed out that ship-building costs in general have risen dramatically over the past several years, making it difficult to predict the acquisition costs of any new ships with a high degree of certainty, particularly for ships of radically different construction, such as hydrofoils. In view of these uncertainties, the acquisition costs were biased in that study in favor of the conventional cutter, so that possible superiority of the hydrofoil could not be attributed to more favorable acquisition cost assumptions.

Conventional Cutter Costs

The study used costs for conventional cutters, obtained from Coast Guard Headquarters; these were approximately 25 percent lower than costs that can be obtained

TABLE III-14

LIFETIME AND UTILIZATION RATES FOR VEHICLES OTHER THAN AIRSHIPS

Vehicle	Lifetime (years)	Utilization rate (hrs/yr)
Flagstaff II	20	2,000
WMEC-210	25	3,000
HEC-MEC	25	3,000
WHEC-378	25	3,000
HH-X	20	650
HH-3	20	700
MRS	30	1,000
HC-130	25	800

TABLE III-15

INVESTMENT COSTS FOR VEHICLES
OTHER THAN AIRSHIPS
(FY 1976 dollars)

Vehicle	Acquisition cost ($)	Annual cost ($/yr.)	Hourly cost ($/hr.)
FLAGSTAFF II	10,800,000	540,000	270
WMEC-210	17,200,000	688,000	229
HEC-MEC	24,600,000	984,000	328
WHEC-378	37,500,000	1,500,000	500
HH-X	1,400,000	70,000	108
HH-3	2,400,000	120,000	171
MRS	5,400,000	180,000	180
HC-130	7,300,000	292,000	365

by applying Navy shipbuilding indices to the actual costs experienced in building the WMEC-210 and WHEC-378.

Hydrofoil Costs

Acquisition cost estimates for 4 hydrofoils were plotted versus light ship weight (minus payload and growth margin) to provide a basis in the hydrofoil study for estimating cost uncertainties. The $9.4 million cost estimated for FLAGSTAFF II for the hydrofoil study was a cost between the "tooling required" and "no tooling required" cost lines for a buy of 10 ships. These cost lines were based on detailed projected costs of the PHM, a Navy missile patrol boat. The Navy's PHM Project Office provided data on projected costs.

Aircraft Investment Costs

Acquisition costs of the helicopters and the HC-130 fixed wing aircraft were provided in 1975 dollars by Coast Guard Headquarters, Aviation Branch, Office of Operations. An independent assessment of these cost estimates was not made by the hydrofoil study group because of limited resources and because investment costs for aircraft costs are a smaller percent of total costs than they are for cutters. This uncertainty in aircraft cost estimates should not be a serious problem.

The Coast Guard cost estimate for the MRS aircraft was based on plans to acquire medium range search aircraft of the Dassault-Breguet/Falcon Jet Corp., Falcon 20G type. Acquisition cost was estimated to be $5.4 million in 1976 dollars. This cost is about 50 percent greater than the cost estimated in the hydrofoil study, based on a smaller aircraft similar to the Rockwell Sabreliner 75. Considering inflation, the cost increase is only 35 percent.

Personnel Costs

Unit personnel costs were calculated in the hydrofoil study using the Navy Billet Cost Model. Since that time the Coast Guard contracted with B-K Dynamics to develop a similar methodology for computing Coast Guard personnel costs.

A brief description of the Coast Guard Billet Cost Model is presented in appendix C along with detailed unit costs by rating and paygrade in FY 1974 dollars. These unit costs are combined with the personnel requirements to arrive at total annual personnel costs for each vehicle type. These costs are then inflated to FY 1976 dollars, using a factor of 1.1046 (5.2 percent from 1974 to 1975, and 5 percent from 1975 to 1976). Both annual and hourly costs for the vehicles other than airships are presented in table III-16.

TABLE III-16

PERSONNEL COSTS FOR VEHICLES
OTHER THAN AIRSHIPS
(FY 1976 dollars)

Vehicle	Annual personnel cost ($)	Annual utilization (hours)	Hourly personnel cost ($/hr.)
FLAGSTAFF II	299 ,000	2000	150
WMEC-210	1,231,000	3000	410
HEC-MEC	2,200,000	3000	733
WHEC-378	3,017,000	3000	1006
HH-X	305,000	650	469
HH-3	478,000	700	682
MRS	536,000	1000	536
HC-130	794,000	800	993

Maintenance Costs

Maintenance costs for vehicles other than airships are based on the costs presented in table 11 of the hydrofoil study. By applying cost inflation factors to each type of vehicle we obtain the annual and hourly costs in 1976 dollars shown in table III-17.

The maintenance costs for the WHEC-378 and WMEC-210 cutters were based on historical costs taken from "Operating Cost of Coast Guard Cutters," Chief of Staff Budget Division - FY 1973. The cost estimate for the HEC-MEC was computed as 50 percent of the WHEC-378 annual cost.

All maintenance costs for aircraft were obtained directly from the Aviation Branch of the Office of Operations.

The FLAGSTAFF II maintenance cost was estimated in the hydrofoil study assuming the need for a 3-person shore-based maintenance crew, at $20,000 per crew member year. Grumman's estimates were used with modifications to reflect a lower utilization rate for the cost of expendables, repair parts, and shipyard work. Thus, the total annual maintenance cost for FLAGSTAFF II was assumed to be: $46,000 for expendable and repair parts, $20,000 for shipyard work, and $60,000 for shore-based maintenance crew. This came to $126,000 (FY 1975 dollars); projecting this 1975 cost to 1976 dollars, however, requires cost inflation factors that can be approximated only roughly.

Maintenance Cost Inflation Factors

A weighted cost inflation factor for FLAGSTAFF II can be estimated, based on separate materiel and labor cost inflation factors. For this purpose, it is assumed that: (1) the materiel inflation factor is the same as the investment cost inflation factor for ships (14.5 percent) and (2) the labor cost inflation factor is the same as the personnel cost inflation factor (5 percent).

If we assume further that about 25 percent, or $4,000, of the $20,000 shipyard work cost is a materiel cost and the remainder a labor cost the total cost may be considered to be made up of about 40 percent materiel and 60 percent labor costs. The weighted cost inflation factor for FLAGSTAFF II is thus equal to:

$$0.4 \times 14.5 + 0.6 \times 5.0 = 8.8 \text{ percent.}$$

The same procedure is used for the other resources applying a different assumption about the division of materiel and labor costs. In these cases, the maintenance labor cost is considered to be accounted for to a large extent by shipboard maintenance personnel (for cutters) or land-based squadron maintenance personnel (for aircraft). Assuming an 80/20 division between material and labor costs, the following cost inflation factors are obtained: conventional cutters, 12.6 percent; helicopters, 6.5 percent; and fixed-wing aircraft, 10.6 percent.

TABLE III-17

MAINTENANCE COSTS FOR VEHICLES
OTHER THAN AIRSHIPS
(FY 1976 dollars)

Vehicle	Annual maintenance cost ($)	Planned annual utilization (hrs.)	Hourly maintenance cost ($/hr.)
FLAGSTAFF II	137,000	2000	69
WMEC-210	186,000	3000	62
HEC-MEC	274,000	3000	91
WHEC-378	547,000	3000	182
HH-X	142,000	650	218
HH-3	273,000	700	390
MRS	350,000	1000	350
HC-130	390,000	800	488

Fuel Costs

Fuel costs are estimated by applying an inflation factor to the fuel costs presented in tables 9 and 10 of the hydrofoil study (volume I). Updated fuel costs for hydrofoils and conventional cutters are given in table III-18; aircraft fuel costs are given in table III-19.

For this study, a cost of $0.39 per gallon is assumed for marine diesel fuel and $0.408 per gallon for JP-5 fuel. Fuel prices were supplied by the Navy Fuel Supply Office (NFSO) in November 1975 and inflated to 1976 dollars.

Because both cutter and hydrofoil hourly fuel costs are extremely dependent on speed, costs are presented in table III-18 for both low and high speeds.

Except for the MRS aircraft, aircraft fuel costs shown in table III-19 are based on overall annual aircraft fuel consumptions experienced by the Coast Guard. These costs are documented in the CNA hydrofoil study, reference 4.

For existing aircraft, fuel costs represent average values for operational speed profiles actually experienced. Values for the HH-X and MRS aircraft were estimated (refer to table II-6 for fuel consumption rates).

Total Costs

The total cost attributed to each hour of vehicle operation is the sum of the amortized investment cost and the total hourly operating cost. (Total operating cost comprises personnel, maintenance, and fuel hourly costs.) The total and component hourly costs are summarized in table III-20. The same information, omitting the low speed cases for the hydrofoil and conventional cutters, is presented graphically in figure III-7. The distributions of the component hourly costs are shown in figure III-8.

The total hourly costs shown in table III-20 are used directly in performing cost-effectiveness analyses described in the following chapters of this report. The costs of the hydrofoil and conventional cutters were developed for both low and high speeds, so that the amount charged for performing each task would correspond to the speed used in the performance of that task. Because cutters operate over their entire speed ranges, the actual hourly costs would be somewhere between the costs indicated for high and low speeds.

The smallest vehicles in each category have total hourly costs ranging from about $600 for FLAGSTAFF II to about $1,200 for the MRS aircraft. The intermediate size cutter and the larger aircraft have total hourly costs ranging from about $1,200 to $2,100. The largest cutter (WHEC-378) has the greatest hourly cost (about $2,700), at high speed (29 knots); at low speed, the fuel cost is reduced to about $1,700 per hour.

TABLE III-18

FUEL COSTS FOR FLAGSTAFF II AND CONVENTIONAL CUTTERS (FY 1976 dollars)

Vehicle	Speed (smooth water) (kts.)	Hourly fuel cost ($/hr.)
FLAGSTAFF II	10	16
	45	92
	48	107
WMEC-210	low	8
	18	123
HEC-MEC	low	18
	18	95
WHEC-378	low	37
	19	134
	29	980

TABLE III-19

AIRCRAFT FUEL COSTS (FY 1976 dollars)

Vehicle	Annual fuel costs ($)	Planned annual utilization (hrs.)	Hourly fuel costs ($/hr.)
HH-X	24,000	650	37
HH-3	53,000	700	76
MRS	116,000	1,000	116
HC-130	210,000	800	262

TABLE III-20

HOURLY COSTS FOR VEHICLES OTHER THAN AIRSHIPS (FY 1976 dollars)

Vehicle	Personnel ($/hr.)	Maintenance ($/hr.)	Fuel ($/hr.)	Total operating cost ($/hr.)	Investment ($/hr.)	Total cost ($/hr.)
FLAGSTAFF II	150	69	107(16)*	326(235)*	270	596(505)*
WMEC-210	410	62	123(8)*	595(480)*	229	824(709)*
HEC-MEC	733	91	95(18)*	919(842)*	328	1247 (1170)*
WHEC-378	1006	182	980(37)*	2168(1225)*	500	2668(1725)*
HH-X	469	218	37	724	108	832
HH-3	682	390	76	1148	171	1319
MRS	536	350	116	1002	180	1182
HC-130	993	488	262	1743	365	2108

* The low speed case is shown in parentheses.

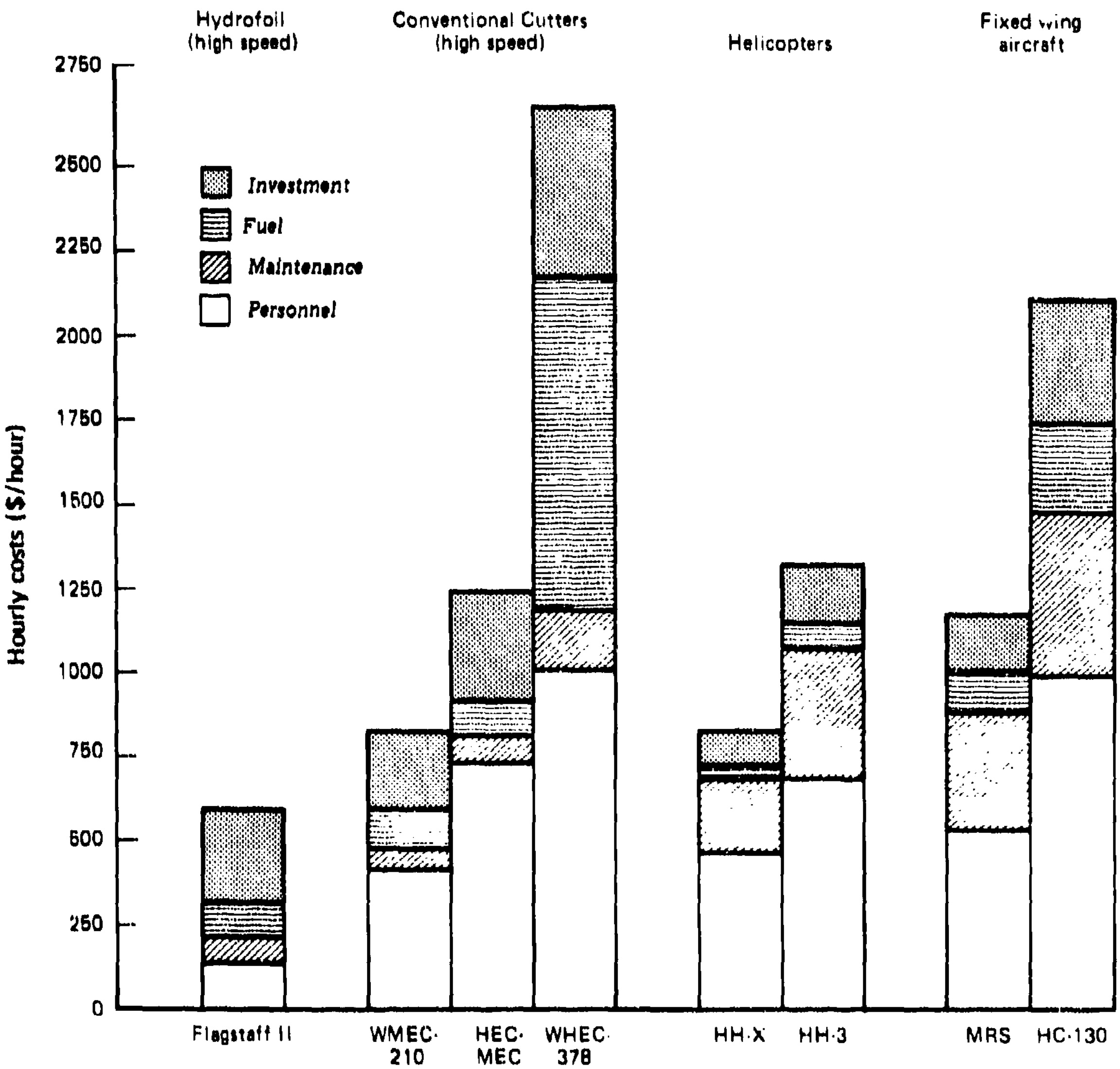


FIG. III-7: HOURLY COSTS FOR VEHICLES OTHER THAN AIRSHIPS (FY 1976 DOLLARS)

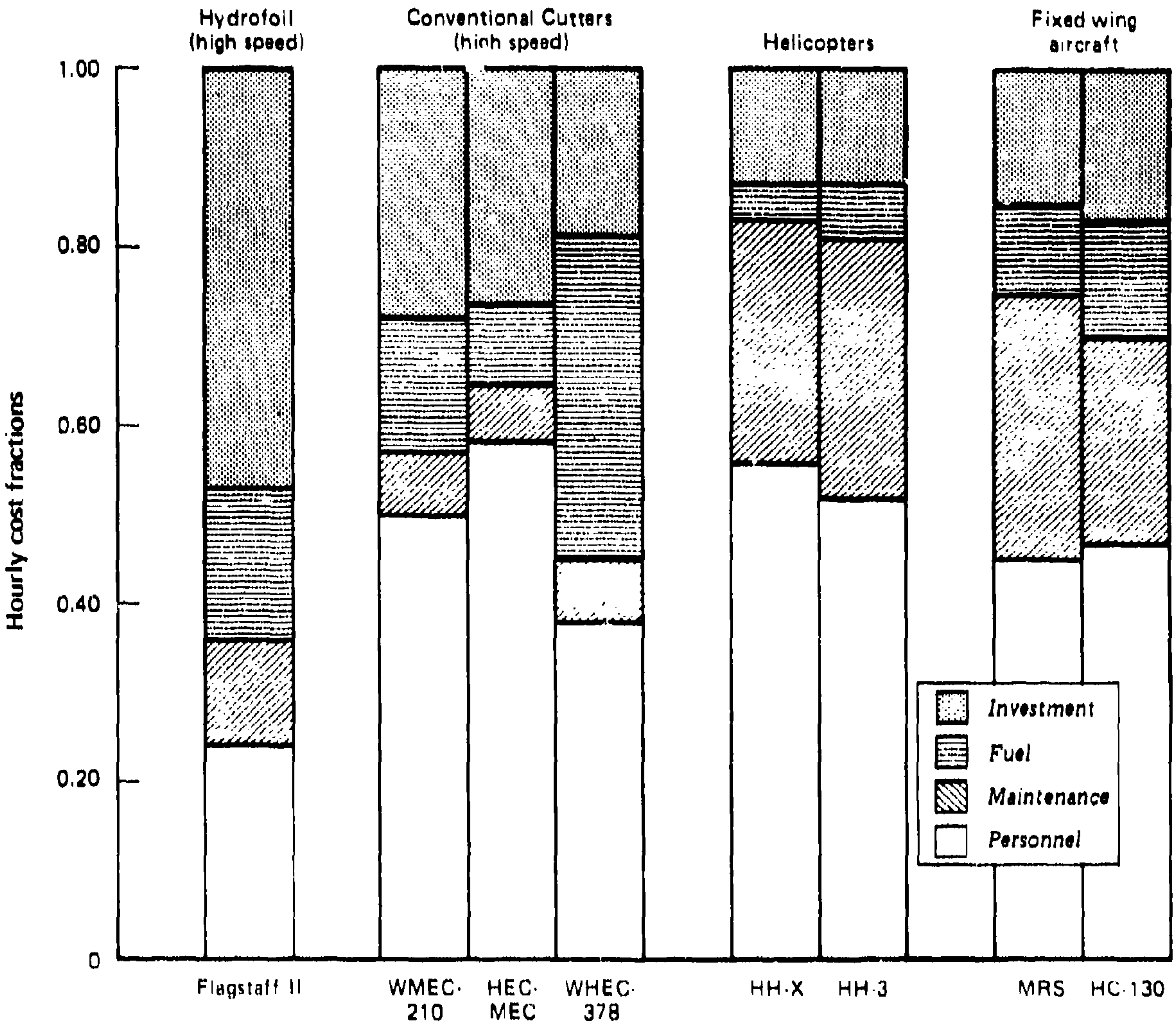


FIG. III-8: HOURLY COST DISTRIBUTIONS FOR VEHICLES OTHER THAN AIRSHIPS (FY 1976 DOLLARS)

For all vehicles except the hydrofoil and the largest cutter, the personnel costs represent the dominant cost component and average about 50 percent of the total hourly cost. In the case of the hydrofoil, the investment cost is the dominant factor, amounting to about half of the total cost. For the largest cutter (at 29 knots), the fuel and personnel costs are approximately equal (about 40 percent).

Maintenance cost is the second largest contributor for all aircraft and varies from 24 to 30 percent of the total. For the hydrofoil and conventional cutters, maintenance cost is the smallest factor, varying from 6 to 12 percent.

Investment is the smallest cost component for aircraft and does not exceed 18 percent. For conventional cutters, the investment costs range between about 18 and 28 percent. As noted above, FLAGSTAFF II has an investment fraction close to 50 percent.

Cost Sensitivity

The sensitivity of the total hourly cost to a 50 percent change in the component costs is illustrated in table III-21 for vehicles other than airships. For all vehicles except the hydrofoil, changes in personnel costs have the greatest effect on total costs. The effect of 50 percent changes in fuel and investment costs is less than 9 percent for all aircraft resources.

For most of the vehicles, the component cost uncertainty is considered to be much less than 50 percent because actual Coast Guard data are available for them.

A rough estimate of the effect of aircraft crew "augmentation" can be made using table III-21. Assuming that a 50 percent increase in annual utilization rate can be obtained by increasing aircraft allowances by 50 percent, the hourly personnel cost would be unchanged; hourly fuel and maintenance cost would also be approximately constant. The hourly investment cost, however, would be decreased 50 percent, resulting in 6 to 9 percent decreases in total hourly costs, as shown in table III-21.

COMPARISON OF AIRSHIP AND OTHER VEHICLE COSTS

The family of airships is compared with the other vehicles on a total hourly cost basis in figure III-9. The costs of the 1,000 mile range airships are between those of FLAGSTAFF II (about $600/hour) and the smallest conventional cutter and helicopter (about $800/hour). These airships are 39 to 47 percent less costly than the MRS aircraft.

The 2,000 mile range airships vary in hourly cost between about $800 and $1,700; the cost of the higher speed airships (100 knots and above) exceeds that of the MRS.

The next chapter compares vehicles on the basis of cost and effectiveness in performing Coast Guard missions.

TABLE III-21

SENSITIVITIES OF TOTAL HOURLY COSTS OF OTHER VEHICLES TO 50 PERCENT CHANGES IN COMPONENT COSTS

Vehicle	Hourly cost change (percent)			
	Personnel	Maintenance	Fuel	Investment
FLAGSTAFF II	12	6	9	23
WMEC-210	25	4	8	14
HEC-MEC	29	4	4	13
WHEC-378	19	3	18	9
HH-X	28	13	2	6
HH-3	26	15	3	7
MRS	23	15	5	7
HC-130	24	12	6	9

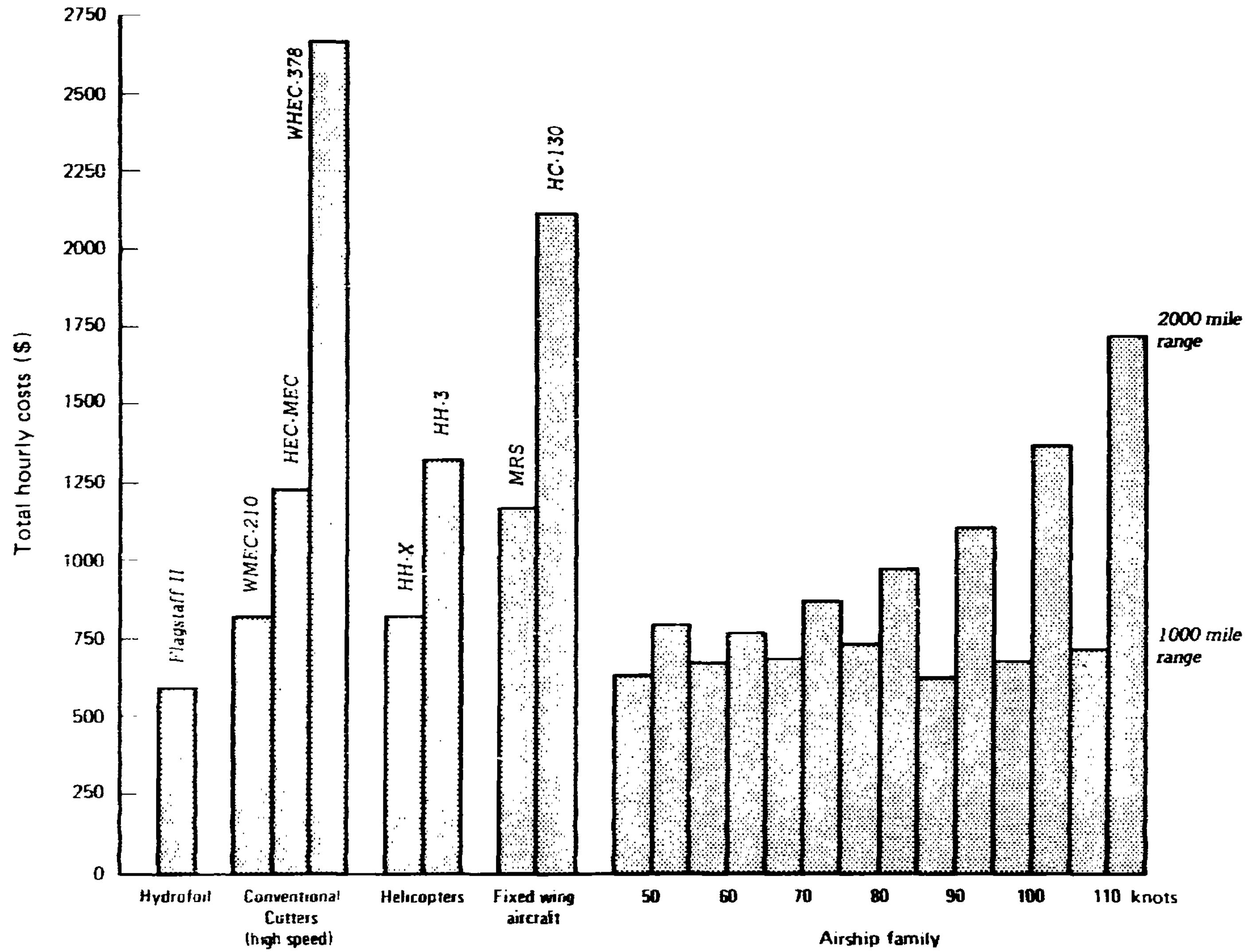


FIG. III-9: COST COMPARISON OF AIRSHIPS AND OTHER VEHICLES (FY 1976 DOLLARS)

IV. TASK ANALYSIS

INTRODUCTION

This chapter compares vehicles on a cost effectiveness basis for a set of mission-related tasks. The tasks considered are those included in the missions of Enforcement of Laws and Treaties (ELT), Search and Rescue (SAR), Marine Environmental Protection (MEP), and Short-range Aids to Navigation (AN). Tasks such as boarding and inspection that apply only to surface craft, are not considered. The tasks considered most appropriate for aviation vehicles involve detection, investigation, observation (or trailing), and transit to station. The tasks examined in the analysis and the corresponding measures of cost/effectiveness are identified. The family of 24 airships is reduced to a set of three airships (LTA 1 (8), LTA 2 (11), and LTA 3 (14)) that are most cost effective in patrol tasks at zero distance to station.[1]

Effectiveness in detection and investigation tasks is influenced directly by vehicle speed. Such tasks are called "patrol" tasks to distinguish them from trailing or observation tasks that depend only indirectly on vehicle speed.

A summary table is presented for each task showing the cost/effectiveness values computed for the reduced set of airships and other vehicles, as well as the values used in the computations.

The investigation of optimum airships for trail tasks required the introduction of an additional 18 airships with increased aircrew size to accommodate the endurances that result from the slow speeds employed in these tasks.

Finally, two summary tables are presented which show, for selected tasks, the cost/effectiveness of each vehicle and the ratios relative to the most cost/effective airships (LTA 1 (8) and LTA 1 (11)) in patrol and trail tasks at zero station distance.

MEASURES OF COST/EFFECTIVENESS

The tasks, or functions, selected for evaluating airships cover the activities that are normally performed in support of the four missions of interest (ELT, SAR, EMP, and AN). These are listed in table IV-1 along with measures of cost/effectiveness selected for analysis. Each of these tasks will be discussed in the following sections of this chapter.

[1] The numbers in parentheses next to the LTA number represent the crew size.

TABLE IV-1

SELECTED TASKS AND DEFINITIONS OF MEASURES OF COST/EFFECTIVENESS

Task	Measure of cost/effectiveness
Patrol tasks	
Transit to station	Cost per mile
Gross surveillance	Cost per square mile
Local surveillance	Cost to perform task
Investigation of dispersed targets	Cost per track mile
Trail tasks	
Trail/observation	Cost per hour
Presence	Cost per hour

Cost/effectiveness is defined as the cost required to provide a unit measure of effectiveness. For most tasks the measures are presented in two ways - cost per effectiveness and the inverse, effectiveness per cost. In the latter form, high values indicate more effectiveness per dollar spent than low values.

The cost/effectiveness measure for vehicles in transit is cost ($) per mile of transit. This is obtained by dividing vehicle cost per hour (developed in chapter III) by vehicle speed (miles per hour), which yields cost per mile:

$$\frac{\text{cost/hour}}{\text{miles/hour}} = \text{cost/mile}$$

It must be remembered that the cost/effectiveness value obtained is speed dependent, since speed not only is the denominator in the equation, but also affects the value of the numerator because of fuel cost. A detailed description of the methodology used in computing cost/effectiveness values for all other tasks is contained in appendix G (volume II).

The cost/effectiveness for two of the tasks in table IV-1 is computed in two different ways: a long-term average and for short terms (three hours) when a cutter-based helicopter is assumed to be flying. This distinction in measuring cost/effectiveness is necessary only for cutter/helo teams. This procedure is necessary because the helicopter, in the long term, can fly only a limited number of hours per day, but is very effective in performing some tasks, such as surveillance, compared with conventional cutters. Therefore, for the long term, a weighted average of performance must be computed; this results in an estimated value of performance of the cutter/helo team that is somewhere between that of the cutter working alone and that estimated for the helicopter when airborne. However, the latter estimate is also of interest because high performance for a relatively short period of time is very important in some situations.

In this analysis, long term average values for cutter/helo teams are computed on an annual basis, assuming 650 flight hours per year for the HH-X helicopter (700 flight hours per year for the HH-3) and 3,000 hours per year for the cutter. This is equivalent to 5.2 flight hours per cutter-day for the HH-X and 5.6 flight hour per cutter-day for the HH-3. These assumed average daily flight hour values are considered to be quite favorable to the cutter/helo teams; i.e., the helicopters are likely to average fewer flight hours per day.

Effectiveness in the transit to station task and investigation of dispersed targets tasks depends only on vehicle speed. The two tasks are treated separately because the speeds involved may differ, and usually do for fixed-wing aircraft that transit at high altitude and search at low altitude.

In the investigation task the effectiveness may also depend on target density, if target investigation involves some delay. In this case, effectiveness is measured by "effective speed," which is the miles made good along the track in the operating area divided by total hours of mission time, including transits to station.

Vehicle and sensor capability are combined in the gross surveillance and local surveillance tasks. Effectiveness in the gross surveillance task is measured by search rate in square miles per hour. Search rate is the product of search speed and sweepwidth, and is a measure of sensor/vehicle detection capability.

Local surveillance is the task of searching a fixed area to achieve a prescribed detection probability. It will be shown to be equivalent to gross surveillance, and depend also on search rate capability in square miles per hour.

The trail/observation task is the task of maintaining close observation on a target ship or tracking a group of ships. Because all vehicles are assumed capable of trailing a target at 15 knots, effectiveness is compared based on the hourly cost to trail while maintaining an average speed slightly higher than 15 knots.

The presence task requires a platform to simply maintain a minimum speed for headway. Cost/effectiveness is thus measured by cost per hour at low speed. The trail task differs to some extent in requiring sufficient speed to keep up with the target under trail or observation. The speed of the target being trailed is a significant factor when the trailing units are surface craft, but the target speed is only a secondary factor for trail by aircraft or airships.

AIRSHIP COST/EFFECTIVENESS IN TRANSIT

The transit to station task will be treated initially for airships. The results of this analysis will be used to reduce the family of 24 airships to a smaller set of three airships designated LTA 1 (8), LTA 2 (11), and LTA 3 (14). Each of these airships is the least cost per mile airship in its endurance class. It will be seen later that these airships are also optimum for all patrol tasks.

The transit to station task is simply the function of moving a platform from one location to another, typically from its base to an area of operation, where it is considered to be "on station." To the extent that the effect of altitude changes during the transit can be neglected, the actual transit distance considered does not effect the cost/effectiveness measure for this task, which is cost per mile. The method used to compute this measure was given as an example in the preceding section of this chapter. For illustrative purposes a transit distance of 500 miles has been assumed, corresponding to a one-way distance to station of 250 miles.

The time, cost, and cost per mile are given in table IV-2 for each of the 20[1] airships with varying speeds and range. The least cost per mile airships (in each range class) are also indicated. In the 1,000-mile range class, the minimum is obtained at 110 knots. This airship is designated the LTA 1 (8). In the 2,000- and 3,000-mile range classes the least cost per mile occurs at 80 and 70 knots, respectively. These are called LTA 2 (11) and LTA 3 (14). The cost per mile comparison is summarized in table IV-3.

TABLE IV-3

LEAST COST/MILE AIRSHIPS[a]

Airship	Speed (kts.)	Range (mi.)	Endurance (hrs.)	Aircrew (no.)	Cost/mile ($/mi.)	Relative (cost/mi.)
LTA 1 (8)	110	1,000	9.1	8	6.5	1.00
LTA 2 (11)	80	2,000	25.0	11	12.1	1.86
LTA 3 (14)	70	3,000	42.9	14	17.2	2.65

[a]Costs are in FY 1976 dollars.

TRANSIT TASK COMPARISON

All vehicles are compared in the transit task (500 mile) in table IV-4 on a cost/mile and miles/cost basis. For convenience, the latter measure is expressed in miles per $1,000 cost. These units are also used in the graphical comparison shown in figure IV-1. For this task the MRS aircraft is clearly superior to all other vehicles,

[1]Four airships with volumes greater than 3 million cubic feet have been deleted from the basic family of 24 airships.

TABLE IV-2

COST/EFFECTIVENESS OF AIRSHIPS IN TRANSIT[a]

500-mile transit

Speed (kts.)	Range (n.mi.)	Time (hrs.)	Cost ($)	Cost/mile ($/mi.)	Least cost/mile airship
50	1000	10.00	6,340	12.7	
	2000	10.00	8,100	16.2	
	3000	10.00	9,090	8.2	
60	1000	8.33	5,490	11.0	
	2000	8.33	6,480	13.0	
	3000	8.33	8,580	17.2	
70	1000	7.14	4,910	9.8	
	2000	7.14	6,140	12.3	
	3000	7.14	8,580	17.2	LTA 3 (14)
80	1000	6.25	4,510	9.0	
	2000	6.25	6,070	12.1	LTA 2 (11)
	3000	6.25	9,090	18.2	
90	1000	5.56	3,450	6.9	
	2000	5.56	6,270	12.5	
	3000	5.56	9,670	19.3	
100	1000	5.00	3,320	6.6	
	2000	5.00	6,790	13.6	
110	1000	4.55	3,250	6.5	LTA 1 (8)
	2000	4.55	7,750	15.5	
120	1000	4.17	3,270	6.54	

a/ Costs are in FY 1976 dollars.

presumably because of high (375-knot) speed. The lower cost per hour of LTA 1 (8) relative to MRS is not enough to overcome the large speed advantage of the MRS aircraft.

TABLE IV-4

COST/EFFECTIVENESS OF VEHICLES IN TRANSIT[a]

Resource	Speed (kt.)	Time (hr.)	Cost ($)	Cost/mile ($/mi.)	Miles/cost (mi./$10^3$$)
LTA 1 (8)	110	4.55	3,250	6.5	154
LTA 2 (11)	80	6.25	6,070	12.1	82
LTA 3 (14)	70	7.14	8,580	17.2	58
MRS	375	1.33	1,572	3.1	317
HC-130	290	1.72	3,630	7.3	138
HH-X	125	4.00	3,330	6.7	150
HH-3	126	3.97	5,240	10.5	96
Flagstaff II	45	10.4	6,040	12.1	83
WMEC-210	18	27.8	22,900	45.8	22
HEC-MEC	18	27.8	34,700	69.3	14
WHEC-378	29	17.2	45,900	92.0	11

[a]Costs are in FY 1976 dollars.

The LTA 1 (8) compares closely with the HC-130 and HH-X and is cheaper than the HH-3 and Flagstaff II in transit. Conventional cutters are the most expensive in transit, but they fulfill other functions that aircraft cannot accomplish, such as boarding and towing.

These results only address the cost of getting to and from stations. Neither remaining time on station nor cost effectiveness in performing tasks are analyzed. Assuming a 500-mile transit distance, the HH-X and HH-3 helicopters would have only .2 and 1.7 hours, respectively, of on-station time at transit speed. If transit distance were greater, neither could reach the assigned area.

GROSS SURVEILLANCE

Effectiveness in the gross surveillance task is measured by the area of ocean a given platform or cutter/helo team can effectively observe on radar in a fixed amount of time. This function does not include detouring to the location of any contacts that might be made to investigate them. The gross surveillance task, for example, might be performed to

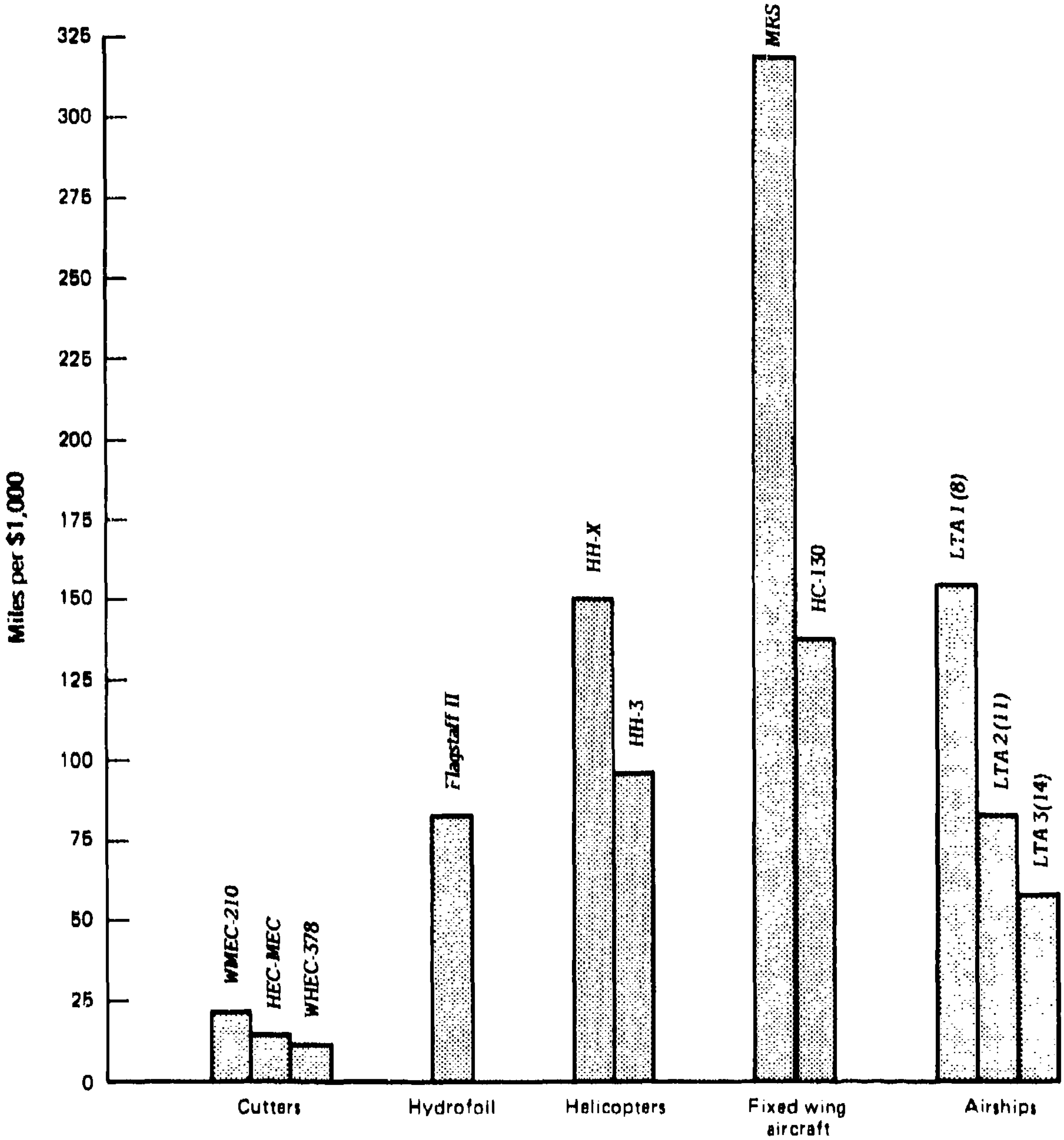


FIG. IV-1: COST/EFFECTIVENESS OF VEHICLES IN TRANSIT (FY 1976 DOLLARS)

locate heavy concentrations of fishing vessels, and would not be disrupted to investigate sparse contacts. Generally, it is a measure of the maximum surveillance capability of each vehicle or combination assigned as a team. As indicated earlier, the measure of gross surveillance effectiveness is search rate, which is equal to the product of vehicle speed and sensor sweepwidth measured in square miles per hour. The sweepwidths assumed for the various vehicles are shown in chapter II (table II-7) against both small and medium size targets.

Gross surveillance is particularly important in the case of search for small targets, such as oil slicks (MEP mission) or small boats in distress (SAR mission). Surveillance in these situations normally involves a planned flight pattern with occasional detours to investigate when a target of special interest appears on the radarscope. Gross surveillance is defined here to include only the search phase of the mission. Short investigation periods are not considered in this analysis.

Detection of small targets is more difficult than for medium and large targets. The performance of the sensor and vehicle differences become critical factors. Relatively unsophisticated sensors are generally adequate to detect larger targets in the ELT mission.

Airship sweepwidths against small targets were assumed in chapter II to be 50 percent greater than fixed-wing aircraft sweepwidths; against medium size targets the airship sweepwidth was assumed to be only 20 percent greater.

Cost/effectiveness of the various vehicles is measured in terms of cost (dollars) per square mile of ocean swept, and inversely, as square miles swept per unit cost. The unit cost in the latter case is $1, 000. Values for the cutter/helo team are computed two ways as previously described in this chapter: a long term average value, and maximum performance as measured during a short (3-hour) helicopter flight. In computing cutter/helo values, the helicopter is not given credit for surveillance area already covered by the cutter. Such double coverage occurs for a short period of time immediately after takeoff and before recovery of the helicopter. The computational methodology is described in appendix G (volume II).

Vehicles are compared against medium and small targets in tables IV-5 and IV-6, respectively. Against medium targets, the MRS has the lowest cost per mile for gross surveillance but the LTA 1 (8) is a close second. In the small target case, the cost per mile of LTA 1 (8) is about 17 percent less than the MRS. This improvement over the transit task is principally due to the reduction in MRS speed from 375 knots in transit (high altitude) to 230 knots in gross surveillance (low altitude). In the small target case, the LTA advantage is helped by the assumption that the LTA sweepwidth is reduced by less than that of the MRS for small targets. The latter case is shown graphically in figure IV-2. The LTA 1 (8) has a large advantage over all other vehicles except the MRS aircraft. The next closest competitor is the HH-X, which has a speed advantage of about 15 percent over the LTA 1 (8).

TABLE IV-5

COST/EFFECTIVENESS OF VEHICLES
IN PERFORMING GROSS SURVEILLANCE
Medium Target

Resource	Speed (kt.)	Sweepwidth (n.mi.)	Search rate (sq.mi./hr.)	Cost[a]/sq.mi. ($/sq.mi.)	Sq.mi./cost (sq.mi./$1,000)
LTA 1 (8)	110	60	6,600	0.11	9,230
LTA 2 (11)	80	60	4,800	0.22	4,940
LTA 3 (14)	70	60	4,200	0.29	3,500
MRS	230	50	11,500	0.10	9,730
HC-130	210	50	10,500	0.20	4,980
HH-X	125	40	5,000	0.17	6,010
HH-3	126	40	5,040	0.26	3,820
Flatstaff II	48	36	1,728	0.34	2,900
WMEC-210	18	36	648	1.27	790
HEC-MEC	18	36	648	1.92	520
WHEC-378	29	36	1,044	2.56	390
WMEC-210+ HH-X	18/ 125	36/40	1,627 (5,168)	0.62 (0.32)	1,620 (3,120)

() based on 3-hour surveillance flight

[a]Costs are in FY 1976 dollars.

TABLE IV-6

COST/EFFECTIVENESS OF VEHICLES IN PERFORMING GROSS SURVEILLANCE

Small Target

Resource	Speed (kt.)	Sweepwidth (n.mi.)	Search rate (sq.mi./hr.)	Cost[a]/sq.mi. ($/sq.mi.)	Sq.mi./cost (sq. mi./$1,000)
LTA 1 (8)	110	38	4, 180	0.17	5, 850
LTA 2 (11)	80	38	3, 040	0.32	3, 130
LTA 3 (14)	70	38	2, 660	0.43	2, 210
MRS	230	25	5, 750	0.21	4, 860
HC-130	210	25	5, 250	0.40	2, 490
HH-X	125	20	2, 500	0.33	3, 000
HH-3	126	20	2, 520	0.52	1, 910
Flagstaff II	48	18	864	0.69	1, 450
WMEC-210	18	18	324	2.54	393
HEC-MEC	18	18	324	3.85	260
WHEC-378	29	18	522	5.11	196
WMEC-210+ HH-X	18/ 125	18/20	814 (2, 584)	1.23 (0.64)	811 (1, 560)

() based on 3-hour surveillance flight

[a]Costs in FY 1976 dollars.

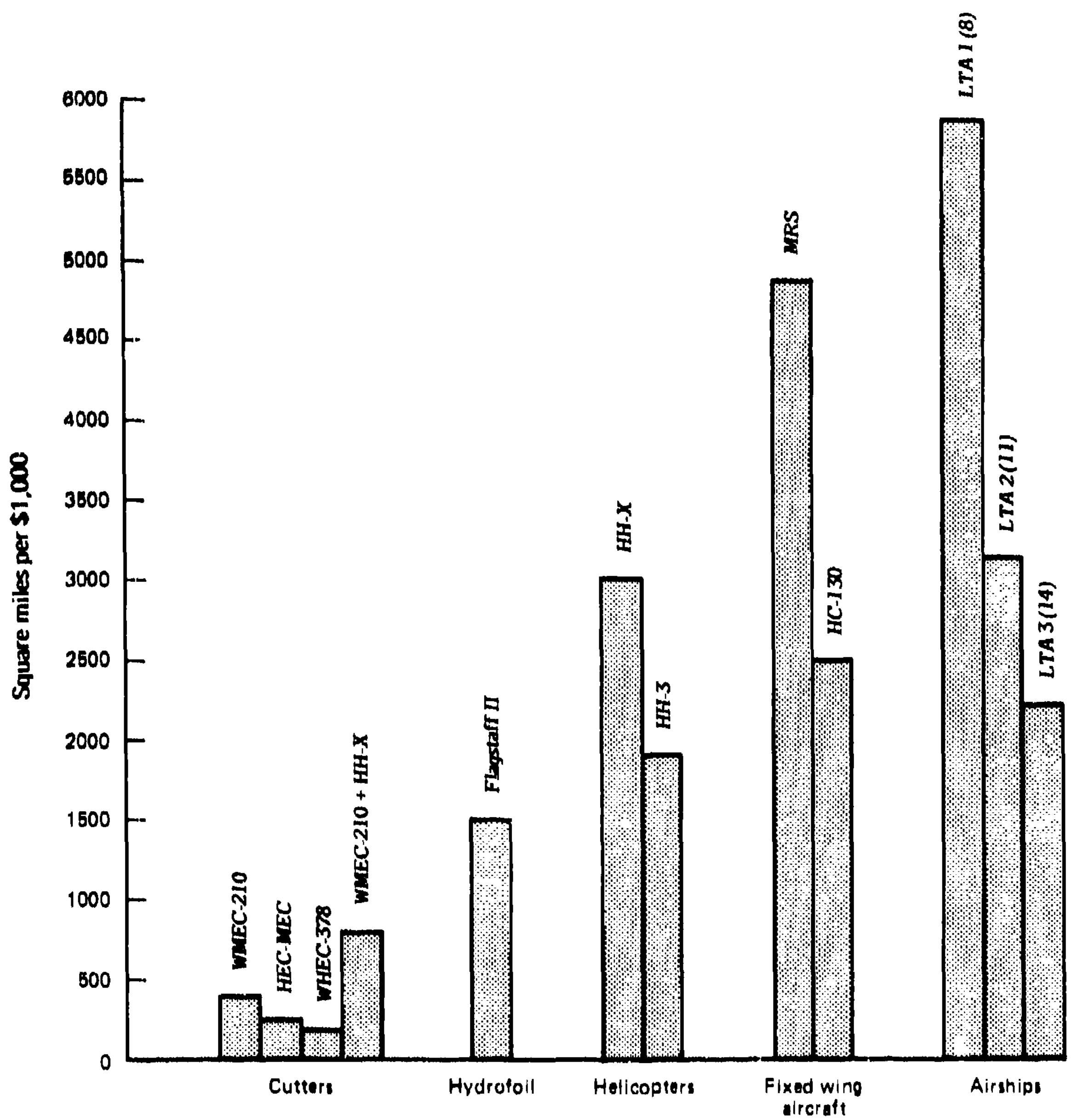


FIG. IV-2: COST/EFFECTIVENESS OF VEHICLES IN PERFORMING GROSS SURVEILLANCE (SMALL TARGETS) (COSTS IN FY 1976 DOLLARS)

LOCAL SURVEILLANCE

This task was included in the Hydrofoil Study to take advantage of the unique characteristics of the cutter/helo teams. It differs from gross surveillance in that the area to be swept is bounded and relatively small in size. Local surveillance involves a planned search effort to achieve a prescribed detection probability. In the ELT mission, a typical scenario for this task might involve a cutter or cutter/helo team approaching a new patrol area in search of a concentration of foreign fishing vessels. In this study, a typical scenario might be represented by a SAR search about a datum. In both cases the search effectiveness can be approximated closely using the standard formula for the probability of detection; $p(t)$, in random search:

$$p(t) = 1 - e^{-\frac{St}{A}}$$

where S is the search rate and A is the area to be searched. For a prescribed detection probability, the exponent St/A is constant. The detection times t_1 and t_2 for systems with search rates S_1 and S_2, respectively, are thus inversely proportional:

$$\frac{t_1}{t_2} = \frac{S_2}{S_1} \quad ,$$

so that the cost ratio is given by

$$\frac{c_1 t_1}{c_2 t_2} = \frac{c_1 S_2}{c_2 S_1}$$

where c_1 and c_2 are the hourly costs of the two systems. The cost ratio is thus equal to the ratio of the gross surveillance cost/effectiveness ratios c_1/S_1 and c_2/S_2.

Hence, local surveillance and gross surveillance are equivalent with respect to cost/effectiveness measures. The results of the preceding section are applicable to gross and local surveillance tasks.

INVESTIGATION OF DISPERSED TARGETS

The objective of this task in the ELT mission is to approach and visually inspect as many fishing vessels as possible in a given time, assuming that the cutter (or other vehicle) is already located amongst a widely dispersed fishing fleet. The true measure of effectiveness is the number of ships inspected regardless of ship density. This measure is directly proportional to the number of miles traveled. Therefore, cost/effectiveness can be measured in terms of cost per mile traveled. This can be computed simply by dividing the hourly cost (cost/hour) of each vehicle by its speed in miles/hour, assuming the investigating vehicle does not need to slow down to look at targets. This case is referred to here as the "no investigation delay" case to distinguish it from later cases with time delays.

Investigation of dispersed targets is a task that is possibly relevant in other missions, such as SAR and MEP. The fundamental assumption in this analysis, for all cases, is that the investigating vehicle does not have a detection problem, and can proceed from one target directly to the next nearest one.

The vehicles are compared in the investigation of dispersed targets task in table IV-7 and figure IV-3. The transit speed in this case is the speed between targets investigated. It is the same as the cruise speed used for low altitude surveillance. Effective speed is equal to transit speed for all resources except the cutter/helo team. In the latter case, the effective speed is less than the sum of the cutter and HH-X speed because the helicopter flies only a fraction of the time.

Except for the fixed-wing aircraft, the cost/effectiveness values for this task are the same as in the transit to station task. As in the gross surveillance task, the MRS and HC-130 employ lower speeds for search and investigation at low altitude. The MRS is about 27 percent more cost/effective than the LTA 1 (8) in this task.

Investigation with Time Delays

For the scenario considered in the Hydrofoil Study (Fisheries Law Enforcement), the "no delay" assumption was reasonable. Time delays are important in analyzing the set of missions of concern in this study, and to compare the costs and effectiveness of aviation vehicles with other vehicles in performing Coast Guard missions.

An example of direct interest to the ELT mission is rigging of ships during large area patrols by fixed-wing aircraft. Rigging requires close passes at low altitude to observe distribution details and photograph targets of interest. Delay time per rigging is assumed to be about 6 minutes (0.1 hour) on the basis of experience during the Cuban blockade reported in reference 2.

The extension of the investigation task to include delay times makes it necessary to also consider target density. The typical ELT aircraft mission is conducted in low contact density situations, i.e., several hundred miles are flown between rigging events. Mission planning for the MRS aircraft is understood to be based on a 10 percent reduction in speed to allow for rigging delays. This is roughly equivalent to the requirement to "rig" one target per hour, spending approximately one hour investigating the target and then flying roughly 200 miles to the next target to be rigged. This is termed a condition of "low contact density."

TABLE IV-7

COST/EFFECTIVENESS OF VEHICLES CONDUCTING INVESTIGATIONS OF DISPERSED TARGETS
(No investigation delay)

Resource	Transit speed (kts.)	Effective speed (kts.)	Cost[a]/mile ($/mi.)	Miles/cost[a] (mi./$1,000)
LTA 1 (8)	110	110	6.5	154
LTA 2 (11)	80	80	12.1	82
LTA 3 (14)	70	70	17.2	58
MRS	230	230	5.1	195
HC-130	210	210	10.0	100
HH-X	125	125	6.7	150
HH-3	126	126	10.5	96
Flagstaff II	48	48	12.4	81
WMEC-210	18	18	45.8	22
HEC-MEC	18	18	69.3	14
WHEC-378	29	29	92.0	11
WMEC-210 + HH-X	16/125	45.1 (143)	22.3 (11.6)	45 (86)

( ) For short-term periods when helicopter is flying.

[a]Cost in FY 1976 dollars.

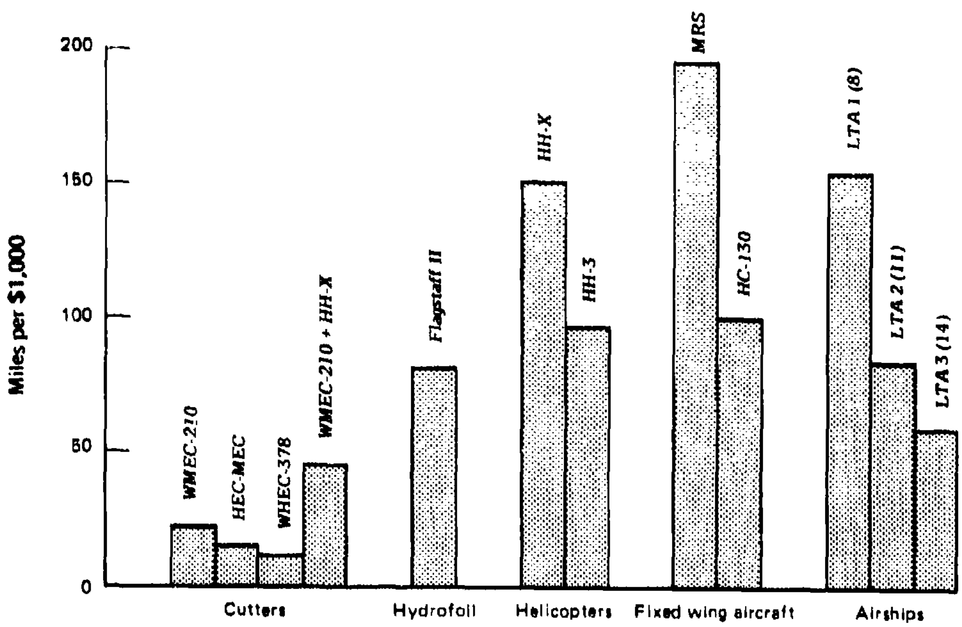


FIG. IV-3: COST/EFFECTIVENESS OF VEHICLES CONDUCTING INVESTIGATIONS OF DISPERSED TARGETS – NO INVESTIGATION DELAY (COSTS IN FY 1976 DOLLARS)

Investigation with delays could occur also in situations of considerably higher contact density. While no specific examples are available, it is conceivable that high density situations of this type can occur in certain SAR missions. A 2-mile track distance between contacts will be used to define a "high contact density" situation. A delay time of 0.01 hour for this case will also be assumed for each investigation.

The effect of delays is to reduce the actual cruise speed, v_c, by the factor

$$1 - f_L = \frac{1}{1 + \frac{\tau}{t_d}}$$

where f_L is the fraction of time spent in investigation, τ is the delay time, and t_d is the time to travel an average distance between targets equal to d. Thus, $t_d = d/v_c$.

The "effective" speed made good along the track connecting the investigated targets is given by $(1 - f_L)v_c$.

The resources are compared in the low and high target density cases in tables IV-8 and IV-9, respectively. The effective speeds were calculated using the formula given

TABLE IV-8

COST/EFFECTIVENESS OF VEHICLES CONDUCTING INVESTIGATIONS OF DISPERSED TARGETS--LOW TARGET DENSITY
(0.1 hour investigation delay)
(200 mi. track distance between targets)

Resource	Speed (kts.)	Transit time between targets (hrs.)	Number of targets per hour	Effective speed (kts.)	Track miles/cost[a] (mi./$1,000)	Targets investigated/cost[a] (no.tgts./$1,000)
LTA 1 (8)	110	1.82	.52	104	146	0.73
LTA 2 (11)	80	2.50	.38	77	79	0.39
LTA 3 (14)	70	2.86	.34	68	56	0.28
MRS	230	0.87	1.03	206	174	0.87
HC-130	210	0.95	.95	190	90	0.45
HH-X	125	1.6	.59	118	141	0.71
HH-3	126	1.6	.59	119	90	0.45
Flagstaff II	48	4.2	.23	47	79	0.39
WMEC-210	18	11.1	.09	17.8	22	0.11
HEC-MEC	18	11.1	.09	17.8	14	0.07
WHEC-378	29	6.9	.14	28.6	11	0.05
WMEC-210 +	18/125	9.3	.22	43	43	0.22
HH-X		(2.8)	(.68)	(136)	(82)	(0.41)

( ) For short-term periods when helicopter is flying.

[a]Costs in FY 1976 dollars.

TABLE IV-9

COST/EFFECTIVENESS OF VEHICLES CONDUCTING INVESTIGATIONS OF DISPERSED TARGETS--HIGH TARGET DENSITY (2 mi. track distance between targets)

Resource	Speed (kts.)	Transit time between targets (hrs.)	Number of targets per hour	Effective speed (kts.)	Track miles/cost[a] (mi./$1,000)	Targets investigated/cost[a] (no.tgts./$1,000)
LTA 1 (8)	110	0.018	35.5	71	102	51
LTA 2 (11)	80	0.025	28.6	57	60	30
LTA 3 (14)	70	0.029	25.9	52	44	22
MRS	230	0.009	53.0	107	91	45
HC-130	210	0.010	51.2	102	48	24
HH-X	125	0.016	38.5	77	93	46
HH-3	126	0.016	38.7	77	58	29
Flagstaff II	48	0.042	19.4	39	65	33
WMEC-210	18	0.111	8.3	16.5	20	10
HEC-MEC	18	0.111	8.3	16.5	13	7
WHEC-378	29	0.069	12.7	25.3	9	5
WMEC-210 +	18/125	0.094	16.6	33.2	33	17
HH-X		(0.033)	(47)	(93)	(56)	(28)

( ) For short-term periods when helicopter is flying.

[a]Costs in FY 1976 dollars.

above. For the cutter/helo team effective speed includes the effects of time delays and the fraction of time the helicopter is not flying.

The measure of track miles per unit of cost is equal to the effective speed divided by the hourly cost. The final column shows targets investigated per unit of cost. The two cases are compared in figures IV-4 and IV-5, which show that the faster vehicles are affected most by the increase in target density. Figure IV-4 shows what occurs for the high target density case; figure IV-5 shows results for the low density case.

In the high density case, the MRS, HH-X, and LTA 1 (8) are roughly equal in cost per unit of effectiveness.

TRAIL/OBSERVATION TASK

The trail task envisions that a Coast Guard vehicle is required to remain in the vicinity of a target and keep track of its activity. Trail targets would normally including fishing trawlers at 5 to 8 knots or merchant ships at 12 to 18 knots. The task can either be performed at a distance from or close to the target for detailed observations. No formal requirement presently exists for these; however, the possibility of greatly extended surveillance demands in the near future suggests that trailing might become an important task. Airships might be particularly valuable for this purpose.

For purposes of analysis, a 15-knot target is assumed; all vehicles are assumed to be capable of trailing such a target. In other words, the differences in the trailing effectiveness of the vehicles are not taken into account. The measure of cost/effectiveness is therefore the cost per hour of trailing or the hours of trailing per unit cost. The hourly costs differ from those presented in chapter 3, because the fuel costs are reduced for some vehicles. Fuel consumption rates are based on vehicle speed required to maintain trail with a target proceeding at an average speed of 15 knots.

The trail task is analyzed from two points of view, depending on the relative importance that is placed on trail and patrol type tasks. Initially, patrol is assumed to be the dominant task and airships optimized for patrol are examined in trail tasks. Some modifications in the least cost per mile airships are required because of the longer endurances obtained when operating at the lower speeds employed in the trail tasks. A second comparison is made assuming that trail tasks are dominant. The original LTA family, with modifications to account for increased endurance at low speed, is optimized on the basis of flight hours per $1000.

The airships are assumed to cruise at 30 knots whenever possible.

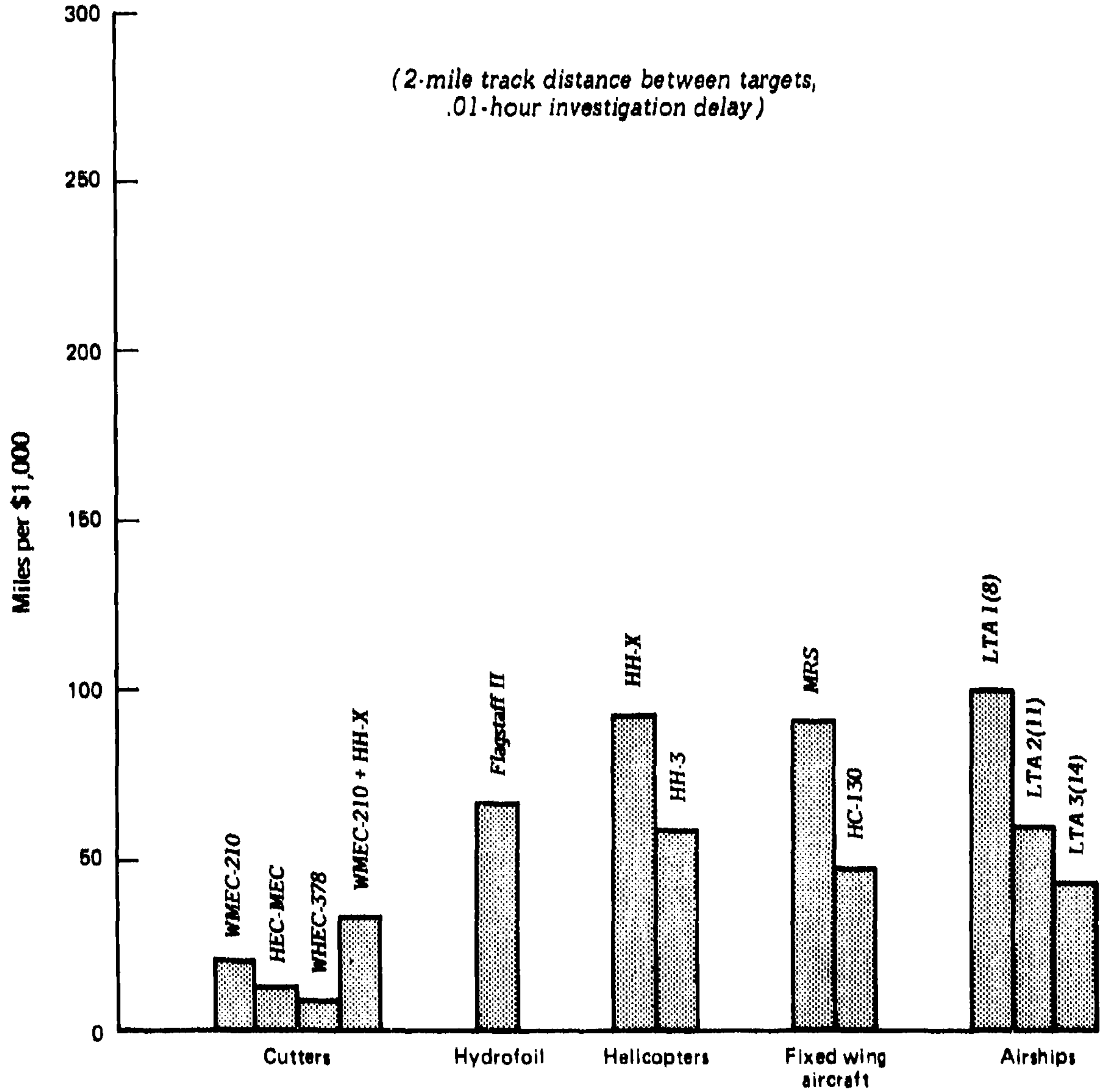


FIG. IV-4: COST/EFFECTIVENESS OF VEHICLES CONDUCTING INVESTIGATIONS OF DISPERSED TARGETS – HIGH TARGET DENSITY (COSTS IN FY 1976 DOLLARS)

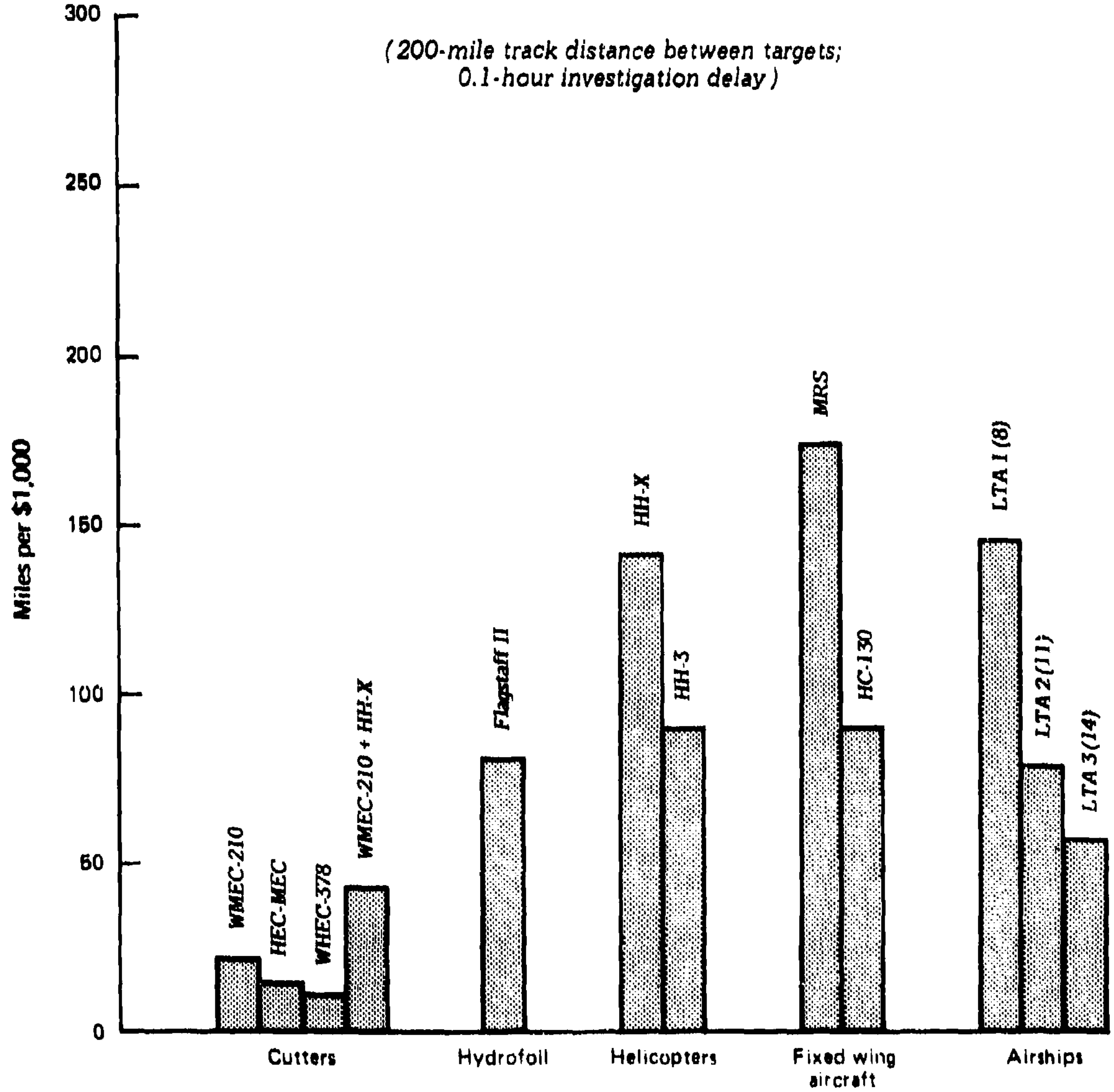


FIG. IV-5: COST/EFFECTIVENESS OF VEHICLES CONDUCTING INVESTIGATIONS OF DISPERSED TARGETS – LOW TARGET DENSITY (COSTS IN FY 1976 DOLLARS)

Fixed-wing aircraft and helicopters are assumed to operate at normal low altitude speeds. Cutters are assumed to operate at 18 to 19 knots. The average fuel rate for Flagstaff II (82.6 gal/hr.) was based on figure 6 of the Hydrofoil Study, assuming a sprint/drift mode of operation, with a 23 percent foilborne fraction.

Patrol Tasks Dominant

The airship speed of 30 knots was selected to minimize fuel consumption while maintaining enough speed to maintain trail on targets heading into winds of 15 knots or less. In some cases the dynamic lift available at 30 knots may not be enough to compensate for the airship heaviness in the initial phase of the mission; fuel must be consumed before flying at 30 knots is possible. The dynamic lift available depends on the maximum angle of attack allowed in flight. A practical limit of 10 degrees was assumed in this study. Constraining the attack angle to 10 degrees provides a fuel consumption rate that is very near the minimum rate that could be obtained at somewhat higher (about 15 degrees) attack angles. With this constraint, speed varies as the square root of the heaviness. A constant speed of 30 knots is possible when the heaviness decreases to about 10 percent. The procedure used to calculate flight endurance for such variable speed operations is presented in appendix J of volume II.

The low speeds employed in trail tasks result in endurance extensions that require increased aircrew sizes and hence increased airship sizes and costs. Thus, LTA 1 (8) is replaced by the larger LTA 1 (11) and LTA 2 (11) is replaced by LTA 2 (14) as indicated in table IV-10. Airship characteristics and costs were calculated using the same methods that were employed for the original LTA family. Fuel costs were based on the average fuel consumption rates for the trail flight times.

TABLE IV-10

COMPARISON OF LEAST COST/MILE AIRSHIPS
EMPLOYED IN PATROL AND TRAIL TASKS
(Patrol tasks dominant)

Airship	Speed (kts.)	Range (mi.)	Aircrew (no.)	Volume (cu. ft.)	Patrol endurance (hrs.)	Trail endurance (hrs.)
LTA 1 (8)	110	1000	8	411,000	9.1	-
LTA 1 (11)	110	1000	11	551,000	9.1	33
LTA 2 (11)	80	2000	11	903,000	25.0	-
LTA 2 (14)	80	2000	14	985,000	25.0	101
LTA 3 (14)	70	3000	14	1,363,000	42.9	197

The resources are compared in table IV-11 and figure IV-6. Flagstaff II is the most cost/effective vehicle, with the LTA 1 (11) in second place. The HH-X ranks well, but is limited in endurance (and range) for this task. The cutters are well suited to this task and have very high endurance. However, except for WMEC-210, the hourly costs of the cutters are high. Airships and aircraft also have an advantage over surface ships in that they provide an elevated platform for improved radar and visual surveillance of the targets being trailed or observed.

TABLE IV-11

COST/EFFECTIVENESS OF VEHICLES
IN THE TRAIL TASK
(FY 1976 dollars)

Vehicle	Cost/hour ($/hr.)	Hours/cost (hrs./$1,000)	Endurance (hrs.)
LTA 1 (11)	807	1.24	33
LTA 2 (14)	1,035	0.97	101
LTA 3 (14)	1,161	0.86	197
MRS	1,182	0.85	4.5
HC-130	2,108	0.47	11.8
HH-X	832	1.20	4.2
HH-3	1,319	0.76	7.3
Flagstaff II	523	1.91	61
WMEC-210	824	1.21	150
HEC-MEC	1,247	0.80	167
WHEC-378	1,822	0.55	752
WMEC-210+ HH-X	1,004	1.00	150

Trail Tasks Dominant

The original LTA family was designed with aircrew sizes determined by the endurance in patrol tasks. When the airships are designed for trail tasks, the endurance exceeds 36 hours for all airships except LTA 1 (11) and the 120-knot/1,000-mile range airship. The aircrew size is thus 14 in all but two of the cases considered. The principal characteristics and cost effectiveness values of 1,000 and 2,000-mile range airships employed in trail tasks are compared in table IV-12. Cost effectiveness is measured by flight hours per $1,000. Further detailed characteristics and costs of these airships are presented in appendix F of volume II. Flight endurances and average fuel consumption rates for the variable speed flight profiles were calculated using the methodology presented in appendix J of volume II.

TABLE IV-12

COMPARISON OF AIRSHIPS
EMPLOYED IN TRAIL TASKS

(Trail tasks dominant)

Range = 1,000 miles

Speed (kts)	Aircrew (no.)	Volume (cu. ft.)	Trail endurance (hrs.)	Cost/ per hour ($/hr.)	Hours/ cost (hrs./$1000)	
50	14	371,000	53	729	1.37	
60	14	402,000	48	750	1.33	
70	14	436,000	48	773	1.29	
80	14	472,000	46	800	1.25	
90	14	513,000	42	831	1.20	
100	14	564,000	38	869	1.15	
110	11	551,000	33	807	1.24	LTA 1 (11)
120	11	706,000	31	976	1.02	

Range = 2,000 miles

Speed (kts)	Aircrew (no.)	Volume (cu. ft.)	Trail endurance (hrs.)	Cost/ per hour ($/hr.)	Hours/ cost (hrs./$1000)	
50	14	517,000	113	803	1.25	
60	14	632,000	124	862	1.16	
70	14	778,000	102	936	1.07	
80	14	985,000	101	1,035	0.97	LTA 2 (14)
90	14	1,283,000	98	1,167	0.86	
100	14	1,734,000	93	1,355	0.74	
110	14	2,450,000	89	1,631	0.61	
120	14	3,628,000	71	2,053	0.49	

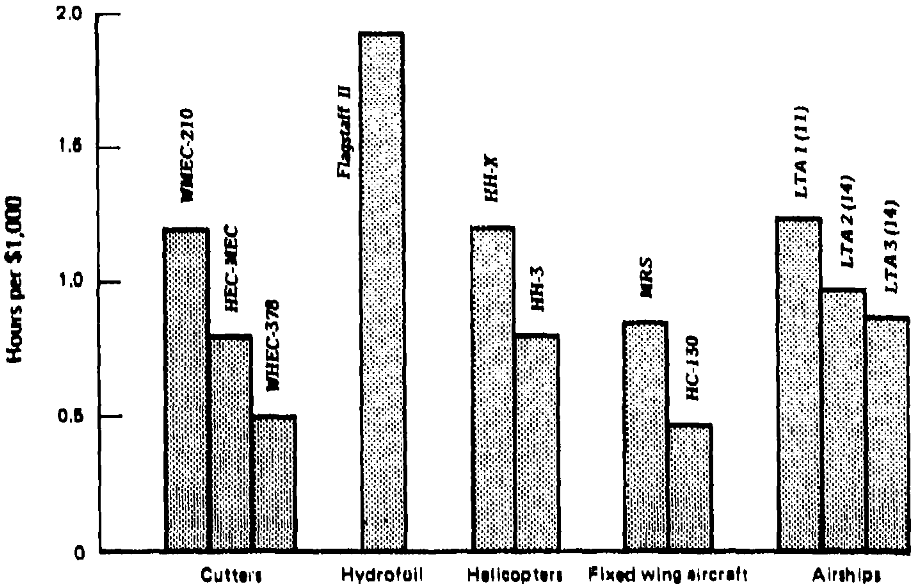


FIG. IV-6: COST/EFFECTIVENESS OF VEHICLES IN THE TRAIL TASK – PATROL TASKS DOMINANT (COSTS IN FY 1976 DOLLARS)

Compared to LTA 1 (11), the 1,000-mile range airships do not achieve a higher cost effectiveness until the speed is reduced to 80 knots. The 50-knot airship is only about 10 percent better in trail tasks than LTA 1 (11), which also provides much better performance in patrol tasks (124 vice 68 miles per $1,000).

The 2,000-mile range airships, except for the 50-knot case, are all poorer than LTA 1 (11) for the zero distance to station situation treated in this chapter.

PRESENCE (AS A DETERRENT)

The task is similar to the trail task and is measured in the same way, i.e., cost per hour. The objective in this task is to serve as a deterrent to a potential violator of fisheries laws and treaties. The degree to which a potential violator might be deterred by different types of Coast Guard vehicles or cutter/helo teams is subjective. For purposes of analysis, we assume (as did the Hydrofoil Study) that each vehicle exerts the same amount of deterrence. The relative cost/effectiveness in this mission is equivalent to the relative hourly costs of the vehicles when operated at low speed. The airship fuel costs were based on the same low speed profiles employed in trail tasks. The results shown in table IV-13 are similar to these trail task values given in table IV-11.

[1]For zero station distance, the optimum airship range is less than 1,000 miles for trail tasks. See chapter V for other station distances.

TABLE IV-13

COST/EFFECTIVENESS OF VEHICLES [a]
IN THE PRESENCE TASK

Resource	Cost/hour ($/hr.)	Hours/cost (hrs./$1,000)	Endurance (hrs.)
LTA 1 (11)	805	1.24	33
LTA 2 (14)	1,030	0.97	101
LTA 3 (14)	1,161	0.86	197
MRS	1,182	0.85	4.5
HC-130	2,108	0.47	11.8
HH-X	832	1.20	4.2
HH-3	1,319	0.76	7.3
Flagstaff II	505	1.98	125
WMEC-210	709	1.41	2,363*
HEC-MEC	1,170	0.85	835*
WHEC-378	1,725	0.58	2,670*
WMEC-210 + HH-X	889	1.12	2,363*

[a]Costs in FY 1976 dollars.
*Low (one engine idle) speed.

SUMMARY OF RESULTS

Table IV-14 summarizes for all of the tasks examined, the cost/effectiveness results of all the resources. Table IV-15 presents the same results on a relative basis, with the LTA 1 (8) being taken as the unit reference for patrol tasks and LTA 1 (11) the reference for trail and presence tasks. The values shown are ratios of the cost/effectiveness results presented in table IV-13. Values greater than unity indicate an advantage for the resource relative to the LTA 1 (8) or LTA 1 (11).

TABLE IV-14

SUMMARY
COST/EFFECTIVENESS COMPARISONS

Vehicle	Transit (mi./$1,000	Investigation of dispersed targets: No delay (mi./$1,000)	Investigation of dispersed targets: With delay, low den.	Investigation of dispersed targets: With delay, high den. (mi./$1,000)	Gross surveillance (small tgt.) (sq.mi./$1,000)	Presence (hrs./$1,000)	Trail: Hours/cost (hrs./$1,000)	Trail: Endurance (hrs.)
LTA 1 (8)	154	154	146	102	5,850	-	-	-
LTA 1 (11)	125	125	118	83	4,730	1.24	1.24	33
LTA 2 (11)	82	82	79	60	3,130	-	-	-
LTA 2 (14)	74	74	71	54	2,820	0.97	0.97	101
LTA 3 (14)	58	58	56	44	2,210	0.86	0.86	197
LTA(50/1000)	68	68	66	54	2,580	1.37	1.37	53
MRS	317	195	174	91	4,860	0.85	0.85	4.5
HC-130	138	100	90	48	2,490	0.47	0.47	11.8
HH-X	150	150	142	93	3,000	1.20	1.20	4.2
HH-3	96	96	90	58	1,910	0.76	0.76	7.3
Flagstaff II	83	81	79	65	1,450	1.98	1.91	61
WMEC-210	22	22	22	20	393	1.41	1.21	150
HEC-MEC	14	14	14	13	260	0.85	0.80	167
WHEC-378	11	11	11	9	196	0.58	0.55	752
WMEC-210 + HH-X	[illegible]	45 (86)	43 (82)	33 (56)	811 (1,560)	1.12	1.00	150

( ) For short-term periods when helicopter is flying.

TABLE IV-15

SUMMARY

COST/EFFECTIVENESS COMPARISON RELATIVE TO LTA 1 (8) AND LTA 1 (11)

Vehicle	Transit (mi./$1,000)	Investigation of dispersed targets: No delay (mi./$1,000)	Investigation of dispersed targets: With delay, low den. (mi./$1,000)	Investigation of dispersed targets: With delay, high den. (mi./$1,000)	Gross surveillance (small tgt.) (sq.mi./$1,000)	Presence (hrs./$1,000)	Trail: Hours/cost (hrs./$1,000)	Trail: Endurance (hrs.)
LTA 1 (8)	1.00 (2)	1.00 (2)	1.00 (2)	1.00 (1)	1.00 (1)	-	-	-
LTA 1 (11)	0.81	0.81	0.81	0.81	0.81 (3)	1.00 (4)	1.00 (3)	1.00
LTA 2 (11)	0.53	0.53	0.54	0.59	0.53	-	-	-
LTA 2 (14)	0.48	0.48	0.49	0.53	0.48	0.78	0.78	3.06
LTA 3 (14)	0.38	0.38	0.39	0.43	0.38	0.69	0.69	5.97
LTA(50/1000)	0.44	0.44	0.45	0.53	0.44	1.10 (3)	1.10 (2)	1.61
MRS	2.06 (1)	1.27 (1)	1.19 (1)	0.89 (3)	0.83 (2)	0.69	0.69	.14
HC-130	0.90	0.65	0.62	0.47	0.43	0.38	0.38	.36
HH-X	0.97 (3)	0.97 (3)	0.97 (3)	0.91 (2)	0.51	0.97	0.97	.13
HH-3	0.62	0.62	0.62	0.57	0.33	0.61	0.61	.22
Flagstaff II	0.54	0.53	0.54	0.64	0.25	1.60 (1)	1.54 (1)	1.85
WMEC-210	0.14	0.14	0.15	0.20	0.07	1.14 (2)	0.98	4.54
HEC-MEC	0.09	0.09	0.10	0.13	0.04	0.69	0.65	5.06
WHEC-378	0.07	0.07	0.08	0.09	0.03	0.47	0.36	22.8
WMEC-210 + HH-X	0.14	0.29 (0.56)	0.29 (0.56)	0.32 (0.55)	0.14 (0.27)	0.90	0.81	4.54

( ) For short-term periods when helicopter is flying.

_ Indicates largest values and rank.

There are only two tasks for which the LTA 1 (8) or LTA 1 (11) are superior. LTA 1 (8) exceeds its prime competitor, the MRS aircraft, in the small target gross surveillance and high density investigation tasks, but the gain is not more than 25 percent. The higher speed of the MRS makes it the most cost/effective vehicle in all other patrol tasks. The hydrofoil provides the best trail potential; but it must operate largely in the hullborne mode to achieve this trail capability. The LTA 1 (11) and WMEC-210 are similar in trail cost/effectiveness, but the small cutter has less capability for over-the-horizon surveillance and observation from high angles. When the cutter operates together with a helicopter it is less cost/effective in trail than the airship.

When airships are optimized for trail tasks, the 50-knot/1,000-mile range airship provides only a 25 percent gain relative to LTA 1 (11).

The above results apply to the case of zero distance to station. The effects of transit to station are treated in the next chapter.

V. ON STATION TASK ANALYSIS

INTRODUCTION

This chapter extends the task analysis of chapter 4 to include the effects of transit to station. Vehicles are compared on the basis of miles on station per unit cost for investigation tasks; square miles on station per unit cost for gross surveillance tasks; and hours on station per unit cost for trail tasks.

AIRSHIP TIME-ON-STATION FRACTION AND EFFECTIVE SPEED

In the case of patrol tasks (gross surveillance and investigation) the airship speeds for transit to station and cruise on station are based on obtaining the maximum miles on station per flight hour, i.e., maximum "effective" speed, measured by the product of cruise speed and the fraction of time on station. In the trail task, airship speed on station is assumed to be 30 knots whenever airship heaviness permits; the transit speed to station is calculated to maximize the hours on station per flight hour, i.e., fraction of time on station.

The estimation of optimum transit and cruise speeds is based on a simple model that ignores effects of airship heaviness changes during flight. The optimum transit speeds are shown in appendix J of volume II to be the same for both patrol and trail tasks. In both cases, the transit speed varies with distance to station to maximize the fraction of time on station. For patrol tasks the optimum cruise speed on station is equal to the transit speed.

The ratio of optimum transit speed to maximum cruise speed is determined using the following approximate formula:

$$\frac{v_T}{v_M} = \begin{cases} 1.0 & 2D/R_M < 0.43 \\ 0.6\left(\dfrac{R_M}{2D}\right)^{0.6} & 2D/R_M > 0.43 \end{cases}$$

where D is the distance to station and R_M is the airship range at speed, v_M. Optimum transit speeds for LTA 1 (8), LTA 2 (11), and LTA 3 (14) are given in table V-I.

TABLE V-1

AIRSHIP TRANSIT SPEEDS
(knots)

	Distance to station (miles)				
	100	200	300	400	500
LTA 1(8)	110	110	90	75	66
LTA 2(11)	80	80	80	80	73
LTA 3(14)	70	70	70	70	70

The time-on-station fractions and effective speeds are calculated in appendix J taking account of the changes in airship heaviness during the flight, and possible changes in cruise speed in the case of trail tasks where the initial heaviness on station may be too great for cruising at 30 knots. Formulas are also presented in appendix J for the effects of investigation with time delays.

The time-on-station fractions and effective speeds for the case of investigation with no time delays are shown in figure V-1 for 110 knot/1,000-mile range airships LTA 1 (8) and LTA 1 (11). Effective speed is the miles made good on station divided by the total mission time. The values are presented as a function of the distance to station. When both transit and on-station cruise speeds are equal to the 110 knot maximum sustained speed the time on station fraction decreases linearly with distance, becoming zero at 500 miles, or one-half the range at 110 knots. Effective speed (measured by miles on station per flight hour) also decreases linearly to zero at 500 miles. These are shown by the lower curves in each set in figure V-1.

The solid lines in figure V-1 show the effect of varying transit and cruise speed to optimize the time-on-station fraction and effective speed. The optimum transit and cruise speeds are equal to the maximum cruise speed for distances less than 215 miles distance to station. Beyond this critical distance the optimum transit speed decreases inversely in proportion to the 0.6 power of the distance to station. Beyond 270 miles the flight endurance exceeds 12 hours, so that the aircrew size is increased from 8 to 11.

AIRSHIP COMPARISON IN PATROL TASKS

Figure V-2 compares the optimal effective speeds and time-on-station fractions of the three airships in the case of investigation with no delay. Between 200 and 300 miles station distance, LTA 2 (11) has the greatest effective speed. LTA 1 (8) and LTA 3 (14) are more effective at shorter and longer distances, respectively.

When the three airships are compared on a cost/effectiveness basis in investigation tasks, the LTA 1 (8) is superior for distances out to 270 miles. Figure V-3 shows the comparison in terms of miles on station per $1,000 cost as a function of distance to station. Beyond 270 miles, LTA 2 (11) is more cost effective than LTA 1 (11). The discontinuity at 270 miles is caused by the increased cost of LTA 1 (11) over LTA 1 (8) ($807/hr versus $715/hr.), mostly as a result of increased aircrew size.

The relative cost effectiveness of these airships is the same for the gross surveillance task, because all airships are assumed to have the same sweepwidth.

The airship speed optimization for patrol tasks was based initially on the zero distance to station. This optimization is also valid for other station distances because effective speed is a function principally of airship range.

VEHICLE TIME-ON-STATION FRACTIONS AND EFFECTIVE SPEEDS

The time-on-station fractions for all vehicles are given in table V-2 for the investigation task with no delay. Figure V-4 shows the same information graphically,

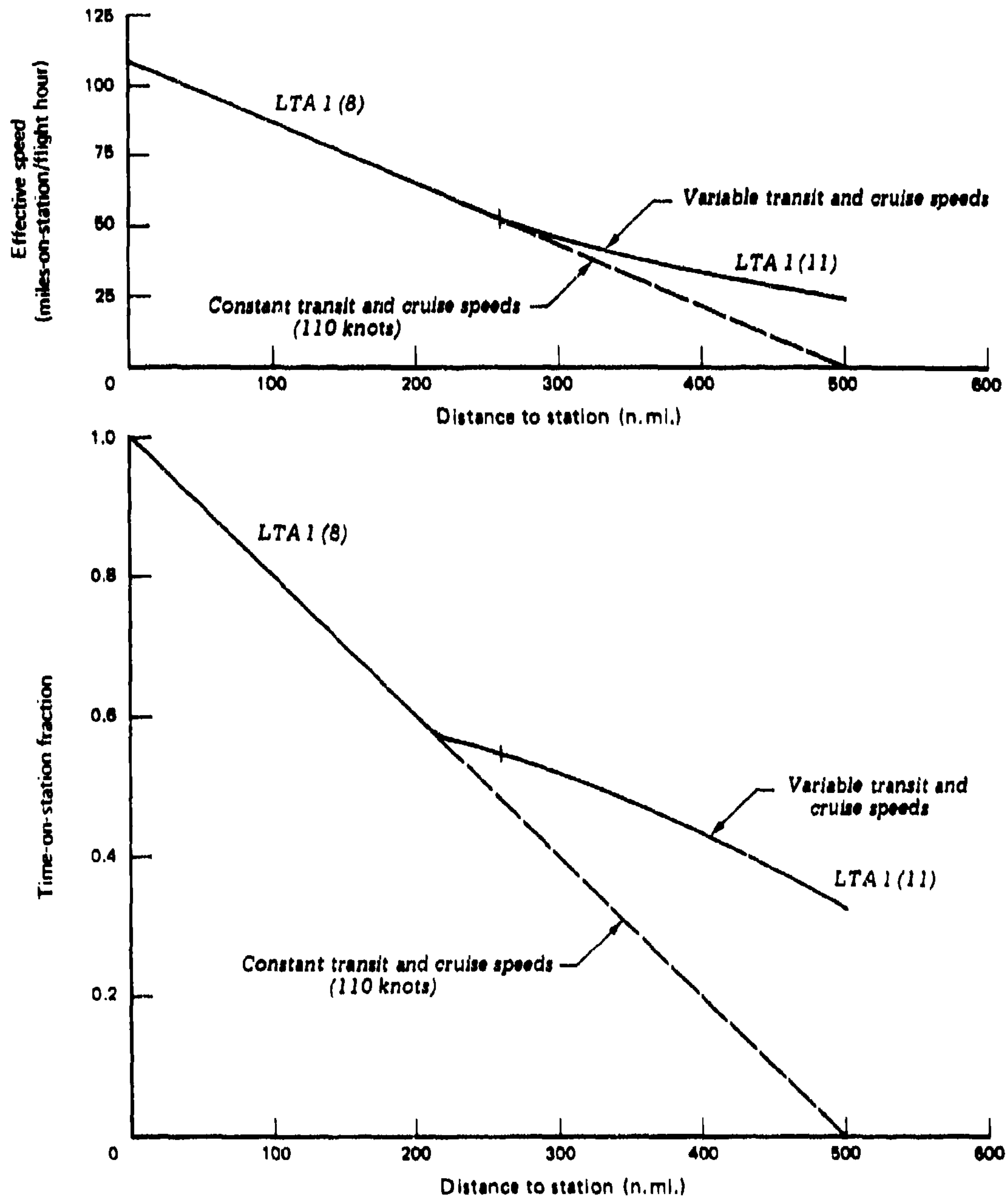


FIG. V-1: AIRSHIP TIME ON STATION AND EFFECTIVE SPEED (110 KNOTS/1000 MILE RANGE)

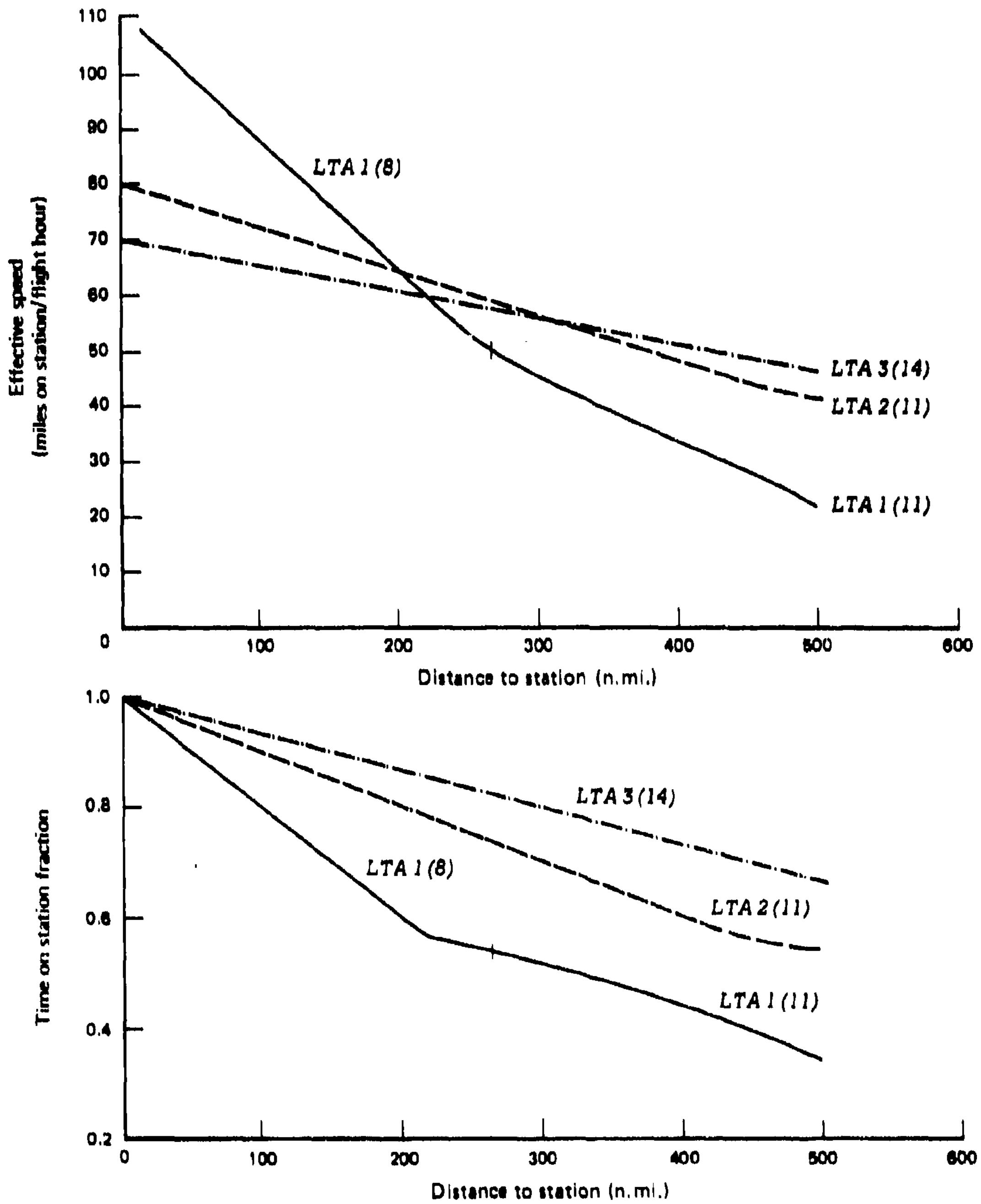


FIG. V-2: AIRSHIP TIME ON STATION AND EFFECTIVE SPEED IN PATROL TASKS

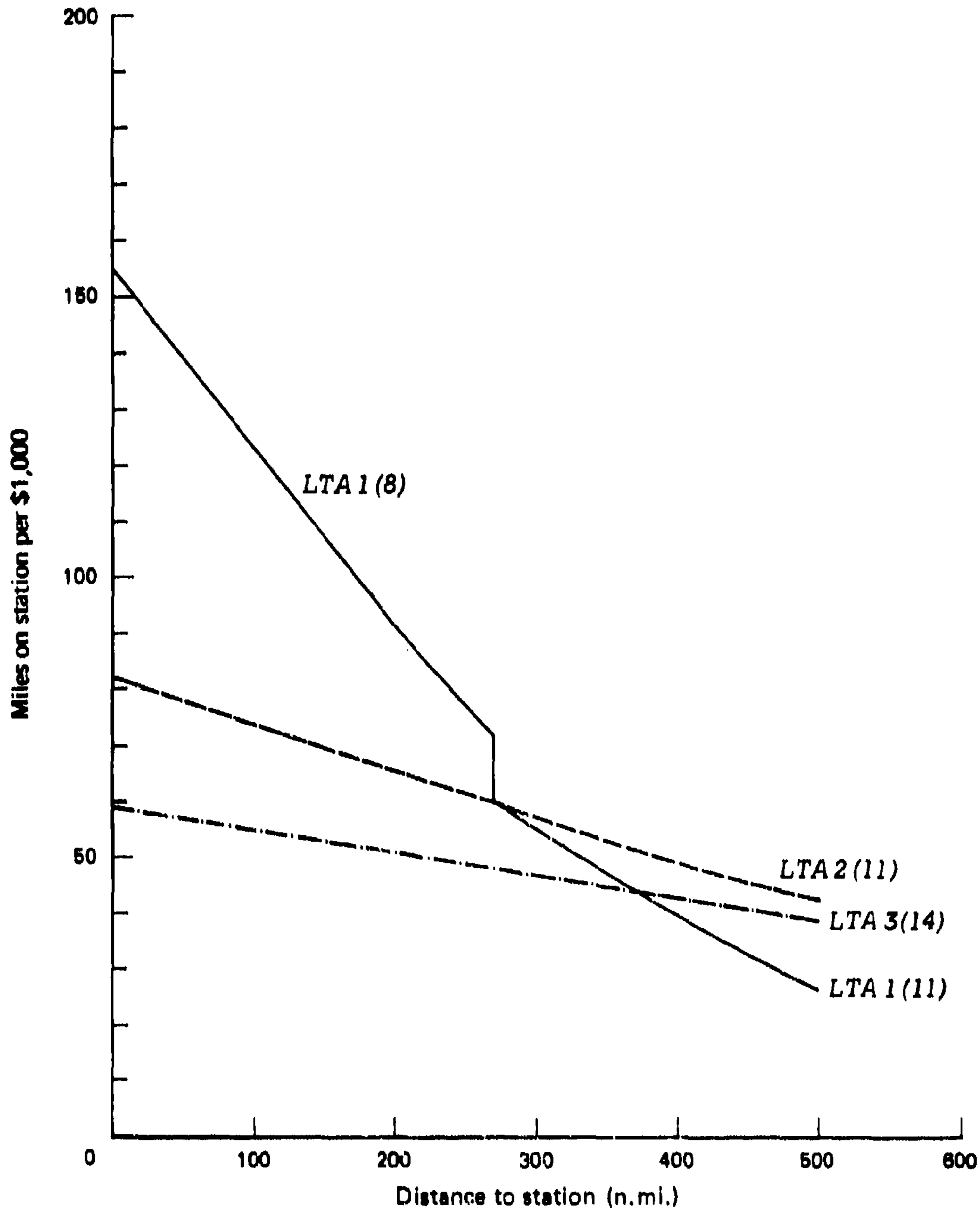


FIG. V-3: AIRSHIP COST/EFFECTIVENESS IN PATROL TASKS (INVESTIGATION WITH NO DELAY)

TABLE V-2

TIME-ON-STATION FRACTIONS

(Investigation task with no delay)

Distance to Station (miles)

Vehicle	100	200	300	400	500
LTA 1 (8)	0.80	0.60	-	-	-
LTA 1 (11)	-	-	0.52	0.44	0.33
LTA 2 (11)	0.90	0.80	0.70	0.60	0.56
LTA 3 (14)	0.93	0.87	0.80	0.73	0.67
MRS	0.88	0.76	0.65	0.53	0.41
HC-130	0.93	0.87	0.80	0.74	0.68
HH-X	0.63	0.26	0	0	0
HH-3	0.72	0.44	0.17	0	0
Flagstaff II	0.80	0.60	0.40	0.20	0
WMEC-210	0.93	0.85	0.78	0.70	0.63
HEC-MEC	0.93	0.87	0.80	0.73	0.67
WHEC-378	0.93	0.87	0.80	0.73	0.67
WMEC-210 + HH-X	0.93	0.85	0.78	0.70	0.63

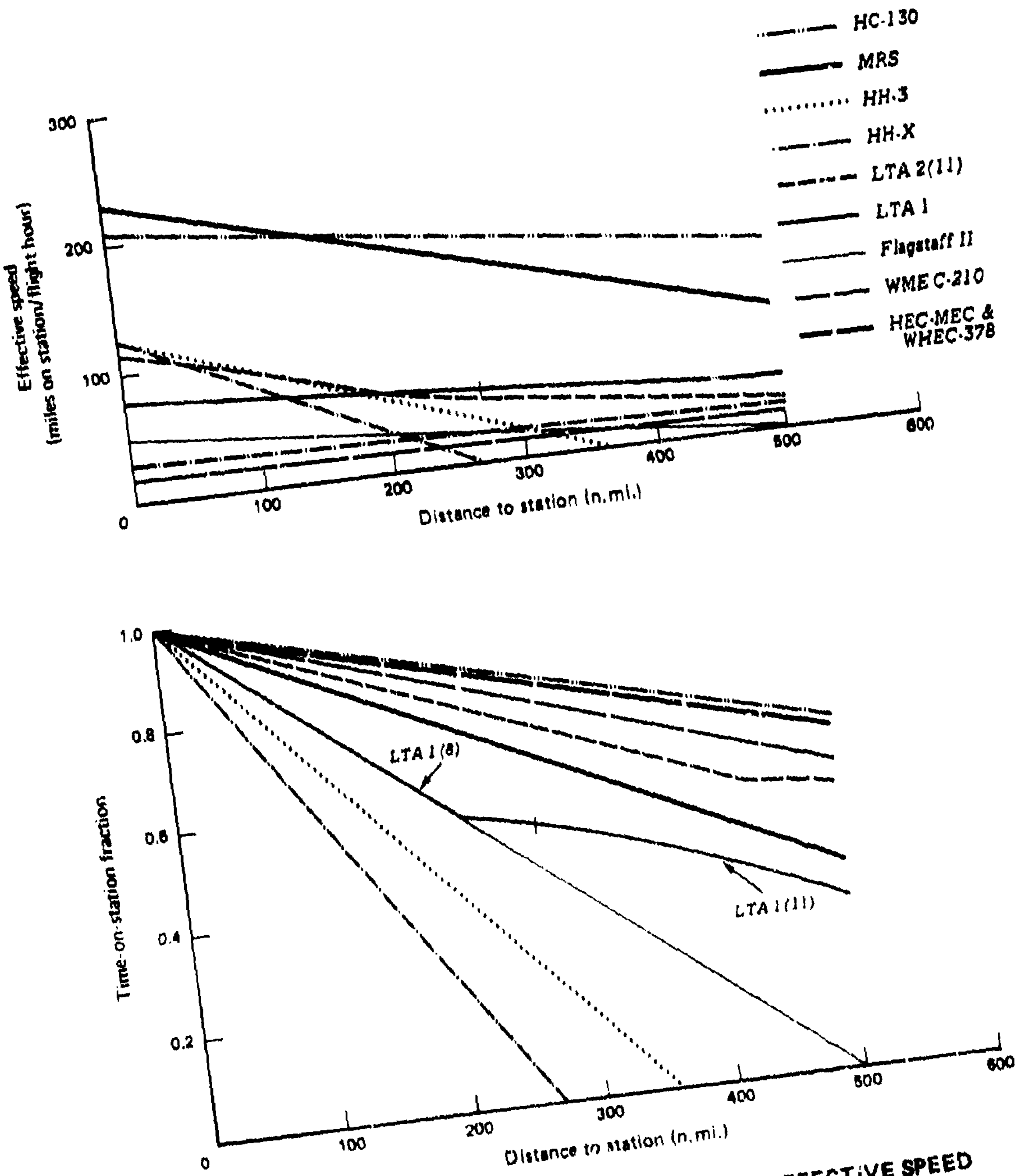


FIG. V-4: VEHICLE TIME ON STATION AND EFFECTIVE SPEED including the effective speeds of all vehicles. All vehicles except the airships show a linear decrease to zero at half the cruise range. All surface units and helicopters transit and cruise on station at maximum sustained speed. No allowance is made in this analysis for possible hover time by the helicopters. The fixed-wing aircraft transit and cruise at the speeds indicated in chapter 4. The HC-130 time-on-station fraction is actually not quite linear because the fuel consumption rate at low altitude is 16 percent greater than the rate at high altitude. See appendix J of volume II for further details.

The fixed-wing aircraft have a large advantage in effective speed over all other vehicles. Out to 130 miles station distance the HH-3 exceeds LTA 1 (8) in effective speed; the HH-X exceeds LTA 1 (8) only out to 50 miles.

COMPARISON OF VEHICLES IN INVESTIGATION TASKS

Investigation Task With No Delay

All vehicles are compared with the optimum airships in table V-3 on the basis of cost/effectiveness in investigation tasks with no time delays. Miles on station per $1,000 is shown graphically in figure V-5 as a function of distance to station. Out to 500 miles the MRS aircraft is superior to all other vehicles in this task. The relative superiority of the MRS aircraft is greatest (over 100 percent) at intermediate distances (about 300 miles). At short range, HH-X is a close competitor to the LTA 1 (8); LTA 1 is second most cost effective from 0 to 220 miles. At greater ranges, the HC-130 is superior to the airships.

With Delay-High Target Density

The effect of investigation delays on the cost/effectiveness comparison of vehicles is shown in table V-4 and figure V-6 for the case of high target density. The average track distance between targets in the high density case is assumed to be 2 miles; an investigation delay time of 0.01 hour per target is also assumed.

At distances less than 180 miles, the LTA 1 (8) is the most cost/effective vehicle; the MRS maintains its superiority at greater distances to station with LTA 1 (8) and LTA 2 (11) in second place out to about 500 miles. At distances less than 100 miles, the HH-X is close to the MRS in cost/effectiveness.

COMPARISON OF VEHICLES IN GROSS SURVEILLANCE TASKS

Airships are compared with other vehicles in gross surveillance tasks in tables V-5 and V-6 and figures V-7 and V-8. Cost/effectiveness is measured by square miles on station per $1,000 cost. The results shown in figure V-7 are for the case of small targets, for which the airship sweepwidth is assumed to be 50 percent greater than that of the MRS and HC-130. Figure V-8 gives similar measures for the medium targets where the LTA enjoys a 20 percent advantage over the aircraft.

Against small targets LTA 1 (8) is superior to MRS out to 160 miles station distance. From that distance to 400 miles LTA 1 (8) and LTA 2 (11) are in second place. HC-130 is slightly superior to LTA 2 (11) beyond 400 miles. At about 300 miles distance, the MRS relative superiority reaches a maximum of about 44 percent. Just beyond 500 miles distance, MRS, LTA 1 and HC-130 become equal in cost/effectiveness.

TABLE V-3

COST/EFFECTIVENESS OF VEHICLES
IN INVESTIGATION TASKS
(No investigation delay)

Miles on station per cost
(mi. on sta./$1,000)

Distance to station (miles)

Vehicle	100	200	300	400	500
LTA 1 (8)	122	92	-	-	-
LTA 1 (11)	-	-	55	40	27
LTA 2 (11)	74	66	58	50	42
LTA 3 (14)	54	51	47	43	39
MRS	172	148	127	103	80
HC-130	93	87	80	74	68
HH-X	95	39	0	0	0
HH-3	69	42	16	0	0
Flagstaff II	65	49	32	16	0
WMEC-210	20	19	17	15	14
HEC-MEC	13	12	11	10	9
WHEC-378	10	10	9	8	7
WMEC-210 + HH-X	42	38	36	32	28

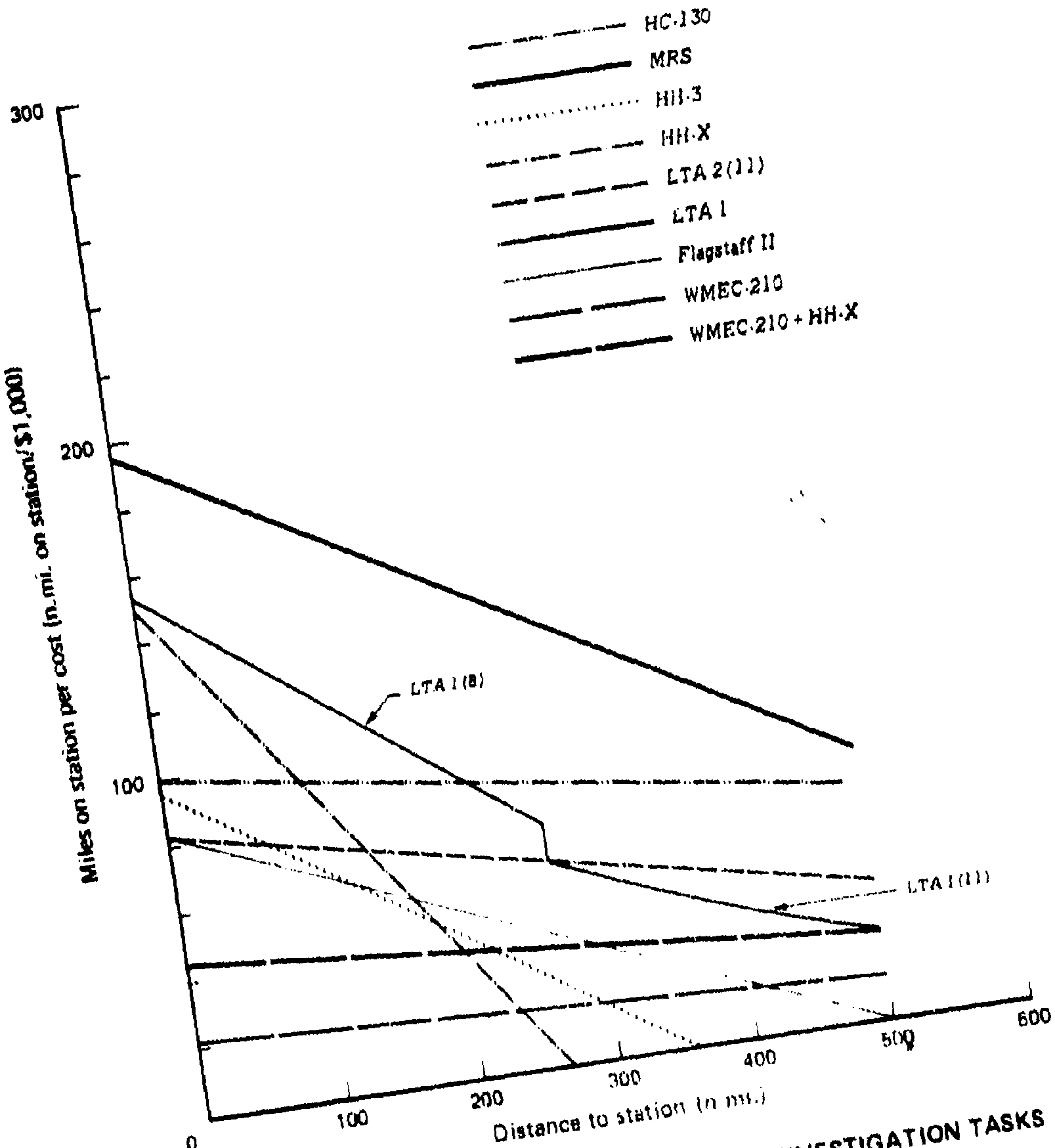


FIG. V-6: COST/EFFECTIVENESS OF VEHICLES IN INVESTIGATION TASKS (WITH NO DELAY)

TABLE V-4

COST/EFFECTIVENESS OF VEHICLES
IN INVESTIGATION TASKS

(0.01 hour delay, high
target density)

Vehicle	Miles on station per cost (mi. on sta./$1,000) Distance to station (miles) 100	200	300	400	500
LTA 1 (8)	85	67	-	-	-
LTA 1 (11)	-	-	42	31	21
LTA 2 (11)	55	50	45	40	35
LTA 3 (14)	41	39	36	34	31
MRS	80	69	59	48	37
HC-130	45	42	38	36	33
HH-X	59	24	0	0	0
HH-3	42	26	10	0	0
Flagstaff II	52	39	26	13	0
WMEC-210	19	17	16	14	13
HEC-MEC	12	11	10	9	9
WHEC-378	8	8	7	7	6
WMEC-210 + HH-X	31	28	26	23	21

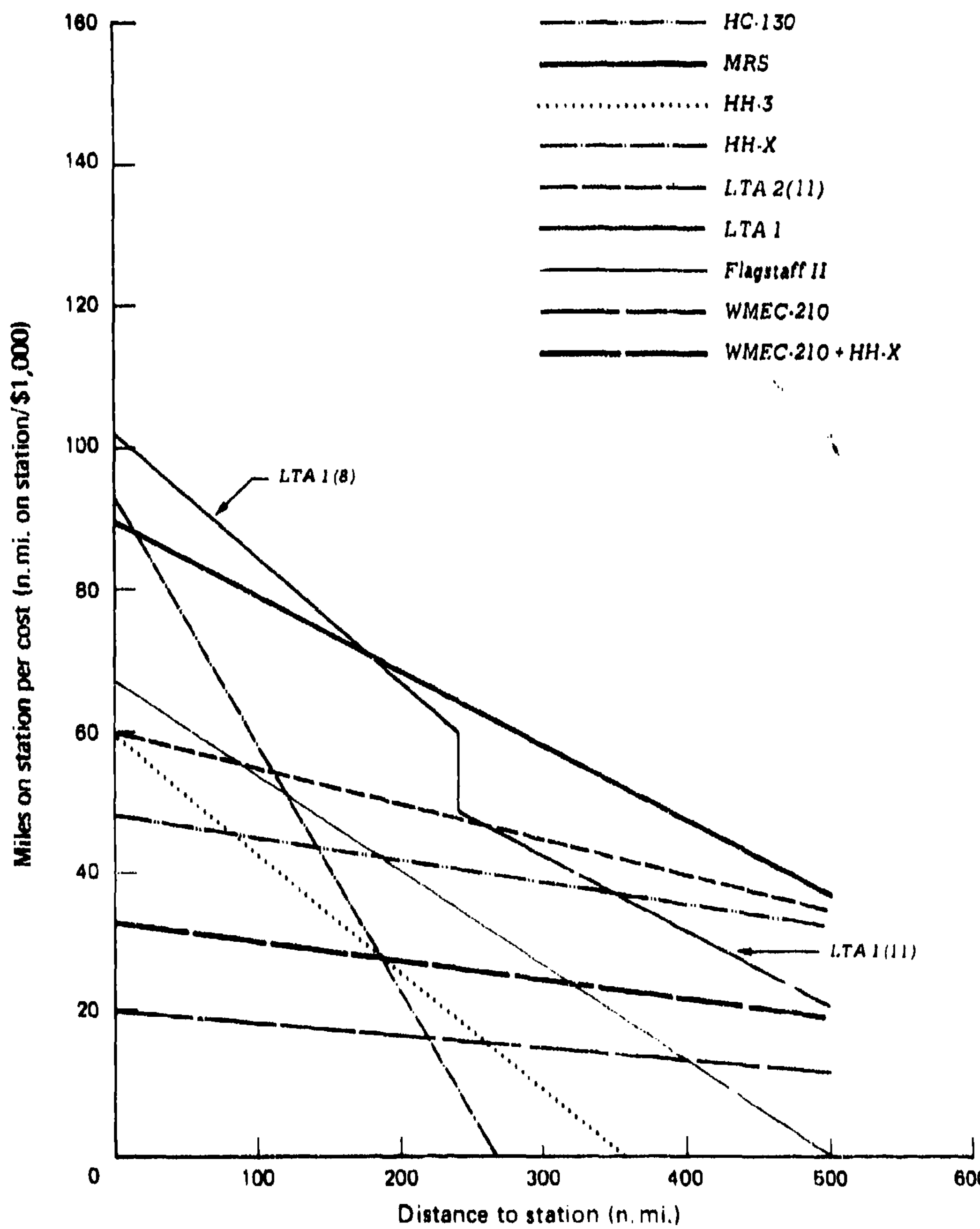


FIG. V-6: COST/EFFECTIVENESS OF VEHICLES IN INVESTIGATION TASKS (0.01 HOUR DELAY, HIGH TARGET DENSITY)

TABLE V-5

COST/EFFECTIVENESS OF VEHICLES
IN GROSS SURVEILLANCE TASKS

(Small targets)

Square miles on station per cost
(sq. mi. on sta./$1,000)

Distance to station (miles)

Vehicle	100	200	300	400	500
LTA 1 (8)	4640	3450	-	-	-
LTA 1 (11)	-	-	2080	1510	1020
LTA 2 (11)	2820	2510	2190	1880	1610
LTA 3 (14)	2070	1920	1770	1630	1480
MRS	4280	3690	3160	2580	1990
HC-130	2320	2170	1990	1840	1690
HH-X	1890	780	0	0	0
HH-3	1380	840	320	0	0
Flagstaff II	1160	870	580	290	0
WMEC-210	370	330	310	280	250
HEC-MEC	240	230	210	190	170
WHEC-378	180	170	160	140	130
WMEC-210 + HH-X	750	690	630	570	510

TABLE V-6

COST/EFFECTIVENESS OF VEHICLES
IN GROSS SURVEILLANCE TASKS

(Medium targets)

Square miles on station per cost
(sq. mi. on sta./$1,000)

Distance to station (miles)

Vehicle	100	200	300	400	500
LTA 1 (8)	7330	5450	-	-	-
LTA 1 (11)	-	-	3280	2380	1600
LTA 2 (11)	4450	3960	3460	2970	2540
LTA 3 (14)	3260	3030	2800	2570	2340
MRS	8560	7390	6320	5160	3990
HC-130	4630	4330	3980	3690	3390
HH-X	3790	1560	0	0	0
HH-3	2750	1680	650	0	0
Flagstaff II	2320	1740	1160	580	0
WMEC-210	730	670	620	550	500
HEC-MEC	480	450	420	380	350
WHEC-378	360	340	310	280	260
WMEC-210 + HH-X	1510	1380	1260	1130	1020

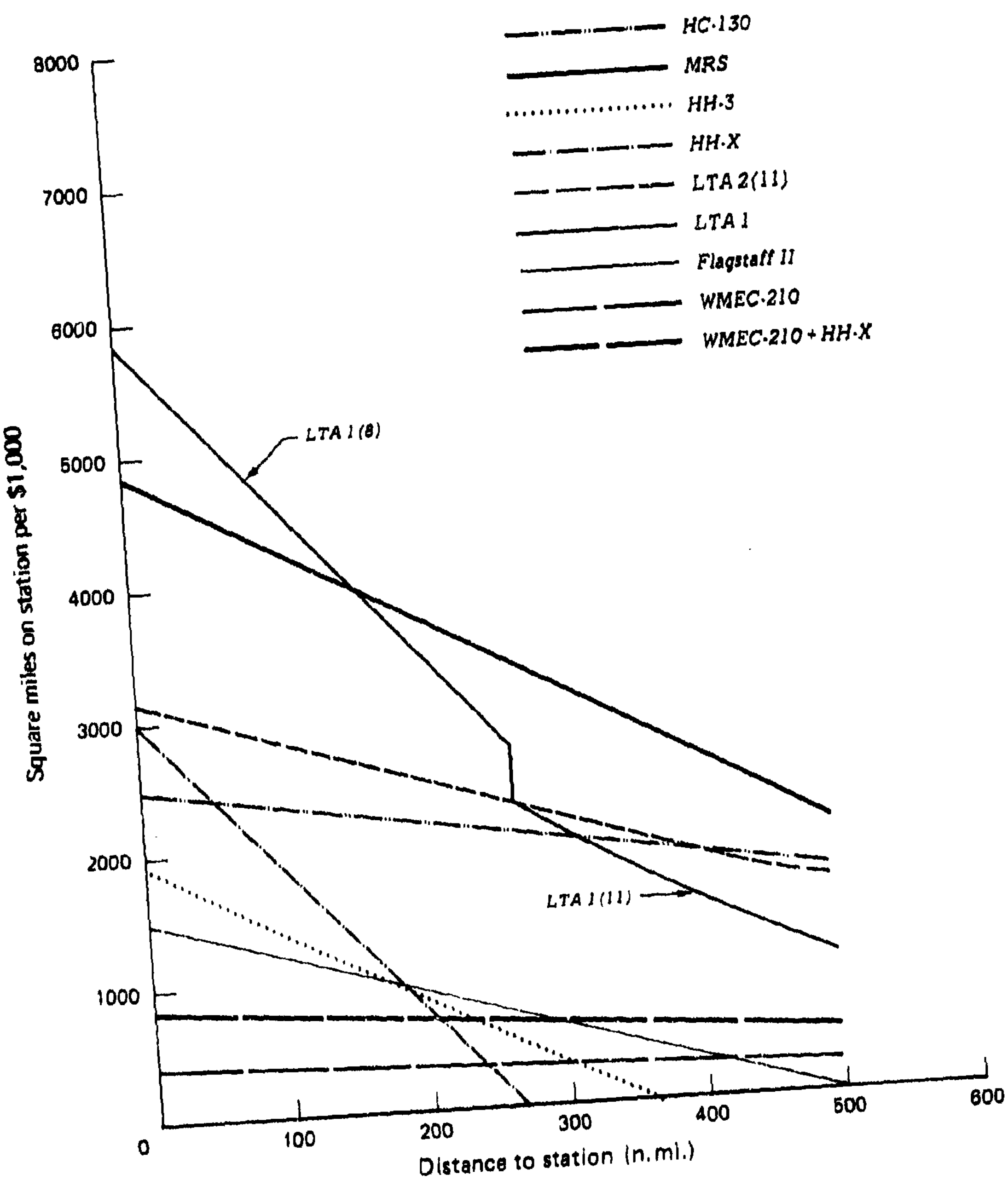


FIG. V-7: COST/EFFECTIVENESS OF VEHICLES IN PERFORMING GROSS SURVEILLANCE (SMALL TARGETS)

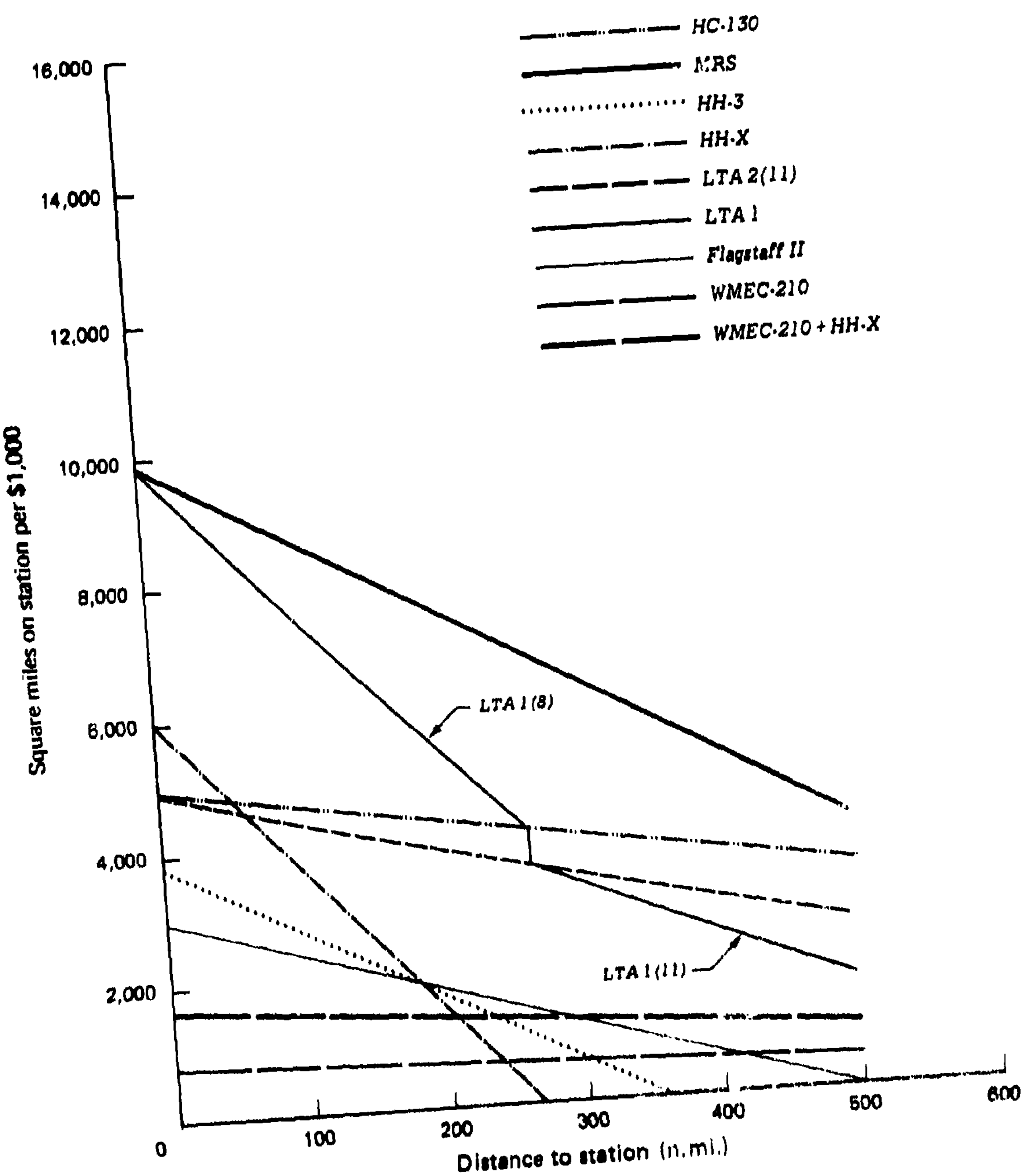


FIG. V-8: COST/EFFECTIVENESS OF VEHICLES IN PERFORMING GROSS SURVEILLANCE (MEDIUM TARGETS)

COMPARISON OF VEHICLES IN TRAIL/OBSERVATION TASKS

Cost effectiveness in trail/observation tasks is measured by hours on station per unit of cost. Vehicle speeds on station are dictated by the requirement to maintain trail on a target making good a speed of 15 knots. The on-station assumptions were given in chapter 4. To optimize cost/effectiveness, transit speeds are based on maximizing the fractional time on station. Conventional cutters and helicopters transit at maximum sustained speeds; MRS and HC-130 aircraft transit at high altitude speeds of 375 and 290 knots, respectively. Airship transit speeds that maximize the fraction of time-on-station were presented in table V-1.

Optimum transit speed for Flagstaff II was based on the assumption of a mixed foilborne/hullborne mode of operation. Optimum tactics are shown in appendix J of volume II to require 100 percent foilborne mode for distances less than 473 miles, and 100 percent hullborne for greater distances to station.

The optimum time-on-station fraction for all vehicles is given in table V-7, and shown graphically as a function of station distances in figure V-9.

As in the previous chapter, trail tasks are analyzed from two points of view, depending on the relative importance of patrol and trail tasks. When the patrol tasks are dominant the airships are first optimized for patrol and then compared with other vehicles in trail tasks. Airship endurance and aircrew sizes are increased as necessary for the trail task.

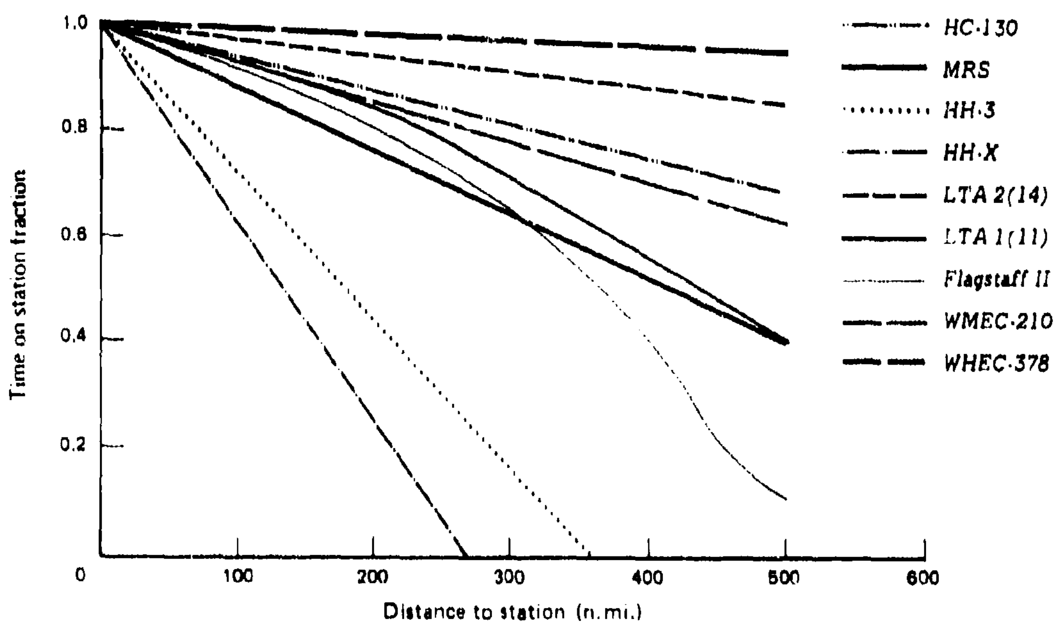


FIG. V-9: TIME-ON-STATION FRACTIONS FOR TRAIL TASKS

TABLE V-7

TIME-ON-STATION FRACTIONS IN TRAIL TASKS

	Distance to station (miles)				
Vehicle	100	200	300	400	500
LTA 1 (11)	0.93	0.84	0.71	0.56	0.40
LTA 2 (14)	0.97	0.94	0.93	0.89	0.85
LTA 3 (14)	0.99	0.97	0.95	0.94	0.92
MRS	0.88	0.76	0.65	0.53	0.41
HC-130	0.93	0.87	0.80	0.74	0.68
HH-X	0.63	0.26	0	0	0
HH-3	0.72	0.44	0.17	0	0
Flagstaff II	0.92	0.80	0.65	0.41	0.11
WMEC-210	0.93	0.85	0.78	0.70	0.63
HEC-MEC	0.93	0.87	0.80	0.73	0.67
WHEC-378	0.99	0.98	0.97	0.95	0.94
WMEC-210 + HH-X	0.93	0.85	0.78	0.70	0.63

Patrol Tasks Dominant

Cost/effectiveness comparisons for this case are presented in table V-8 and figure V-10 as a function of distance to station. The measure is hours on station per $1,000 cost. For distances less than about 370 miles, Flagstaff II is most cost/effective in the trail task. At greater distances, LTA 2 (14) is superior; WMEC-210 is also relatively high on a cost/effectiveness basis. When helicopters are added to WMEC-210 to give it a more versatile capability the added cost brings it below the airships in cost effectiveness. The same vehicles are compared with respect to endurance on station in table V-9. Airship endurance varies from half day to 8 days. In comparison, Flagstaff II endurance varies from half to 2 days and the conventional cutters can maintain trail for about 4 days (WMEC-210) to 21 days (WHEC-378) in areas 500 miles from port.

Trail Tasks Dominant

As in the previous chapter, trail tasks are analyzed from two points of view depending on the relative importance of patrol and trail tasks. When the patrol tasks are dominant the airships are first optimized for patrol and then compared with other vehicles in trail tasks. Airship endurance and aircrew sizes are increased as necessary for the trail tasks.

The airships presented in table IV-11 of chapter IV are compared here in trail tasks at station distances out to 500 miles. Cost effectiveness comparisons are presented graphically in figures V-11 and V-12 for 1,000 mile and 2,000 mile range airships, respectively.

Beyond 140 miles station distance the 60 knot/1,000 mile range LTA is superior in hours on station per $1,000. The LTA 1 (11), however, is seen to be highly competitive in trail cost effectiveness.

Differences in trail performance are shown in figure V-12 to be greater for the longer range airships. At 500 miles station distance the LTA 2 (14) is only about 15 percent below the 50 and 60 knot optimum airships.

SUMMARY OF RESULTS

Cost/effectiveness comparisons of all vehicles are presented in table V-10 for investigation, gross surveillance, and trail tasks at 200 miles distance to station. Comparisons on a relative basis are shown in table V-11. The investigation task results are given for two cases -- no delay and 0.1 hour delay/high target density. The gross surveillance task is shown for the case of small target sweepwidths. Table V-12 presents the same information for a station distance of 500 miles.

Summary results are presented on a relative basis in table V-13. Values greater than 1.00 indicate a higher cost/effectiveness.

At 200 miles station distance the 100 knot/1,000 mile range airships LTA 1 (8) and LTA 1 (11) are the reference airships for patrol and trail tasks, respectively. The MRS aircraft is superior in all tasks except trail/observation, in which case Flagstaff II has a 47 percent advantage. The MRS advantage in investigation tasks varies from 61 percent

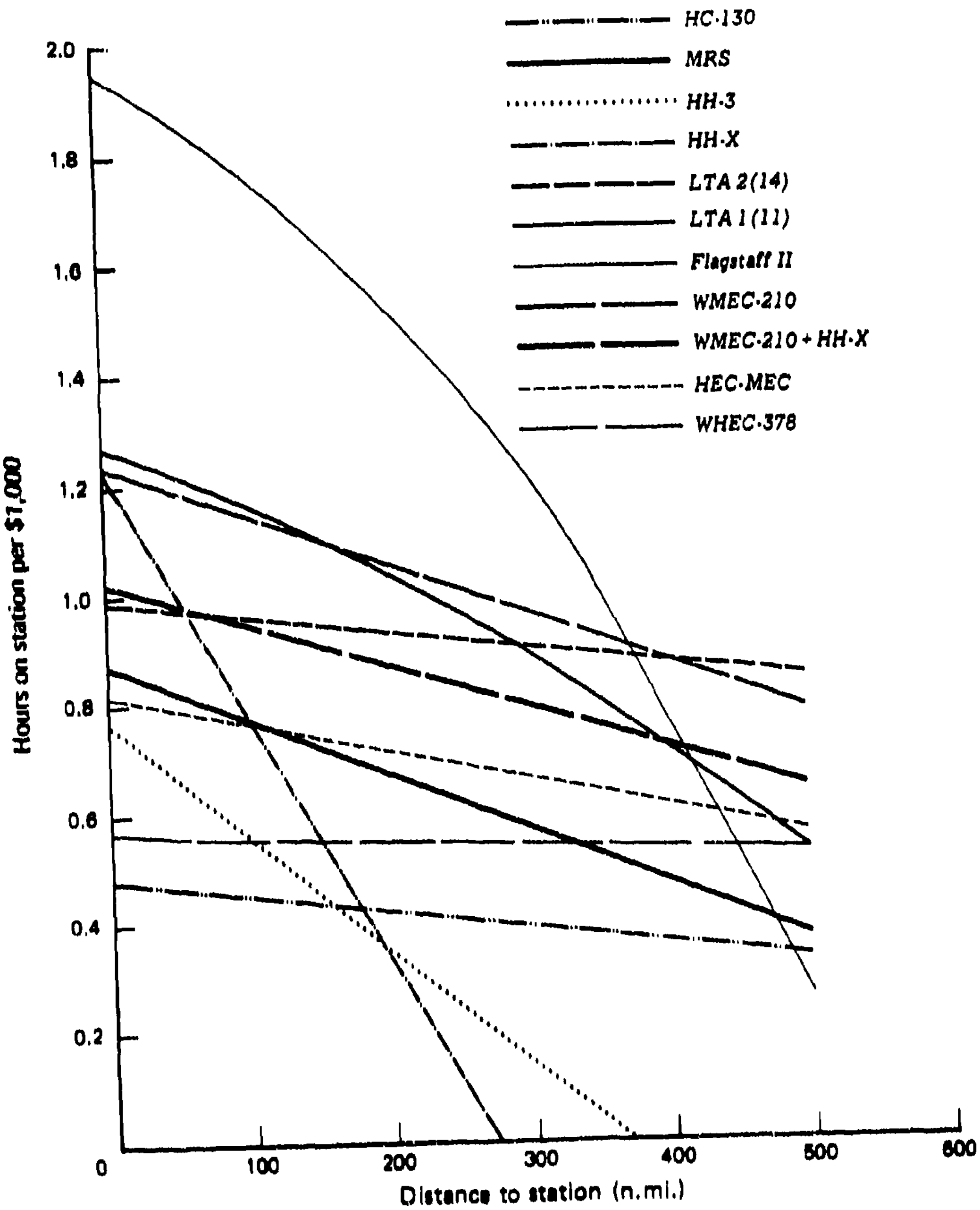


FIG. V-10: COST/EFFECTIVENESS OF VEHICLES IN TRAIL TASKS (PATROL TASKS DOMINANT)

TABLE V-9

ENDURANCE ON STATION IN TRAIL TASKS
(Patrol tasks dominant)
(hours)

Resource	Distance to station (miles) 100	200	300	400	500
LTA 1 (11)	26	19	16	14	10
LTA 2 (14)	92	83	93	81	76
LTA 3 (14)	192	186	181	173	165
MRS	4.0	3.4	2.9	2.4	1.8
HC-130	9.7	9.1	8.5	7.9	7.3
HH-X	2.6	1.1	0	0	0
HH-3	4.1	2.5	1.0	0	0
Flagstaff II	51	36	25	12	12
WMEC-210	140	128	117	105	95
HEC-MEC	155	145	134	122	112
WHEC-378	705	655	605	554	504
WMEC-210 + HH-X	140	128	117	105	95

in the no delay case to 3 percent with delays and high target density. In the gross surveillance task against small targets, MRS is 7 percent more cost/effective.

When trail tasks are dominant the 60 knot/1,000 mile range airship is about 10 percent superior to LTA 1 (11). At 500 miles station distance the best airship for patrol tasks is the 80 knot/2,000 mile range LTA 2 (11). When patrol tasks are dominant the optimum airship for trail tasks is the slightly larger LTA 2 (14). When trail tasks are dominant the 50 and 60 knot airships are about 15 percent more cost effective than the 80 knot airship.

The MRS aircraft remains superior in patrol tasks, but the airships are superior in trail tasks. The MRS advantage in investigation tasks is greater than at 200 miles, increasing to 90 percent in the no delay case, 6 percent with delays and high target density, and 24 percent in the gross surveillance task against small targets.

For trail tasks the WMEC-210 is a close competitor to the airships. The airship superiority increases to about 30 percent when the WMEC-210 includes an HH-X helicopter.

TABLE V-8

HOURS ON STATION PER COST IN TRAIL TASKS
(Patrol tasks dominant)
(hrs./$1,000)

Resource	Distance to station (miles) 100	200	300	400	500
LTA 1 (11)	1.15	1.02	0.86	0.69	0.50
LTA 2 (14)	0.94	0.91	0.90	0.86	0.82
LTA 3 (14)	0.85	0.84	0.82	0.81	0.79
MRS	0.74	0.64	0.55	0.45	0.35
HC-130	0.44	0.41	0.38	0.35	0.32
HH-X	0.76	0.31	0	0	0
HH-3	0.55	0.33	0.13	0	0
Flagstaff II	1.75	1.50	1.20	0.74	0.22
WMEC-210	1.13	1.03	0.95	0.85	0.76
HEC-MEC	0.75	0.70	0.64	0.59	0.54
WHEC-378	0.54	0.54	0.53	0.52	0.52
WMEC-210 + HH-X	0.93	0.85	0.78	0.70	0.63

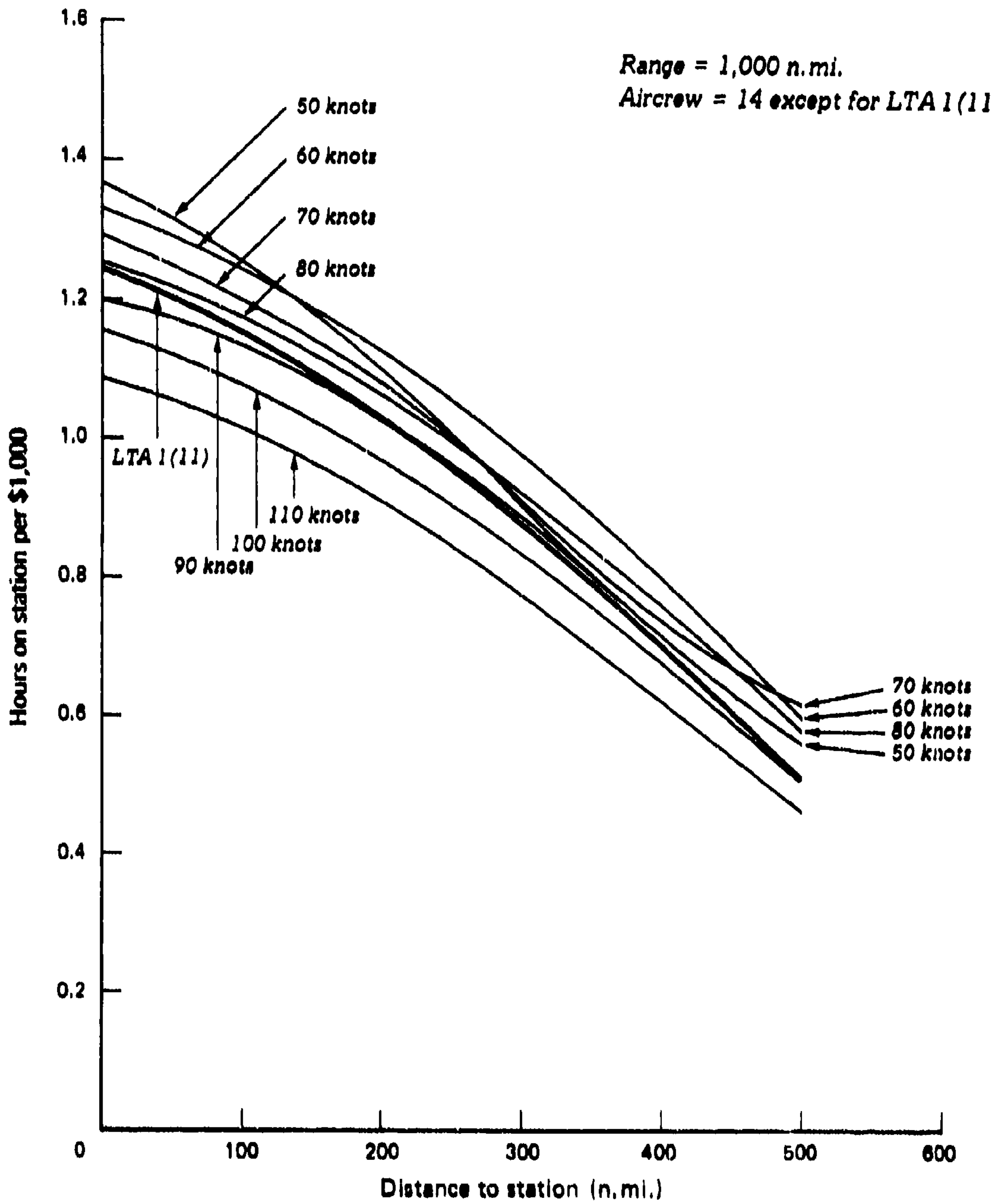


FIG. V-11: COMPARISON OF AIRSHIPS IN TRAIL TASKS (TRAIL TASKS DOMINANT)

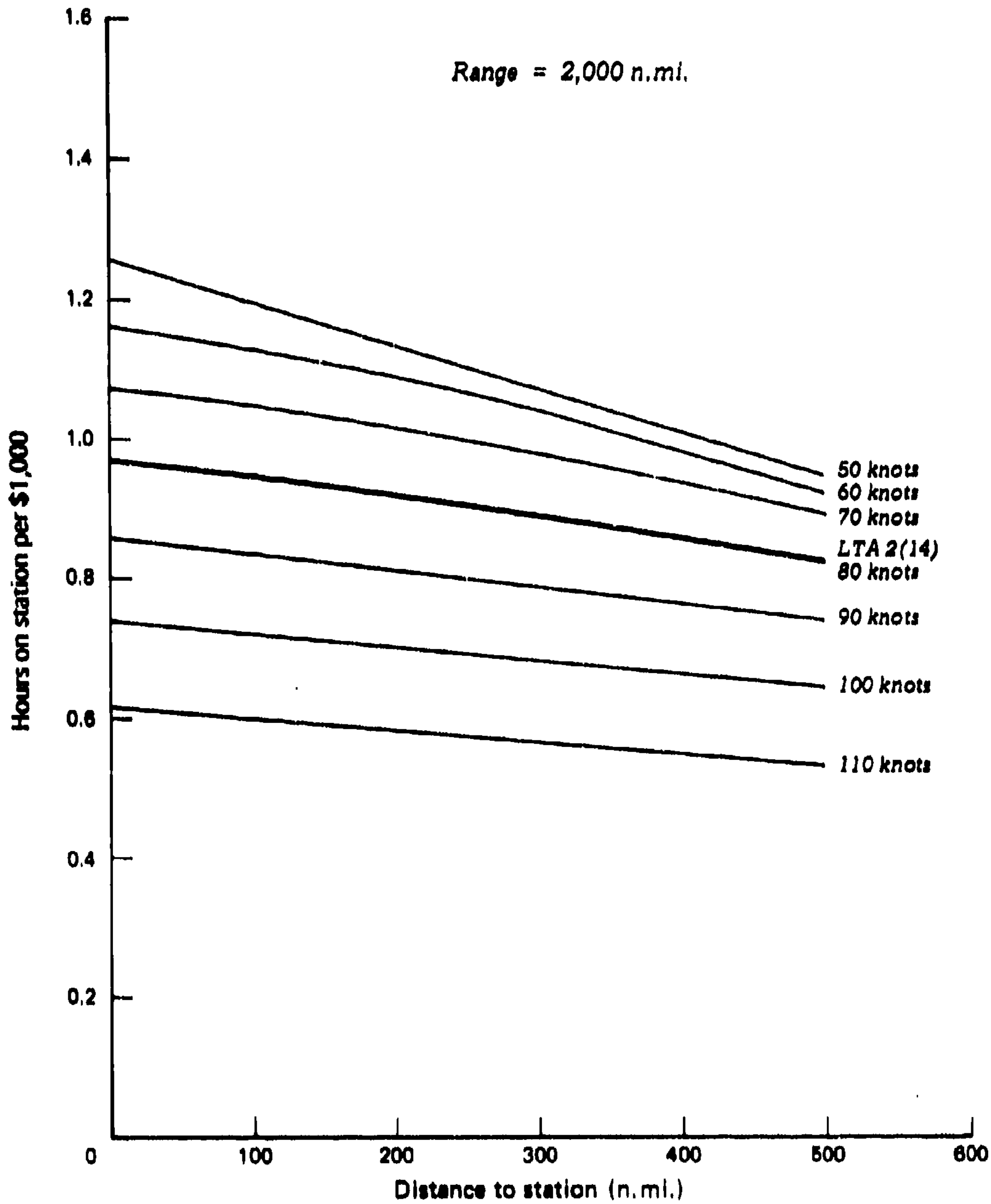


FIG. V-12: COMPARISON OF AIRSHIPS IN TRAIL TASKS
(TRAIL TASKS DOMINANT)

TABLE V-10

SUMMARY:
COST/EFFECTIVENESS COMPARISONS FOR 200 MILES
DISTANCE TO STATION

Vehicle	Investigation of dispersed targets: No delay (mi. on sta./ $1,000)	Investigation of dispersed targets: 0.01 hr. delay, high target density (mi. on sta./ $1,000)	Small target gross surveillance (sq.mi.on sta./ $1,000)	Trail: Hours/cost (hrs. on sta./ $1,000)	Trail: Endurance (hrs.on sta.)
LTA 1 (8)	92	67	3,450	-	-
LTA 1 (11)	74	54	2,800	1.02	19
LTA 2 (11)	66	50	2,510	-	-
LTA 2 (14)	60	45	2,260	0.91	83
LTA 3 (14)	51	39	1,920	0.84	186
LTA (60/1000)	47	39	1,800	1.13	43
MRS	148	69	3,690	0.65	3.4
HC-130	87	42	2,170	0.41	9.1
HH-X	39	24	780	0.31	1.0
HH-3	42	26	840	0.33	2.5
Flagstaff II	49	39	870	1.50	36
WMEC-210	19	17	330	1.03	128
HEC-MEC	12	11	230	0.70	145
WHEC-378	10	8	170	0.54	655
WMEC-210 + HH-X	38	28	690	0.85	128

TABLE V-11

SUMMARY:
COST/EFFECTIVENESS COMPARISONS RELATIVE TO LTA 1 (8) AND LTA 1 (11) FOR 200 MILES DISTANCE TO STATION

Vehicle	Investigation of dispersed targets: No delay (mi. on sta./ $1,000)	Investigation of dispersed targets: 0.01 hr. delay, high target density (mi. on sta./ $1,000)	Small target gross surveillance (sq.mi.on sta./ $1,000)	Trail: Hours/cost (hrs. on sta./ $1,000)	Trail: Endurance (hrs.on sta.)
LTA 1 (8)	1.00 (2)	1.00 (2)	1.00 (2)	-	-
LTA 1 (11)	0.80	0.81 (3)	0.80 (3)	1.00 (4)	1.00
LTA 2 (11)	0.72	0.75	0.72	-	-
LTA 2 (14)	0.65	0.67	0.65	0.89	4.37
LTA 3 (14)	0.55	0.58	0.55	0.82	9.79
LTA (60/1000)	0.51	0.58	0.51	1.11 (2)	2.26
MRS	1.61 (1)	1.03 (1)	1.07 (1)	0.64	0.18
HC-130	0.95 (3)	0.63	0.63	0.40	0.48
HH-X	0.42	0.36	0.23	0.30	0.05
HH-3	0.46	0.39	0.24	0.32	0.13
Flagstaff II	0.53	0.58	0.25	1.47 (1)	1.89
WMEC-210	0.21	0.25	0.10	1.01 (3)	6.74
HEC-MEC	0.13	0.16	0.07	0.69	7.63
WHEC-378	0.11	0.12	0.05	0.53	34.5
WMEC-210 + HH-X	0.41	0.42	0.20	0.83	6.74

__( ) indicates largest values and rank

TABLE V-12

SUMMARY:
COST/EFFECTIVENESS COMPARISONS FOR 500 MILES
DISTANCE TO STATION

	Investigation of dispersed targets			Trail	
Vehicle	No delay (mi. on sta./ $1,000)	0.01 hr. delay, high target density (mi. on sta./ $1,000)	Small target gross surveillance (sq.mi.on sta./ $1,000)	Hours/cost (hrs-on sta./ $1,000)	Endurance (hrs.on sta.)
LTA 2 (11)	42	35	1610	-	-
LTA 2 (14)	38	31	1440	0.82	76
LTA 3 (14)	39	31	1480	0.79	165
LTA 1 (11)	27	21	1020	0.50	10
LTA (60/2,000)	35	29	1330	0.94	77
LTA (60/1,000)	18	16	680	0.60	23
MRS	80	37	1990	0.35	1.8
HC-130	68	33	1690	0.32	7.3
HH-X	0	0	0	0	0
HH-3	0	0	0	0	0
Flagstaff II	0	0	0	0.22	12
WMEC-210	14	13	250	0.76	95
HEC-MEC	9	9	170	0.54	112
WHEL-378	7	6	130	0.52	504
WMEC-210 + HH-X	28	21	510	0.63	95

TABLE V-13

SUMMARY:
COST/EFFECTIVENESS COMPARISONS RELATIVE TO LTA 2 (11)
AND LTA 2 (14) FOR 500 MILES
DISTANCE TO STATION

Vehicle	Investigation of dispersed targets: No delay (mi. on sta./ $1,000)	Investigation of dispersed targets: 0.01 hr. delay, high target density (mi. on sta./ $1,000)	Small target gross surveillance (sq.mi.on sta./ $1,000)	Trail: Hours/cost (hrs. on sta./ $1,000)	Trail: Endurance (hrs.on sta.)
LTA 2 (11)	1.00 (3)	1.00 (2)	1.00 (3)	—	—
LTA 2 (14)	0.90	0.89	0.90	1.00 (2)	1.00
LTA 3 (14)	0.93	0.89	0.93	0.96 (3)	2.17
LTA 1 (11)	0.64	0.60	0.64	0.61	0.13
LTA (60/2000)	0.83	0.83	0.83	1.15 (1)	1.01
LTA (60/1000)	0.43	0.46	0.43	0.73	0.30
MRS	1.90 (1)	1.06 (1)	1.24 (1)	0.43	0.02
HC-130	1.62 (2)	0.94 (3)	1.05 (2)	0.39	0.10
HH-X	0	0	0	0	0
HH-3	0	0	0	0	0
Flagstaff II	0	0	0	0.27	0.16
WMEC-210	0.33	0.37	0.16	0.93	1.25
HEC-MEC	0.21	0.26	0.11	0.66	1.47
WHEL-378	0.17	0.17	0.08	0.63	6.63
WMEC-210 + HH-X	0.67	0.60	0.32	0.77	1.25

___( ) indicates largest values and rank.

VI. SEARCH AND RESCUE ANALYSIS

BACKGROUND

One of the important missions performed by the U.S. Coast Guard is that of Search and Rescue (SAR). Thus, any vehicle that the Coast Guard considers using should be evaluated in a SAR role.

Previous studies performed by CNA indicated that increased speed does not substantially improve capability to perform SAR; such speed advantages are essentially nullified by the fact that many SAR cases required towing a distressed vehicle at a speed of about 7 knots. Based on these results and the fact that it is unlikely that an LTA vehicle could perform any towing service (see volume III), this analysis assumed that the LTA would be performing a primary mission of, perhaps, ELT or MEP, and evaluated it in a secondary SAR role.

GENERAL APPROACH

This analysis was based on the servicing of actual SAR cases; the capability of LTAs to handle historical cases was evaluated. The LTAs were assumed to be positioned on bases from which ELT or MEP patrols would be staged. When a particular search and rescue case meets established criteria, an LTA is assumed to be diverted from its primary role to service the case. If the particular case does not meet criteria for an airship, the vehicle that historically handled the case is allowed to do so in the analysis.

A simple computer model was constructed that takes the historical SAR cases one at a time and determines whether the established criteria that would permit an LTA to respond are met. For each SAR case, the model stores data relative to the case. The data are summarized and printed out after the entire case load has been serviced. Results are obtained in terms of:

- The number of SAR sorties performed by LTAs.
- What current Coast Guard vehicles the LTA replaced when performing a sortie.
- What types of cases (in terms of severity) the LTA handled.

The model was used to obtain results for the 1st (New England) Coast Guard District, and LTAs were assumed to be located at Cape Cod Air Station. The model is described below and is discussed in detail in appendix H of volume II.

THE MODEL

General Description

A model is a simple simulation and was used to study the effects of introducing LTA vehicles into the Coast Guard Search and Rescue operations. It consists of two major parts:

- Resource assignment
- Calculation of statistics

Because the purpose of this study was to consider the effects of LTA vehicles on SAR, the model actually simulates only the LTA's performance. If, by the criteria established, the LTA does not service a particular sortie, the model uses the vehicle that serviced it historically. This approach is simple and straight-forward. The model required few inputs in addition to those from the historical data base -- principally the characteristics and assumed positions of LTAs.

Inputs and Assumptions

The detailed capabilities of the LTA as assumed for this analysis were shown in appendix H of volume II. Table VI-1 lists some of the more important characteristics.

Because the model assumed LTA vehicles had a primary mission other than SAR, a built-in assumption prevents the LTA from accepting a sortie that is estimated to require more than 12 hours to complete.

The only inputs other than LTA characteristics required by the model are the locations of the LTAs and their availability factors.

TABLE VI-1

ASSUMED CAPABILITIES OF LTA VEHICLES FOR SAR

Rescue up to 17 persons	
Operate in winds under 60 knots	
Operate in all temperatures and visibilities	
Ability to operate at all distances offshore	
Cannot icebreak, refloat, or dewater	
Cannot fight fires or make repairs	
Cannot tow	
Delay before getting underway	15 minutes
Search time	15 minutes
Assistance time	1 hour
Speed	60, 80, and 100 knots

Resource Assignment Routine

This routine decides which vehicle to assign to a particular historical SAR sortie; either an LTA is assigned, or the sortie is given to the resource that performed it historically. Figure VI-1 presents the flowchart for this routine.

If an LTA is both available and capable, the routine calculates the response time of each available LTA and selects as the candidate LTA the one with the shortest response time. This time, and the response time of the actual resource, are then compared against the allowable tolerance time for the severity of the case. Tolerance times are shown in table VI-2.

TABLE VI-2

TOLERANCE TIMES

Severity	Tolerance
None/unknown	4 hours
Slight	3 hours
Severe, property only	1 hour
Severe, personnel	.5 hour

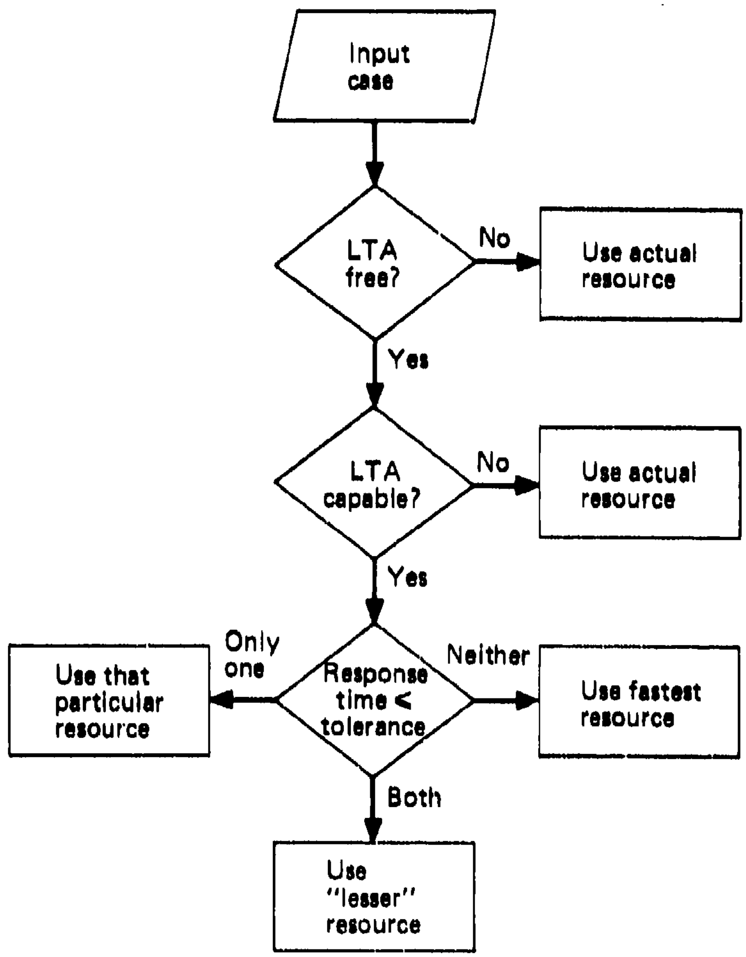
If neither LTAs nor historical vehicles can arrive on scene within the tolerance time, the routine assigns the fastest resource. If only one of the two resources can arrive within the tolerance time, the routine assigns that one. Should both the LTA and the actual resource be able to arrive on scene within the tolerance time, the routine assigns the "lesser" resource. The "lesser" resource is chosen from a ranking list which attempts to model the decision made by the person assigning resources at the RCC center. For the purposes of this analysis, resources "less" than an LTA are taken to be small boats, and WPBs; those "greater" than an LTA are cutters, helicopters, and aircraft.

DISTRICT 1 ANALYSIS

Inputs

Much of the fishing activity in District 1 centers around Cape Cod. Thus, assuming that the LTAs would be on a primary mission of ELT, Cape Cod Air Station was chosen as the base from which LTA patrols would be staged.

Each case assumed that there would be one LTA available on a 24-hour basis 100 percent of the time. LTA speeds of 60, 80, and 100 knots were considered. Table VI-3 summarizes the cases analyzed for District 1.



Lesser: Boats ≤ 52 ft., WPBs
Greater: WMEC, HELOS, C-130

FIG. VI-1: VEHICLE ASSIGNMENT FLOWCHART

TABLE VI-3

DISTRICT 1 CASES

Case	Time	LTA location	LTA speed
I	July 21-27, 1972	Cape Cod Air Station	
IA			60 knots
IB			80 knots
IC			100 knots
II	Jan.21-27, 1973	Cape Cod Air Station	
IA			60 knots
IB			80 knots
IC			100 knots

The analysis was performed for two different seasonal cases: typical one-week periods in the summer and winter. The summer workload was provided by the actual caseload experienced during the week of July 21-27, 1972; the winter analysis was based on SAR cases experienced the week of January 21-27, 1973.

RESULTS

During the week of July 21-27, 1972, there was a total of 354 SAR sorties contracted in District 1 compared with 34 during the week of January 21-27, 1973. Table VI-4 shows which U.S. Coast Guard resources performed these sorties. The columns labeled Case I (July) and Case II (Jan) show which resources performed the sorties historically. The remaining 6 columns show resource utilization when the LTA was introduced in accordance with table VI-3.

Table VI-5 shows the Coast Guard resources replaced by the LTA when performing the SAR sorties.

The severity of cases serviced by the LTA are summarized in table VI-6.

During the week of 21-27 July, the 60-knot LTA handled 11 SAR cases, and the 80-knot and 100-knot LTA handled 12 cases each. Of these, only 3 or less were severe danger cases. In order to prevent undue distraction from the LTA's primary mission, one might limit its SAR response to only moderately severe or severe danger cases.

TABLE VI-4

RESOURCE UTILIZATION
(DISTRICT 1)

Resource	Case I (July) w/o LTA	Case IA	Case IB	Case IC	Case II (Jan) w/o LTA	Case IIA	Case IIB	Case IIC
	Number of Sorties							
Amphibious	6	6	6	6	2	2	2	2
WMEC	4	3	3	3	-	-	-	-
WPB	5	5	5	5	3	3	3	3
WYTM, WYTL	2	2	2	2	1	1	1	1
HU-16E	1	1	1	1	-	-	-	-
HH-52A	9	5	5	5	2	-	-	-
HH-3F	16	10	9	9	4	2	2	2
Non-ship boats	10	10	10	10	-	-	-	-
40'-41'	183	183	183	183	15	15	15	15
30'	9	9	9	9	-	-	-	-
UTL, IB/OB launches	25	25	25	25	-	-	-	-
44'	59	59	59	59	7	7	7	7
36'	1	1	1	1	-	-	-	-
MRB	1	1	1	1	-	-	-	-
Skiffs	6	6	6	6	-	-	-	-
Auxiliary	17	17	17	17	-	-	-	-
LTA	-	11	12	12	-	4	4	4
TOTAL	354	354	354	354	34	34	34	34

TABLE VI-5

RESOURCE SORTIES REPLACED BY LTA

Resource	Case IA	Case IB	Case IC	Case IIA	Case IIB	Case IIC
WMEC	1	1	1	-	-	-
HH-52A	4	4	4	2	2	2
HH-3F	6	7	7	2	2	2
TOTAL	11	12	12	4	4	4

TABLE VI-6

SEVERITY OF LTA CASES
(DISTRICT 1)

Severity	Number of sorties					
	Case IA	Case IB	Case IC	Case IIA	Case IIB	Case IIC
None/unknown	6	6	6	1	1	1
Slight	1	1	1	0	0	0
Moderate	2	2	2	2	2	2
Severe, property	0	0	0	0	0	0
Severe, personnel	2	3	3	1	1	1
TOTAL	11	12	12	4	4	4

During the winter, SAR activity occurs much less frequently. (Only 4 cases were handled by the LTA during the week of January 21-27.) Therefore, such a restriction would be unnecessary. Increased speed does not affect the LTA caseload; in fact, at 100 knots, the LTA becomes more expensive to operate and would probably not be sent on a SAR mission that could be satisfied by a less expensive conventional resource. This would reduce its caseload to less than the 12 indicated previously.

In general, based on the assumptions in the analysis, it appears that the LTA does not perform better than current Coast Guard vehicles in a secondary SAR role. However, it should be noted that for a very small number of isolated cases, the LTA with a good radar and extended endurance could possibly provide an improved search and location capability not readily available on current vehicles.

VII. ENERGY CONSUMPTION ANALYSIS

Fuel consumption for airships and the Coast Guard vehicles is analyzed in this chapter for both patrol and trail tasks. Since the 1973 embargo, fuel conservation has become important in the United States. It was shown in chapter 3 on costs that fuel costs are a relatively small fraction of the overall cost for each of the vehicle types. But, if fuel prices continue to increase rapidly, fuel costs may be a greater portion of overall cost.

The fuel rate in gallons per hour for the airships of 1,000-, 2,000-, and 3,000-mile range are shown in figure VII-1 as a function of airspeed.

The figure shows that fuel rate for airships increases rapidly as airspeed and range increase.

PATROL TASKS

A comparison of the vehicles on the basis of energy efficiency is shown in table VII-1 for patrol tasks at zero station distance. The fuel rates of the airships at their design speed is low relative to the other vehicles. The airships provide about 0.5 mile per gallon. At its low-altitude surveillance speed the MRS provides about 0.8 mile per gallon. (At its transit speed of 375 knots, the MRS gives 1.3 miles per gallon.) The HH-X helicopter provides the most miles per gallon (1.37). Table VII-1 also shows a comparison of the square miles of search per gallon for the vehicles. For this measure the airships and MRS are about equal and the HH-X helicopter remains superior.

The calculations assume sweepwidths against small targets as described in chapter 2. Airships yield relatively higher areas of search per gallon of fuel because of 50 percent larger sweepwidths than other vehicles.

The influence of distance to station on airship energy efficiency is shown in table VII-2. The effective speed, actual transit and cruise speeds, and fuel rates are shown for the airships optimized for patrol tasks. The energy efficiency in terms of miles on station per gallon of fuel is shown at the bottom of the table. As distance to station increases, the miles on station per gallon decreases for LTA 3 (14). Miles on station per gallon decrease for LTA 2 (11) out to distances of 430 miles and then increase at greater distances to station. This increase is a result principally of the reduced airship speeds beyond 430 miles station distance. However, for the shorter range LTA 1 (8) and LTA 1 (11) the decrease in miles per gallon continues only to a distance of about 215 miles, remains relatively constant out to 400 miles and then continues to decrease again.

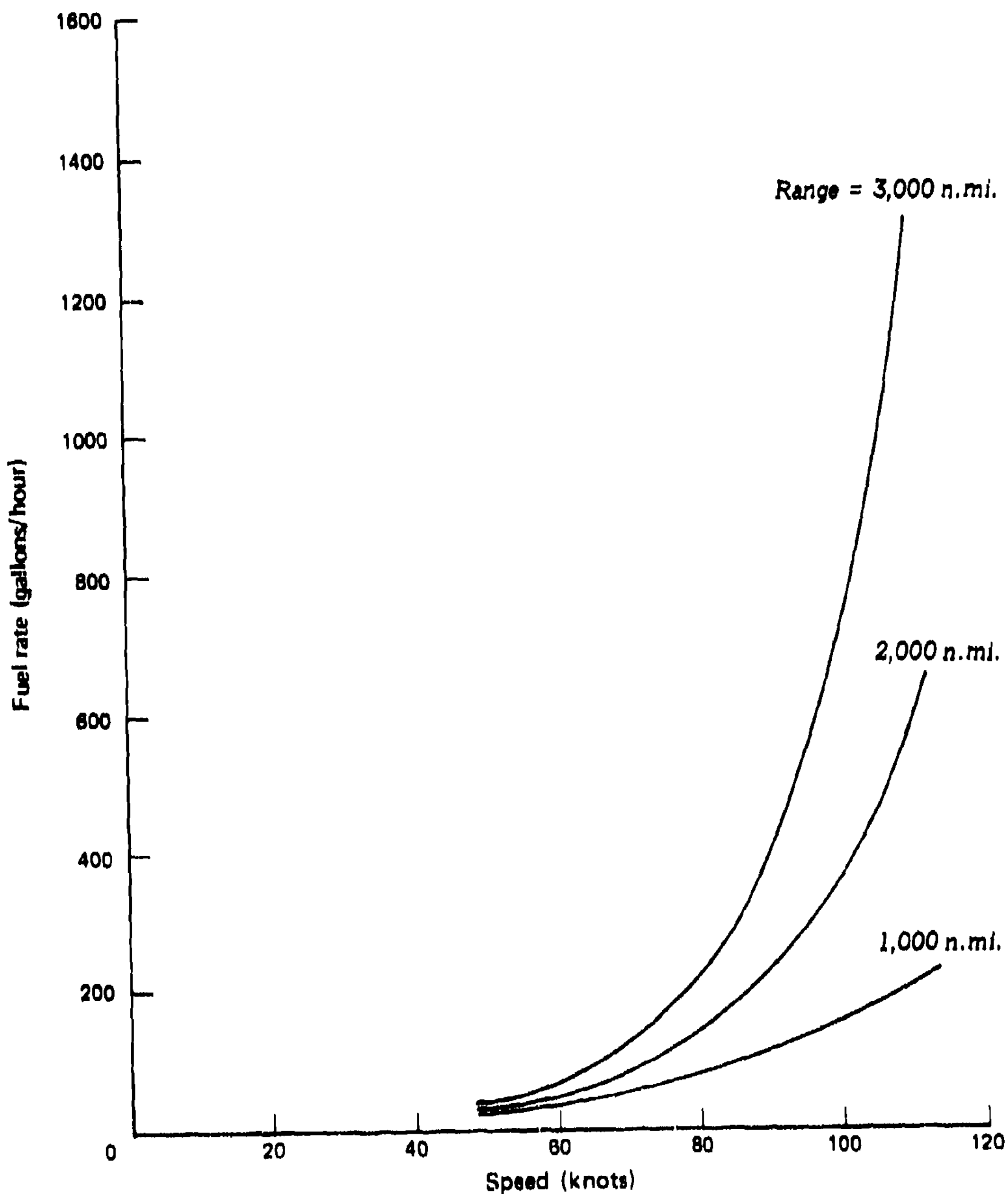


FIG. VII-1: AIRSHIP FUEL CONSUMPTION RATES

TABLE VII-1

ENERGY EFFICIENCY COMPARISON
FOR PATROL TASKS AT ZERO STATION DISTANCE

Vehicle	Fuel rate (gal./hr.)	Speed (kts.)	Miles/ gallon	Square miles/ gallon[a]
LTA 1 (8)	215	110	0.51	19
LTA 2 (11)	144	80	0.55	21
LTA 3 (14)	129	70	0.54	21
MRS	285	230	0.81	20
HC-130	642	210	0.33	8
HH-X	91	125	1.37	27
HH-3	186	126	0.68	14
Flagstaff II	262	48	0.18	3
WMEC-210	315	18	0.06	1
HEC-MEC	245	18	0.07	1
WHEC-378	2514	29	0.01	0.2

[a] Against small targets.

The miles on station per gallon of fuel for all the vehicles is shown in table VII-3 for increasing distances to station. The variation is also shown graphically in figure VII-2. The HH-X provides the largest miles per gallon for small distances, to about 140 miles. Beyond this range to about 450 miles the MRS is the most efficient. For distances beyond 500 miles, the LTA 2 (14) performs better than other vehicles considered.

TRAIL TASKS

The average fuel consumption rates in trail tasks are presented in table VII-4 for LTA 1 (11) and LTA 2 (14) and all other vehicles as a function of distance to station. The energy efficiency in trail tasks is given in table VII-5, measured by hours on station per 1,000 gallons. A graphic presentation of the energy efficiency comparison is shown in figure VII-3.

Patrol Tasks Dominant

Both airships are superior to all other vehicles. The 2,000-mile range airship is considerably more efficient than the 1,000-mile range airship. The hump in the LTA 2(14) curve at 300 miles distance is caused by arriving on station with the heaviness reduced sufficiently to allow operations at the slow speed of 30 knots. Out to about 400 miles, Flagstaff II is the best of the other vehicles.

TABLE VII-2

AIRSHIP ENERGY EFFICIENCY IN PATROL TASKS VERSUS DISTANCE TO STATION

Effective Speed (actual speed)
(Miles on Station/flight hour) (Knots)

Distance to Station (miles)

Vehicle	0	100	200	300	400	500
LTA 1 (8)	110	88 (110)	65 (110)	-	-	-
LTA 1 (11)	-	-	-	46 (90)	33 (75)	22 (66)
LTA 2 (11)	80	72 (80)	64 (80)	56 (80)	48 (80)	41 (73)
LTA 3 (14)	70	65 (70)	61 (70)	56 (70)	51 (70)	47 (70)
			Fuel Rate (gal./hr.)			
LTA 1 (8)	215	215	215	-	-	-
LTA 1 (11)	-	-	-	167	183	102
LTA 2 (11)	144	144	144	144	144	115
LTA 3 (14)	129	129	129	129	129	129
			Miles on Station Per Gallon			
LTA 1 (8)	0.51	0.41	0.30	-	-	-
LTA 1 (11)	-	-	-	0.28	0.27	0.22
LTA 2 (11)	0.55	0.50	0.44	0.39	0.33	0.36
LTA 3 (14)	0.54	0.50	0.47	0.43	0.40	0.36

TABLE VII-3

VEHICLE ENERGY EFFICIENCY COMPARISON IN PATROL TASKS
VERSUS DISTANCE TO STATION

Miles on Station Per Gallon

Distance to Station (miles)

Vehicle	0	100	200	300	400	500
LTA 1 (8)	0.51	0.41	0.30	-	-	-
LTA 1 (11)	-	-	-	0.28	0.27	0.22
LTA 2 (8)	0.55	0.50	0.44	0.39	0.33	0.36
LTA 3 (14)	0.54	0.50	0.47	0.43	0.40	0.36
MRS	0.81	0.71	0.62	0.53	0.43	0.33
HC-130	0.33	0.31	0.29	0.26	0.24	0.22
HH-X	1.37	0.86	0.36	0	0	0
HH-3	0.68	0.49	0.30	0.12	0	0
Flagstaff II	0.18	0.15	0.11	0.07	0.04	0
WMEC-210	0.06	0.05	0.05	0.04	0.04	0.04
HEC-MEC	0.07	0.07	0.06	0.06	0.05	0.05
WHEC-378	0.01	0.01	0.01	0.01	0.01	0.01

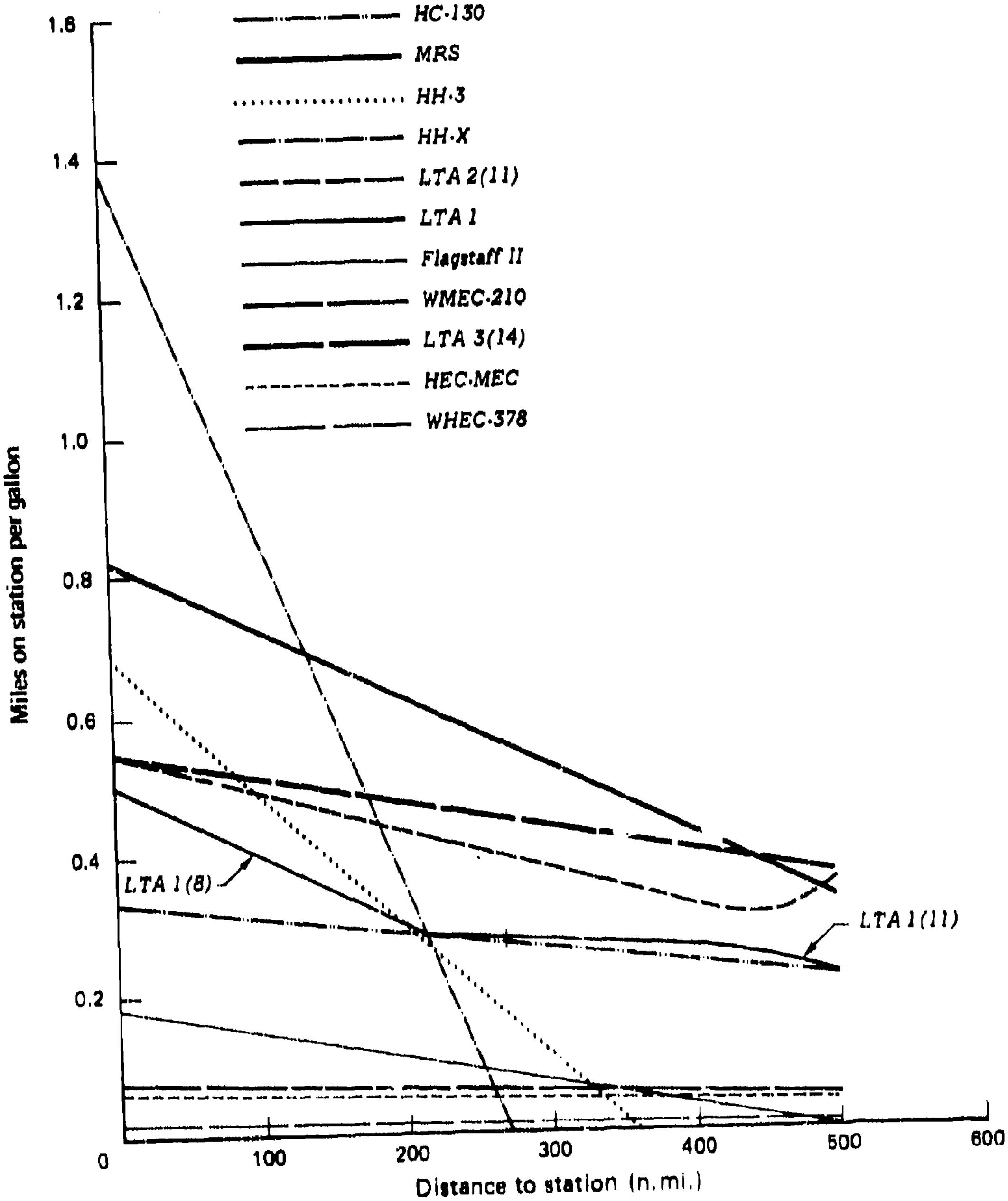


FIG. VII-2: ENERGY EFFICIENCY COMPARISON OF VEHICLES IN PATROL TASKS

TABLE VII-4

AVERAGE FUEL CONSUMPTION RATE
IN TRAIL TASKS
(Patrol tasks dominant)

	Gallons per hour					
	Distance to station (miles)					
Vehicle	0	100	200	300	400	500
LTA 1 (11)	71	84	104	102	97	92
LTA 2 (14)	38	40	43	38	42	42
MRS	285	285	285	285	285	285
HC-130	642	636	631	625	620	614
HH-X	91	91	91	91	91	91
HH-3	186	186	186	186	186	186
Flagstaff II	83	90	113	131	166	45
WMEC-210	315	315	315	315	315	315
HEC-MEC	245	245	245	245	245	245
WHEC-378	344	365	389	415	447	482
WMEC-210 +HH-X	335	335	335	335	335	335

TABLE VII-5

ENERGY EFFICIENCY IN TRAIL TASKS
(Patrol tasks dominant)

Hours on station/1,000 gallons

Distance to station (miles)

Vehicle	0	100	200	300	400	500
LTA 1 (11)	14.1	11.1	8.1	6.9	5.8	4.4
LTA 2 (14)	26.5	24.1	21.8	24.5	21.3	20.0
MRS	3.5	3.1	2.7	2.3	1.9	1.4
HC-130	1.6	1.5	1.4	1.3	1.2	1.1
HH-X	11.0	6.9	2.9	0	0	0
HH-3	5.4	3.9	2.4	0.9	0	0
Flagstaff II	12.1	10.2	7.1	5.0	2.5	2.4
WMEC-210	3.2	3.0	2.7	2.5	2.2	2.0
HEC-MEC	4.1	3.8	3.6	3.3	3.0	2.7
WHEC-378	2.9	2.7	2.5	2.3	2.1	2.0
WMEC-210 + HH-X	3.0	2.8	2.5	2.3	2.1	1.9

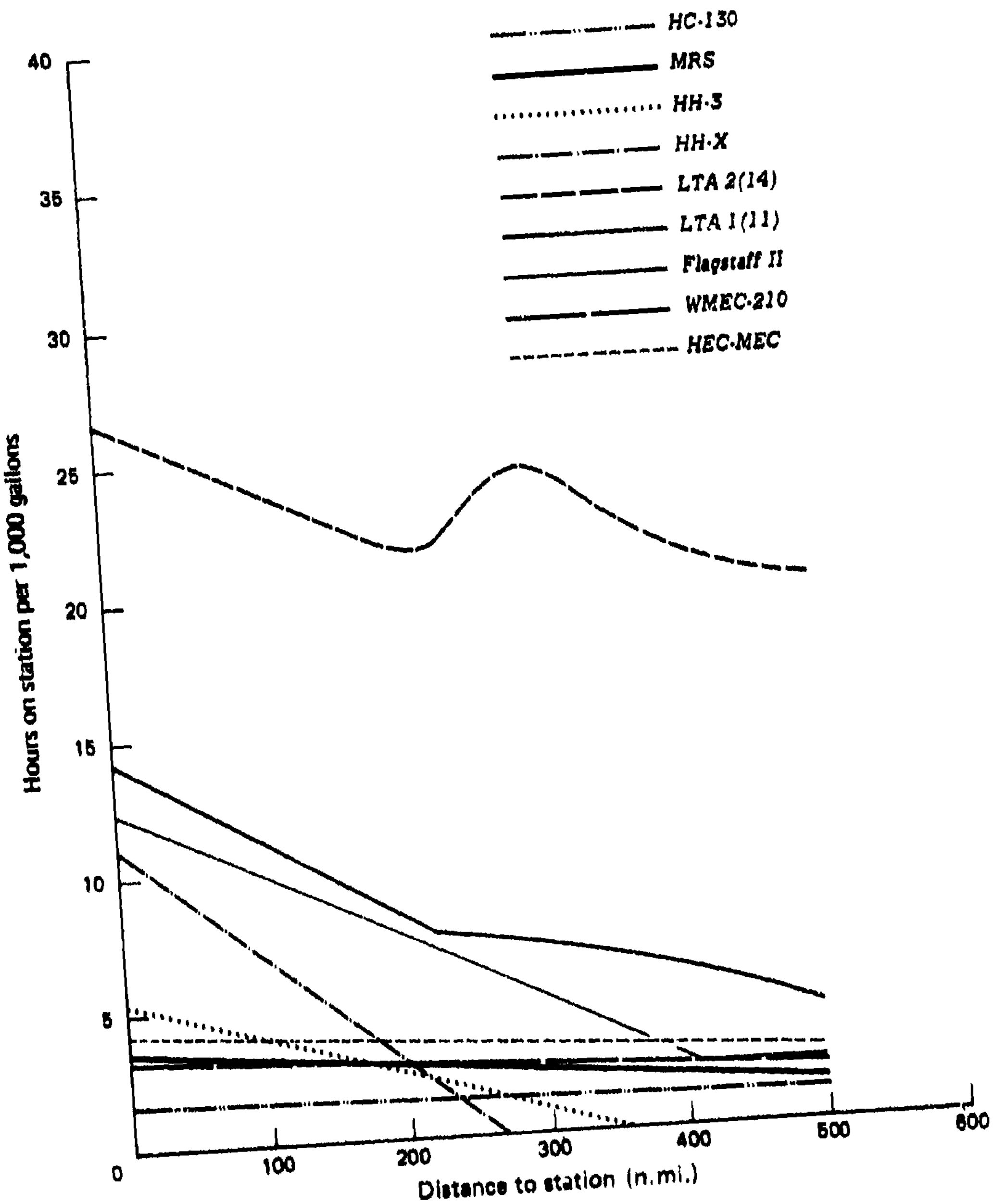


FIG. VII-3: ENERGY EFFICIENCY COMPARISON OF VEHICLES IN TRAIL TASKS (PATROL TASKS DOMINANT)

Trail Tasks Dominant

The energy efficiency when trail tasks are dominant is shown in figures VII-4 and VII-5 for airships of 1,000- and 2,000-mile range, respectively. Airship speeds are varied from 50 to 110 knots in both cases. For the 50- and 60-knot airships, a direct comparison of the effect of airship range is shown in figure VII-6. LTA 1 (11) and LTA 2 (14) are also shown in figure VII-6 to present further comparisons of energy efficiency.

In general, it can be seen that fuel efficiency is greatly improved for airship speeds of 50 and 60 knots. Beyond 130 miles distance to station, the 50 knot/2,000-mile range airship is slightly superior to the 50 knot/1,000-mile range airship. Extension of these results to lower speeds would require a consideration of the effect of winds both in transit and on station.

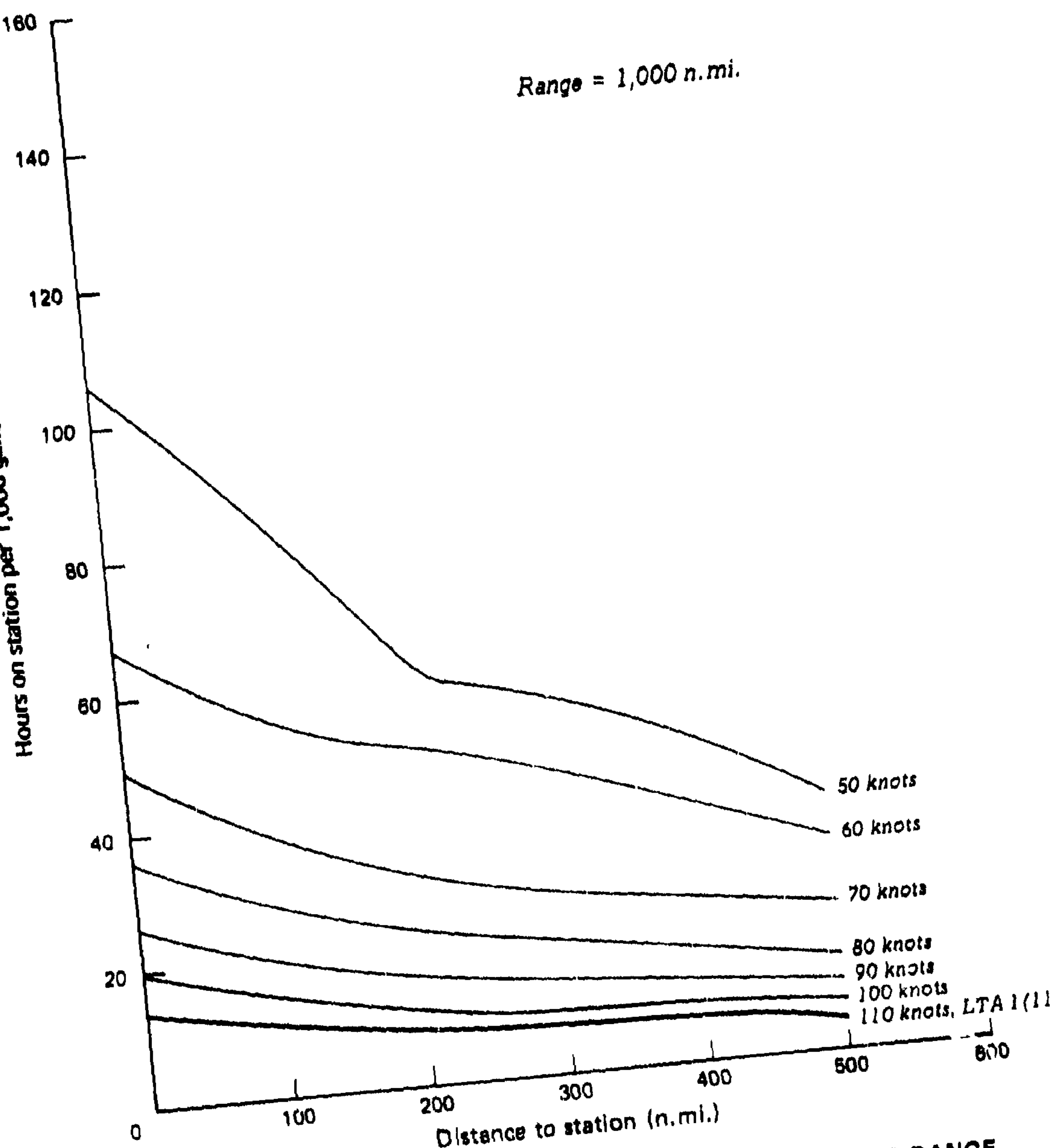


FIG. VII-4: ENERGY EFFICIENCY COMPARISON OF 1,000 MILE RANGE AIRSHIPS IN TRAIL TASKS (TRAIL TASKS DOMINANT)

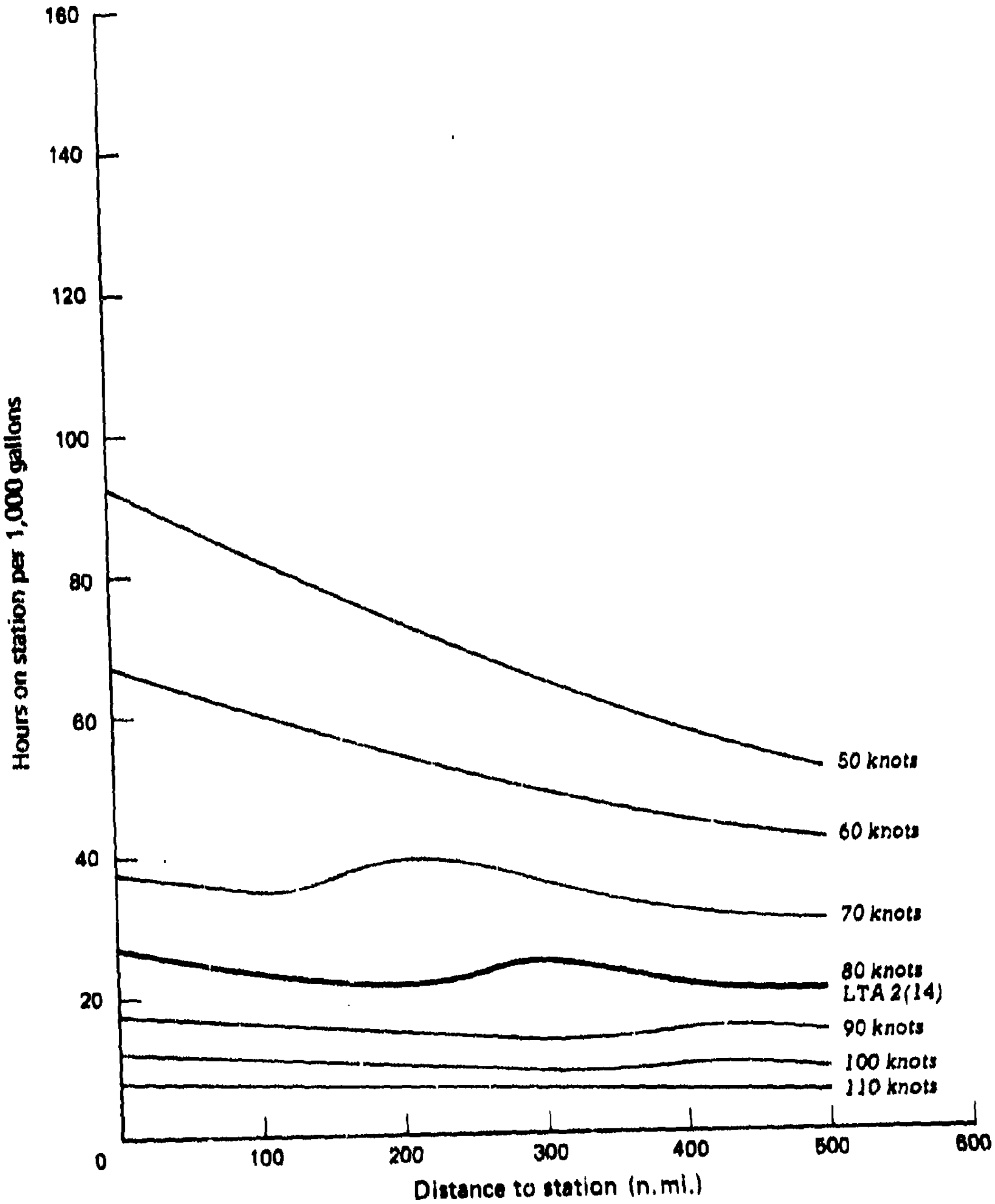


FIG. VII-5: ENERGY EFFICIENCY COMPARISON OF 2,000 MILE RANGE AIRSHIPS IN TRAIL TASKS (TRAIL TASKS DOMINANT)

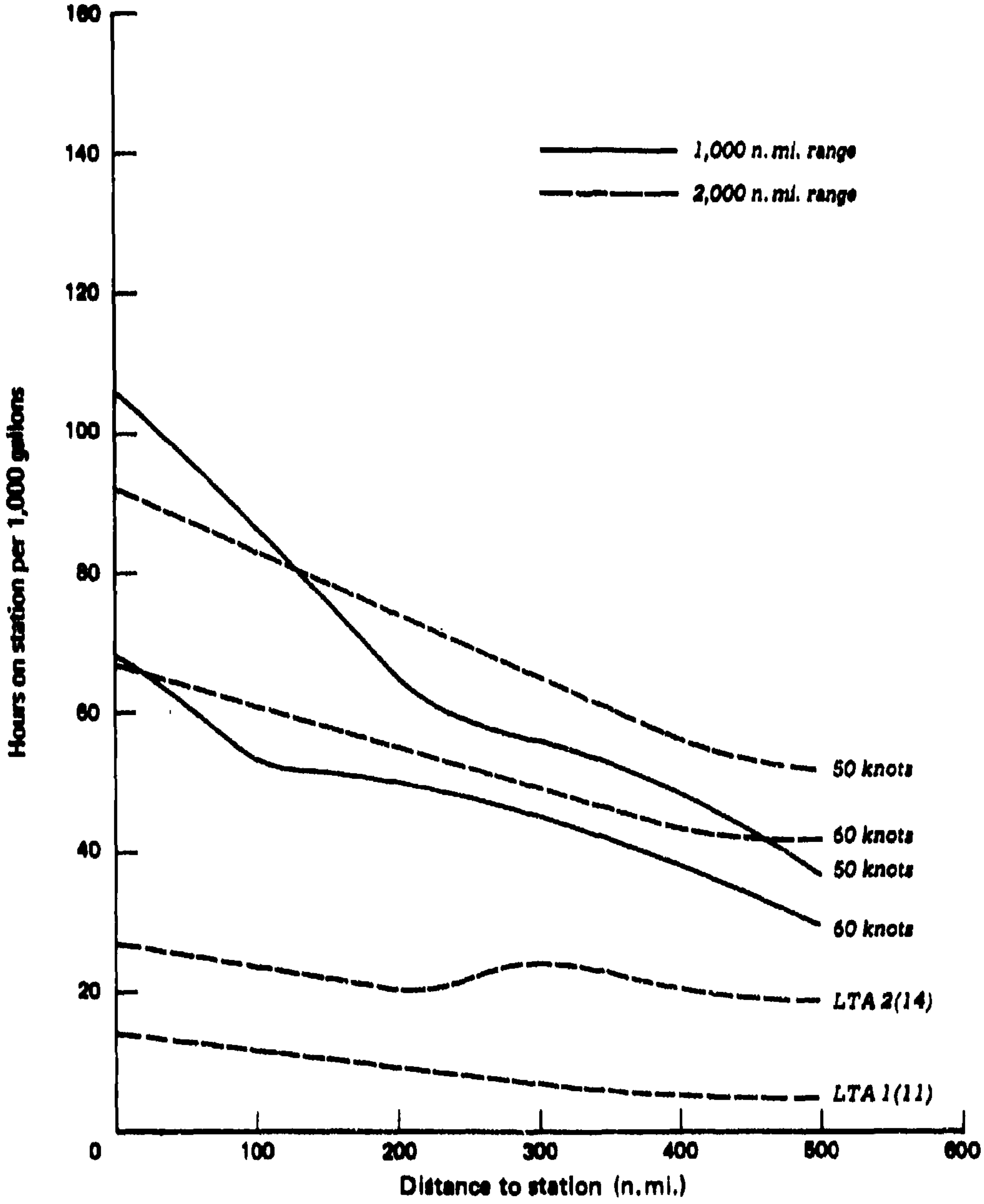


FIG. VII-6: ENERGY EFFICIENCY COMPARISON OF 1,000 AND 2,000 MILE RANGE AIRSHIPS IN TRAIL TASKS (TRAIL TASKS DOMINANT)

VIII. SUMMARY AND CONCLUSIONS

This study analyzed the cost effectiveness of using lighter-than-air vehicles to perform some Coast Guard mission tasks. The analysis compared LTA's effectiveness with other vehicles in three principal missions: Enforcement of Laws and Treaties, Marine Environmental Protection, Search and Rescue. Within these missions, the tasks analyzed include surveillance, investigation, and trail or observation.

Within the above framework, the study analyzed the gross characteristics of LTA vehicles such as size, speed, range, and detailed characteristics such as type of propulsion plant and envelope material. All the airships considered were semi-buoyant hybrids with heaviness determined by maximum takeoff angle of attack.

Investment costs (acquisition costs), operating costs (personnel, maintenance, and fuel costs), and vehicle utilization rates were all considered. Total costs were obtained on a per hour of operation basis.

Cost/effectiveness comparisons were made as a function of distance to station. Patrol tasks of investigation and surveillance were measured by miles on station per $1,000 and square miles on station per $1,000, respectively, trail tasks were measured by hours on station per $1,000.

The study also compared the fuel consumption rate and energy efficiency of LTAs with that of other vehicles.

Our general conclusions are as follows:

- Of the many conceptual designs of LTAs that we examined, we found that the 110-knot, 1,000-mile design was the best for the Coast Guard patrol tasks examined for station distances less than about 300 miles. For greater distances, the 80-knot, 2,000-mile design was superior.
- We developed investment and operating costs for all the alternative vehicles and found that while the LTA was less expensive than most of the alternatives, it was not so cheap as the FLAGSTAFF II on a strict per hour basis.
- We looked at the alternative vehicles performing several tasks, and found that the only place where LTA vehicles were clearly superior was in trailing target ships at ranges greater than 370 miles from the base.

- In the energy analysis, both the 110-knot/1,000-mile range and the 80-knot/2,000-mile range airships were more efficient than other vehicles in use of fuel in trail and observation tasks at all station distances considered. For these tasks alone, 50-knot to 60-knot design speeds offer still further benefits in fuel efficiency and cost/effectiveness. For patrol tasks airships fuel efficiency becomes superior only beyond about 450 miles station distance.

Finally, we observe that while there are always risks involved in developing any new system, that blimps of the size discussed here have not been built since the late 1950s. Also, our calculations were based on the assumption that the new polymer materials would be suitable for airships. In short, there may be more development risks in airships than in, say, hydrofoils and other conceptual vehicles.

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APPENDIX A

COAST GUARD MISSIONS

INTRODUCTION

This appendix presents an outline of Coast Guard Operating Programs (termed missions) described more fully in references A-1 through A-4 . These operating programs are listed in table A-1. The Coast Guard estimates of operational flight hour requirements (from reference A-3) for each program are listed in table A-2 by aircraft type -- long-range search (LRS), medium-range search (MRS), medium-range recovery (MRR), and short-range recovery (SRR). Coast Guard estimates of cutter requirements in mission performance days (from reference A-4) are shown in table A-3. Individual missions and potential applications of LTA vehicles, with emphasis on small modern airships, are discussed below.

SEARCH AND RESCUE (SAR) MISSION

The SAR program was established to render aid to people and property in distress on, over, and under the high seas and waters under U.S. jurisdiction. To carry out this traditional Coast Guard mission, more than one-third of Coast Guard aviation hours has been used in the past. Aircraft are effective because they move quickly and cover a large search area. The SAR program is conducted under a National Search and Rescue Plan, with interagency coordination. The Coast Guard is designated as SAR coordinator for the Maritime Region (in contrast to Inland and Overseas Regions).

The search phase of the SAR mission capitalizes on the high speed and search rate capabilities of aircraft. However, data on SAR cases indicate that most of the time an SAR case waits for assistance is consumed by the time required for the Coast Guard to learn of the case. Endurance on station and detection capability of small objects are also important in the search phase. The rescue phase requires providing direct assistance, such as lifesaving equipment. Such assistance can be provided by helicopters, airplanes, and surface vehicles. Physically removing those in distress may be required and cannot be accomplished by fixed wing aircraft. Towing a disabled vessel may be required; this can be done only by a surface vehicle.

The payload for SAR missions appears to be modest, and the moderate speeds of airships may be adequate, so using small airships in Coast Guard SAR missions is investigated further in volume I.

TABLE A-1

COAST GUARD MISSION AREAS

Operating program missions

1. Search and Rescue (SAR)
2. Domestic Icebreaking (DI)
3. Marine Environmental Protection (MEP)
4. Enforcement of Laws and Treaties (ELT)
5. Radionavigation Aids (RA)
6. Short-Range Aids to Navigation (AN)
7. Marine Science Activities (MSA)
8. Port Safety and Security (PSS)
9. Polar Operations (PO)
10. Recreational Boating Safety (RBS)
11. Ocean Station (OS)
12. Commercial Vessel Safety (CVS)
13. Coast Guard Reserve Forces (CGRF)
14. Military Operations and Preparedness (MOP)
15. Bridge Administration (BA)

TABLE A-2

COAST GUARD AVIATION REQUIREMENTS
(FY 1977 operational hours)

	Aircraft Type				
Mission	LRS (HC-130)	MRS (HU-16)*	MRR (HH-3F)	SRR (HH-52A)	Total (percent)
SAR	3,755	10,235	6,064	10,881	30,935 (36)
DI	56	510	40	670	1,276 (1)
MEP	1,600	8,788		8,112	18,500 (22)
ELT	7,619	6,640	50	6,500	20,809 (24)
RA	1,245				1,245 (1)
AN	159	96	1,828	1,150	3,233 (4)
MSA	989	2,426	83	110	3,608 (4)
PSS	3	54	296	582	935 (1)
Other	1,328	1,058	1,147	1,665	5,198 (6)
Total	16,754	29,807	9,508	29,670	85,739
(percent)	(20)	(35)	(11)	(35)	

* or replacement for the MRS

TABLE A-3

COAST GUARD CUTTER REQUIREMENTS
(FY 1977 mission performance days)

	Cutter Type						
Mission	High performance (WHEC)	Medium performance (WMEC)	Patrol boat (WPB)	Tenders	Ice-breakers	Other	Total (percent)
SAR	436	419	3,156				4,011 (13)
DI/PO				230	2,817		3,047 (10)
MEP	15	30	255	40			340 (1)
ELT	1,347	1,674	330				3,351 (11)
AN				9,737		1,049	10,786 (35)
MSA	559	629	610			90	1,888 (6)
PSS			2,508				2,508 (8)
RBS		47	470	36			553 (2)
CGRF		258				320	578 (2)
MOP	1,167	600	375	759			2,901 (9)
Other	340	12	55	75		320	802 (3)
Total	3,864	3,669	7,759	10,877	2,817	1,779	30,765
(percent)	(13)	(12)	(25)	(35)	(9)	(6)	

DOMESTIC ICEBREAKING (DI) MISSION

The DI mission is seasonal; it is performed from December through April. Its purpose is to increase the availability of national waterways to commercial transportation and to help prevent floods caused by ice jams. The mission involves making estimates of both overall ice conditions and best locations for using icebreaker ships. Making these estimates requires surveillance, now accomplished by helicopters and airplanes.

The surveillance phase of the DI mission appears to require a small payload, hence using small airships is a possibility. However, the number required appears to be small, and to the extent that airships are best suited for operating over water, their use for surveillance could be undesirable. Therefore, airships used for DI mission surveillance will not be further considered in this study.

MARINE ENVIRONMENTAL PROTECTION (MEP)

Primary responsibility for marine environmental protection lies with the Coast Guard. The MEP mission's objective is to minimize human-caused damage to the marine environment and its living marine resources. The Coast Guard program consists of four elements:

- Impact assessment (investigation of effects of pollutants; pollutant data collection including use of sensors and monitoring equipment).
- Prevention and enforcement (deterrent policing to warn of defective equipment and obtain a basis for prosecution of intentional offenders).
- Response (rapid initiation and completion of cleanup of pollutants, principally major petroleum spills).
- In-house abatement (to control any possible Coast Guard pollution).

The prevention and enforcement element and the response element appear to provide possible applications for airships. Therefore only these two elements are considered in this MEP mission discussion.

A study (reference A-5) for the Coast Guard estimated that 80 percent of past marine oil spills occurred within 10 miles of shore and 75 percent occurred within 25 miles of the nearest port. It also appears that oil spills occur at a greater rate during hours of darkness and periods of limited visibility caused by fog.

To accomplish the prevention and enforcement element of the MEP mission, the Coast Guard currently uses aircraft for surveillance. Sweeps along the shore occur twice a week. There are also daily sweeps of 13 port areas handling more than 10 million tons of oil annually.

The surveillance vehicles serve a twofold purpose: detection and prevention. Detection involves discovering oil on the water surface and determining its source. Prevention involves inhibiting other illegal activities by vehicles present in the area. For detection, the sensor is of principal importance. The Coast Guard currently has 4 pieces of equipment to use for this task: Air-Deliverable Anti-Pollution Transfer System (ADAPTS); a high seas containment device; and 2 oil recovery devices. All 4 pieces of equipment are designed to be air transportable by HH-3F helicopters and HC-130 airplanes. The Coast Guard has nearly completed development of an Airborne Oil Surveillance System (AOSS) (reference A-6) for this application. Given detection, full accomplishment of the mission requires identifying the source of the pollutant and quantifying the amount.

Response to oil spills or other pollutants includes transportation, delivery, and operation of the equipment. Decisions about which air vehicle should be selected to respond to oil spills should be based on the flexibility to deliver rather than on the speed of the vehicle.

Airships are potentially applicable to the MEP mission because the payloads are small and the moderate speeds of airships may be adequate. The MEP mission is considered further in volume I.

ENFORCEMENT OF LAWS AND TREATIES (ELT) MISSION

The U.S. Coast Guard is the primary maritime law enforcement agency of the federal government. With other agencies, the Coast Guard is responsible for enforcing laws relating to customs and revenue, immigration, and protecting fish and game. The ELT mission is concerned principally with enforcing laws and treaty agreements concerned with conservation of fish and game. In order to carry out its ELT mission, the Coast Guard must (a) know how many fishing fleets (by nationality and type of fishing activity) there are in various fishing areas, (b) deter treaty violations, and (c) seize those violating the treaty (people, equipment, or vessels).

To accomplish the ELT mission, the Coast Guard conducts surveillance of fishing vessels and deters law breakers. Close-in visual and photographic surveillance are essential. This information is also used by the National Marine Fisheries Service for planning fisheries resource management and conservation policies. The Coast Guard conducts boarding operations for on-board inspection for compliance with fisheries laws and, when violations are found, for seizure.

The ELT mission expanded significantly in the 1950s when the Soviet Union began using 450 to 2,100 ton fishing vessels off the U.S. coasts. During fiscal year 1971, there were about 500 foreign fishing vessels from 14 countries fishing at any given time off U.S. coasts.

Currently, the Coast Guard uses aircraft, principally the HU-16E (about 75 percent), for general and close-in surveillance and deterrence. Surface vehicles, mostly WMEC and WHEC cutters, are used to obtain the majority of the close-in detailed surveillance information, to provide on-site deterrence, and to accomplish the boarding inspections and and seizures for which aircraft are not capable.

Some of the current Fisheries Laws and Treaties apply to the Contiguous Fisheries Zone only (12-mile limit), some to a 25-mile limit, and some to areas farther from shore. If the proposed 200-mile economic zone should be established in the near future, the Coast Guard fisheries ELT mission area would become greater than 2 million square miles, with frequent patrols desirable over the various fishing season times in different areas.

Coast Guard ELT patrols are also concerned with many other tasks, including preventing illegal entry of drugs and aliens into the United States, protecting U.S. property (such as offshore oil/energy/port facilities) and detecting violations of U.S. neutrality laws. For ELT mission purposes it appears that airships may have the potential for at least the surveillance, presence, and deterrence. These uses of airships are considered in more detail in volume I.

RADIONAVIGATION AIDS (RA) MISSION

The primary task of the Radionavigation Aids mission is to provide scheduled and emergency logistics transportation of personnel and electronic equipment. A secondary mission task is to schedule flight hours for periodic calibration, where suitable commercial or DoD aircraft services are not reasonably available, to isolated LORAN-A, LORAN-C, and OMEGA electronic aids to navigation stations. This minor service mission often uses the relatively large payload capability of the HC-130 airplane. The required flight hours and total away-from-base times for both the primary and secondary tasks are expected to decrease markedly during the next decade, as LORAN-A stations are disestablished.

It is possible that tethered airships would have potential as replacements for the very high towers of these electronic navigation aid systems.

It is also possible that airships would have potential for the logistic support responsibility of the Coast Guard in the RA mission. However, as a minor and decreasing service mission, it will not be considered further in this study.

SHORT-RANGE AIDS TO NAVIGATION (AN) MISSION

The Short-Range Aids to Navigation mission is concerned with aids characterized by audio, visual, or electronic signals that consist of buoys, lights, and radio beacons. The AN program includes all aids and any equipment and personnel required to keep the aids operating. Aids are located on shore near U.S. navigable waters and in U.S. waters extending 200 miles from shore. The program activities include construction, signal checks, routine and emergency service visits, logistic support, and search for missing floating aids.

Several kinds of vehicles are used in the AN mission: automotive (where feasible), Coast Guard small boats, buoy tender cutters with small boats, and aircraft, principally helicopters.

It is possible that airships, or heavy lift vehicles, could find some use in AN missions, but probably only on a part-time basis. Further investigation of this case of airships is presented in volume I.

MARINE SCIENCE ACTIVITIES (MSA) MISSION

The objective of the Marine Science Activities mission is to conduct oceanographic and meteorological activities. There are three phases: the International Ice Patrol (IIP); the Airborne Radiation Thermometer (ART) surveys; and miscellaneous support on specific tasks for government agencies and academic institutions. From January to July the IIP makes weekly patrols using 1 dedicated HC-130. Ten-hour flights are made south of Newfoundland.

Fog and cloud cover require low altitude flight for visual search. If Side-Looking Airborne Radar becomes available, low altitudes may not be required.

The ART surveys produce charts of isotherms off the U.S. coasts for estimating surface currents, fog conditions, personnel survival time, and many derived conditions. The data for these charts are obtained by monthly readings of the water surface temperature with an infrared thermometer. The patrols use nondedicated HU-16E aircraft with 2 or 3 technicians and 50 to 100 pounds of equipment in 8-hour sorties at 500 feet altitude and 140 knots. Deviations from patrol pattern are not permitted during the flight.

The payloads for MSA missions appear small, and low altitudes and low air speeds are needed, so airships might have a limited potential for MSA missions. However, MSA missions will not be considered further in this report.

PORT SAFETY AND SECURITY (PSS) MISSION

The objective of the Port Safety and Security mission is to deter violations of and enforce several groups of laws relating to dangerous cargo safety, cargo safety against theft, vessel traffic safety, and port safety as these relate to national defense, in the 57 U.S. ports that have Captains of The Port (COTP).

Enforcement of safe handling of dangerous cargo must require on-board inspection. The development of cargo safety enforcement (security against theft) is in an embryonic stage. It appears that "police" presence and frequent patrol would be a major element of the cargo safety task.

Enforcing vessel traffic safety rules requires development of procedures in Vessel Traffic Systems (VTS) involving specification of traffic separation lanes for vessel routing, shore-based radar for surveillance, and radio communications operations centers using computerized information storage, retrieval, and display.

The above overt inspection involved in planning and coordinating port activities might be supported by some similar covert activities for checking for safety against threats to national defense.

Aircraft can respond quickly to trouble signals and inspect from an elevated position. Low altitude aircraft provide a visible presence even in low visibility conditions. Aircraft can provide surveillance to a large area with appropriate sensors. (Harbors are relatively small so high air speeds are not essential.) Shore-based radar provides essential accurate position data, and surface craft operations appear to be essential for follow-up.

It is possible that small airships (possibly unmanned with TV sensors) could provide a reasonably large visible police presence on a random schedule for the COTP. However, PSS missions are a minor-use mission and will not be considered further in this study.

COAST GUARD OTHER OPERATING PROGRAMS

Several small miscellaneous Coast Guard programs are grouped together under an administrative heading of "Other Operating Programs." These programs are described briefly and screened for potential application of airships.

Polar Operations (PO) Missions

This program provides icebreakers, aircraft, and personnel to conduct polar (Arctic and Antarctic) marine operations, including convoy escorting, oceanographic study, and logistics support. Plans call for 5 icebreakers, operating about 6 months per year, requiring 12 helicopters for the same time. The HH-52 is the largest helicopter compatible with the icebreakers; about 1,000 helicopter flight hours are required annually in the Polar Operations mission.

The helicopters attached to icebreakers provide ice reconnaissance from low altitudes that markedly increase the icebreaker's speed of advance by appropriately chosen routes. Helicopters also provide rapid and safe above-the-surface transportation of short-term "shore"-based scientific parties and longer-range emergency and logistic resupply for the icebreaker. On-board maintenance is minimized by accomplishing major maintenance during the half-year the helicopter is assigned to training uses.

It appears that small airships might have potential for the aircraft support aspect of the PO mission. However, this application will not be considered further.

Recreational Boating Safety (RBS) Mission

The purpose of the Recreational Boating Safety mission is to minimize personal injury and death and property damage. In 1971, about 500 aircraft flight hours were used for this mission, principally for transporting personnel to the scene of regattas. Surface vessels are generally needed for accomplishing this mission, e.g., for on-scene search and rescue. The RBS mission will not be considered further.

Ocean Station (OS) Mission

The Ocean Station mission provides several Coast Guard cutters on station 1,000 miles or more from the U.S. coast to obtain and report several local weather conditions, distress radio frequencies, etc. These stations are being closed.

Therefore, this mission will not be considered further.

Commercial Vessel Safety (CVS) Mission

The objective of the Commercial Vessel Safety mission is to minimize personal injury and death and property damage associated with commercial, scientific, and exploratory activity in the marine environment, principally by liaison and on-site inspection. Coast Guard aircraft (helicopters) have been used to provide ad hoc transportation of inspectors where commercial transportation is not available, especially to off-shore oil rigs. A small number of flight hours (less than 100 per year) have been used to carry out the commercial vessel safety mission.

Airships might have potential for this mission because the off-shore distances are small. Because of the small Coast Guard aviation effort expended on CVS, it will not be considered further.

Coast Guard Reserve Forces (CGRF) Mission

The Coast Guard Reserve Forces mission involves recruiting, training, and maintaining the proficiency of reserve personnel for rapid expansion of Coast Guard forces in case of national need. Formerly, the principal use of aircraft for this mission has been transporting reserve personnel to stations for training. Commercial transportation is usually available for this purpose. Therefore, the CGRF mission will not be considered further.

Military Operations and Preparedness (MOP) Mission

The Military Operations and Preparedness mission for the Coast Guard provides rapid transition to appropriate military missions as a specialized branch of the U.S. Navy. If airships have cost-effective applications in some Coast Guard peacetime missions, if use of airships is adopted for these missions, and if such airships would also be suitable for U.S. Navy missions directly or by rapid change of payload, then applications of airships for the MOP mission should be considered. However, such considerations are premature at this time, and this mission will not be considered further.

Bridge Administration (BA) Mission

It appears that aircraft have no applications for this mission. It will not be considered further.

SUMMARY OF SCREENING OF COAST GUARD MISSIONS

Table A-4 repeats the list of Coast Guard mission areas shown previously in table A-1 but with the results of the screening discussion indicated. The missions that appear inappropriate for airship application are indicated with an 'A'. Those that may be appropriate but not of great importance in relation to the required number of vehicles are marked with a 'B'. Those that appear promising and important are marked with an 'X'; they will be considered in more detail in volume I.

TABLE A-4

COAST GUARD MISSION AREAS

Operating program missions	Screening Results
1. Search and Rescue (SAR)	X
2. Domestic Icebreaking (DI)	A
3. Marine Environmental Protection (MEP)	X
4. Enforcement of Laws and Treaties (ELT)	X
5. Radionavigation Aids (RA)	B
6. Short-Range Aids to Navigation (AN)	X
7. Marine Science Activities (MSA)	B
8. Port Safety and Security (PSS)	B
Other operating program missions	
1. Polar Operations (PO)	B
2. Recreational Boating Safety (RBS)	A
3. Ocean Station (OS)	A
4. Commercial Vessel Safety (CVS)	B
5. Coast Guard Reserve Forces (CGRF)	A
6. Military Operations and Preparedness (MOP)	B
7. Bridge Administration (BA)	A

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APPENDIX B

THE HYDROFOIL STUDY

GENERAL

This appendix presents a brief summary of the hydrofoil study conducted by CNA for the Coast Guard (reference B-1). An earlier screening of high performance watercraft (reference B-2) resulted in the assessment shown in figure B-1 and table B-1. These results indicated that the submerged-foil hydrofoil vehicle had the best potential for cost-effective use in Coast Guard missions, specifically in the Enforcement of Laws and Treaties (fisheries) mission.

More exactly, the submerged-foil vehicle promises excellent seakeeping characteristics in rough seas, both foilborne and hullborne, at displacements in order of magnitude less than displacements of conventional monohull cutters with comparable characteristics.

These characteristics of hydrofoils lead to the following relative comparisons:

- When a mission requires only a small payload, and operation in all-weather seas is essential, a hydrofoil considerably smaller than conventional cutters can be used with a smaller crew, and at less cost.
- The higher speed capability of a hydrofoil relative to conventional cutters makes the hydrofoil more effective in those mission tasks that are speed dependent.

The state-of-the-art of the technology was also considered in the preliminary screening. Seagoing hovercraft are still being developed. It appears that they have very poor seakeeping capabilities in small sizes. The first SWATH ship is in early testing; hence SWATH technology will not be available for several years. It appears that SWATH ships will have good seakeeping capabilities, but will be limited to much lower speeds than the hydrofoil (though greater than displacement monohulls). Also, the SWATH ship design requires more power than that needed to provide either the same volume or payload compared to a displacement monohull ship of the same speed. SWATH ships will, however, have much greater deck area than monohulls, which provides a potential for helicopter landing facilities. As SWATH technology is developed, a small-SWATH/helicopter team should be investigated for Coast Guard use.

Alternatively, hydrofoil development for the useful vehicle sizes for some Coast Guard missions is well advanced, so the potential benefits to the Coast Guard could be utilized at low technical risk.

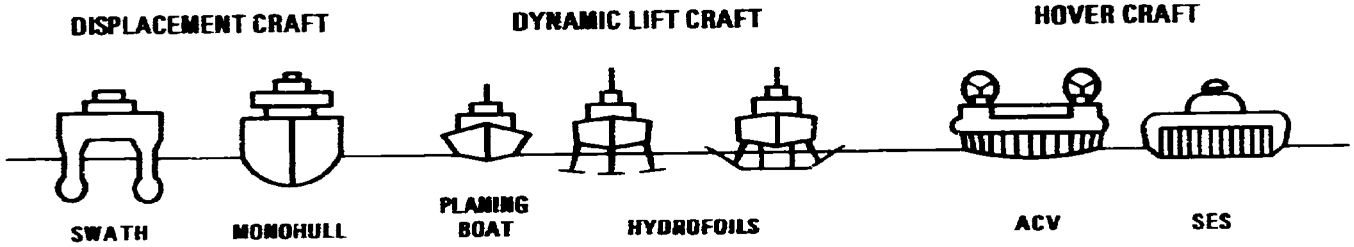

FIG. B-1: THE DESIGN SPECTRUM OF HIGH PERFORMANCE WATERCRAFT

TABLE B-1

PRELIMINARY SCREENING OF HIGH PERFORMANCE WATERCRAFT DESIGN CONCEPTS FOR COAST GUARD ELT MISSION

High performance watercraft design concept	Results of preliminary assessement of potential effectiveness in ELT mission
Hovercraft	
Air cushion vehicle (ACV)	No potential due to very poor seakeeping capabilities in practical sizes
Surface effects ship (SES)	
Dynamic lift craft	
Planing boat	Limited potential due to poor seakeeping capabilities
Surface piercing hydrofoil	
Submerged foil hydrofoil	Best potential for ELT mission patrol craft; has demonstrated excellent seakeeping capabilities
Displacement craft	
Monohull	Conventional Coast Guard cutter design
Small water plane area twin hull (SWATH)	Good potential as helicopter carrier; excellent seakeeping

HYDROFOIL COMPARISON

The CNA Hydrofoil Study compared the effectiveness and costs of hydrofoil craft with those of conventional Coast Guard resources in the performance of the fisheries law enforcement (ELT) mission and investigated the degree to which such hydrofoils could contribute to the search and rescue (SAR) mission without undue detraction from their primary mission.

In performing the ELT mission, the FLAGSTAFF II (an existing hydrofoil) was compared with conventional Coast Guard cutters and cutter-helicopter teams. Three conventional cutters were chosen for the comparisons: the existing WHEC-378; the WMEC-210; and a conceptual cutter currently being designed by the Coast Guard, called the HEC-MEC, with a displacement between that of the WHEC-378 and the WMEC-210. Cutter-helicopter teams were composed of each of these three cutters operating with a helicopter flying off its deck. Helicopters considered were the HH-52, the HH-3, and a conceptual helicopter, the HH-X. The HH-X was assumed to be a small, inexpensive helicopter equipped with radar.

Fixed wing aircraft were also analyzed to compare their surveillance and "hot pursuit" potential. Specifically, the HC-130 and a small turbo-jet aircraft (MRS), a conceptual replacement for the HU-16, were considered.

The study developed the hourly operation cost for each of the vehicles examined. Cost components consisted of amortized investment costs, personnel costs, maintenance costs, and fuel costs. These results were used to compare costs among the vehicles.

Cost-effectiveness comparisons between hydrofoils and conventional vehicles were made in three ways:

- On an individual task basis with each task examined independently.
- In a specific northeast fisheries region scenario comprising specific tasks performed in the Atlantic off New England.
- In a specific ELT scenario located in Alaskan waters.

The ELT tasks examined independently were:

- Transit
- Gross surveillance
- Local surveillance
- Locating and approaching a special target ship in a larger population of ships

- Boarding
- Pursuit
- Visual inspection of dispersed ships
- Presence
- Boundary patrol

This analysis showed hydrofoils to be superior to cutters over the entire spectrum of tasks, in most cases by wide margins. The comparisons were made by looking at the least costly vehicle that provided a specified level of effectiveness. Even with the addition of helicopters to the cutters, the hydrofoils were shown, overall, to be more favorable from a cost effectiveness point of view.

A northeast fisheries region scenario was developed using actual fishing fleet locations. The Flagstaff II hydrofoil was assumed to be based on Nantucket Island and conventional cutters assumed to operate out of their existing bases. Helicopters were assumed to fly out of Coast Guard Air Station Cape Cod and rendezvous with cutters to form teams for the patrol duration.

Each vehicle or team was required to spend the same amount of time on productive patrol, excluding nonproductive transit time to and from base. Each was also required to perform a fixed set of tasks a given number of times. In the time remaining after these tasks were completed, effectiveness was measured in terms of patrol capability, in miles.

Total mission cost for each vehicle or team was based on both productive and nonproductive time. Helicopters were charged only for hours flown.

The study also examined the extent to which hydrofoils, working primarily in an ELT role, could contribute to the SAR mission. Results indicated that the hydrofoil could respond to all SAR cases in its area of operations involving moderate to severe danger to personnel or property, without undue detraction from the ELT role.

TABLE B-2

COST EFFECTIVENESS OF RESOURCES RELATIVE TO FLAGSTAFF II
(NORTHEAST U.S. SCENARIO)

	Cost-Effectiveness	
Resource	Case I[a]	Case II[b]
Flagstaff II	1.0	1.0
WMEC-210	3.9	1.03
HEC-MEC	5.2	1.36
WHEC-378	6.2	2.45
WMEC/HH-X team	1.5	1.07
HEC-MEC/HH-X team	1.9	1.40
WHEC/HH-X team	2.8	2.48

[a]Fixed tasks assumed to have no value.

[b]Fixed tasks assumed to be all important.

REFERENCES

B-1. Center for Naval Analyses, Study 1061, "Hydrofoils for the Fisheries Law Enforcement Mission of the U.S. Coast Guard," Unclassified, Jul 1975

B-2. Center for Naval Analyses, Systems Evaluation Group Study Number 13, "The Utility of High Performance Watercraft for Selected Missions of the U.S. Coast Guard," Unclassified, Nov 1972

APPENDIX C

OTHER VEHICLE PERSONNEL COSTS

INTRODUCTION

For most Coast Guard resources, personnel is the largest single component of the total cost. This is particularly true of large cutters like the WHEC-378, with a complement of more than 150 men. Accurate estimates of total manpower costs are therefore an important input to decisions concerning the selection of new resources. The true cost of manpower includes much more than pay and allowances. Other costs, such as training, retirement, and fringe benefits must also be taken into account.

At the time that the CNA Hydrofoil Study was performed, the Coast Guard had no capability for estimating personnel costs other than pay and allowances. Other factors such as training and retirement were not considered. CNA therefore used the Navy Billet Cost Model to provide more realistic estimates of personnel costs. Since that time the Coast Guard contracted with B-K Dynamics to develop a methodology similar to the Navy's Billet Cost Model. This appendix presents new personnel costs for the vehicles used in the Hydrofoil Study based on the Coast Guard Billet Cost Model described in reference (C-1) Billet unit costs in FY 1974 dollars from reference (C-1) are converted to annual and hourly costs per vehicle in FY 1976 dollars.

THE BILLET COST MODEL

The Billet Cost Model (BCM) was developed to provide a current means for computing military personnel costs. The Billet Cost Model currently includes most of the U.S. government cost; it does not include all costs. (Post separation costs, e.g., G.I. educational benefits, are not currently included.) The model for the military billet cost includes the following elements:

- Base pay
- Clothing allowance
- Family separation
- FICA (social security)
- Hazardous duty pay -- aviation
- Medical expenses
- Mess/subsistence
- Sea duty
- Foreign duty

- Proficiency pay
- Responsibility pay
- Quarters allowance (BAQ)
- Government housing
- Reenlistment pay
- Tuition aid
- Unused terminal leave and settlement
- Severance and readjustment pay
- School and training
- Travel
- Death gratuity

Some elements were not included because reliable data were difficult to obtain:

- Command and administration
- Dependent school
- Commissary-exchange
- Personnel procurement
- Unemployment compensation
- Capital plant construction costs
- V.A. benefits

The BCM produced billet cost figures for each Coast Guard rating by pay grade and length of service. Coast Guard ratings are defined in table C-1.

The weakest data in the military data base and output are costs of Coast Guard schools. The present school cost report system does not request information on how base operating expenses (overhead) to the school are allocated. Consequently, the cost of Coast Guard training is undervalued in terms of resources.

FY 1974 Coast Guard billet costs (as estimated by the CG BCM) by pay grade and rating are shown in table C-2. The BCM does not directly compute billet costs for warrant officers; Coast Guard surface officer costs were used as substitutes.

TABLE C-1

COAST GUARD ENLISTED RATINGS

Designator	Rating name
AD	Aviation Machinist Mate
AE	Aviation Electricians Mate
AM	Aviation Structural Mechanic
AN	Airman
ASM	Aviation Survivalman
AT	Aviation Electronics Technician
BM	Boatswains Mate
DC	Damage Controlman
DT	Dental Technician
EM	Electricians Mate
ET	Electronics Technician (includes ETN)
FN	Fireman
FT	Fire Control Technician
GM	Gunners mate
HM	Hospital Corpsman
MK	Machinery Technician
MST	Marine Science Technician
PA	Photojournalist
QM	Quartermaster
RD	Radarman
RM	Radioman
SK	Storekeeper
SN	Seaman
SS	Subsistence Specialist
ST	Sonar Technician
TT	Telephone Technician
YN	Yeoman

TABLE C-2

COAST GUARD BILLET COSTS
BY PAY GRADE AND RATING: FY 1974

	Officers' Costs ($)					
	ENS O-1	LTJG O-2	LT O-3	LCDR O-4	CDR O-5	CAPT O-6
All Officers	$21050	$24524	$34107	$39258	$48553	$64663
Aviator	40696	49583	54834	61008	70429	87291
Surface	19213	23485	32899	37818	47035	63103
	W-1	W-2	W-3	W-4		
Warrant	19213	23485	32899	37818		

	Enlisted Personnel, Rated Costs ($)					
Rating	3rd E-4	2nd E-5	1st E-6	Chief E-7	Sr.Chief E-8	M.Chief E-9
AD	$15111	$17841	$25419	$28961	$31986	$38586
AE	14584	18630	25377	29501	31281	40935
AM	14336	17679	23369	26878	30291	39823
ASM	14940	17516	22627	25625	29629	36121
AT	14367	16968	23925	28132	31089	37381
BM	14262	15487	21060	25939	29972	33358
DC	13682	15748	20645	24606	28052	33716
DT	12503	14947	19085	24674	28315	34385
EM	13522	15023	20240	22850	25971	30398
ET(ETN)	14221	15805	19918	25205	30272	33241
FT	16083	17333	21854	24338	28692	32059
GM	14763	16139	23328	25719	30237	37287
HM	12578	15426	19273	22839	27109	36294

(continued)

TABLE C-2 (continued)

COAST GUARD BILLET COSTS
BY PAY GRADE AND RATING: FY 1974

Enlisted Personnel, Rated (continued)

Rating	E-4	E-5	E-6	E-7	E-8	E-9
MK	$15425	$16911	$23215	$29028	$31858	$36124
MST	14156	15821	19120	25704	34161	37890
PA	13604	14913	19377	21280	25832	28472
QM	14351	15395	20316	26173	27821	32447
RD	13984	15304	19739	24144	28240	30493
RM	14032	16133	23409	25094	27623	33928
SK	12952	14488	19378	24540	26279	32174
SS	15165	21265	26088	28717	31488	37655
ST	15042	16951	21087	25985	30900	35340
TT	14322	16475	23606	26574	29009	33111
YN	14932	15469	20859	25451	30718	33299

Enlisted Personnel, Unrated Costs ($)

Rating	E-2	E-3
AN	$11560	$12160
FN	10542	11545
SN	11015	12024

At the time this task was performed, only FY 1974 billet costs were available from the Coast Guard BCM. Thus, these costs were used, and the total personnel costs were then multiplied by a factor of 1.1046 to arrive at cost estimates for FY 1976. This increase is the actual increase experienced in pay and allowances between FY 1974 and FY 1976 (5.2 percent from 1974 to 1975, and 5 percent from 1975 to 1976), and most costs that are included in the BCM are directly related to pay and allowances.

Table C-3 summarizes the FY 1976 personnel costs for the resources examined in the CNA Hydrofoil Study (reference C-2). The table shows the total annual on-board personnel costs for each resource, lists the annual hours of utilization from table 8 of the CNA Hydrofoil Study and gives personnel cost per hour of utilization in the right-hand column.

Tables C-4 to C-11 (from reference C-2) provide a breakdown by rating from the personnel requirements of each resource. Each table shows the number of officers and enlisted personnel by rating assigned to each vehicle, the unit cost from table C-2, and the total cost for the listed number of each rating. The grand total results are the annual personnel costs for FY 1974. These are then multiplied by 1.1046 to arrive at the FY 1976 costs shown in the summary table C-3.

TABLE C-3

RESOURCE PERSONNEL COSTS
(FY 1976 DOLLARS)

Resource	Annual personnel cost ($)	Planned annual utilization (hours)	Hourly personnel cost ($/hr)
Hydrofoils			
PHM-variant	391,731	3000	131
Grumman - 178 ton	391,731	3000	131
JETFOIL - variant	299,900	2000	150
FLAGSTAFF II	299,900	2000	150
Conventional cutters			
WMEC-210	1,231,399	3000	410
HEC-MEC[a]	2,200,249	3000	733
WHEC-378	3,016,816	3000	1006
Helicopters			
HH-52	305,019	650	469
HH-X[b]	305,019	650	469
HH-3	477,553	700	682
Fixed wing aircraft			
MRS	535,650	1000	536
HC-130	794,245	800	993

[a]HEC-MEC costs assumed to be 79 percent higher than WMEC-210 costs, based on the ratio of manning levels (log/61).

[b]HH-X costs assumed to be the same as HH-52.

TABLE C-4

TOTAL FY 1974 PERSONNEL COSTS
FOR PHM-VARIANT AND GRUMMAN-178 TON

Personnel requirements	Number	Unit cost($)	Total cost($)
Officers			
LT	2	32,899	65,798
LTJG	1	23,435	23,435
Total officers	3		89,233
Enlisted personnel			
BMC	1	25,939	25,939
BM1	1	21,060	21,060
GM2	1	16,139	16,139
SN	3	12,024	36,072
QM1	1	20,316	20,316
ET1	1	19,918	19,918
SS2	1	21,265	21,265
MKC	1	29,028	29,028
MK2	1	16,911	16,911
MK3	1	15,425	15,425
FN	2	11,545	23,090
EM1	1	20,240	20,240
Total enlisted	15		265,403
Grand total	18		354,636

TABLE C-5

TOTAL FY 1974 PERSONNEL COSTS
FOR FLAGSTAFF II AND JETFOIL-VARIANT

Personnel requirements	Number	Unit cost($)	Total cost($)
Officers			
LT	1	32,899	32,899
Enlisted personnel			
BMC	1	25,939	25,939
MKC	1	29,028	29,028
BM1	1	21,060	21,060
BM3	1	14,262	14,262
QM1	1	20,316	20,316
SN	2	12,024	24,048
GM2	1	16,139	16,139
MK1	1	23,215	23,215
EM1	1	20,240	20,240
FN	2	11,545	23,090
SS2	1	21,265	21,265
Total enlisted	13		238,602
Grand total	14		271,501

TABLE C-6

TOTAL FY 1974 PERSONNEL COSTS
FOR WMEC-210 (RESOLUTE)

Personnel requirement	Number	Unit cost($)	Total cost($)
Officers			
CDR	1	47,035	47,035
LCDR	1	37,818	37,818
LT	2	32,899	65,798
LTJG	2	23,485	46,970
Total officers	6		197,621
Warrant officers			
ENG4	1	37,818	37,818
Enlisted personnel			
BMC	1	25,939	25,939
BM1	1	21,060	21,060
BM2	1	15,487	15,487
BM3	1	14,262	14,262
QMCS	1	27,821	27,821
QM1	1	20,316	20,316
QM2	1	15,395	15,395
QM3	1	14,351	14,351
RD2	1	15,304	15,304
SN	8	12,024	96,192
SA	8	11,015	88,120
GM1	1	23,328	23,328
DC2	1	15,748	15,748
MKC	2	29,028	58,056
MK1	2	23,215	46,430
MK2	1	16,911	16,911
MK3	2	15,425	30,850
ET1	1	19,918	19,918
ETN3	1	14,221	14,221
EMC	1	22,850	22,850
EM2	1	15,023	15,023
FN	3	11,545	34,635
FA	2	10,542	21,084
RM1	1	22,409	22,409
RM2	1	16,133	16,133
RM3	2	14,032	28,064
YN1	1	20,859	20,859
SK1	1	19,378	19,378
SS1	1	26,088	26,088
SS2	2	21,265	42,530
SS3	1	15,165	15,165
HM2	1	15,426	15,426
Total enlisted personnel	54	581,483	879,353
Grand total	61	760,538	1,114,792

TABLE C-7

TOTAL FY 1974 PERSONNEL COSTS
FOR WHEC-378 (MUNRO)

Personnel requirement	Number	Unit cost($)	Total cost($)
Officers			
CAPT	1	63,103	63,103
CDR	1	47,035	47,035
LCDR	1	37,818	37,818
LT	1	32,899	32,899
LTJG	7	23,485	164,395
Total officers	11		345,250
Warrant officers			
ENG4	4	37,818	151,272
Enlisted personnel			
HMC	1	22,839	22,839
BMC	1	25,939	25,939
BM1	1	21,060	21,060
BM2	1	15,487	15,487
BM3	3	14,262	42,786
QMC	1	26,173	26,173
QM1	1	20,316	20,316
QM2	1	15,395	15,395
QM3	1	14,351	14,351
RDC	1	24,144	24,144
RD1	1	19,739	19,739
RD2	2	15,304	30,608
RD3	1	13,984	13,984
STC	1	25,985	25,985
ST1	1	21,087	21,087
ST2	2	16,951	33,902
ST3	3	15,042	45,126

(continued)

TABLE C-7 (continued)

TOTAL FY 1974 PERSONNEL COSTS
FOR WHEC-378 (MUNRO)

Personnel requirement	Number	Unit cost($)	Total cost($)
Enlisted personnel(continued)			
SN	22	12,024	264,528
SA	16	11,015	176,240
GMC	1	25,719	25,719
GM1	1	23,328	23,328
GM3	2	14,763	29,526
FT1	1	21,854	21,854
FT2	1	17,333	17,333
FT3	1	16,083	16,083
MKCS	1	31,858	31,858
MKC	2	29,028	58,056
MK1	4	23,215	92,860
MK2	3	16,911	50,733
MK3	5	15,425	77,125
DCC	1	24,606	24,606
DC2	1	15,748	15,748
DC3	1	13,682	13,682
ETC	1	25,205	25,205
ET1	1	19,918	19,918
ET2	1	15,805	15,805
ET3	1	14,221	14,221
ETN1	1	19,918	19,918
ETN3	1	14,221	14,221
EMCS	1	25,971	25,971
EM1	1	20,240	20,240
EM2	1	15,023	15,023
EM3	2	13,522	27,044
TT2	1	16,475	16,475
FN	10	11,545	115,450
FA	5	10,542	52,710

(continued)

TABLE C-7 (continued)

TOTAL FY 1974 PERSONNEL COSTS
FOR WHEC-378 (MUNRO)

Personnel requirements	Number	Unit cost($)	Total cost($)
Enlisted personnel (continued)			
RMC	1	25,094	25,094
RM1	1	22,409	22,409
RM2	2	16,133	32,266
RM3	3	14,032	42,096
YNC	1	25,451	25,451
YN2	1	15,469	15,469
YN3	1	14,932	14,932
SKC	1	24,540	24,540
SK2	1	14,488	14,488
SK3	1	12,952	12,952
SSC	1	28,717	28,717
SS1	2	26,088	52,176
SS2	2	21,265	42,530
SS3	7	15,165	106,155
MST1	1	19,120	19,120
MST2	1	15,821	15,821
Total enlisted personnel	140		2,234,617
Grand total	155		2,731,139

TABLE C-8

TOTAL FY 1974 PERSONNEL COSTS FOR HH-52

Personnel requirements	Number	Unit cost($)	Total cost($)
Officers			
LT	2	54,834	109,668
Enlisted personnel			
ADC	1	28,961	28,961
AD2	1	17,841	17,841
AD3	1	15,111	15,111
AT1	1	23,925	23,925
AT3	1	14,367	14,367
AE1	1	25,377	25,377
AM1	1	23,369	23,369
ASM2	1	17,516	17,516
Total enlisted personnel	8		166,467
Grand total	10		276,135

TABLE C-9

TOTAL FY 1974 PERSONNEL COSTS FOR HH-3

Personnel requirements	Number	Unit cost ($)	Total cost ($)
Officers			
LCDR	1	61,008	61,008
LT	1	54,834	54,834
LTJG	1	49,583	49,583
Total officers	3		165,425
Enlisted personnel			
ADC	1	28,961	28,961
AD1	1	25,419	25,419
AD2	1	17,841	17,841
AD3	1	15,111	15,111
AT1	2	23,925	47,850
AT3	1	14,367	14,367
AEC	1	29,501	29,501
AE2	1	18,630	18,630
AE3	1	14,584	14,584
AM2	1	17,679	17,679
AM3	1	14,336	14,336
ASM1	1	22,627	22,627
Total enlisted personnel	13		266,906
Grand total	16		432,331

TABLE C-10

TOTAL FY 1974 PERSONNEL COSTS
FOR MRS OR HU16-E

Personnel requirements	Number	Unit cost($)	Total cost($)
Officers			
LCDR	1	61,008	61,008
LT	2	54,834	109,668
LTJG	2	49,583	99,166
Total officers	5		269,842
Enlisted personnel			
ADC	1	28,961	28,961
AD2	2	17,841	35,682
AT1	1	23,925	23,925
AT2	1	16,968	16,968
AT3	1	14,367	14,367
AE1	1	25,377	25,377
AE3	1	14,584	14,584
AM1	1	23,369	23,369
AM3	1	14,336	14,336
ASM2	1	17,516	17,516
Total enlisted personnel	11		215,085
Grand total	16		484,927

TABLE C-11

TOTAL FY 1974 PERSONNEL COSTS FOR HC-130

Personnel requirements	Number	Unit cost($)	Total cost($)
Officers			
LCDR	1	61,008	61,008
LT	2	54,834	109,668
LTJG	1	49,583	49,583
Total officers	4		220,259
Enlisted personnel			
ADCS	1	31,986	31,986
AD1	2	25,419	50,838
AD2	3	17,841	53,523
AD3	2	15,111	30,222
ATC	1	28,132	28,132
AT1	2	23,925	47,850
AT2	2	16,968	33,936
AT3	1	14,367	14,367
AEC	1	29,501	29,501
AE1	1	25,377	25,377
AE2	1	18,630	18,630
AE3	1	14,584	14,584
AMC	1	26,878	26,878
AM1	1	23,369	23,369
AM2	1	17,679	17,679
AM3	1	14,336	14,336
ASM1	1	22,627	22,627
ASM3	1	14,940	14,940
Total enlisted personnel	24		498,775
Grand total	28		719,034

REFERENCES

C-1. Department of Transportation, U.S. Coast Guard, Study Report, "U.S. Coast Guard Military and Civilian Manpower Billet and Life Cycle Costing,"(based on B-K Dynamics Report No. TR-3-195, July 14, 1975), Unclassified, Jul 1975

C-2. Center for Naval Analyses, Study 1061, "Hydrofoils for the Fisheries Law Enforcement Mission of the U.S. Coast Guard," Unclassified, Jul 1975

APPENDIX D

AIRSHIP LIFETIME AND UTILIZATION RATES

INTRODUCTION

This appendix presents estimates of airship lifetime and utilization rates. Airship lifetime is assumed to be a constant when measured in terms of total flying hours. Lifetime in years is thus a function of the annual utilization rate. Historical utilization rates are summarized and extended using a simple model of scheduled flight operations. Two utilization rates are used depending on the assumed aircrew ratio (the number of separate aircrews per assigned airship).

LIFETIME

Historical data provide little basis for estimating airship lifetime. Both the World War II K-ships and the 1950-era ZPG-2 class blimps were retired after only a few operating years. During the 1950s, the lifetime of nonrigid envelopes, however, was apparently considered to be about 4 to 5 years; experience with commercial blimps confirms those figures. The longest life experienced to date for commercial blimps was about 7 years. The newer envelope materials are expected to increase the expected airship lifetime. Information from Goodyear representatives indicates that a 10-year lifetime for the the envelope and related "age sensitive" items is reasonable at a utilization rate of 3,000 hours per year. The lifetime of the remainder of the vehicle should be similar to that of heavier-than-air vehicles.

A total lifetime of about 30,000 flying hours is typical of the type of conventional aircraft most comparable to the nonenvelope portion of airships. The total lifetimes for the Coast Guard MRS would be 30,000 (30 years x 1,000 hours/year) hours; for the HC-130 aircraft about 20,000 (25 years x 800 hours/year) hours. The U.S. Air Force C5A aircraft is expected to have a lifetime of about 30,000 operational hours. Commercial airlines aircraft that average between 2,500 and 3,000 hours per year are normally depreciated over a period of about 12 years.

The airship utilization rate was assumed to be either 3,000 or 1,500 hours per year, depending on the aircrew ratio. The higher figure corresponds to an aircrew ratio of 2 aircrews per airship; the lower figure corresponds to a ratio of 1 aircrew per airship. The corresponding lifetimes are thus 10 and 20 years, respectively. The estimation method is described later in this appendix.

For the higher utilization rate of 3,000 hours per year, the envelope lifetime matches the vehicle lifetime. For the lower utilization rate of 1,500 hours per year, the vehicle lifetime is 20 years, but the envelope needs to be replaced after 10 years of operation. In both cases, major airship overhauls are scheduled every 3-1/3 years.

UTILIZATION RATE

Utilization rates achieved historically for dirigibles in the 1930s, and for blimps in World War II and the late 1950s, are presented here as a basis for extrapolation to furture airships. A simple analytical model of scheduled flight operations is used.

Utilization rate is measured by flying hours per year per possessed airship. An airship is considered to be possessed when it is in the custody of an operational squadron or unit. A possessed airship may be in 3 possible conditions or states: (1) up and flying, (2) up and on standby, or (3) down and undergoing routine repairs. Major overhauls and repairs are assumed to be carried out at a separate site, similar to the Aircraft Repair and Service Center at Elizabeth City, North Carolina.

Utilization rate is a function of the airship schedule of operations and availability. Operations depend on mission time and the aircrew ratio; availability depends on failure and repair rates and the schedule of flying and nonflying periods.

Failure rates are properties of airships and their payloads; they vary mainly with vehicle size and vehicle complexity. Failure rates might also be affected by maintenance procedures, such as the use of airline-style progressive maintenance, or the ability to perform inflight repairs. Repair rates, on the other hand, depend mainly on the maintenance resources available (both personnel and materiel) and the magnitude of the maintenance tasks to be performed. While using modern testing concepts (such as Built In Test Equipment (BITE) and Automatic Test Equipment (ATE)) might reduce the maintenance burden for future airships; the increasing complexity of modern systems may make it difficult to achieve significant reductions in maintenance personnel required at the squadron level.

Estimating failure and repair rates for future airship systems is a difficult and uncertain process because these systems differ in type from the more common aircraft systems. In addition, it is difficult to locate historical information on failure and repair rates of airships.

HISTORICAL UTILIZATION RATES

Past military operations, such as World War II operations with K-ships (400-500 thousand cubic feet) and U.S. Navy operations in the late 1950s with the larger airships of the ZPG-2 class (1 million cubic feet), provide some data on utilization. Comparative data are also available for the considerably larger dirigibles (4.2 to 7.6 million cubic feet) that were commercially operated by the Germans in the 1930s.

The data base for World War II operations is by far the most extensive, at least when measured in terms of blimp-years covered. Over a period of 3-2/3 years the average number of blimps assigned to operational squadrons was approximately 55, making a total of about 200 blimp-years. In April 1944, the peak number assigned was slightly more than 100. An assigned blimp was either in overhaul or possessed directly by an operating squadron.

The data available for operations in the 1950s only cover slightly more than 4 blimp-years. Most of this latter data cover a 1-year period of intensive operations by a squadron (ZW-1) of Airborne Early Warning (AEW) airships (ZPG-2W class). Also included is a 2-month period of high intensity operations by a squadron (ZP-3) of ASW airships (ZPG-2 class). During most of the 1950s the number of operational Navy airships averaged between 30 and 40. The intensity of operations was normally at a moderate level -- apparently about 80 hours per month, or slightly less than 1,000 hours per year.

World War II Operations

A large fleet of blimps was constructed during World War II to perform escort and antisubmarine patrol operations. In addition to their major wartime duties, airships performed other useful missions including search operations, observations, photography, mine operations, rescue operations, and assistance to vessels and persons. These missions are described in more detail in reference D-1 that presents a broad overview of World War II blimp operations. According to reference D-1, the blimp inventory peaked at 168 in 1945. This inventory consisted predominantly of 134 K-ships with volumes of about 400 to 500 thousand cubic feet. At the peak of operations, U.S. Navy airships patrolled about 3 million square miles of the Atlantic, Pacific, and Mediterranean coasts. In all, airships escorted 89,000 ships on 55,900 flights totaling 550,000 flight hours.

At the peak of the WW II airship operational activity, the squadrons and wings were dispersed, as shown in figure D-1. Airship Wing ONE operated off the east coast headquartered at Lakehurst, New Jersey. Wing TWO covered the Caribbean with headquarters in Richmond, Florida; Houma, Louisiana; and the island, Jamaica. Wing THREE covered the west coast with headquarters at Tillamook, Oregon; Moffett Field, California; and Santa Ana, California. Wing FOUR protected the South Atlantic from headquarters in Brazil. Wing FIVE covered the Antilles from an operating base in Trinidad. In 1944, a squadron was deployed to North Africa to patrol the western Mediterranean and Straits of Gibraltar. An airship utility squadron provided many services and utility operations including ASW training.

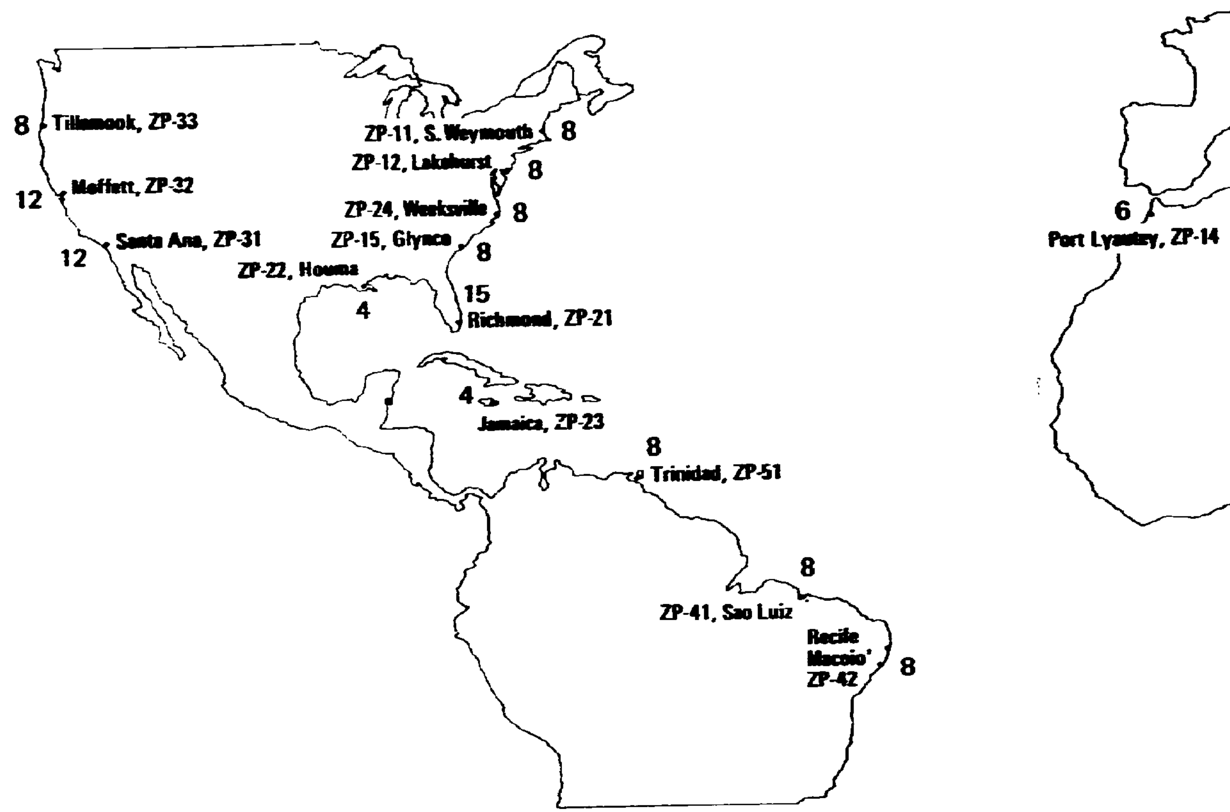

FIG. D-1: WORLD WAR II AIRSHIP DEPLOYMENTS

Reference (D-2) provides more specific information on airship assignments by squadron and monthly flight activity. The buildup of the number of airships assigned to operational units is shown in figure D-2 for both the Atlantic and Pacific fleets. At the peak in April 1944, 102 airships were deployed. An additional 8 airships (6G/2K) were assigned to Utility Squadron ONE, deployed on the east coast, with headquarters in Key West, Florida. Statistics in reference D-2 do not include the 280,000 hours flown during the war by training airships (mostly L class, of which 18 were built) assigned to the Naval Air Stations at Moffett Field, California and Lakehurst, New Jersey. These stations were also the places where all major repairs and overhauls were accomplished.

The utilization rate data in reference D-2 are presented in terms of operational (nontraining, etc.) and total flight hours per available airship, or per assigned airship. An available airship was an airship in squadron custody in flying condition, or "on the line." An assigned airship was defined to be an airship continuously associated with a particular squadron, whether it was in squadron custody, or away from the squadron for overhaul or major repair.

The average mission time of the World War II K-ships was 11.5 hours, and the average utilization rate for operational flights was 193.9 hours per month per available airship, or 2,327 hours per year. Because 87.2 percent of the airships assigned to a squadron were "on the line" and available for operations, the operational utilization rate per assigned airship was 2,029 hours per year.

The operational flight hours were about 76 percent of the total flight hours that included nonoperational hours for utility, experimental ferry, and training flights. Thus, total annual utilization rate was 3,077 flight hours per available airship, or 2,683 hours per assigned airship. To achieve these rates, the aircrew ratio was between 2 and 3 crews per assigned airship.

Post-World War II Operations

The operations of Airship Airborne Early Warning Squadron One (ZW-1) during the period 1 July 1957 to 30 June 1958 are reported in reference D-3 . Four ZPG-2W blimps were used to fill a Continental Air Defense requirement of 288 hours per month on-station approximately 200 miles from the base at Lakehurst, New Jersey. Personnel requirements for these operations are discussed in appendix E. Four aircrews flew 163 operational sorties for a total of 5,118 hours during this 1-year period. Average mission time was thus 31.4 hours. Because the average number of airships the squadron possessed was about 3 (see table D-1), the annual utilization rate achieved was 1,706 hours per possessed airship. The monthly rate was 142 hours per possessed airship, assuming 3 airship per squadron. The aircrew ratio was 4 crews for 3 airships.

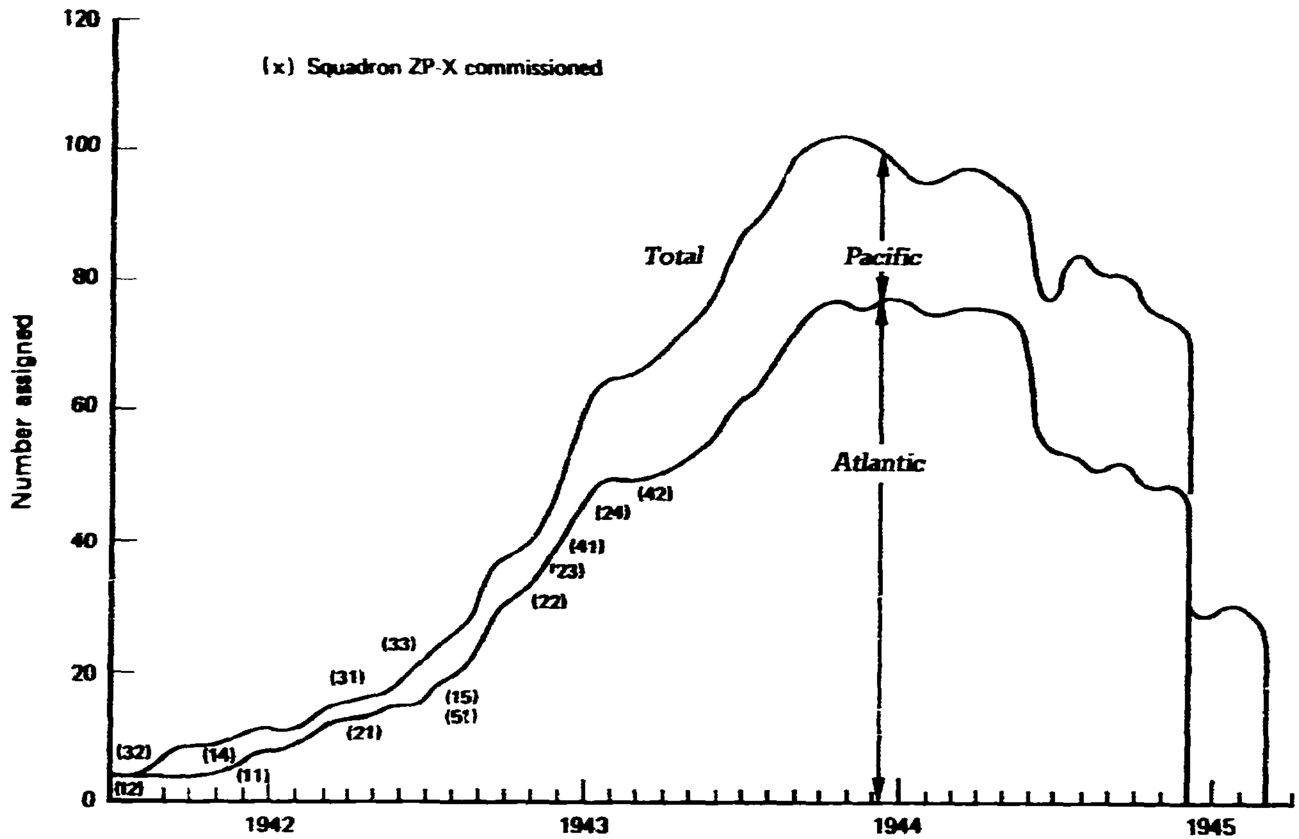

FIG. D-2: NUMBER OF AIRSHIPS ASSIGNED TO ATLANTIC/PACIFIC OPERATIONAL SQUADRONS IN WORLD WAR II

TABLE D-1

ZW-1 OPERATIONAL FLIGHTS
(1957/1958)

Year	Month	ZPG-2W Bureau No. 335	334	918	832	Monthly total	By Quarter: Operational flights	Operational hours	Total hours
1957	Jul.	6	3	6		15			
	Aug.	4		5	5	14	44	1,415	1,493
	Sept.	5		6	4	15			
	Oct.	5	6		3	14			
	Nov.	5	4	1	4	14	41	1,326	1,581
	Dec.	2	6		5	13			
1958	Jan.	5	6		3	14			
	Feb.	4	5		4	13	42	1,236	1,295
	Mar.	4	6		5	15			
	Apr.	2	4		5	11			
	May	5	2		5	12	36	1,141	1,452
	Jun.	4		4	5	13			
Airship totals		51	42	22	48		163	5,118	5,821

Airship ASW squadron Three (ZP-3) conducted operations during the winter of 1959 and 1960 while assisting in the development and evaluation of the newly installed offshore sound surveillance system. Four ZPG-2 blimps were employed in these operations from 15 September 1959 to 31 March 1960. During the last 2 months of this period, ZP-3 was committed to maintain an airship continuously on-station -- a total commitment of 1,440 on-station hours. During the period 1 February 1960 to 31 March 1960, 5 crews and 4 airships were used to obtain the greatest utilization rate ever obtained by ZPG airships -- 205.9 hours per month, 2,471 hours on an annual basis. Further discussion of these operations is presented in reference D-4 and appendix E.

Summary and Discussion

The results achieved in all of the operations described above are summarized in table D-2 for operational flights and table D-3 for total flights.

TABLE D-2
HISTORICAL UTILIZATION RATES
(operational flights)

Source (date)	Average mission time (hrs.)	Aircrew ratio	Utilization rate per possessed, or "on line" (World War II) airship (hrs./yr.)
World War II (1942/45)	11.5	~ 2/1	2327
ZW-1 (1957/58)	31.4	4/3	1706
ZP-3 (1960)	~ 36	5/4	2471

TABLE D-3
HISTORICAL UTILIZATION RATES
(total flights)

Source (date)	Utilization rate (hrs./yr.) Per possessed (or available) airship	Per assigned airship	Percent possessed (or "on line") airship
World War II (1942/45)	3077 [a]	2683	87.2 [b]
World War II (1943)	3412 [a]	3067	89.9 [b]
ZW-1 (1957/58)	1940	1455	75
ZP-3 (1960)	2471	2471	100

NOTES: [a] Per available airship
[b] Per "on line" airship

In the case of ZW-1 and ZP-3, the percentages possessed indicated in table D-3 refer essentially to long-term availability to the squadron; detailed information on short-term availability while in squadron custody was not available. The World War II availability ("on the line") figures include an unknown mixture of long- and short-term availability.

The significance of the above historical rates depends not only on differences in types of airships involved, but also on the extent to which the results represent maximum capabilities. From what is known about the ZW-1 and ZP-3 operations it is reasonable to presume that the results are close to the maximum capability. The ZP-3 operation was clearly a maximum effort, lasting only 2 months. The World War II results, however, are less than the maximum that might have been obtained if more sorties had been needed. They are the average over more than 3 years, during which time the requirements varied.

To interpret the World War II rates it is necessary to indicate how the operations were scheduled. The typical pattern during World War II was to attempt a flight every day with each available airship. Each aircrew would then fly every other day. In 1945, the operational flights were scheduled less frequently -- approximately at half the rate that was typical during the peak of activity in 1943. Also, in 1944, there was a reduction in operational flights in the Atlantic due to a reduction in U-boat operations and a decision to hold back resources. Thus, a better estimate of maximum capability can be obtained by considering only the results during 1943. These are indicated in table D-3 to be 3,412 and 3,067 total hours per possessed and assigned airship, respectively -- 11 and 14 percent greater, respectively, than the averages for the entire war period.

On a squadron basis, operational sorties for ZW-1 in 1957 and 1958 were scheduled approximately every other day. Because 3 airships were normally available to the squadron, each available airship was scheduled for operational missions about every 6 days. In addition, training sorties were flown at intervals of about 6 days, or 18 days per available airship. These flights were less than 12 hours whereas operational flights averaged 31.4 hours.

The schedule of operations for ZP-3 in 1960 is not known. If we assume a 36-hour mission time, the flights must have been scheduled about every 5 days for each airship.

This period of 5 days is typical of the scheduled commercial flights of the German dirigibles during the 1930s. According to data presented in reference (D-5), the Graf Zeppelin averaged about 2,000 hours per year over the 8-year period from 1929 to 1936, but reached a maximum rate of 3,519 hours per year in 1935. The Hindenberg averaged slightly less than this during its brief 14-month period of service in 1936 and 1937.

FUTURE AIRSHIP UTILIZATION RATE

With modern airships of moderate size (less than 3 million cubic feet in volume) it should be possible to exceed the utilization rates achieved by the ZPG-2 class airships in the late 1950s. To do so, however, the aircrew ratio must be approximately 2 crews per airship assigned to a squadron. With 2 crews, a utilization rate of 3,000 hours per year per possessed airship is achievable. This estimate is based both on aircrew capability and airship availability calculations using a formula developed for this study.

To estimate airship availability a flight schedule must first be specified. Each airship is assumed to operate 50 weeks per year, with 2 weeks allocated to intermediate level overhaul and upkeep. This is similar to the way Goodyear blimps are operated today. For planning purposes, a 6-day week is assumed reasonable. Each aircrew is estimated to be capable of flying at a rate of 125 hours per month, or 1,500 hours per year. With 2 aircrews per airship, it is possible for each airship to obtain 60 flight hours per week. But, to achieve this level of activity, approximately 72 flight hours per week must be scheduled because the availability factor is estimated to be about 84 percent as shown below.

To illustrate how the flight schedules might be arranged for various mission lengths, figure D-3 shows 3 possible patterns of operation for mission times of 12, 24, and 36 hours.

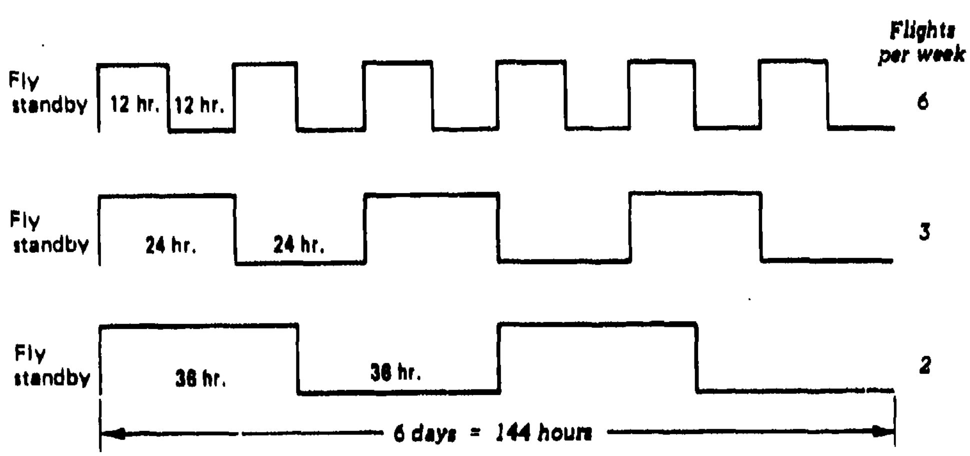

FIG. D-3: TYPICAL WEEKLY FLIGHT SCHEDULES

In the case of the 12-hour missions, flights are scheduled every day for a total of 6 sorties per week. Presumably, launch times would normally be early in the morning to permit maximum daylight time on station. The 24-hour missions would be scheduled on alternate days, for a total of 3 sorties per week. These would provide day and night coverage on station. The 36-hour missions could provide coverage for 2 days and 1 night, twice a week. The requirement for preflight and postflight inspections or maintenance (approximately 15 to 20 percent of flight time) would set an upper limit on the frequency of scheduled operations. The desirability of maintaining regularity in launch times also is a factor limiting the schedule frequency.

When no failures occur, the flight hours achieved are the same as the hours scheduled, i.e., some fraction, $f = t/T$, of the time period considered. This fraction is the mission time, t, divided by the cycle time, T. When failures occur and repairs are necessary, some scheduled flights will be missed, and the flight hours are then a fraction, A, of total time T, where A is an availability fraction. To determine A, the average failure rate is set equal to the average repair rate. A simple steady-state queueing model shows that A can be obtained using the following:

$$A = \frac{1}{1 + p_1 \dfrac{e^{-\mu_1 (T-t)}}{1-e^{-\mu_1 T}} + \dfrac{\lambda_2}{\mu_2} f}$$

where the λ's and μ's are failure and repair rates, respectively, of 2 different kinds, and

$$p_1 = p_{10} + \lambda_1 t$$

is the probability of being down at the end of a mission. The probability of having a type of failure that does not depend upon flight time is denoted by p_{10}. Routine short-term failure rates and repair rates are represented by λ_1 and μ_1, respectively, while λ_2 and μ_2 represent rates for infrequent failures with unusually long repair times corresponding to long delays waiting for spare parts.

Rough estimates of these parameters were made using the above availability formula and previous ZPG-2 results. The failure probability, p_1, was assumed to vary directly with mission time, so that p_{10} was zero. The failure rate, λ_1, was based on an assumed 10 percent failure probability per 12-hour mission. Thus, $\lambda_1 = 0.010/12 = 0.0083$ per hour. The average repair time, $1/\mu_1$, is estimated to be 24 hours, so that $\mu_1 = 0.042$ per hour.

The long-term failure rate, λ_2, was also assumed to vary directly with mission time at a rate one-tenth the short-term failure rate, so that $\lambda_2 = 0.00083$ per hour. The long-term repair rate was based on an average repair time, $1/\mu_2 = 10$ days, so that $\mu_2 = 0.0042$ per hour. Hence, the ratio, λ_2/μ_2, was equal to 0.2.

When the above parameters are inserted in the availability formula for the case of 24-hour missions, and a scheduled flight time fraction of one-half, an availability of 84.4 percent is obtained. The availability is relatively insensitive to changes in mission time. For example, decreasing the mission time to 12 hours reduces the availability to 83.6 percent; increasing the mission time to 36 hours increases the availability to 85.5 percent.

If the utilization rate is increased still further by using more than 2 aircrews per airship, and sorties are scheduled at a greater fraction than one-half, it should be theoretically possible to reach a rate of about 4,400 hours per year. This result is obtained using the availability formula with f increased to the practical limit of 0.85. This fraction allows for a turnaround time between recovery and launch of 3.6 hours, or 15 percent of the 24-hour mission time. There are several reasons, however, for questioning the value of going beyond the aircrew ratio limit of 2 to a ratio as high as 3. The principal reason is, from appendix F, that costs increase almost in proportion to the increase in aircrew ratio and utilization rate, so that cost per hour is not decreased appreciably. The cost per hour decreases only by 18 percent when the utilization rate is increased from 1,500 hours to 3,000 hours per year because the variable operating costs dominate the fixed investment costs.

There is another reason for not exceeding 3,000 hours per year. Our availability model assumes a constant repair rate, whereas one would expect the repair rate to decrease when the utilization rate increases. There are also questions about the parameters used in estimating the availability factor. Our estimate of p_1 and the ratio λ_2/μ_2 are believed to be on the optimistic side. Changing each of these parameters by a factor of 2 would reduce the theoretical maximum annual utilization rate per possessed airship to about 3,400 hours per year from 4,400 hours.

An additional factor to consider is the relative value of day and night coverage. For missions where daytime operations are much more effective than night operations little is gained by increasing the scheduling factor, f, above 50 percent.

For operations with mission times considerably longer than 24 hours, the availability factor decreases with increased mission time for scheduling factors close to unity. The reverse is true when the scheduling factor, f, is one-half or less; changes are small.

Based on the above reasons, a utilization rate of 3,000 hours per year appears to be a good estimate to use for possible future Coast Guard airship operations. However, the lower rate of 1,500 hours has also been considered to show the effect of changing the utilization rate and the aircrew ratio at the same time. Because the aircrew ratio is assumed to be a crucial factor in determining utilization rate, further discussion of this factor is presented below.

AIRCREW RATIO

It is assumed that a single aircrew is limited to fly 1,500 hours per year, or 125 hours per month. This aircrew capability is based on performance achieved in past airship operations with K-ships and ZPG-2 class blimps. The annual and monthly aircrew utilization rates are summarized in table D-4.

TABLE D-4

HISTORICAL AIRCREW UTILIZATION RATES

Source (date)	Aircrew ratio	Annual rate (hrs./crew)	Monthly rate (hrs./crew)
World War II (1943) (K-ships)	∿2	1,416	118
ZW-1 (1957/58)	1.33	1,280	106.7
ZP-3 (1960)	1.25	1,976	164.7

The World War II aircrew utilization rate is an approximate figure for 1943, the peak year of activity. The lack of accurate data on the aircrew ratio makes the results uncertain. The best peacetime data are provided by the ZW-1 results in 1957 and 1958 because the data base covers a full year of operations. The ZP-3 results are considered well above average as a consequence of the short period involved (2 months).

Compared with aircraft crew utilization rates, 125 hours per month is considered more representative of maximum capability than the average peacetime rate for routine operations. Information obtained from the aviation branch of the U.S. Coast Guard Office of Operations suggests that, on the average, Coast Guard pilots accumulate about 26 hours of flight time per month. Helicopter-only pilots have a slightly lower average, while fixed wing pilots are somewhat higher. The average monthly flight hours for commercial pilots is about 50 hours per month. The airlines generate an average aircraft utilization rate of 2,700 hours per year by employing 4.5 crews per aircraft.

Aircrew utilization of lighter-than-air vehicles should differ, of course, from aircrew utilization of heavier-than-air vehicles. For short mission times the differences may not be great. However, for the longer mission times typical of LTA vehicles, aircrews should be capable of higher utilization rates, because the workload will be divided between 2 or 3 rotating sections, or watches. Aircrew size as a function of mission time is discussed further in appendix E.

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D-3. Goodyear Aircraft Corp. Report GER-8438, S/2, "An Operational Evaluation of Airship Early Warning Squadron ONE (ZW-1)," Unclassified, 26 Sep 1958

D-4. Goodyear Aerospace Corp., paper presented at the AIAA Lighter-Than-Air Technology Conference, Aspen, Colorado, July 15-17, 1975, "LTA Vehicles - Historical Operations, Civil and Military," R.R. Huston, and G.L. Faurote

D-5. Goodyear Aerospace Corp., report NASA CR-137692, "Feasibility Study of Modern Airships, Phase I, Volume III - Historical Overview," G.L. Faurote, Unclassified, Aug 1975

APPENDIX E

AIRSHIP PERSONNEL REQUIREMENTS

This appendix presents estimates of personnel requirements for a family of airships with different speeds and maximum ranges when operated at utilization rates of either 1,500 or 3,000 hours per year. The 6 speeds considered vary from 50 to 100 knots at airship ranges of 1,000, 2,000, and 3,000 miles.

Personnel are divided into two categories -- aircrew and ground personnel. Aircrew includes the pilots and the sensor/equipment operators; ground personnel include workers required to maintain, service, and handle the airship and payload on the ground plus other administrative, support, and command and control staff.

For purposes of determining aircrew requirements, the airships are divided into 3 classes according to their mission times or endurances:

- low endurance -- less than 12 hours
- intermediate endurance -- between 12 and 36 hours
- high endurance -- greater than 36 hours.

Aircrew requirements depend also on the aircrew ratio, or number of crews per airship. This ratio depends on the utilization rate that is in turn, related to airship lifetime.

Ground personnel requirements are based on the size of the airship and the utilization rate.

AIRCREW

The aircrew required to operate an airship on a given mission includes the flight crew needed to fly the vehicle and the payload personnel needed to operate the equipment appropriate to the mission. The size of the flight crew is assumed to be independent of the mission, but the number of equipment operators depends on the type of mission. To estimate the payload personnel requirement, we assume that 2 equipment operators will be required on duty throughout each flight. All missions are assumed to require a rotating watch; both the flight crews and payload crews vary in size with the airship endurance. The aircrew ratio is estimated in appendix D to range from 1 to 2 when the utilization rate is increased from 1,500 to 3,000 hours per year.

As a point of reference for size of single aircrews, the World War II K-ships, with an average mission time of 11.5 hours, had aircrews of about 8 to 10 people. Approximately half were assigned to operate the vehicle and half to operate equipment, such as radar, radio, ECM, and MAD. At the other extreme, the ZPG-2/2W class airships that could operate for several days, had aircrew sizes of 14 to 21 people. In both cases, the flight crew size was 8. The AEW airship (ZPG-2W) had 7 more payload personnel than the ASW airship (ZPG-2) to provide an extensive radar tracking and air control capability.

Current U.S. Navy patrol aircraft normally operate with an aircrew of about 12 personnel, including:

5 Officers

- Pilot
- Co-pilot
- 3rd-pilot
- TACCO (Tactical Coordinator)
- Navigator

7 Enlisted

- Flight engineer
- Field mechanic
- Radio operator
- Ordnance man
- 3 sensor operators
- \+ 1 inflight technician (electronic repair) when available

Flight Crew

The personnel required to operate the vehicle are based on experience with previous U.S. Navy nonrigid airships and Goodyear commercial blimps, while making some allowance for airship control improvements and possible dual functions. The minimum flight crew to operate airships with low mission times of 6 to 12 hours is estimated to be a crew of 4, comprising 2 officers (pilot/co-pilot) and 2 enlisted people (mechanic/rigger). Following suggestions made by Goodyear representatives, the responsibilities of the flight crew members might be as follows:

- Pilot - Responsible for airship and mission operation. Flies airship from command position.
- Co-Pilot - Assists pilot on controls when required. Relieves pilot on controls when required. Conducts mechanical operation of navigation at pilot's direction. Handles communication in support of pilot.

- Mechanic - Operates any mechanical subsystems, such as APUs electrical equipment, and emergency devices. Performs mechanical inflight repair as required. Assists pilots during takeoff and landing.
- Rigger - Performs envelope and cabling inflight repairs as required. Depending on flight duration, performs cook duties.

For airships with mission times exceeding 36 hours, the flight crew requirement is increased to 8, comprising 4 officers and 4 enlisted personnel as follows:

Officers

- Command pilot
- Pilot
- Co-pilot
- Navigator

Enlisted

- Radio operator
- 2 Mechanic/Electricians
- Rigger/Cook

For intermediate mission times from 12 to 36 hours, the flight crew is reduced to 6 by omitting 1 officer (navigator) and 1 enlisted (radio operator).

Payload Crew

For mission times less than about 12 hours, it is assumed that a 2-watch rotation system will be adequate for relief of sensor operators and provision of inflight payload equipment maintenance and repair. Payload requirements thus total 4, all enlisted personnel.

For mission times of more than 36 hours, it is necessary to provide for a 3-watch rotation so the sensor operators can adequately rest. The operators not on watch should be able to provide any necessary inflight maintenance and repair of the payload equipment. Thus, the total requirement for this case is 6 people, all enlisted.

The intermediate case, for mission times between 12 and 36 hours, is assumed satisfied by a personnel requirement of 5, all enlisted.

Total Aircrew

Combining the above flight and payload personnel requirements for the 3 classes of mission times produces total aircrew requirements summarized in table E-1.

The requirements shown in table E-1 apply to single aircrews limited to a maximum of 1,500 flight hours per year. To achieve an airship utilization rate up to 3,000 flight hours per year, the aircrew ratio is increased in the same proportion as the utilization rate.

TABLE E-1

AIRCREW REQUIREMENTS
Total (Officer/Enlisted)

Airship endurance	Crew		
	Flight	Payload	Total
Low	4(2/2)	4(0/4)	8(2/6)
Intermediate	6(3/3)	5(0/5)	11(3/8)
High	8(4/4)	6(0/6)	14(4/10)

GROUND PERSONNEL

Ground personnel include the personnel required to perform routine maintenance at the squadron or unit level. Major repair and overhaul personnel are assumed to be based at a separate activity, similar to the Coast Guard Aircraft Repair and Service Center at Elizabeth City, North Carolina.

The ground personnel include not only the routine maintenance workers, but also those required to service and handle the airship on the ground.

The ground personnel requirements estimated here are presented on the basis of numbers per possessed airship. The ground maintenance personnel are assumed to vary directly with the number of airships possessed by the squadron. Maintenance personnel are also assumed to vary with the airship utilization rate. Ground maintenance personnel are divided into two groups, vehicle and payload maintenance. Both types of maintenance personnel are assumed to vary with the airship utilization rate. The vehicle maintenance personnel group is also assumed to vary with airship size.

Ground Handling Personnel

Ground personnel required for airship landing or docking are modest for airships up to the size of the ZPG-3W. These airships could be handled with a single mobile mast and 2 mobile winches, called ground mules. Each mule had a 2-person crew: one drove the mule while the other operated the winch. According to reference E-1, the November 1, 1958 U.S. Navy Handbook, "Airship Ground Handling Instructions," listed a total of 11 or 12 people for the undocking operation; 3 or 4 for the mast and tractor; 4 for the 2 mules;

a ground handling officer; a ground handling CPO; a safety inspector; and a flag operator. Walker (reference E-1) believed that the undocking evolution could be accomplished with a minimum of 8 people, and unmasting, launching, landing, masting, and docking with a minimum of 10. Airship operations are discussed further in volume III.

Around-the-clock flight operations would result in a requirement for at least 3 watches of ground handling crews. It is assumed, however, that flight operations would normally be scheduled to reduce the requirements for ground handling personnel outside normal working hours. In addition, ground maintenance personnel working outside normal hours are assumed to be assigned a dual responsibility to provide ground handling capability during these periods. A capability for ground handling outside normal hours could arise either as a consequence of mission times in excess of 8 hours, or when an airship unit is assigned SAR duties and must be prepared for unscheduled operations.

Ground Maintenance Personnel

Ground maintenance personnel are required for routine maintenance of the vehicle, payload, and ground support equipment. For vehicle maintenance, 3 types of personnel are required: mechanics, riggers, and electricians. Their duties are as follows:

- Mechanics -- Mechanics perform maintenance on engines and other equipment.
- Riggers -- Riggers are responsible for all fabric (envelope and empennage) repair as well as cable maintenance. Surface (interior-exterior) inspection is time consuming for riggers' maintenance due to the large areas involved. Also, the high work requires using ladders and bosun chairs. In both cases, one person must stay on the ground to support the one working above.
- Electricians -- Electricians service various electrical items such as blowers, servo motors, lights, radios, navigation devices, heaters, air conditioners, galley equipment, etc.

It is standard procedure for each of these crew types to provide supporting labor to the others where and when it is needed.

Payload maintenance personnel would consist predominantly of electronics technicians to repair the sensors and associated equipment making up a particular payload, such as the Airborne Oil Surveillance System (AOSS) used in MEP missions.

Ground support equipment maintenance is assumed to be accomplished principally by the ground handling crews themselves.

Maintenance Personnel Requirements

Estimates of maintenance personnel are based mainly on past experience with U.S. Navy airship operations in the late 1950 period, in the case of the larger size airships, and on Goodyear commerical experience, in the case of the smaller airships. In each case, however, it was necessary to make some adjustments to account for differences resulting from technology improvements and lack of similarity in equipment and operations.

World War II

Data on maintenance personnel for World War II K-ship operations was difficult to obtain. It was considered that such data, even if it had been available, would have limited utility, chiefly because personnel resources were relatively easy to obtain during World War II. The highly aggregated data on ground personnel presented in reference E-2 suggests, however, that the total ground personnel per blimp was surprisingly high. In 1945, 1 year after the peak of operations in 1944, when the blimp inventory was about 150 ships (reference E-3) and the number of blimps in operational squadrons was approximately 100 (reference E-4), there were about 8,000 administrative ground officers and enlisted personnel in the fleet airship program. Ground personnel per blimp in the inventory was about 53: 9 percent officers and 91 percent enlisted. Ground personnel per blimp in operational squadrons is more difficult to estimate. Interviews with people who participated in World War II blimp operations suggest, however, that the number of ground personnel per blimp may have been much less in operational squadrons, at least in the early phase of the war, prior to the extensive buildup in trained personnel achieved at the end of the war.

Post-World War II

More specific and pertinent information is available on personnel requirements for U.S. Navy lighter-than-air squadrons during the late 1950s. The most detailed information is available for the Airborne Early Warning Squadron, ZW-1 that conducted extensive Continental Air Defense operations with 4 ZPG-2W blimps in 1957-1958. Personnel information is also available for the Antisubmarine Warfare Squadron, ZP-3 that conducted high intensity surveillance operations in 1960. The utilization rates obtained in these operations are discussed in appendix D.

During the period from 1 July 1957 to 30 June 1958, ZW-1 employed 3 aircrews to fly 163 sorties for a total of 5,118 hours. Thus, average mission time was 31.4 hours. Because the average number of airships available to the squadron was about 3, the annual utilization rate achieved was 1,706 hours per airship; on a monthly basis this equals 142 hours. From 1 February 1960 to 31 March 1960, ZP-3, with the assistance of ZW-1, employed 5 crews at an average rate of 164.7 hours per month. The average utilization rate per airship was the greatest attained by ZPG airships -- 205.9 hours per month, 2,471 hours on an annual basis.

ZW-1 Personnel Requirements

Prior to the start of the ZW-1 operations the personnel allowance was based on 4 airships, each operated by 2 crews comprising 6 officers and 15 enlisted people. Ground support and staff brought the total allowance to 278 -- 53 officers and 225 enlisted. After several months of experimentation the conclusion was reached that the squadron needed radical reorganization.

According to reference E-5 that reports on a preliminary AEW Barrier exercise during the period from 1 May to 18 May 1957, the most efficient system of personnel employment required specialization in 3 fields: flight, maintenance, and other ground support. Four crews of the absolute minimum size were chosen. These consisted of 9 officers and 15 enlisted people, thus removing 12 officers and 60 enlisted people from the squadron proper. Remaining personnel were divided into groups working a 7-day week. This permitted maintenance to continue 24 hours a day, 7 days a week. All normal functions such as training, education, filing, housekeeping, etc., were sacrificed in order to permit 24-hour maintenance. Toward the end of the May exercise period, the strain was noticeable, although morale was high. Officers not in flight crews worked 64 hours per week. Flight crews flew an average of 140.1 hours per crew during the exercise and maintained a 24-hour standby watch between flights. Maintenance and support personnel were on a staggered 6-day work week.

From July to September 1957, ZW-1 had 298 officers and enlisted people. By the end of December 1957, ZW-1 had 63 officers and 302 enlisted people for a total of 365. In reference E-6 , there is an evaluation report based on the first 6 months of operations. This evaluation presents a cost comparison of ZPG-2W airships and WV-2 aircraft that was made using 417 personnel to obtain continuous on-station coverage, (11,340 hours per year, including 2,580 hours of transit time) with 4 airships. In commenting on personnel requirements, the statement was made that with adequate supervision, rotation, and active utilization of the flight crews, their operational effectiveness is such that should ZW-1 allowance be filled to 488 personnel, and 1 station assigned to them, full-time flights on-station up to 36 hours is completely practical. According to reference E-7 , that reports on the year period ending in June 1958, the squadron onboard count actually increased from 289 to 387 officers and enlisted people during the evaluation period.

In order to determine what fraction of the total personnel was involved in maintenance, the following approximate breakdown was obtained from the former commanding officer of ZW-1, Capt. (ret.) Charles A. Mills, Jr.

106	Flight crews (4 x 24 plus 10 percent on leave)
30	Station support (10 percent of total allowance, plus 10 percent)
20	Administration
20	Duty section
20	HTA maintenance
82	LTA maintenance
278	Total allowance

The 10 percent requirement for station support was standard practice to provide people for such things as the motor pool and BOQ. This percent was used only to estimate early manning; it is not used elsewhere in this report. Administrative personnel included those involved in various nonmaintenance types of services. The HTA maintenance line provided maintenance for 3 to 5 aircraft also assigned to the squadron. The duty section included personnel for the hangar watch and pressure watch (2 on each LTA) and the duty driver. We did not include station support in our estimates of required LTA ground personnel.

When the squadron allowance increased to 387, the maintenance personnel increased by only 22, because the add-on included 2 flight crews and additional nonmaintenance personnel. The extra flight crews were not used, however, in the operations because they were relatively untrained. The number of maintenance personnel increased from 82 to 104. Because there were 3 airships assigned, the average number of maintenance personnel per possessed airship was about 27 to 35.

The distribution of the maintenance personnel was estimated by Capt. (ret.) Charles A. Mills, Jr. to be:

60 percent--Electricians and ETs
26 percent--Mechanics
14 percent--Riggers

It was further estimated that approximately one-sixth of the electricians and electronic technicians (ETs) were needed for the airship proper and the remainder for the large AEW payload of radars, consoles, etc. Thus, the maintenance personnel was divided about evenly between vehicle and payload. Vehicle maintenance personnel per airship increased from about 14 to 18 during the period of operations.

ZP-3 Personnel Requirements

Less personnel information is available for the lighter-than-air ASW squadrons. Two sources, however, indicate that the normal allowance for a 4-ship squadron was about 250 people.

In reference E-8 , a feasibility study of deployment of airship squadron ZP-3 to the Mediterranean area in 1957, it was stated that 246 personnel (54 officers/22 CPOs/170 POs and nonrated people) would be required to operate 4 ZPG-2 airships based at Rota, Spain.

In reference E-9 , a presentation made by Capt. (ret.) Charles A. Mills, Jr., Operations officer of Fleet Airship Wing ONE on 19 April 1960, at the critique of the ZP-3 Airship-SOSUS project, the total squadron onboard count was indicated to be less than 260. This same reference also included the comments that 6 airships, rather than the 4 available, were required to maintain station continuously and that a maintenance force of at least 300 was needed to mount this type of operation.

During February and March 1960, the personnel level was increased by 40 maintenance people obtained from ZW-1 squadron. The ZW-1 squadron was being disestablished at that time. Thus, for these operations the total ground personnel was approximately 220 (250 + 40 less 5 aircrews at 14 each), or 55 for each of the 4 assigned airships. (See appendix D.) If we assume that about 60 percent (compared to 48 percent for ZW-1 in 1957) of the original ZP-3 squadron ground personnel were maintenance personnel, then the final maintenance level would have been about 148 (108 + 40 from ZW-1), or 37 per assigned airship. While this level is about the same as for ZW-1 in 1958, the fraction associated with the vehicle was probably higher for the ASW squadron. This fraction was estimated by Captain (ret.) Mills, to about 2/3, which implies that about 24 maintenance personnel officers and enlisted (officers and enlisted) per airship were involved in vehicle maintenance and 12 per airship were maintaining the payload of ASW equipment.

Future Maintenance Personnel Requirements

To extend these historical maintenance personnel requirements to future modern airships of the same size, it was necessary to make an assumption about the effects of technological improvements on maintenance requirements and repair capabilities. We have reduced the personnel requirements by approximately one-third so that 12 people are required at a utilization rate of 1,500 hours per year. As was noted earlier, doubling the utilization rate was assumed to increase the maintenance requirement by 50 percent. This assumption holds both for vehicle and payload maintenance personnel separately.

The assumed future maintenance requirements for modern airships of 1 million cubic feet are compared with the estimates of historical maintenance levels in table E-2.

TABLE E-2

VEHICLE MAINTENANCE PERSONNEL (OFFICER AND ENLISTED) FOR AIRSHIP VOLUME OF 1 MILLION CUBIC FEET

	Historical		Future Airships	
Source (date)	Utilization rate* (hrs./yr.)	Personnel per airship*	Utilization rate* (hrs./yr.)	Personnel per airship*
ZW-1 (1957/58	1706	18	1500	12
ZP-3	2471	24	3000	18

*Per possessed aircraft.

The above historical results pertained to airship mission times of about 30 to 36 hours. These long mission times were obtained by cruising at speeds of about 40 knots. Because of fuel capacity constraints, when the average speeds are increased to about 80 or more knots the mission times are reduced to about 12 hours or less for this size airship. Maintenance requirements are assumed, however to depend on utilization rate, and not on sortie rate. In appendix D it is shown that sortie rate has a small effect on utilization rate when repair rates are constant.

To estimate the effect of airship size on maintenance requirements, information was obtained from Goodyear Aerospace Corporation on the operations of their small (about 200,000 cubic feet) commercial airships. There are 3 Goodyear advertising blimps at present. Each of these is operated by about 21 people from widely dispersed bases (such as Santa Ana, California; Houston, Texas; and Miami, Florida) to provide coast-to-coast coverage. The 21 persons include, on the average: 2 pilots, 5 direct vehicle maintenance/support people, 7 nonmechanized landing crew, 6 payload maintenance crew, and 1 publications person. Two weeks are used for an annual major overhaul.

The 5 direct vehicle maintenance/support people are responsible for both maintenance and ground handling operations. The blimps operate from a truck-mounted mast on tour. Flight hours are believed to be on the order of 1,500 to 2,000 hours per year.

The assumption that vehicle maintenance personnel varies $(\text{volume})^{0.5}$ provides a reasonable approximate fit to the effect of size using the figures of 12 vehicle maintenance people for 1 million cubic feet and 5 for 200,000 cubic feet (in the case of 1,500 flight hours per year). Table E-3 shows estimated numbers of vehicle maintenance personnel for various airship sizes scaled from 1,000,000 cubic feet airships in accordance with this relationship. Maintenance manhours per flight hour (MMH/FH) are equal to 8 for the 500,000 cubic feet airship at the high rate.[1]

TABLE E-3

VEHICLE MAINTENANCE PERSONNEL (OFFICER AND ENLISTED) PER AIRSHIP

Airship volume (million cu.ft.)	Utilization rate (hrs./yr.) 1,500	3,000
0.2	5	8
0.5	8	12
1.0	12	18
1.5	15	22
3.0	21	31

[1]Assuming 2,000 maintenance hours per year per person, on the same basis, the MMH/FM for the MRS=22, HH-3=37 amd JC-130=48.

Total ground maintenance personnel requirements are obtained by adding the payload maintenance requirements that are assumed to be 6 and 9 people for the 1,500 and 3,000 hours per year utilization rates, respectively, for a payload similar to the AOSS used in MEP missions, as shown in tables E-4 and E-5

TABLE E-4

TOTAL GROUND MAINTENANCE PERSONNEL (OFFICER AND ENLISTED) PER AIRSHIP
(Utilization rate: 1,500 hrs./yr.)

Airship volume (million cu. ft.)	Maintenance		Total
	Vehicle	Payload	
0.2	5	6	11
0.5	8	6	14
1.0	12	6	18
1.5	15	6	21
3.0	21	6	27

TABLE E-5

TOTAL GROUND MAINTENANCE PERSONNEL (OFFICER AND ENLISTED) PER AIRSHIP
(Utilization rate: 3,000 hrs./yr.)

Airship volume (million cu. ft.)	Maintenance		Total
	Vehicle	Payload	
0.2	8	9	17
0.5	12	9	21
1.0	18	9	27
1.5	22	9	31
3.0	31	9	40

Total ground maintenance personnel for the two utilization rates are compared in table E-6.

TABLE E-6

SUMMARY OF TOTAL GROUND MAINTENANCE PERSONNEL (OFFICER AND ENLISTED) PER AIRSHIP

Airship volume (million cu. ft.)	Utilization rate (hrs./yr.) 1,500	3,000
0.2	11	17
0.5	14	21
1.0	18	27
1.5	21	31
3.0	27	40

Figure E-1 presents the total ground personnel requirements in graphic form as a function of volume for the two utilization rates.

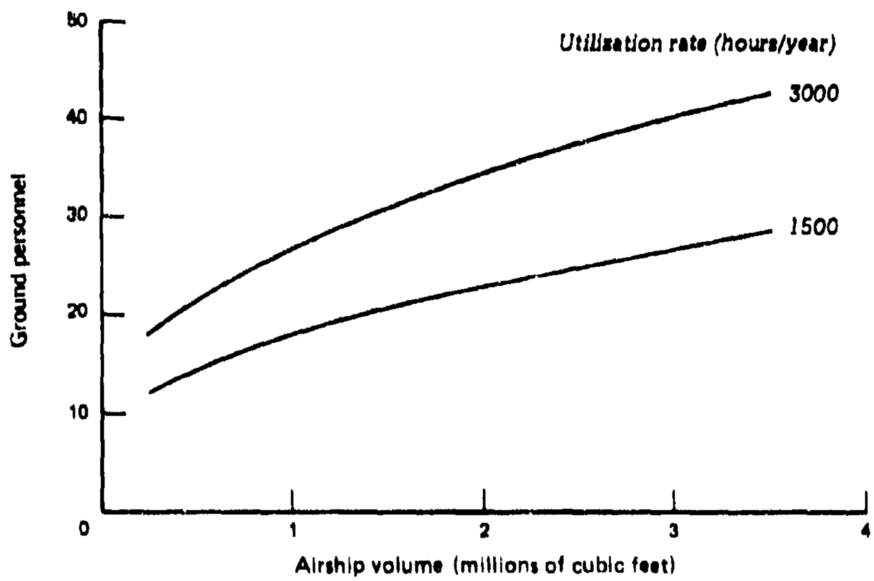

FIGURE E-1

The estimated personnel requirement for a 3 million cubic foot airship at 3,000 hours per year compares closely with the number 50, used in reference E-10 for a proposed AEW airship of that size and utilization rate.

TOTAL PERSONNEL REQUIREMENTS

Table E-7 presents the personnel requirements in detail for the entire family of airships as a function of speed, range, and utilization rate. Aircrew requirements are taken from table E-1 using the appropriate mission time in accordance with the airship speed and range. Ground personnel requirements are calculated using the airship volumes provided in appendix F and determined by the performance model described in volume III. Ground personnel officers are assumed to be 10 percent of the total ground personnel. See annex F-1 for a summary of the formulas used to calculate all personnel requirements as a function of volume and utilization rate.

TABLE E-7

AIRSHIP PERSONNEL REQUIREMENTS

Speed (kts.)	Range (n.mi.)	Utilization (hrs.)	Personnel	Aircrew	Ground personnel	Total
50	1000	1500	officers	3	1	4
			enlisted	8	12	20
			Total	11	13	24
		3000	officers	6	2	8
			enlisted	16	17	33
			Total	22	19	41
50	2000	1500	officers	4	1	5
			enlisted	10	14	24
			Total	14	15	29
		3000	officers	8	2	10
			enlisted	20	20	40
			Total	28	22	50
50	3000	1500	officers	4	2	6
			enlisted	10	14	24
			Total	14	16	30
		3000	officers	8	2	10
			enlisted	20	22	42
			Total	28	24	52
60	1000	1500	officers	3	1	4
			enlisted	8	12	20
			Total	11	13	24

(continued)

TABLE E-7

AIRSHIP PERSONNEL REQUIREMENTS (continued)

Speed (kts.)	Range (n.mi.)	Utilization (hrs.)	Personnel	Aircrew	Ground personnel	Total
60	1000	3000	officers	6	2	8
			enlisted	16	18	34
			Total	22	20	42
60	2000	1500	officers	3	2	5
			enlisted	8	13	21
			Total	11	15	26
		3000	officers	6	2	8
			enlisted	16	21	37
			Total	22	23	45
60	3000	1500	officers	4	2	6
			enlisted	10	16	26
			Total	14	18	32
		3000	officers	8	3	11
			enlisted	20	24	44
			Total	28	27	55
70	1000	1500	officers	3	1	4
			enlisted	8	12	20
			Total	11	13	24
		3000	officers	6	2	8
			enlisted	16	18	34
			Total	22	20	42

(continued)

TABLE E-7

AIRSHIP PERSONNEL REQUIREMENTS (continued)

Speed (kts.)	Range (n.mi.)	Utilization (hrs.)	Personnel	Aircrew	Ground personnel	Total
70	2000	1500	officers	3	2	5
			enlisted	8	14	22
			Total	11	16	27
		3000	officers	6	2	8
			enlisted	16	22	38
			Total	22	24	46
70	3000	1500	officers	4	2	6
			enlisted	10	18	28
			Total	14	20	34
		3000	officers	8	3	11
			enlisted	20	27	47
			Total	28	30	58
80	1000	1500	officers	3	1	4
			enlisted	8	13	21
			Total	11	14	25
		3000	officers	6	2	8
			enlisted	16	19	35
			Total	22	21	43
80	2000	1500	officers	3	2	5
			enlisted	8	15	23
			Total	11	17	28
		3000	officers	6	3	9
			enlisted	16	23	39
			Total	22	26	48
80	3000	1500	officers	4	2	6
			enlisted	10	21	31
			Total	14	23	37

TABLE E-7

AIRSHIP PERSONNEL REQUIREMENTS (continued)

Speed (kts.)	Range (n.mi.)	Utilization (hrs.)	Personnel	Aircrew	Ground personnel	Total
80	3000	3000	officers	8	3	11
			enlisted	20	31	51
			Total	28	34	62
90	1000	1500	officers	2	1	3
			enlisted	6	12	18
			Total	8	13	21
		3000	officers	4	2	6
			enlisted	12	17	29
			Total	16	19	35
90	2000	1500	officers	3	2	5
			enlisted	8	17	25
			Total	11	19	30
		3000	officers	6	3	9
			enlisted	16	26	42
			Total	22	29	51
90	3000	1500	officers	3	3	6
			enlisted	8	23	31
			Total	11	26	37
		3000	officers	6	4	10
			enlisted	16	35	51
			Total	22	39	61
100	1000	1500	officers	2	1	3
			enlisted	6	12	18
			Total	8	13	21
		3000	officers	4	2	6
			enlisted	12	18	30
			Total	16	20	36

TABLE E-7

AIRSHIP PERSONNEL REQUIREMENTS (continued)

Speed (kts.)	Range (n.mi.)	Utilization (hrs.)	Personnel	Aircrew	Ground personnel	Total
100	2000	1500	officers	3	2	5
			enlisted	8	19	27
			Total	11	21	32
		3000	officers	6	3	9
			enlisted	16	29	45
			Total	22	32	54
100	3000	1500	officers	3	3	6
			enlisted	8	29	37
			Total	11	32	43
		3000	officers	6	5	11
			enlisted	16	43	59
			Total	22	48	70
110	1000	1500	officers	2	1	3
			enlisted	6	13	19
			Total	8	14	22
		3000	officers	4	2	6
			enlisted	12	19	31
			Total	16	21	37
110	2000	1500	officers	3	2	5
			enlisted	8	22	30
			Total	11	24	35
		3000	officers	6	4	10
			enlisted	16	32	48
			Total	22	36	58
110	3000	1500	officers	3	4	7
			enlisted	8	35	43
			Total	11	39	50
		3000	officers	6	6	12
			enlisted	16	53	69
			Total	22	59	81
120	1000	15000	officers	2	1	3
			enlisted	6	13	19
			Total	8	14	22
		3000	officer	4	2	6
			enlisted	12	19	31
			Total	16	21	37

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E-5. Commanding Officer AEW Squadron ONE, ltr ser 015, "AEW exercise conducted during the period 1 May - 18 May, 1957; report of," 4 Jun 1957

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E-9. Cdr. Charles A. Mills, Jr., Operations officer, Fleet Airship Wing ONE, presentation on 1 Apr 1960, "Critique of the Airship-SOSUS project,"

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APPENDIX F

AIRSHIP COSTS

INTRODUCTION

This appendix presents cost estimates for a family of airships. Investment costs and operating costs -- divided among personnel, maintenance, and fuel -- are developed for utilization rates of 1,500 and 3,000 hours per year. Annual and hourly costs are all in 1976 dollars.

Costs are related to vehicle size and weight; both vary with speed and range. The conceptual design model described in volume III was used to obtain figures for airship volume, empty weight, and fuel consumption rate. These cost-determining characteristics are presented in table F-1.

Airship investment cost, for a buy of 20 airships, is based on the average cost per pound of empty weight estimated in volume III. The average acquisition cost, expressed in terms of cost per flight hour, is based on airship lifetime in hours estimated in appendix D.

Personnel costs are based on air and ground personnel requirements estimated in appendix E. Individual personnel costs per year for Coast Guard officer and enlisted aviation billets are developed in appendix C.

Total maintenance cost includes routine maintenance, based on cost information for U.S. Navy blimp operations in 1957-1959, and major overhaul costs.

Fuel costs are obtained using the consumption rates shown in table F-1 together with a November 1975 cost per gallon. This cost per gallon was supplied by the Navy Fuel Supply Office.

The investment and operating costs estimated here do not include base and ground support equipment costs. The location and characteristics of existing airship hangars are presented in volume III. Ground equipment for blimp operations is also treated in volume III.

INVESTMENT COST

Airship investment costs are based on the cost factors developed in chapter 8 of volume III. These factors were based on analysis of historical blimp costs and cost escalation factors to arrive at 1976 dollar costs. For a production quantity of 20 vehicles,

TABLE F-1

AIRSHIP CHARACTERISTICS

Speed (kts.)	Range (mi.)	Volume (cu. ft.)	Empty weight (lbs.)	Fuel consumption rate (gal./hr.)
50	1000	319,000	9,800	23
	2000	514,000	14,400	30
	3000	727,000	18,700	37
60	1000	347,000	11,100	40
	2000	569,000	15,900	52
	3000	980,000	24,900	71
70	1000	377,000	12,500	62
	2000	709,000	19,900	88
	3000	1,360,000	34,400	129
80	1000	408,000	14,200	93
	2000	903,000	25,700	144
	3000	1,958,000	49,800	227
90	1000	340,000	11,800	112
	2000	1,188,000	34,500	231
	3000	2,854,000	72,900	394
100	1000	374,000	13,800	157
	2000	1,623,000	47,900	372
	3000	4,580,000	118,100	714
110	1000	411,000	16,400	215
	2000	2,322,000	69,400	606
	3000	7,587,000	197,900	1,300
120	1000	465,000	19,700	293
	2000	3,480,000	105,000	1,003
	3000	12,917,000	342,000	2,380

the average cost was estimated to be $124 per pound of empty weight. This cost includes engineering and prototype costs, but excludes exploratory R&D costs.

To determine the estimated acquisition costs for the family of airships treated here (shown in table F-2), we combine the $124 per pound factor with the empty weights listed in table F-1. (The acquisition costs are an output of the computer program described in volume III.)

To determine the hourly cost we divide the acquisition cost by the total airship lifetime (30,000 flight hours) estimated in appendix D.

PERSONNEL COSTS

Airship personnel requirements were determined previously in appendix E. Table F-3 summarizes the officer and enlisted personnel requirements for the family of airships operated at 1,500 and 3,000 hours per year. (Also see table E-7.)

Personnel costs indicated in these tables were based on the costs estimated in appendix C using the Coast Guard Billet Model. Because there was no information available about exact ratings of airship air and ground personnel, average officer and enlisted costs were assumed to be the same as for the MRS and HU-16E aircraft. The unit costs shown in table F-4 were obtained by using the same inflation factor (1.1046) that was applied in appendix E to convert FY 1974 costs to FY 1976 costs.

TABLE F-4

ANNUAL UNIT COSTS FOR AIRSHIP PERSONNEL
(FY 1976 Dollars)

Billet	Unit cost ($/yr.)
Officers	$59,613
Enlisted	$21,598

By applying the unit cost factors in table F-4 to the personnel requirements in table F-3 we obtain the personnel costs listed in table F-5.

Increasing the utilization rate from 1,500 to 3,000 hours per year reduces the personnel hourly costs. While the annual costs are almost doubled, the hourly costs at the higher utilization rate are 77 to 85 percent of the hourly costs at the lower utilization rate. These reductions are caused by the manner in which ground personnel requirements are assumed to vary with utilization rate. While aircrews increase in direct proportion to the utilization rate, the ground personnel increase by about only 40 percent when the utilization rate doubles.

TABLE F-2

AIRSHIP INVESTMENT COSTS

(1976 dollars)

Speed (kts.)	Range (mi.)	Acquisition cost ($)	Investment cost per hour of utilization ($/hr.)
50	1000	1,220,000	41
	2000	1,790,000	60
	3000	2,350,000	78
60	1000	1,360,000	45
	2000	1,970,000	66
	3000	3,120,000	104
70	1000	1,530,000	51
	2000	2,480,000	83
	3000	4,320,000	144
80	1000	1,730,000	58
	2000	3,190,000	106
	3000	6,250,000	208
90	1000	1,440,000	48
	2000	4,270,000	142
	3000	9,140,000	305
100	1000	1,680,000	56
	2000	5,920,000	197
	3000	14,790,000	493
110	1000	1,980,000	66
	2000	8,570,000	286
	3000	24,750,000	825
120	1000	2,370,000	79
	2000	12,960,000	432
	3000	42,670,000	1,422

TABLE F-3

AIRSHIP PERSONNEL REQUIREMENTS

Speed (kts.)	Range (mi.)	Utilization rate: 1,500 hr./yr. Officers	Enlisted	Total	3,000 hr./yr. Officers	Enlisted	Total
50	1000	4	20	24	8	33	41
	2000	5	24	29	10	40	50
	3000	6	24	30	10	42	52
60	1000	4	20	24	8	34	42
	2000	5	21	26	8	37	45
	3000	6	26	32	11	44	55
70	1000	4	20	24	8	34	42
	2000	5	22	27	9	38	46
	3000	6	28	34	11	47	58
80	1000	4	21	25	8	35	43
	2000	5	23	28	9	39	48
	3000	6	31	37	11	51	62
90	1000	3	18	21	6	29	35
	2000	5	25	30	9	42	51
	3000	6	31	37	10	51	61
100	1000	3	18	21	6	30	36
	2000	5	27	32	9	45	54
	3000	6	37	43	11	59	70
110	1000	3	19	22	6	31	37
	2000	5	30	35	10	48	58
	3000	7	43	50	12	69	81
120	1000	3	19	22	6	31	37

TABLE F-5

AIRSHIP PERSONNEL COSTS

(1976 dollars)

Speed (kts)	Range (mi.)	Utilization rate (hr./yr.)	Annual personnel cost ($)	Personnel cost per hour of utilization ($/hr)
50	1000	1500	676,000	451
		3000	1,190,000	397
	2000	1500	825,000	550
		3000	1,465,000	488
	3000	1500	867,000	578
		3000	1,527,000	509
60	1000	1500	683,000	456
		3000	1,201,000	400
	2000	1500	734,000	489
		3000	1,277,000	426
	3000	1500	909,000	606
		3000	1,590,000	530
70	1000	1500	691,000	461
		3000	1,212,000	404
	2000	1500	761,000	507
		3000	1,317,000	439
	3000	1500	962,000	641
		3000	1,671,000	557
80	1000	1500	699,000	466
		3000	1,224,000	408
	2000	1500	794,000	529
		3000	1,366,000	455
	3000	1500	1,033,000	689
		3000	1,777,000	592
90	1000	1500	579,000	386
		3000	993,000	331
	2000	1500	836,000	557
		3000	1,430,000	477

Table F-5 (continued)

Speed (kts.)	Range (mi.)	Utilization rate (hr./yr.)	Annual personnel cost ($)	Personnel cost per hour of utilization ($/hr.)
	3000	1500	1,019,000	679
		3000	1,704,000	568
100	1000	1500	588,000	392
		3000	1,006,000	335
	2000	1500	892,000	595
		3000	1,514,000	505
	3000	1500	1,156,000	771
		3000	1,910,000	637
110	1000	1500	597,000	398
		3000	1,019,000	340
	2000	1500	969,000	646
		3000	1,629,000	543
	3000	1500	1,344,000	896
		3000	2,191,000	730
120	1000	1500	609,000	406
		3000	1,038,000	346

The two utilization rates are compared on a total hourly cost basis. Results are presented elsewhere in this appendix.

MAINTENANCE AND OVERHAUL COSTS

Airship costs are developed separately for routine maintenance and major overhauls. The routine maintenance cost is the cost of maintenance material only; personnel costs take into account maintenance labor. Overhaul cost includes both labor and material costs.

Routine Maintenance Costs

The airship maintenance cost is assumed to vary directly with the utilization rate for a given airship size. Thus, the maintenance cost per flight hour is constant for a fixed size airship. It is assumed, following reference a, that the maintenance cost will increase by 50 percent for a 100 percent increase in airship volume. This assumption implies that the maintenance cost varies as $(\text{volume})^{0.585}$. Taking a volume of 1 million cubic feet as a reference, the relative maintenance cost factor varies as indicated in figure F-1.

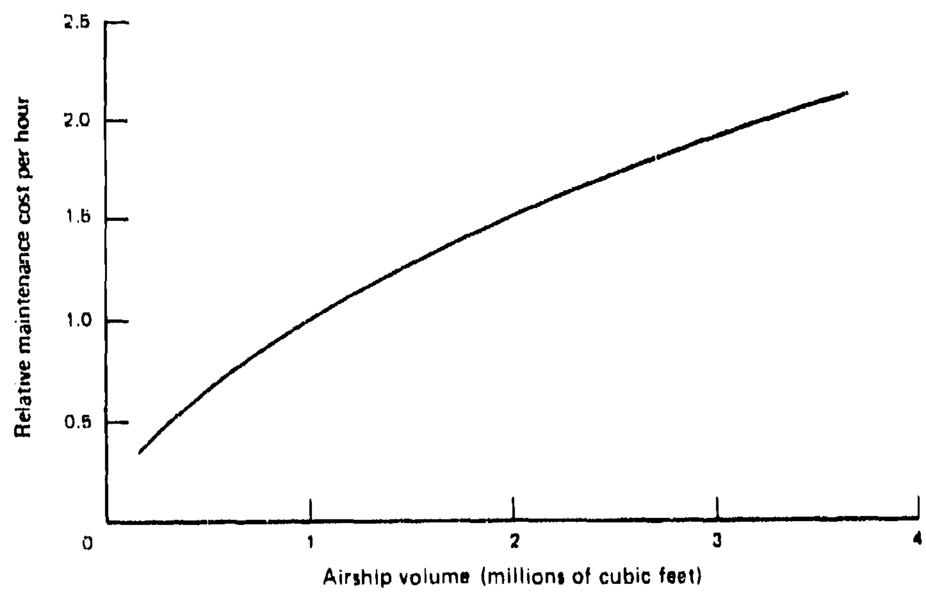

FIG. F-1: RELATIVE MAINTENANCE COST FACTOR

The maintenance cost for a million cubic foot airship is based on operating costs experienced by an AEW airship squadron during a 21-month period in 1957-1959. The airships involved were the nonrigid ZPG-2W type with a volume of 975,000 cubic feet. Vehicle maintenance spare parts cost approximately $150 per flight hour (see reference F-2). In 1976 dollars this amounts to about $350 per flight hour using the price indices given in chapter 8 of volume III.

The reference cost of $350 per hour does not include engine overhaul costs. Based on an engine overhaul cycle of 1,500 hours and a cost per horsepower of about $7, the engine overhaul costs would be less than 10 percent of the routine maintenance costs. Routine maintenance costs presumably cover these relatively small costs.

We also assume that routine maintenance costs include other omitted maintenance costs: maintaining ground support equipment and helium replacement.

In the past, it was customary to plan on replacing the entire volume of helium annually. With the new envelope materials available today, we expect that helium would be replaced every 5 to 10 years. Today helium costs about $40 per thousand cubic feet; thus replacing the helium of a million cubic foot airship would cost about $40,000. The annual cost would range from $4,000 to $8,000 depending on when helium was replaced.

The results indicated in table F-6 were based on the $350 cost per hour and the relation indicated in figure F-1 for the effect of size variation.

Major Overhaul Costs

Major overhaul costs are calculated as a fraction of the investment costs. Normal overhaul, conducted every 3-1/3 years, is assumed to cost 10 percent of the investment cost. An airship with a lifetime of 10 years, corresponding to a utilization rate of 3,000 hours per year, would require 2 overhauls, costing 20 percent of the investment cost.

An airship with a lifetime of 20 years, corresponding to a utilization rate of 1,500 hours per year, is assumed to require a special overhaul at 10 years to replace the envelope and recover the empennage. The special overhaul is assumed to be one-third of the investment cost. This fraction is consistent with estimates provided by Goodyear Aerospace Corp. for replacement of age sensitive items.

Thus, the total major overhaul costs equal .10 + .10 + .33 + .10 + .10, or 73 percent, for the 20-year lifetime cases.

Annual and hourly overhaul costs for both cases are indicated in table F-7.

Total Maintenance and Overhaul Costs

The routine maintenance costs (table F-6) and major overhaul costs (table F-7) are combined to make up the total annual and hourly maintenance and overhaul costs shown in table F-8.

TABLE F-6

AIRSHIP ROUTINE MAINTENANCE COST
(1976 dollars)

Speed (kts.)	Range (mi.)	Utilization rate (hr/yr.)	Annual cost ($)	Maintenance cost per hour of utilization ($/hr.)
50	1000	1500	269,000	179
		3000	538,000	179
	2000	1500	356,000	237
		3000	711,000	237
	3000	1500	436,000	291
		3000	872,000	291
60	1000	1500	283,000	188
		3000	565,000	188
	2000	1500	377,000	252
		3000	755,000	252
	3000	1500	519,000	346
		3000	1,038,000	346
70	1000	1500	296,000	198
		3000	593,000	198
	2000	1500	429,000	286
		3000	859,000	286
	3000	1500	628,000	419
		3000	1,257,000	419
80	1000	1500	311,000	207
		3000	622,000	207
	2000	1500	494,000	330
		3000	989,000	330
	3000	1500	778,000	518
		3000	1,555,000	518
90	1000	1500	279,000	186
		3000	559,000	186
	2000	1500	581,000	387
		3000	1,161,000	387

Table F-6 (continued)

Speed (kts.)	Range (mi.)	Utilization rate (hr./yr.)	Annual cost ($)	Maintenance cost per hour of utilization ($/hr.)
	3000	1500	970,000	646
		3000	1,939,000	646
100	1000	1500	295,000	197
		3000	590,000	197
	2000	1500	697,000	465
		3000	1,394,000	465
	3000	1500	1,279,000	852
		3000	2,557,000	852
110	1000	1500	312,000	208
		3000	625,000	208
	2000	1500	859,000	573
		3000	1,719,000	573
	3000	1500	1,718,000	1,145
		3000	3,436,000	1,145
120	1000	1500	335,000	224
		3000	671,000	224

TABLE F-7

AIRSHIP MAJOR OVERHAUL COSTS
(1976 dollars)

Speed (kts.)	Range (mi.)	Utilization rate (hr/yr)	Annual cost ($)	Major overhaul cost per hour of utilization ($/hr)
50	1000	1500	44,500	30
		3000	24,400	8
	2000	1500	65,300	44
		3000	35,800	12
	3000	1500	85,800	57
		3000	47,000	16
60	1000	1500	49,600	33
		3000	27,200	9
	2000	1500	71,900	48
		3000	39,400	13
	3000	1500	113,900	76
		3000	62,400	21
70	1000	1500	55,800	37
		3000	30,600	10
	2000	1500	90,500	60
		3000	49,600	17
	3000	1500	157,700	105
		3000	86,400	29
80	1000	1500	63,100	42
		3000	34,600	12
	2000	1500	116,400	78
		3000	63,800	21
	3000	1500	228,100	152
		3000	125,000	42
90	1000	1500	52,600	35
		3000	28,800	10
	2000	1500	155,900	104
		3000	85,400	28

Table F-7 (continued)

Speed (kts.)	Range (mi.)	Utilization rate (hr./yr.)	Annual cost ($)	Major overhaul cost per hour of utilization ($/hr.)
	3000	1500	333,600	222
		3000	182,800	61
100	1000	1500	61,300	41
		3000	33,600	11
	2000	1500	216,100	144
		3000	118,400	39
	3000	1500	539,800	360
		3000	295,800	99
110	1000	1500	72,300	48
		3000	39,600	13
	2000	1500	312,800	209
		3000	171,400	57
	3000	1500	903,400	602
		3000	495,000	165
120	1000	1500	86,500	58
		3000	47,400	16

TABLE F-8

AIRSHIP TOTAL MAINTENANCE COST

(1976 dollars)

Speed (kts.)	Range (mi.)	Utilization rate (hr./yr.)	Annual cost ($)	Total maintenance cost per hour of utilization ($/hr.)
50	1000	1500	314,000	209
		3000	562,000	187
	2000	1500	421,000	281
		3000	747,000	249
	3000	1500	422,000	348
		3000	919,000	306
60	1000	1500	332,000	221
		3000	592,000	197
	2000	1500	449,000	300
		3000	794,000	265
	3000	1500	633,000	422
		3000	1,100,000	367
70	1000	1500	352,000	235
		3000	624,000	208
	2000	1500	520,000	347
		3000	908,000	303
	3000	1500	786,000	524
		3000	1,343,000	448
80	1000	1500	374,000	249
		3000	656,000	219
	2000	1500	611,000	407
		3000	1,053,000	351
	3000	1500	1,006,000	671
		3000	1,680,000	560
90	1000	1500	332,000	221
		3000	588,000	196

Table F-8 (continued)

Speed (kts.)	Range (mi.)	Utilization rate (hr./yr.)	Annual cost ($)	Total maintenance cost per hour of utilization ($/hr.)
	2000	1500	736,000	491
		3000	1,247,000	416
	3000	1500	1,303,000	869
		3000	2,122,000	707
100	1000	1500	356,000	238
		3000	624,000	208
	2000	1500	913,000	609
		3000	1,513,000	504
	3000	1500	1,819,000	1,212
		3000	2,853,000	951
110	1000	1500	385,000	256
		3000	664,000	221
	2000	1500	1,172,000	782
		3000	1,890,000	630
	3000	1500	2,621,000	1,748
		3000	3,931,000	1,310
120	1000	1500	422,000	281
		3000	718,000	239

FUEL COSTS

A cost of 40.8 cents per gallon is assumed for JP-5 fuel. This price was supplied by the Navy Fuel Supply Office in November 1975.

Combining the cost per gallon with the fuel consumption rates indicated in table F-1, we obtain the results shown in table F-9.

TOTAL COSTS

The component costs estimated above are combined in table F-10 to determine total hourly costs. Total and component costs are also presented graphically in figures F-2 and F-3 for the 3,000 hr./yr. utilization rate case, for airship ranges of 1,000 and 2,000 miles. The fractional distributions of the hourly costs are shown in figures F-3 and F-4, respectively.

Investment cost is seen to be a relatively small fraction (6 to 17 percent) of the total cost.

The dominant cost fraction is clearly the personnel cost, varying from 1/3 to 1/2 for the largest airships (110 knot speed) to about 60 percent for the smallest (100 knot speed).

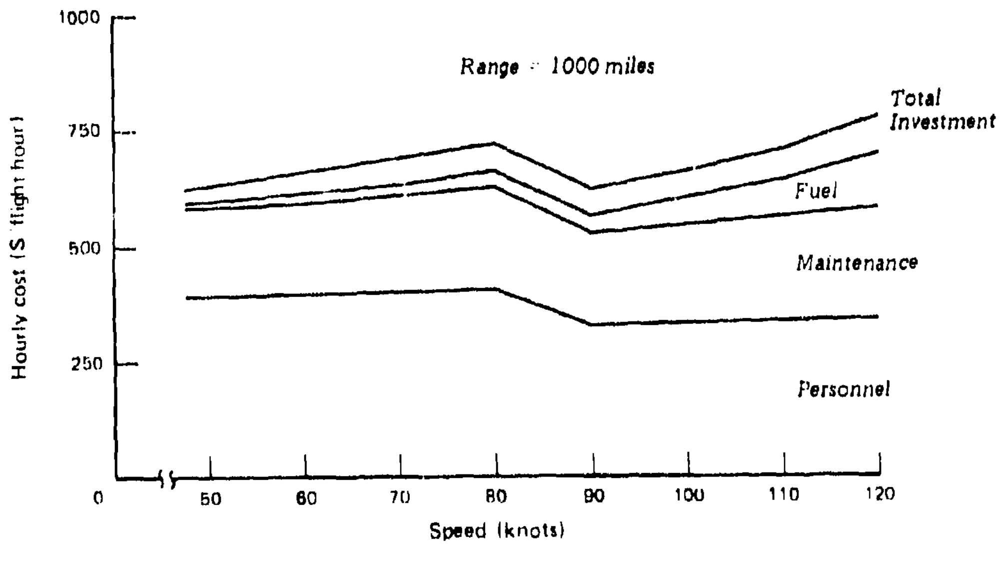

FIG. F-2: TOTAL AND COMPONENT HOURLY COSTS

TABLE F-9

AIRSHIP FUEL CONSUMPTION RATES AND COSTS

(1976 dollars)

Speed (kts)	Range (mi.)	Fuel consumption rate (gal./hr.)	Fuel costs per hour of utilization ($/hr.)
50	1000	23	9
	2000	30	12
	3000	37	15
60	1000	40	16
	2000	52	21
	3000	71	29
70	1000	62	26
	2000	88	36
	3000	129	52
80	1000	93	38
	2000	144	59
	3000	227	93
90	1000	112	46
	2000	231	94
	3000	294	161
100	1000	157	64
	2000	372	152
	3000	714	291
110	1000	215	88
	2000	606	247
	3000	1,300	530
120	1000	293	120

TABLE F-10

AIRSHIP HOURLY COSTS
(1976 dollars)

Speed (kts.)	Range (mi)	Utilization rate (hr/yr)	Personnel ($/hr)	Maintenance ($/hr)	Fuel ($/hr)	Total operating cost ($/hr)	Investment ($/hr)	Total cost per hour of utilization ($/hr)
50	1000	1500	451	209	9	669	41	710
		3000	397	187	9	594	41	634
	2000	1500	550	281	12	843	60	903
		3000	488	249	12	750	60	810
	3000	1500	578	348	15	941	78	1,019
		3000	509	306	15	830	78	909
60	1000	1500	456	221	16	693	45	739
		3000	400	197	16	614	45	659
	2000	1500	489	300	21	810	66	876
		3000	426	265	21	712	66	777
	3000	1500	606	422	29	1,057	104	1,161
		3000	530	367	29	926	104	1,030
70	1000	1500	461	235	25	721	51	772
		3000	404	208	25	637	51	688
	2000	1500	507	347	36	890	83	972
		3000	439	303	36	778	83	861
	3000	1500	641	524	52	1,218	144	1,362
		3000	557	448	52	1,057	144	1,201
80	1000	1500	466	249	38	753	58	811
		3000	408	219	38	665	58	722
	2000	1500	529	407	59	995	106	1,101
		3000	455	351	59	865	106	971
	3000	1500	689	671	93	1,452	208	1,660
		3000	592	560	93	1,245	208	1,454

TABLE F-10 (Continued)

Speed (kts.)	Range (mi.)	Utilization rate (hr./yr.)	Personnel ($/hr.)	Maintenance ($/hr.)	Fuel ($/hr.)	Total operating cost ($/hr.)	Investment ($/hr.)	Total cost per hour of utilization ($/hr.)
90	1000	1500	386	221	46	653	48	701
		3000	331	196	46	573	48	621
	2000	1500	557	491	94	1,143	142	1,285
		3000	477	416	94	986	142	1,129
	3000	1500	679	869	161	1,709	305	2,013
		3000	568	707	161	1,436	305	1,741
100	1000	1500	392	238	64	693	56	749
		3000	335	208	64	607	56	663
	2000	1500	595	609	152	1,355	197	1,553
		3000	505	504	152	1,161	197	1,358
	3000	1500	771	1,212	291	2,274	493	2,768
		3000	637	951	291	1,879	493	2,372
110	1000	1500	398	256	88	742	66	808
		3000	340	221	88	649	66	715
	2000	1500	646	782	247	1,674	286	1,960
		3000	543	630	247	1,420	286	1,706
	3000	1500	896	1,748	530	3,173	825	3,998
		3000	730	1,310	530	2,571	825	3,396
120	1000	1500	406	281	120	807	79	886
		3000	346	239	120	705	79	784

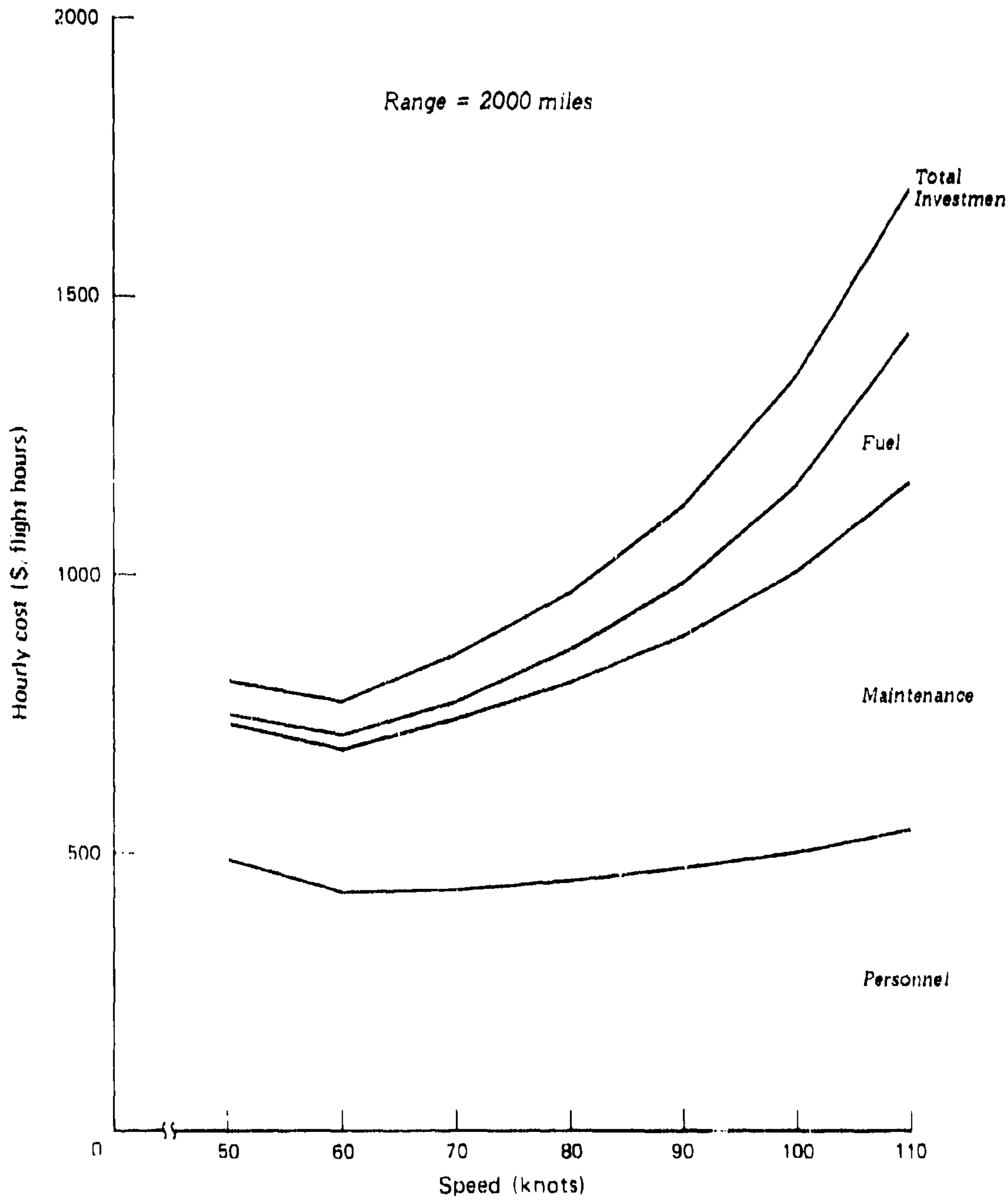

FIG. F-3: TOTAL AND COMPONENT HOURLY COSTS

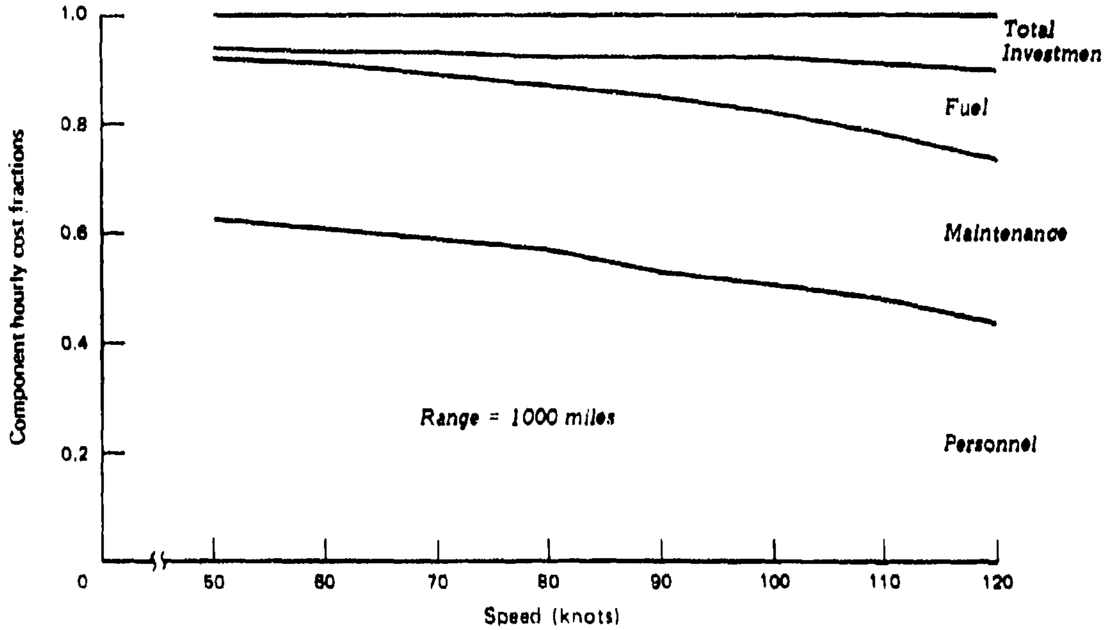

FIG. F-4: DISTRIBUTION OF HOURLY COSTS

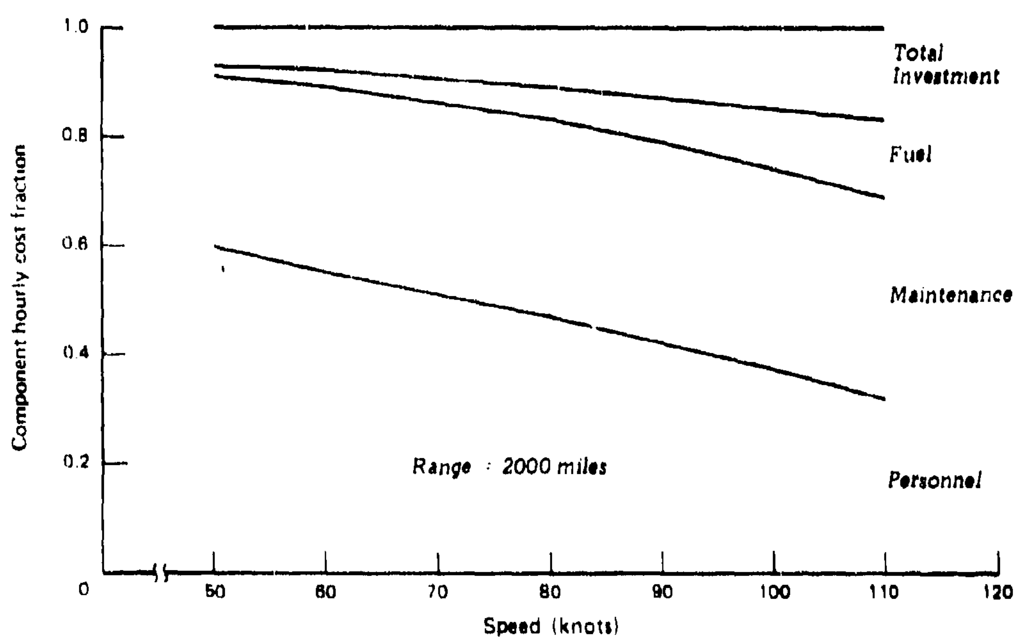

FIG. F-5: DISTRIBUTION OF HOURLY COSTS

The maintenance cost fraction increases from about 0.3 to 0.4 as airship size varies from the smallest to the largest.

Fuel cost is the smallest fraction, increasing from a low value of 2 percent to a high value of 14 percent.

The 3,000 mile range airship has slightly smaller personnel cost fractions (.21 to .56) and correspondingly higher fuel, investment, and maintenance cost fractions.

The effect of utilization rate on the total hourly costs is indicated in table F-11. In all cases the cost is about 15 percent less at the higher utilization rate. The larger reductions indicated earlier for personnel cost alone are offset to some extent when the other cost components (maintenance, fuel, and investment) are included, because these costs are either constant or nearly constant on an hourly basis.

Total and component hourly costs for the extended family of airships are presented in table F-12. Detailed characteristics are given in table F-13.

TABLE F-11

AIRSHIP HOURLY COSTS VS. UTILIZATION RATE

Speed (kts.)	Range (mi.)	Utilization rate 1,500 hr/yr.	Utilization rate 3,000 hr/yr.
50	1000	710	634
	2000	903	810
	3000	1,019	909
60	1000	739	659
	2000	876	777
	3000	1,161	1,030
70	1000	772	688
	2000	972	860
	3000	1,362	1,201
80	1000	811	722
	2000	1,101	971
	3000	1,660	1,454
90	1000	701	621
	2000	1,285	1,129
	3000	2,013	1,741
100	1000	749	663
	2000	1,553	1,358
	3000	2,768	2,372
110	1000	808	715
	2000	1,960	1,706
	3000	3,998	3,396
120	1000	886	784

TABLE F-12

HOURLY COSTS OF EXTENDED AIRSHIP FAMILY

(1976 dollars)

Speed/Range (kts./mi.)	Personnel	Maintenance	Fuel	Total Operating	Investment	Total
			Aircrew = 14			
50/1000	472	205	10	688	47	735
2000	489	250	13	751	60	811
60/1000	476	216	18	709	52	762
2000	500	282	23	805	73	879
70/1000	480	227	28	735	59	793
2000	514	320	38	872	91	963
80/1000	484	239	41	764	66	830
2000	530	370	62	963	116	1079
90/1000	488	252	59	799	75	874
2000	552	436	99	1087	154	1240
100/1000	494	269	83	844	86	930
2000	580	525	158	1263	211	1474
110/1000	500	286	114	899	100	999
2000	618	652	256	1525	301	1827
			Aircrew = 11			
90/1000	413	233	55	700	66	766
100/1000	418	247	77	742	76	818
110/1000	424	265	105	794	89	883

TABLE F-13

CHARACTERISTICS OF EXTENDED SET OF AIRSHIPS

Aircrew = 14

Speed (knots)	Range (miles)	Volume (1,000 cu. ft.)	Average cost ($1,000)	Hull length (feet)	Engine power (h.p.)	Fuel rate (gal./hr.)
50	1,000	371	1,410	263	307	25
50	2,000	517	1,800	294	374	31
50	3,000	719	2,320	328	458	37
60	1,000	402	1,570	270	546	43
60	2,000	632	2,200	314	717	56
60	3,000	979	3,120	363	942	71
70	1,000	436	1,760	278	901	68
70	2,000	778	2,730	337	1,276	93
70	3,000	1,363	4,330	406	1,824	129
80	1,000	472	1,980	285	1,398	101
80	2,000	985	3,490	364	2,188	152
80	3,000	1,966	6,270	458	3,412	228
90	1,000	513	2,240	293	2,080	145
90	2,000	1,283	4,610	398	3,654	243
90	3,000	2,968	9,520	526	6,309	404
100	1,000	564	2,580	302	3,007	203
100	2,000	1,734	6,320	440	6,044	388
110	1,000	625	3,000	313	4,251	279
110	2,000	2,451	9,040	493	10,015	628
120	1,000	706	3,540	326	5,930	381
			Aircrew = 11			
90	1,000	450	1,980	280	1,905	134
100	1,000	495	2,290	289	2,759	187
110	1,000	551	2,670	300	3,907	258

ANNEX F-1

COST FORMULAS

INPUTS

V = Volume (10^6 cu.ft.)

$\$C$ = Investment cost (10^6 \$)

$\dot{W}_F$ = Average fuel rate (gal./hr.)

N_{AO} = Aircrew (officer)

N_{AE} = Aircrew (enlisted)

N_C = Number of flight crews
= 1 for U = 1,500 hr./yr.
= 2 for U = 3,000 hr./yr.

N_{GV} = Reference vehicle ground crew
= 12 for V = 1, U = 1,500

N_{GP} = Reference payload ground crew
= 6 for V = 1, U = 1,500

f_{GV} = Vehicle ground crew factor
= 1 for U = 1,500
= 1.5 for U = 3,000

f_{GP} = Payload ground crew factor
= 1 for U = 1,500
= 1.5 for U = 3,000

U = Utilization rate (hrs./yr.)
= 1,500 hr./yr.
= 3,000 hr./yr.

L_H = Lifetime (hours) = 30,000 hrs./yr.

$\$P_O$ = Annual personnel cost (officer)
= \$59,613

$\$P_E$ = Annual personnel cost (enlisted)
= \$21,598

$\$M_{R1}$ = Reference hourly maintenance cost (for V = 1) = \$3.50/hr.

$\$F_1$ = Hourly fuel cost (per gallon)
= \$.408/gal.

f_{OH} = Overhaul cost fraction
= 0.73 for U = 1,500
= 0.2 for U = 3,000

OUTPUTS

N_G = Ground crew

N_{GO} = Ground crew (officer)

N_{GE} = Ground crew (enlisted)

$\$P_{AO}$ = Hourly aircrew cost (officer)

$\$P_{AE}$ = Hourly aircrew cost (enlisted)

$\$P_{GO}$ = Hourly ground crew cost (officer)

$\$P_{GE}$ = Hourly ground crew cost (enlisted)

\$P = Hourly personnel cost

$\$M_R$ = Hourly routine maintenance cost

$\$M_{OH}$ = Hourly overhaul maintenance cost

\$M = Hourly maintenance cost

\$I = Hourly investment cost

\$F = Hourly fuel cost

\$T = Hourly total cost

PERSONNEL COSTS

$$N_G = N_{GV} f_{GV} V^{0.5} + N_{GP} f_{GP}$$

$$N_{GO} = 0.1\ N_G$$

$$N_{GE} = 0.9\ N_G$$

$$\$P_{AO} = N_C N_{AO} \$P_O / U$$

$$\$P_{AE} = N_C N_{AE} \$P_E / U$$

$$\$P_{GO} = N_{GO} \$P_O / U$$

$$\$P_{GE} = N_{GE} \$P_E / U$$

$$\$P = \$P_{AO} + \$P_{AE} + \$P_{GO} + \$P_{GE}$$

MAINTENANCE COSTS

$$\$M_R = \$M_{RI} V^{0.585}$$

$$\$M_{OH} = f_{OH} \$C / L_H$$

$$\$M = \$M_R + \$M_{OH}$$

INVESTMENT COSTS

$$\$I = \$C / L_H$$

FUEL COSTS

$$\$F = \$F_1\ W_F$$

TOTAL COSTS

$\$T = \$P + \$M + \$I + \$F$

SUMMARY FOR BASIC INPUT SET (U = 3,000 hr./yr.)

$\$P = 152.4\ V^{0.5} + 39.7\ N_{AO} + 14.4\ N_{AE} + 76.2$

$\$M = 350\ V^{0.585} + 6.67\$C$

$\$I = 33.33\$C$

$\$F = .408\ \dot{W}_F$

$$\$T = 152.4\ V^{0.5} + 350\ V^{0.585} + 39.7\ N_{AO} + 14.4\ N_{AE} + 40\$C + .408\ \dot{W}_F + 76.2$$

SENSITIVITY

$$\frac{\partial \$T}{\partial V} = \frac{76.2}{V^{0.5}} + \frac{204.8}{V^{0.415}}$$

$$\frac{\partial \$T}{\partial N_{AO}} = 39.7$$

$$\frac{\partial \$T}{\partial N_{AE}} = 14.4$$

$$\frac{\partial \$T}{\partial \$C} = 40$$

$$\frac{\partial \$T}{\partial \dot{W}_F} = .408$$

REFERENCES

(1) Goodyear Aerospace Corp., Akron, Ohio, "Parametric Study of Dynamic Lift Aerostats for Future Naval Missions," GAC Report GER-13564, 31 Jan 1968

(2) Goodyear Aerospace Corp., paper presented at the AIAA Lighter-Than-Air Technology Conference, Aspen, Colorado, July 15-17, 1975, "LTA Vehicles-Historical Operations, Civil and Military," R.R. Huston, and G.L. Faurote

APPENDIX G

METHODOLOGY USED IN CHAPTER 4 OF VOLUME I

INTRODUCTION

This appendix describes the methodology used in computing the cost-effectiveness of the various resources used in performing the variety of tasks examined independently of one another and of geographic considerations. The discussion is organized by task, in the same order as presented in chapter 4 of volume I of this report.

In applying the mathematical formulas presented in this appendix, care must be taken to use consistent values of speed and cost, since platform operating costs are rather strongly speed dependent. It should also be noted that in all of the following discussion, the term "mile" means "nautical mile"; and that the term "cutter" applies both to conventional cutters and to hydrofoils.

LIST OF SYMBOLS

C = cost (dollars)

- C_c = cutter cost (dollars)
- C_h = helicopter cost (dollars)
- C_a = aircraft cost (dollars)

C_t = cost per hour of operation (dollars/hour)

- C_{ts} = short-term average cost per hour of team operation
- C_{tl} = long-term average cost per hour of team operation
- C_{t_c} = cost per hour of cutter operation (dollar/hour)
- C_{t_h} = cost per hour of helicopter operation (dollar/hour)
- C_{t_a} = cost per hour of aircraft operation (dollar/hour)

D = distance (n.mi.)

- D_s = initial separation distance between cutter and violator (n.mi.)

P = patrol distance rate (miles/hour)

P_c = patrol distance rate of cutter (miles/hr)

P_s = short-term average patrol distance rate of team (miles/hr)

P_l = long-term average patrol distance rate of team (miles/hr)

S = surveillance area (square n.mi.)

S_t = surveillance rate (square n. mi./hr.)

S_{ts} = short-term average surveillance rate of team (square n.mi./hr.)

S_{tl} = long-term average surveillance rate of team (square n.mi./hr.)

T = operating time (hours)

T_c = cutter operating time (hours)

T_h = helicopter operating time (hours)

T_a = aircraft operating time (hours)

T_{a_t} = round-trip transit time for 1 aircraft sortie

$T_{a_{os}}$ = on-station time for 1 aircraft sortie

V = platform speed (n. mi./hr.)

V_c = cutter speed (n.mi./hr)

V_h = helicopter speed (n.mi./hr)

V_v = speed of violator ship (n.mi./hr)

W = sweepwidth (n.mi.)

W_c = cutter sweepwidth (n.mi.)

W_h = helicopter sweepwidth (n.mi.)

TRANSIT

The cost/effectiveness of any platform in accomplishing a transit is measured in terms of cost per mile, and is obtained as follows:

$$\text{Cost per mile} = C_t/V$$

GROSS SURVEILLANCE POTENTIAL

Gross surveillance potential is defined as the area of ocean a given platform or cutter/helo team can observe on radar in a fixed amount of time. Cost effectiveness of the various platforms or teams in performing this function is measured in terms of cost per square mile of ocean observed.

Cutters Working Alone

For surface platforms working alone, cost/effectiveness is computed as follows:

$$S_t = VW$$

$$\text{Cost/sq.mi.} = C_t/S_t = C_t/VW \quad .$$

Cutter/Helicopter Teams

During 3-hour Helicopter Flight (Short Term)

During the time that the helicopter is flying, both the helicopter and the cutter are performing surveillance. However, overlapping coverage which occurs while the helicopter is within the sweepwidth of the cutter must be excluded. Thus, for a 3-hour flight, the computational method is:

$$S = 3\ V_c W_c + (3 - \frac{W_c}{V_h})\ V_h W_h$$

$$S_{ts} = \frac{S}{3} = V_c W_c + (1 - \frac{W_c}{3V_h})\ V_h W_h$$

$$C_{ts} = C_{t_c} + C_{t_h}$$

$$\text{Cost/sq.mi.} = C_{ts}/S_{ts} \quad .$$

Long-Term Average

Over an extended period of time, the average performance of the cutter/helicopter team is considerably worse than that computed above, because the average number of flight hours per day that the helicopter can fly is limited. When the helicopter is not flying, the performance of the cutter/helo team reverts to that of the cutter operating alone. Therefore, weighted average values of S_t and C_t must be obtained, the weighting factors being the fractions of time that the helicopter is flying and that the cutter is working without its benefit. These averaging computations are performed on an annual basis. In the analysis performed for this study, which yielded the results presented in volume I, it is assumed that each cutter operates a total of 3,000 hours per year, during which time a full year's flight capability of a single helicopter is flown off its deck, i.e., 650 flight-hours per year for the HH-X and 700 for the HH-3. These values are equivalent to 5.2 and 5.6 helicopter flight-hours per day of cutter operations, respectively.

The computations to obtain cost/effectiveness are performed as follows:

$$S_{t1} = \frac{S_{ts}T_h + V_c W_c (T_c - T_h)}{T_c}$$

$$C_{t1} = C_{t_c} + \frac{C_{t_h} T_h}{T_c}$$

$$\text{Cost/sq.mi.} = C_{t1}/S_{t1} = \frac{C_{t_c} T_c + C_{t_h} T_h}{S_{ts} T_h + V_c W_c (T_c - T_h)} \quad .$$

The equations above are shown in the general form. In order to reproduce the results presented in chapter 4 of volume I, T_c must be set equal to 3,000 hours for all cutters, and T_h equal to 650 hours for the HH-X and 700 hours for the HH-3. The proper sweep-widths, speeds, and speed related costs must also be used.

PRESENCE

The computation of the relative cost/effectiveness of various platforms in providing presence is performed in an identical manner to that used for the "boarding" task; i.e., C_t at low speed is a measure of the relative cost/effectiveness.

VISUAL INSPECTION OF DISPERSED SHIPS (No delays)

The objective of this task is to approach and visually inspect as many fishing vessels as possible, assuming that the Coast Guard resource is already located in the midst of a widely dispersed fishing fleet. As explained in chapter 4 of volume I, cost/effectiveness is measured in terms of cost per mile traveled. The computational procedure is explained in detail in the paragraphs below.

<u>Cutters Working Alone</u>

$$\text{Cost per mile} = C_t/V$$

Cutter/Helicopter Teams

During Helicopter Flight (Short Term)

In the performance of this task, the helicopter is assumed to be effective immediately after launch (i.e., overlapping radar coverage is not subtracted), because both platforms can begin patrolling in different directions. Therefore, the results are independent of flight time, providing that the flight time is considerably larger than the average time of flight between fishing vessels.

The equations used to compute cost/effectiveness are:

$$C_{ts} = C_{t_c} + C_{t_h}$$

$$P_s = V_c + V_h$$

$$\text{Cost per mile} = \frac{C_{ts}}{P_s} + \frac{C_{t_c} + C_{t_h}}{V_c + V_h} \quad .$$

Long-Term Average

The long term average cost/effectiveness is computed on an annual basis. It is obtained by dividing the total annual cost of the team by the total annual patrol distance capability of the team. Thus,

$$\text{Cost per mile} = \frac{C_{t_c} T_c + C_{t_h} T_h}{V_c T_c + V_h T_h} \quad .$$

The average distance patrolled by the team per hour of cutter operation is computed as follows:

$$P_1 = \frac{V_c T_c + V_h T_h}{T_c} \quad .$$

In computing the results presented in chapter 4 of volume I, values of 3000 hours and 650 hours were assumed for T_c and T_h, respectively. This is equivalent to 5.2 flight-hours per cutter-day.

VISUAL INSPECTION OF DISPERSED SHIPS (With delays)

See appendix J for the methodology used in the analysis of this task.

APPENDIX H

SAR METHODOLOGY

SAR DATA BASE

Description

The crew of every U.S. Coast Guard resource that services a search and rescue case is required to fill out an Assistance Report in accordance with the SAR manual (reference 2). The information contained in these reports can be categorized by the following types:

- Identification data
- Case data
- Sortie data

A sample SAR Assistance Report is shown in figure H-1.

A copy of the information contained in these reports is kept on magnetic tape. For the purpose of this study, data were obtained for fiscal years 1970-1973. The results shown are based on the data for July 1972 and January 1973.

Coding

Using the Fortran computer routines shown at the end of this appendix, the items needed from the SAR data base were extracted and recorded for input to the resource assignment routine. The case parameters generated by this process are shown in table H-1.

Each SAR case is coded as to its severity in terms of potential danger. Severity codes are recorded for severity to personnel and severity to property.

Possible severity levels are coded as shown:

(1) none/unknown
(2) slight
(3) moderate
(4) very severe, property only
(5) very severe, personnel

The subroutine that handles the recoding of the severity actually combines these two items into one - the maximum of the two severities. For example, if a case is coded moderately severe to property, but very severe to personnel, the combined severity

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DEPARTMENT OF TRANSPORTATION U. S. COAST GUARD CG-3272 (Rev. 3-69)	ASSISTANCE REPORT

REPORTING UNIT: SORTIE OF MORE THAN 99.9 HOURS

UNIT CASE NO.: 0006

NAME OF DISTRESSED UNIT: ALOHA

OWNER (Name, address, zip code):
I. A. Nouno
8788 Ikie Way
Whaeme, Hawaii

NATURE OF DISTRESS	OVERDUE	ADRIFT
SEVERITY	PERSONNEL	SEVERE
	PROPERTY	SEVERE

A. IDENTIFICATION DATA

01	02	14 11 3716	OPFAC
02	00	0 0 1 7	Multi-Unit Case Number
03	13	0 0 0 6	Unit Case Number
04	17	0 9 9	Month and Year Notified
05	20	0 2	Total Number of Sorties on Case

B. CASE DATA

01	22	14 0 7 1 0	Date/Time Notified
02	28	9 9*	Time From Occurrence to Notification
03	30	0 1	Means of Initial CG Notification
04	32	0 1	Nature of Distress
05	34	8	Distance Offshore
06	35	1 9 3 8 N	Latitude
07	39	1 4 9 2 3 W	Longitude
08	44	2	Method of Locating Distress
09	45	3	Severity - Personnel
10	46	3	Severity - Property
11	47	5	Cause of Distress
12	48	2	Sea State
13	49	2	Wind
14	50	6	Visibility
15	51	1	Type
16	52	2	Owner
17	53	0 7	Usage
18	55	0 6	Propulsion
19	57	4	Length
20	58	1	Gross Tonnage
21	59	0 8 8 8 8 7 3 2 6	Off/ Reg No
22	68	0 0	Number of Lives Lost
23	70	0 1	Number of Lives Saved
24	72	0 0 0	No. of Persons Otherwise Assisted
25	75	0 0 0 0 8 0 0 0 0 0	Property Value

(Items 15–20: DESCRIPTION OF DISTRESSED UNIT OR UNIT ASSOCIATED WITH PERSONNEL IN DISTRESS)

C. SORTIE DATA

01	20	2 1	Type of Assisting Resource
02	22	0 0 0 7 8 7	Assisting Resource No.
03	28	1 4 0 8 0 0	Date/Time Underway
04	34	0	Number of Resources Remaining on Stand-by
05	35	1 4 1 7 3 0	Date/Time on Scene
06	41	8	Distance to Scene or Search Area
07	42	9 9 9*	Total Time on Sortie
08	45	0 1	Assistance Rendered to Personnel
09	47	0 1	Assistance Rendered to Property
10	49	0	Performance Index - Use Comments

C. SORTIE DATA

01	20	2 1	Type of Assisting Resource
02	21	0 0 0 7 8 7	Assisting Resource No.
03	28	8 0 1 5 4	Date/Time Underway
04	34	0	Number of Resources Remaining on Stand-by
05	35	8 0 1 5 4	Date/Time on Scene
06	41	0	Distance to Scene or Search Area
07	42	8 5 7*	Total Time on Sortie
08	45	0 3	Assistance Rendered to Personnel
09	47	0 4	Assistance Rendered to Property
10	49	0	Performance Index - Use Comments

* THIS DIGIT REPRESENTS TENTHS OF HOURS

EXPLAIN "OTHER" CODES; ADD ANY CLARIFYING INFORMATION; STATE ANY UNUSUAL OCCURRENCES.

After searching for 146 hours CGC YEATON located Mr. Nouno drifting in his 50 ft. Sampan.

(Two C SECTIONS are completed to break up the 185.6 hours required by the YEATON on this case.)

COMMAND LEVEL	INITIALS	SIGNATURE	DATE
UNIT			
GROUP			
DISTRICT			

PREVIOUS EDITIONS ARE OBSOLETE

AM.3

FIG. H-1: SAR ASSISTANCE REPORT

code for the case would be very severe. Any case in the data base containing incomplete documentation was replaced by the case from another year that most closely coincided in date and time with the "bad data" case.

TABLE H-1

CASE PARAMETERS

Date and time of Coast Guard notification.
Latitude, longitude, position of the case.
Environmental conditions - sea state, wind, visibility.
Distance offshore.
Size of vehicle in distress.
Number of people on board distressed vehicle.
Severity of the case in terms of possible danger to both property and personnel.
Type of Coast Guard resource that responded to the case.
Total time spent on the sortie.
Day and time Coast Guard resources arrived on scene.

Other Inputs

LTA Capabilities

The only other inputs required by the model over those contained in chapter 4 of volume I in the detailed LTA capabilities are shown in table H-2.

FORTRAN PROGRAM

Output from the FORTRAN program, figure H-2 consists of a list of coded SAR sortie information: district, time of occurrence, distance offshore, latitude and longitude of occurrence, size of distressed vehicle, number of people on board, sea state, wind, visibility, needs, severity, resource type servicing the sortie, total sortie time for that resource, and time of arrival on scene. The sortie list is then sorted in chronological order.

SIMULATION MODEL (APL)

The APL simulation model, figure H-2, consists of a list of a main program called PROCESS and three subroutines, CONV, DIST, and HOUR. CONV is a function which simply converts latitude and longitude from degrees, minutes, and seconds to degrees and fractions of degrees. DIST calculates the great circle distance between two points on the globe. HOUR converts time from days, hours, and minutes to hours and fractions of hours. PROCESS uses these three subroutines in analyzing the SAR caseload and produces output giving the total number of cases, resource utilization, and severity.

TABLE H-2

LTA CAPABILITIES

Attribute		Assumption
Provide equipment		Yes
Deliver pump/equipment		Yes
Make repairs		No
Fight fires		No
Vector another unit		No
Dewater		No
Refloat		No
Icebreak		No
Refueled/resupplied		Yes
Surface escort		Yes
Standby		Yes
Locate property-advise owner		Yes
Free from peril		Yes
General - surface		Yes
Tow, 0-20'		No
Evacuate POBs 0-5		Yes
Air escort		Yes
General assistance		Yes
Rescue and tow		No
Tow - 26-65'		No
Tow - 65-100'		No
Tow - 100-200'		No
Tow - 200' +		No
Evacuate POBs	5-9	Yes
	10-17	Yes
	18-24	No
	25 +	No
Ocean swell	0-5'	Yes
	5-10'	Yes
	10-20'	Yes
	20' +	Yes
Wind under 60		Yes
Wind over 60		No
Visibility 0		Yes
Visibility above 0		Yes
Temperature below 20°		Yes
Temperature above 20°		Yes
Distance offshore	0-3 miles	Yes
	3.1-10 miles	Yes
	10.1-25 miles	Yes
	25.1-50 miles	Yes
	> 50 miles	Yes

```
SEQUENCE      1 STARTED  PRINTING 05/16/75 AT 100455 ON LP00
W=  00  PRINT,773,CUICK,S
W=  00  FTN,L,X,R,*
      PROGRAM TEST
      DIMENSION A(360)
      PRINT 102
  102 FORMAT (1X,* IBLK   NC DIST CASE  MON   YR  DAY HOUR  MIN OFFS  LA
     XT LONG SIZE  POB  SEA WIND  VIS NEED NEED  SEV TRES STIM ODAY  OHR
     X OMIN*,//)
      IBLK=0
      NCASE=0
   15 CONTINUE
      IBLK=IBLK+1
      BUFFER IN (1,0) (A(1),A(360))
   10 IF(UNIT,1) 10,11,12,13
   11 DO 20 I=1,18
      IF (IBYTE(A,(I-1)*160+46).NE.1R2)GO TO 20
C********CHANGE THIS CARD FOR EACH DISTRICR   CARD 2****************************
      IF (IBYTE(A,(I-1)*160+2).EQ.1R2) STOP
C********CHANGE THIS CARD FOR EACH DISTRICT  CARD 3*****************************
      IF (IBYTE(A,(I-1)*160+2).NE.1R1.OR.IBYTE(A,(I-1)*160+1).NE.1R0)
     XGO TO 20
      IF (IBYTE(A,(I-1)*160+131).EQ.1P8) GO TO 20
      IF (IBYTE(A,(I-1)*160+45).NE.1R1)GO TO 20
      NCASE=NCASE+1
      IFLAG=1H
      DECODE (150,100,A((I-1)* 20+1)) IDIST,ICASE, MON,IYR,IDAY,IHR,MIN,
     XIOFFS,LAT,LONG,ISEVPER,ISEVPRY,ISEA,IWIND,IVIS,ITYPE,ISIZE,LLOST,
     XLSAVED,LOTHER,IRES,IOSDAY,IOSHR,IOSMIN,STIME,IASSTPER,IASSTPRY
  100 FORMAT (I2,I4,37X,I2,I1,2X,3I2,7X,I1,I4,I5,1X,2I1,1X,4I1,5X,I1,10X
     X,2I2,I3,28X,I2,13X,3I2,1X,F3.1,2I2,1X)
      IF(IASSTPER .EQ. 90 .OR. IASSTPRY .EQ. 90)IFLAG=1H*
      CALL BTSIZE(ISIZE)
      CALL POB(LLOST,LSAVED,LOTHER,NPOB)
      CALL WEATHER(ISEA,IWIND,IVIS)
      CALL OFFSHORE(IOFFS)
      CALL NEED(IASSTPER,1)
      CALL NEED(IASSTPRY,2)
      CALL SEVERITY(ISEVPEP,ISEVPRY,ISEV)
      PRINT 101,IBLK,NCASE,IDIST,ICASE,MON,IYR,IDAY,IHP,MIN,IOFFS,
     XLAT,LONG,ISIZE,
     XNPOB,ISEA,IWIND,IVIS,IASSTPER,IASSTPRY,ISEV,IRES,STIME,IOSDAY,
     XIOSHR,IOSMIN,IFLAG
  101 FORMAT(1X,21I5,F5.1,3I5 ,R1,/)
   20 CONTINUE
      GO TO 15
   13 PRINT 103
  103 FORMAT (1X,*PARITY ERROR*)
   12 CONTINUE
      END
      SUBROUTINE WEATHER(ISEA,IWIND,IVIS)
      GO TO (10,10,11,11,12,13,14)ISEA
   10 ISEA=28  $  GO TO 16
   11 ISEA=29  $  GO TO 16
   12 ISEA=30  $  GO TO 16
   13 ISEA=31  $  GO TO 16
   14 ISEA=0
   16 IF(IWIND  .LE.  6)17,18
   17 IWIND=32
```

FIGURE H-2

```
      GO TO 19
   18 IF(IWIND  .LE.  9)20,21
   20 IWIND=33
      GO TO 19
   21 IWIND=0
   19 IF (IVIS  .EQ.  0)22,23
   22 IVIS=34   $  RETURN
   23 IF(IVIS  .LT.  9)24,25
   24 IVIS=35   $  RETURN
   25 IVIS=0
      END
      SUBROUTINE HTSIZE(I)
      IF(I  .EQ.  0)RETURN
      GO TO (10,10,11,11,13,14,15,15,16)I
   10 I=15  $  RETURN
   11 I=20  $  RETURN
   13 I=21  $  RETURN
   14 I=22  $  RETURN
   15 I=23  $  RETURN
   16 I=0
      END
      SUBROUTINE POB(LL,LS,LO,NPOB)
      ISUM=LL+LS+LO
      IF(ISUM  .GE.  0.AND.ISUM  .LE.  4) GO TO 10
      IF(ISUM  .LE.  9) GO TO 11
      IF(ISUM  .LE.  17) GO TO 12
      IF(ISUM  .LE.  24) GO TO 13
      NPOB=27
      RETURN
   10 NPOB=16   $  RETURN
   11 NPOB=24   $  RETURN
   12 NPOB=25   $  RETURN
   13 NPOB=26   $  RETURN
      END
      SUBROUTINE OFFSHORE (I)
      IF(I .EQ. 0 .OR. I .EQ. 9)5,6
    5 I=0  $  RETURN
    6 GO TO (7,8,9,10,11)I
    7 I=38  $  RETURN
    8 I=39  $  RETURN
    9 I=40  $  RETURN
   10 I=41  $  RETURN
   11 I=42
      END
      SUBROUTINE SEVERITY (I1,I2,ISEV)
      GO TO (10,11,12,10)I1
   10 I1=1  $  GO TO 20
   11 I1=3  $  GO TO 20
   12 I1=5  $  GO TO 20
   20 GO TO (21,22,23,21)I2
   21 I2=1  $  GO TO 30
   22 I2=2  $  GO TO 30
   23 I2=4
   30 ISEV=MAX0(I1,I2)
      RETURN
      END
      SUBROUTINE NEED(M,IOPT)
      IF(M .EQ. 0 .OR. M .EQ. 50 .OR. M .EQ. 90 .OR. M  .EQ. 98 .OR. M
     X.EQ. 99)GO TO 50
```

FIG. H-2 (Continued)

```
      IF(IOPT .EQ. 2) GO TO 51
      GO TO (15,16,16,1,5,18,16,18)M
   51 GO TO (14,14,14,15,5,15,5,9,18,100,4,6,7,2,3,11,15)M
   50 IF (M.EQ.90) RETURN
      M=0  $RETURN
    1 M=1 $ RETURN
    2 M=2 $ RETURN
    3 M=3 $ RETURN
    4 M=4 $ RETURN
    5 M=5 $ RETURN
    6 M=6 $ RETURN
    7 M=7 $ RETURN
    8 M=8 $ RETURN
    9 M=9 $ RETURN
  100 M=0 $ RETURN
   11 M=11 $ RETURN
   12 M=12 $ RETURN
   13 M=13 $ RETURN
   14 M=14 $ RETURN
C*************MAY NEED TO CHANGE STATEMENT 15 TO REFLECT AIRCRAFT
   15 M=15 $ RETURN
   16 M=16 $ RETURN
   17 M=17 $ RETURN
   18 M=18
      END
      SUBROUTINE RESTYPE (IRES)
      IF (IRES.LE.20) GO TO 100
      IF (IRES.GT.20.AND.IRES.LE.30) GO TO 50
      IF (IRES.GT.30.AND.IRES.LE.40) GO TO 51
      GO TO (1,2,100,4,5,100,100,7,100) IRES-40
    1 IRES=1   $RETURN
    2 IRES=2   $RETURN
    3 IRES=3   $RETURN
    4 IRES=4   $RETURN
    5 IRES=5   $RETURN
    6 IRES=6   $RETURN
    7 IRES=7   $RETURN
    8 IRES=8   $RETURN
    9 IRES=9   $RETURN
   10 IRES=10   $RETURN
   11 IRES=11   $RETURN
   12 IRES=12 $RETURN
   13 IRES=13 $RETURN
   14 IRES=14 $RETURN
   15 IRES=15   $RETURN
   16 IRES=16   $RETURN
   17 IRES=17   $RETURN
   18 IRES=18   $RETURN
   50 GO TO (12,100,11,9,100) IRES-20
   51 GO TO (13,14,15,16,100) IRES-30
  100 RETURN
      END
         SCOPE
W=  00  LOAD
W=  00  RUN,,,7,,7
```

FIG. H-2 (Continued)

PROCESS requires that the user provide the following inputs:

(1) PHMTAB - A matrix of size (n x 4), where n denotes the number of LTAs, and the 4 columns are defined as, LTA ID number, latitude, longitude, and day/night availability flag. The latitude and longitude must express the LTAs position in degrees and fractions of degrees. The flag must be either 0, indicating day availability, or 1, indicating night availability. If a particular LTA is to be available both day and night, it must appear in the matrix twice, once with a 0 flag and again with a flag of 1. Refer to the sample case for an example of PHMTAB.

(2) NIGHT - A vector of length 2 containing the beginning and ending night hours.

(3) CAP - The capability vector as previously described. It consists of 0's and 1's.

(4) AVAILFAC - A vector of length n (where n denotes the number of LTAs appearing in PHMTAB) giving the availability rates for each LTA.

(5) TOL - A 5 element vector giving the tolerance time allowed for each severity level.

(6) RANK - A vector of numerical resource codes giving the "picking order" of resources from "lesser" to "greater" relative to code 99 (LTA). Numerical codes must correspond to the codes listed in the SAR manual.

(7) PHMSOA 1 - SOA of the LTA in sea heights less than 10 ft.

(8) PHMSOA 2 - SOA of LTA in sea heights of 10-20 feet.

(9) DELAY - Delay in getting underway for LTA (in hours).

(10) SEARCH - Time (in hours) spent by LTA searching for distressed vehicle.

(11) ASSIST - Time (in hours) spent by LTA in assisting distressed vehicle.

The SAR sortie data that is analyzed by PROCESS must be stored in a matrix of dimensions (nx19) where n denotes the number of sorties in the case load and the 19 columns are defined as shown in table H-3.

PROCESS produces statistics in the form: (1) total sortie time for the caseload, (2) total number of cases, (3) a statistics table giving resource utilization by name of resource, resource code, number of sorties performed and time spent on sorties, (4) a replacement matrix showing what resources each LTA replaced, and (5) severity codes for the LTA sorties.

```
      ∇PROCESS[⎕]∇
    ∇ OPT PROCESS CLOAD;N;SIMTIME;ARTIME;LAT;LONG;PHM;RESOURCE;RDIST;SOA;RTIME;
STIME;I;IND;TOTCASE;TOTTIME
      →BEGIN×⍳(OPT=2)
      FREE←(ρPHMTAB)[1]ρ0
      SEV←5ρ0
      STATTAB←⍉(3 31ρ0 11,(19+⍳27),(29+⍳35),(39+⍳52),90 99,(62ρ0))
      REPLACE←⍉((((ρPHMTAB)[1]+1),31)ρSTATTAB[;1],(((ρPHMTAB)[1]×31)ρ0))
     BEGIN:N←0
     START:SIMTIME←HOUR(CLOAD[N←N+1;⍳3])
      ARTIME←HOUR(CLOAD[N;17 18 19])
      →NITE×⍳(CLOAD[N;2]>NIGHT[1])∨(CLOAD[N;2]<NIGHT[2])
      FLAG←0
      →CAT
     NITE:FLAG←1
     CAT:LAT←CONV CLOAD[N;5]
       LONG←CONV CLOAD[N;6]
      →REAL×⍳(∧/(FREE>SIMTIME))=1
      PHM←∧/CAP[(CLOAD[N;4,(6+⍳13)]>0)/CLOAD[N;4,(6+⍳13)]]
      →L7×⍳PHM=1
     REAL:RESOURCE←CLOAD[N;15 16 14]
      →STAT
     L7:OKAY←(AVAILFAC≥?((ρPHMTAB)[1]ρ100))/[1]PHMTAB
      OKAY←(FREE[OKAY[;1]]≤SIMTIME)/[1]OKAY
      OKAY←(OKAY[;4]=FLAG)/[1]OKAY
      →REAL×⍳(ρOKAY)[1]=0
      RDIST←(LAT,LONG)DIST OKAY[;2 3]
      OKAY←OKAY[(⍋RDIST)[1];]
      RDIST←RDIST[(⍋RDIST)[1]]
      →L3×⍳CLOAD[N;9]>29
      SOA←PHMSOA1
      →L4
     L3:SOA←PHMSOA2
     L4:RTIME←(RDIST÷SOA)+DELAY
      →((RTIME≤TOL[CLOAD[N;14]])+2×(ARTIME-SIMTIME)≤TOL[CLOAD[N;14]])⌽NONE,HYD,
REAL,BOTH
     NONE:→REAL×⍳(ARTIME-SIMTIME)<RTIME
     HYD:→FALSE×⍳(ARTIME=0)
      →L5×⍳(CLOAD[N;12]=15)∨(CLOAD[N;13]=15)
      →L5×⍳(20≤CLOAD[N;12]≤23)∨(20≤CLOAD[N;13]≤23)
      STIME←RTIME+SEARCH+ASSIST+RTIME+REFUEL
      →L6
     L5:STIME←RTIME+SEARCH+ASSIST+(RDIST÷7)+REFUEL
     L6:→REAL×⍳(STIME-(REFUEL+DELAY))>12
      RESOURCE←99,(STIME-(REFUEL+DELAY)),CLOAD[N;14],OKAY[1]
      →L8
     FALSE:RESOURCE←99,CLOAD[N;16 14],OKAY[1]
      STIME←CLOAD[N;16]
      →L8
     L8:FREE[OKAY[1]]←SIMTIME+STIME
      I←REPLACE[;1]⍳CLOAD[N;15]
      REPLACE[I;OKAY[1]+1]←REPLACE[I;OKAY[1]+1]+1
      SEV[RESOURCE[3]]←SEV[RESOURCE[3]]+1
      →STAT
     BOTH:→HYD×⍳(RANK⍳99)<(RANK⍳CLOAD[N;15])
      →REAL
     FALSE:RESOURCE←99,CLOAD[N;16 14],OKAY[1]
     STAT:IND←STATTAB[;1]⍳RESOURCE[1]
      STATTAB[IND;2]←STATTAB[IND;2]+1
      STATTAB[IND;3]←STATTAB[IND;3]+RESOURCE[2]
      →START×⍳N<(ρCLOAD)[1]
```

FIGURE H-3

```
[58]   TOTCASE←+/STATTAB[;2]
[59]   TOTTIME←+/STATTAB[;3]
[60]   'TOTTIME      ';TOTTIME
[61]   'TOTAL NUMBER OF CASES    ';TOTCASE
[62]   'STAT TABLE    '
[63]   L←(STATTAB[;2]≠0)/[1]LABEL
[64]   S←(STATTAB[;2]≠0)/[1]STATTAB
[65]   (L,S[;1 2]⍕10 3 0 0),((((⍴S[;3]),1)⍴S[;3])⍕10 3 3 0
[66]   X←+/(REPLACE[;(1+⍳(⍴REPLACE)[2])])
[67]   XX←(X≠0)/[1]REPLACE
[68]   'REPLACEMENT MATRIX  ';((X≠0)/[1]LABEL),(XX,((((⍴XX)[1],1)⍴(+/XX[;1+⍳(⍴XX)
[2]])))⍕5 3 0 0
[69]   ' TOTREP ';+/[1]REPLACE[;(1+⍳(⍴REPLACE)[2])]
[70]   'SEVERITY';SEV
     ∇
```

FIG. H-3 (Continued)

TABLE H-3

SAR DATA FORMAT

Column number	Information
1 - 3	Day, hour, and minute of occurrence
4	Distance offshore code
5 - 6	Latitude & longitude of distressed vehicle (degrees and minutes)
7	Size of distressed vehicle code
8	Number of people on board code
9	Sea state code
10	Wind code
11	Visibility codes
12 - 13	Need codes
14	Severity code
15	Resource code
16	Total sortie time (hours)
17 - 19	Day, hour, minute of resource arrival on scene

Because of the limited storage space in an APL workspace, it was necessary to store the SAR data outside the active workspace. Thus, the program PROCESS has an option allowing it to process separately any portion of data desired. By using the call 1 PROCESS DATA, the statistics counters are cleared, signifying the beginning of a new data set. The call 2 PROCESS DATA indicates to the program that this is a continuation set of data and should be merged with the previous set when calculating statistics.

```
        PHMTAB
   1       60       172 0
   2       60       172 1
   3 57.783     152.4 0
   4 57.783     152.4 1
   5 57.783     152.4 0
   6 57.783     152.4 1
   7     58.3 134.417 0
   8     58.3 134.417 1
   9     51.5       131 0

        NIGHT
20 6
        CAP
1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 0 1 1 1 0 1 1 1 1 1 1 1 1 1
        1 1

        AVAILFAC
100 100 50 50 50 50 50 50 100

        TOL
4 3 2 1 0.5

        RANK
0 11 24 40 41 42 43 44 45 46 47 48 49 50 51 52 99 20 21 22 23 25 26 27 30 31 32
        33 34 35

        PHMSOA1
50
        PHMSOA2
45
        DELAY
0.25
        SEARCH
0.25
        ASSIST
1
```

SAMPLEA

1	20	45	38	5550	13004	15	16	28	32	35	16	14	1	52	1	1	22	45
2	9	57	38	5455	13100	15	16	28	32	35	0	15	2	41	10.2	2	13	20
2	13	22	38	5455	13059	20	16	28	32	35	0	15	2	41	10.2	2	13	35
2	13	23	38	5455	13100	20	16	28	32	35	0	15	2	41	10.2	2	13	23
3	3	2	38	5824	13446	20	16	28	32	35	16	14	1	44	2.5	3	5	0
3	9	20	38	5610	13158	20	16	28	32	35	0	0	2	25	8.9	3	12	55
3	9	20	38	5610	13158	20	16	28	32	35	0	11	2	52	0.3	3	13	0
3	9	20	38	5610	13158	20	16	28	32	35	0	0	2	52	0.2	3	18	22
3	9	25	38	5610	13158	20	24	28	32	35	0	14	2	32	0.9	3	10	0
3	9	25	38	5610	13158	20	24	28	32	35	0	2	2	33	1.5	3	10	15
3	10	36	38	5708	13528	15	16	28	32	35	10	14	5	25	7.8	4	13	0
3	14	45	38	5707	13419	22	16	28	32	35	0	11	3	24	9.2	3	18	40
3	19	55	38	5650	15340	15	16	28	32	35	0	0	1	33	0.8	0	0	0
3	20	0	38	6442	16200	15	24	28	32	35	0	15	1	25	0.5	3	20	0
3	21	53	38	5652	15341	15	16	28	32	35	0	15	1	25	12.5	4	8	5
3	21	53	38	5652	15341	15	16	28	32	35	0	15	1	25	12.5	4	8	5
3	23	45	0	5928	15129	15	16	28	32	35	16	14	3	90	0.5	4	10	10
4	3	45	38	5712	15253	22	24	28	32	35	0	11	1	25	6.8	5	19	36
4	11	10	38	5657	15341	20	16	28	32	35	0	15	1	25	32.5	4	11	15
4	14	0	0	5502	13135	0	16	28	32	35	18	0	1	33	0.6	4	20	10
4	17	12	38	5606	13200	0	16	28	33	35	18	0	3	33	2.1	4	18	45
5	14	45	38	5822	13441	15	16	28	32	35	0	15	1	44	1.5	4	15	25
6	0	21	0	5250	17310	0	16	0	32	35	18	0	1	33	0.6	6	11	16
6	21	0	39	5506	13043	20	16	28	32	35	0	14	1	33	1	6	21	28
7	22	20	0	5519	13140	0	16	28	32	35	0	0	1	25	0.9	7	22	45
7	22	20	0	5519	13140	0	16	28	32	35	0	0	1	25	0.9	7	22	45
8	0	37	38	5525	13129	20	16	28	32	35	16	14	4	41	1.8	8	1	18
8	0	37	38	5525	13129	20	16	28	32	35	0	11	4	41	4.3	8	6	25
8	9	56	38	5515	13128	15	24	28	32	35	0	15	1	41	4	8	10	40
8	16	49	39	5519	13118	20	16	28	32	35	0	15	2	41	2.3	8	17	22
8	17	45	38	5819	13427	15	16	28	32	35	16	14	1	52	1	8	18	16
8	17	45	38	5819	13427	15	16	28	32	35	0	0	1	52	0.5	8	21	0

SAMPLEB

8	23	0	38	5822	13450	15	16	28	32	35	0	15,	1	44	1.5	8	23	10
9	5	0	0	5517	13131	20	16	28	32	34	0	7	1	41	5.6	9	5	30
9	9	25	38	5510	13121	0	16	28	32	35	18	0	5	33	0.7	9	9	40
9	16	50	38	5650	13248	20	16	28	32	35	0	15	1	52	1.3	9	17	15
9	17	35	0	5517	13137	15	16	28	32	35	0	11	1	41	0.7	9	18	10
9	17	35	0	5517	13137	15	16	28	32	35	0	15	1	41	2.5	9	22	10
10	5	30	38	5822	13450	15	16	28	32	35	0	0	1	44	1.8	0	0	0
10	5	30	38	5822	13450	15	16	28	32	35	0	0	1	31	1.2	0	0	0
10	9	35	0	5503	13134	0	16	0	32	35	18	0	1	33	0.6	7	20	41
10	14	59	38	5600	15643	21	16	28	32	35	18	0	5	34	4.6	10	18	0
10	19	10	39	6017	15140	20	16	28	32	35	0	0	1	31	1.6	0	0	0
11	8	50	0	5512	13249	0	16	0	32	35	0	0	5	33	1.5	0	0	0
11	8	50	0	5512	13249	0	16	0	32	35	18	11	5	33	1.8	11	9	55
12	5	30	38	5822	13440	15	16	28	32	35	0	15	1	44	1	12	7	30
12	23	44	38	5957	14723	20	16	28	32	35	0	15	1	25	16.7	13	7	35
13	0	8	0	5854	13509	15	16	28	32	35	18	15	4	24	20.8	13	9	58
13	0	43	40	5857	[illegible]	15	16	28	32	35	5	5	1	32	3.5	13	7	30
13	1	20	42	5636	[illegible]	23	16	28	32	34	0	0	1	33	1.5	0	0	0
13	4	0	40	6021	15206	20	24	29	32	35	16	14	5	31	6.7	13	5	45
13	8	30	0	5520	13100	15	16	28	32	35	16	14	1	41	7.7	13	11	30
13	10	15	38	5535	13058	15	16	28	32	35	0	0	1	33	1	13	0	0
13	10	15	38	5535	13058	15	16	28	32	35	16	14	1	33	3.5	13	12	35
13	10	15	38	5535	13058	15	16	28	32	35	0	14	1	33	2	13	16	40
13	15	15	42	5350	15512	23	16	28	32	34	18	10	1	34	4.4	13	18	45
13	18	5	0	5502	13134	0	16	28	32	35	18	0	1	33	0.7	13	18	20
14	15	15	38	5829	13455	15	16	28	32	35	0	0	2	44	1.6	14	16	15
15	20	30	0	5529	13117	0	16	28	32	35	18	0	5	33	1.2	15	14	17
16	10	5	38	6037	14810	20	16	28	32	35	0	0	5	34	0.5	0	0	0
16	10	5	38	6037	14810	20	16	28	32	35	16	14	5	51	1.3	16	11	4
16	12	41	40	5940	14028	20	16	28	32	35	0	5	1	32	1	16	12	41
16	13	25	0	5745	15231	0	16	0	32	35	0	0	1	31	1.2	0	0	0
16	16	50	38	5735	13452	20	16	28	32	35	0	15	1	24	10.2	16	21	3
17	22	0	38	5818	13441	15	16	28	32	35	0	15	3	44	8.2	17	23	0

```
     1 PROCESS SAMPLEA
TOTTIME        173.7974176
TOTAL NUMBER OF CASES       32
STAT TABLE
WPB                  24          1      9.20
WLB,WLM              25          8     78.50
HU-16E               32          1      0.89
HH-52A               33          4      5.19
40-41FT              41          6     38.7_
44FT                 44          2      4.__
SHIPS BT             52          4      2.79
LTA                  99          6     36.49
REPLACEMENT MATRIX
WLB,WLM        25    0    0    0    0    0    1    0    0    0    1
HH-52A         33    0    0    0    0    1    0    0    0    1    2
40-41FT        41    0    0    0    0    0    0    0    1    0    1
SHIPS BT       52    0    0    0    0    0    0    1    0    0    1
AUXILIARY      90    0    0    0    1    0    0    0    0    0    1
 TOTREP  0 0 0 1 1 1 1 1 1
SEVERITY 3 1 1 1 0

     2 PROCESS SAMPLEB
TOTTIME        303.1975326
TOTAL NUMBER OF CASES      65
STAT TABLE
WPB                  24          3     40.20
WLB,WLM              25          9     93.20
HC-130               31          2      7.89
HU-16E               32          3      5.4_
HH-52A               33         13     17.7_
HH-3F                34          3      9.50
40-41FT              41         10     55.2_
44FT                 44          7     18.1_
SKIFFS               51          1      1.29
SHIPS BT             52          5      4.09
LTA                  99          9     50.59
REPLACEMENT MATRIX
WLB,WLM        25    0    0    0    0    0    1    0    0    0    1
HC-130         31    0    0    1    0    1    0    0    0    0    2
HH-52A         33    0    0    0    0    1    0    0    0    2    3
40-41FT        41    0    0    0    0    0    0    0    1    0    1
SHIPS BT       52    0    0    0    0    0    0    1    0    0    1
AUXILIARY      90    0    0    0    1    0    0    0    0    0    1
 TOTREP  0 0 1 1 2 1 1 1 2
SEVERITY 6 1 1 1 0
```

APPENDIX I

WIND EFFECTS AND STATISTICAL DATA

INTRODUCTION

Wind speed has little influence on the ground speed, and thus on the effectiveness of Coast Guard cutters, airplanes, and helicopters. Its influence is small on the effectiveness of potential Coast Guard hydrofoils. However, the wind speed influence on the effectiveness of airships traveling at 50 to 120 knots could be significant.

This appendix presents an analysis of wind speed influence on the effectiveness of mission tasks relevant for Coast Guard missions. Equations for wind factors as functions of wind speed are obtained for each of 6 tasks. It is shown that the average wind factor can be expressed in terms of a wind constant that depends on the probability distribution of wind speeds and the vehicle speed.

The wind constant is calculated for several Coast Guard districts and altitudes. The calculations are based on wind speed distributions obtained from the U.S. Naval Weather Service and the Air Weather Service.

The wind factors resulting from using the calculated wind constants are shown to result in marked reductions of average effectiveness of airships that have an airspeed of 50 knots. However, for airships that have an airspeed of 100 knots or more, the reduction is never greater than 10 percent.

The largest reductions of effectiveness occur at the higher altitudes. The largest altitude considered is about 10,000 feet. At lower altitudes of about 2,000 feet the effectiveness reduction is much less at any airspeed. At 100 knots the reduction is never greater than 6 percent.

The surface wind distributions for 42 U.S. coastal marine areas, using U.S. Naval Weather Service data, are presented graphically as cumulative frequency of occurrence in annex I-1. Summer, winter, and annual averages are included.

Wind distributions at discrete altitudes up to about 10,000 feet are presented in annex I-2 for 5 coastal regions. The cumulative frequencies of occurrence for spring, summer, fall, and winter are shown. Annual averages are not included. In general, the wind speeds are greater at higher altitudes.

INFLUENCE OF WIND SPEED ON MISSION EFFECTIVENESS

The Hydrofoil II study considered Coast Guard cutters, potential hydrofoils, airplanes, and helicopters as vehicles. For these four types of vehicles the influence of wind speed in the operating area is important only as regards reduction of habitability due to environment sea state associated with the wind speed. Specifically, the wind speed has little influence on the actual ground speed or fuel-use rate of these vehicles with fixed propulsion power.

The situation with airships is markedly different. Desirable speeds for airships are 50 to 110 knots. Atmospheric wind speeds at altitudes up to 10,000 feet attain speeds of 60 knots with significant probabilities. It is therefore necessary to consider the influence of wind speed explicitly in the comparison of vehicles, including airships.

For a given airship with design speed V_D and design fuel weight W_{FD}, a reasonable model for the influence of wind speed w on operations can be obtained by assuming that the operating conditions require back and forth motion, half upwind and half downwind, with a sufficiently short cycle that winds change little during one cycle. For partial or full cross-wind conditions, the influence would be decreased. Further, depending on the mission, some selection of altitude to obtain decreased wind-speed conditions would be possible. Thus, a potentially "worst case" condition will be considered.

<u>Task Effectiveness</u>

Seven tasks are considered in the LTA study to synthesize the missions. The 7 tasks and associated cost or cost-effectiveness rates are:

1. Transit to station - cost per mile
2. General surveillance - cost per square mile
3. Local surveillance - cost per square mile
4. Pursuit - cost to intercept
5. Visual inspection - cost per mile
6. Boundary patrol - cost per mile
7. Presence - cost per hour

The cost-effectiveness ratios are obtained later by dividing the total operating cost per hour by the measure of effectiveness. Therefore, the effectiveness measures must be on an hourly basis also; that is, the amount produced in one hour. If the effect is not constant over time, as when wind speed affects the result, then the average amount of effect produced in 1 hour over 1 wind-variation cycle must be considered.

For the transit mission, the measure of effectiveness E_1 is the miles traversed in 1 hour. For a transit over a distance D out and back at air speed V_1, assuming a headwind w going out, the times required are:

$$t_{OUT} = D/(V_1 - w) \quad ;$$
$$t_{BAK} = D/(V_1 + w) \quad . \qquad (I-1)$$

The average effectiveness per hour is then:

$$E_1 = \frac{2D}{t_{OUT} + t_{BAK}} = \frac{2D}{\frac{D}{V_1 - w} + \frac{D}{V_1 + w}} \tag{I-2}$$

$$E_1 = \phi_1 V_1$$

$$\phi_1 = 1 - w^2/V_1^2 \quad .$$

In still air the wind factor ϕ_1 for the transit mission is unity. Effectiveness is reduced for any nonzero wind.

For the general surveillance task at airspeed V_2 the measure of effectiveness E_2 is the area swept by a sensor having a detection range d . For surveillance sweep out at distance D , and back, the times are identical in form to those given in equation (I-1). The average effectiveness per hour is then:

$$E_2 = \frac{(2d)\ (2D)}{t_{OUT} + t_{BAK}} = \frac{4dD}{\frac{D}{V_2 - w} + \frac{}{V_2 + w}} \tag{I-3}$$

$$E_2 = \phi\ 2dV_2$$

$$\phi_2 = 1 - w^2/V_2^2 \quad .$$

The wind factor ϕ_2 for general surveillance is identical in form to the factor ϕ_1 for transit, that is, 1 minus w^2/ (a given speed)^2.

For pursuit at airspeed V_3 of a target vehicle moving at speed v_T directly away from the line of approach of the Coast Guard vehicle the measure of effectiveness E_3 is the number of intercepts per hour, that is, the reciprocal of the time required to intercept. The intercept time depends on the direction as well as the magnitude of the wind speed, and on the distance D to the target's position when the mission starts.

When the chase is upwind, the time is:

$$t_{UP} = \frac{D}{(V_3 - v_T) - w} \quad . \tag{I-4}$$

If the chase is directly downwind, the time becomes:

$$t_{DN} = \frac{D}{(V_3 - v_T) + w} \quad . \qquad (I\text{-}5)$$

For various degrees of crosswind of magnitude w the time will be between those two values. Taking the average of the two as an approximation for a typical value for the intercept time gives:

$$E_3 = \frac{1}{t_{UP} + t_{DN}} = \frac{1}{\frac{D}{(V_3 - v_T) - w} + \frac{D}{(V_3 - v_T + w}}$$

$$E_3 = \phi_3(V_3 - v_T)/D \qquad (I\text{-}6)$$

$$\phi_3 = 1 - w^2/(V_3 - v_T)^2 \quad .$$

The wind factor ϕ_3 is of the same form as ϕ_1 and ϕ_2 .

The measure of effectiveness E_4 per hour for the search task with a specified region and search pattern is the number of localizations per hour. The geometry, shape, and lengths of the localization search pattern depend to some extent on the sensor detection-range. Some of the legs of the pattern are crosswind to some extent. If the approximation of half the total distance L upwind and half downwind is assumed, then this case is analogous to case 2, general surveillance:

$$t_{OUT} = \frac{L/2}{V_4 - w} , \quad t_{BAK} = \frac{L/2}{V_4 + w}$$

$$E_4 = \frac{1}{t_{OUT} + t_{BAK}} = \frac{1}{\frac{L/2}{V_4 - w} + \frac{L/2}{V_4 + w}} \qquad (I\text{-}7)$$

$$E_4 = \phi_4/V_4L$$

$$\phi_4 = 1 - w^2/V_4^2 \quad .$$

The wind factor is identical to the factors for the first 3 tasks.

The boundary patrol task is defined as patrolling the boundary length P of a patrol area whose dimensions depend on the sensor detection range, the specific mission, and the coastal and base geography. If crosswind portions of the boundary are not explicitly considered, this task reduces to the transit task, case 1, so:

$$E_5 = \phi_5/V_5 \qquad \text{(I-8)}$$
$$\phi_5 = 1 - w^2/V_5^2 \quad .$$

The visual inspection task involves going from "target" to "target" for a close-up visual inspection. If an insignificant delay for inspection is assumed, cross-wind influences are neglected, and the targets are spaced closer than sensor detection range so that neither general surveillance nor localization is required, then this case reduces to a transit task, and:

$$E_6 = \phi_6/V_6 \qquad \text{(I-9)}$$
$$\phi_6 = 1 - w^2/V_6^2 \quad .$$

The wind factor is of the same form for all 6 of the tasks considered here. Thus, it can be estimated once, independent of the task, and applied as needed for any of the tasks.

Calculation Of The Wind Factor

The wind factors ϕ_J for the effectiveness E_J (per hour) for the different tasks are all of the form:

$$\phi = 1 - w^2/V_D^2 \quad . \qquad \text{(I-10)}$$

The U.S Naval Weather Service and the Air Weather Service publish data on wind speeds for several geographic locations, and at different altitudes. The number of data points in a 10-knot wind speed interval, relative to the total number of data points, can be used as the approximate probability P(w) per knot of occurrence of a wind speed w in that regime.

An average wind factor ϕ_{AV} for probable wind speeds can be obtained by using P(w) :

$$\phi_{AV} = \int_0^\infty P(w)\ (1 - w^2/V^2)dw \quad . \qquad \text{(I-11)}$$

The integral of P(w) is unity, so:

$$\phi_{AV} = 1 - \frac{1}{V^2} \int_0^\infty P(w) w^2 dw \quad . \qquad (I-12)$$

It is convenient to define the remaining integral as the wind constant C :

$$\phi_{AV} = 1 - C/V^2$$

$$C = \int_0^\infty P(w) w^2 dw \quad . \qquad (I-13)$$

For wind speeds up to 60 knots the wind data are in intervals of 10 knots. Designating these intervals by J , the upper limit wind speed w_{UPJ} is equal to 10J and the lower limit w_{LOJ} is equal to 10(J-1). Approximating the probability P_J as the relative frequency F_J of data points up to 60 knots in the interval J leads to:

$$C = \int_0^{60} \frac{F_J}{10} w^2 dw \simeq \sum_J^6 \frac{F_J}{10} \int_{w_{LOJ}}^{w_{UPJ}} w^2 dw$$

$$C \simeq \sum^6 F_J \frac{1}{30} (w_{UPJ}^3 - w_{LOJ}^3) \qquad (I-14)$$

$$C \simeq \frac{100}{3} \sum_J^6 F_J (3J^2 - 3J + 1) \quad .$$

Thus, values of C for different geographic localities and altitudes can be calculated from the wind data.

WIND FACTOR RESULTS

The U.S. Naval Weather Service data for surface winds are presented in annex H-1 as cumulative frequency distributions for summer months, winter months, and for the annual average. Air Service Weather data for winds aloft are presented in annex H-2 in the same forms for summer, fall, winter, and spring.

The winds aloft data were used to calculate wind constants C and average wind factors ϕ_{AV} for 2 cases. In case I, only wind speeds up to 60 knots were considered based on the assumption that an airship would not be likely to attempt to operate in any wind speed greater than 60 knots. Table I-1 presents these results by geographical area and altitude.

Case II results were based on wind speeds up to 150 knots. Values for C in this case are shown in table I-2.

In both tables, the altitudes are given in millibars (MB) or meters (M). The altitudes in feet are as follows:

950 MB:	1,773 feet
850 MB:	4,782 feet
700 MB:	9,877 feet
500 M:	1,640 feet
1,500 M:	4,921 feet
3,000 M:	9,843 feet

The range of values computed for the cases range from 70.738 to 1410.914 in Case I to a range of 70.738 to 1600.536 in Case II.

In general, it can be noted that there is little difference in the results obtained in the 2 cases at low altitudes (around 2,000 feet). Differences do become significant at higher altitudes, however.

Figure I-1 shows the variation of the average wind factor ϕ_{AV} as a function of airship airspeed for the wind constants of Case I for Wallops Island. Curves for 3 altitudes and for summer and winter months are included. The reduction of effectiveness is 56 percent for 50-knot airships at 9,877-foot altitude in winter months. At 100-knot airspeeds, the reduction of effectiveness is 8 percent or less for altitudes up to 4,782 feet.

TABLE I-1

WIND CONSTANTS BASED ON WIND SPEEDS TO 60 KNOTS

AREA	ALTITUDE	WINTER	SPRING	SUMMER	FALL
WALLOPS IS	950MB	650.255	521.946	270.471	411.272
WALLOPS IS	850MB	780.905	577.907	238.093	432.976
WALLOPS IS	700MB	1410.914	1009.116	397.004	723.632
CHARLESTON	950MB	460.454	393.586	241.715	335.700
CHARLESTON	850MB	622.926	459.950	229.393	339.456
CHARLESTON	700MB	1122.337	776.923	258.392	478.607
SAN NIC IS	500M	339.437	464.261	208.900	277.174
SAN NIC IS	1500M	258.579	280.000	162.432	204.800
SAN NIC IS	3000M	526.480	534.773	243.386	337.248
VANDENBERG	950MB	256.749	289.002	167.624	185.551
VANDENBERG	850MB	362.697	295.460	154.961	229.598
VANDENBERG	700MB	674.227	546.763	219.420	382.923
MEDFORD	950 MB	77.202	94.490	106.962	70.738
MEDFORD	850 MB	276.403	166.877	88.694	181.133
MEDFORD	700 MB	949.572	587.979	296.139	610.475
KODIAK	950 MB	385.883	305.943	206.695	313.737
KODIAK	850 MB	567.751	447.040	328.766	485.243
KODIAK	700 MB	713.494	571.389	467.816	593.915
COLD BAY	1500 M	625.951	480.579	419.396	561.551
COLD BAY	3000 M	828.139	582.0[illegible]0	562.329	674.417
ADAK	950 MB	592.095	535.697	389.455	596.390
ADAK	850 MB	750.806	704.909	598.474	786.479
ADAK	700 MB	811.871	827.681	708.015	947.755

TABLE I-2

WIND CONSTANTS BASED ON WIND SPEEDS TO 150 KNOTS

AREA ALTITUDE	WINTER	SPRING	SUMMER	FALL
WALLOPS IS 950MB	652.868	521.946	270.471	411.272
WALLOPS IS 850MB	813.440	594.210	258.093	437.899
WALLOPS IS 700MB	1600.536	1056.980	397.004	764.163
CHARLESTON 950MB	461.453	394.655	241.715	335.700
CHARLESTON 850MB	642.323	472.220	231.431	344.475
CHARLESTON 700MB	1287.952	875.105	258.392	505.426
SAN NIC IS 500M	381.284	482.344	212.092	284.931
SAN NIC IS 1500M	265.094	280.000	162.432	204.800
SAN NIC IS 3000M	550.858	572.597	243.386	342.865
VANDENBERG 950MB	256.749	289.002	167.624	185.551
VANDENBERG 850MB	362.697	295.460	154.961	230.928
VANDENBERG 700MB	694.508	560.938	219.420	388.015
MEDFORD 950 MB	77.202	94.490	106.962	70.738
MEDFORD 850 MB	277.590	166.877	88.694	181.133
MEDFORD 700 MB	1047.525	603.353	296.136	635.801
KODIAK 950 MB	397.717	323.478	206.695	316.605
KODIAK 850 MB	599.167	461.423	334.547	495.804
KODIAK 700 MB	822.972	640.331	485.531	651.403
COLD BAY 1500 M	649.205	483.084	419.396	568.988
COLD BAY 3000 M	911.197	618.433	595.048	702.765
ADAK 950 MB	602.994	554.669	399.225	619.237
ADAK 850 MB	778.015	809.874	676.947	905.875
ADAK 700 MB	1090.185	1081.313	853.317	1250.253

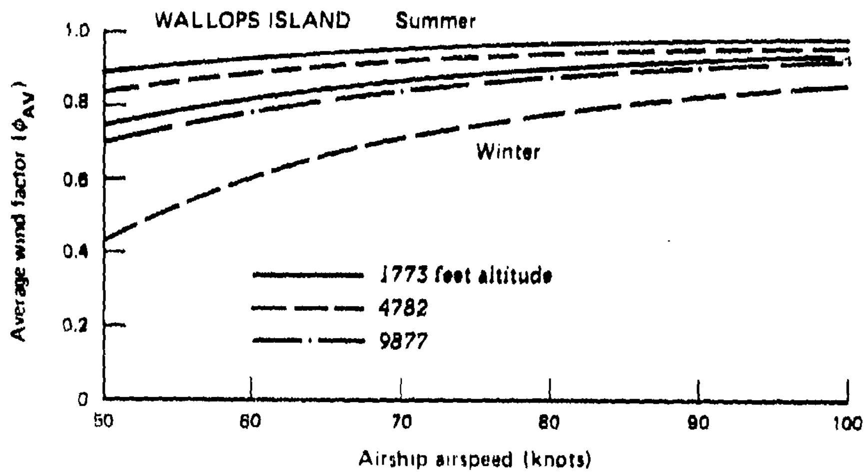


FIG. I-1: VARIATION OF AVERAGE WIND FACTOR

ANNEX I-1

SURFACE WIND DISTRIBUTIONS FOR U.S. COASTAL MARINE DISTRICTS

This annex presents surface wind distributions for 42 United States coastal marine areas. Figures I-1-1 to I-1-4 show the locations of these areas.

The data for these distributions were obtained from volumes of the Summary of Synoptic Meteorological Observations published by the U.S. Naval Weather Service for 1970.

A simple computer model was developed to accumulate the monthly data and plot it as cumulative frequency of occurrence versus wind speed (in knots). The curves on each plot are marked "S" for summer months (June, July, August), "W" for winter months (December, January, February), and "A" for annual totals.

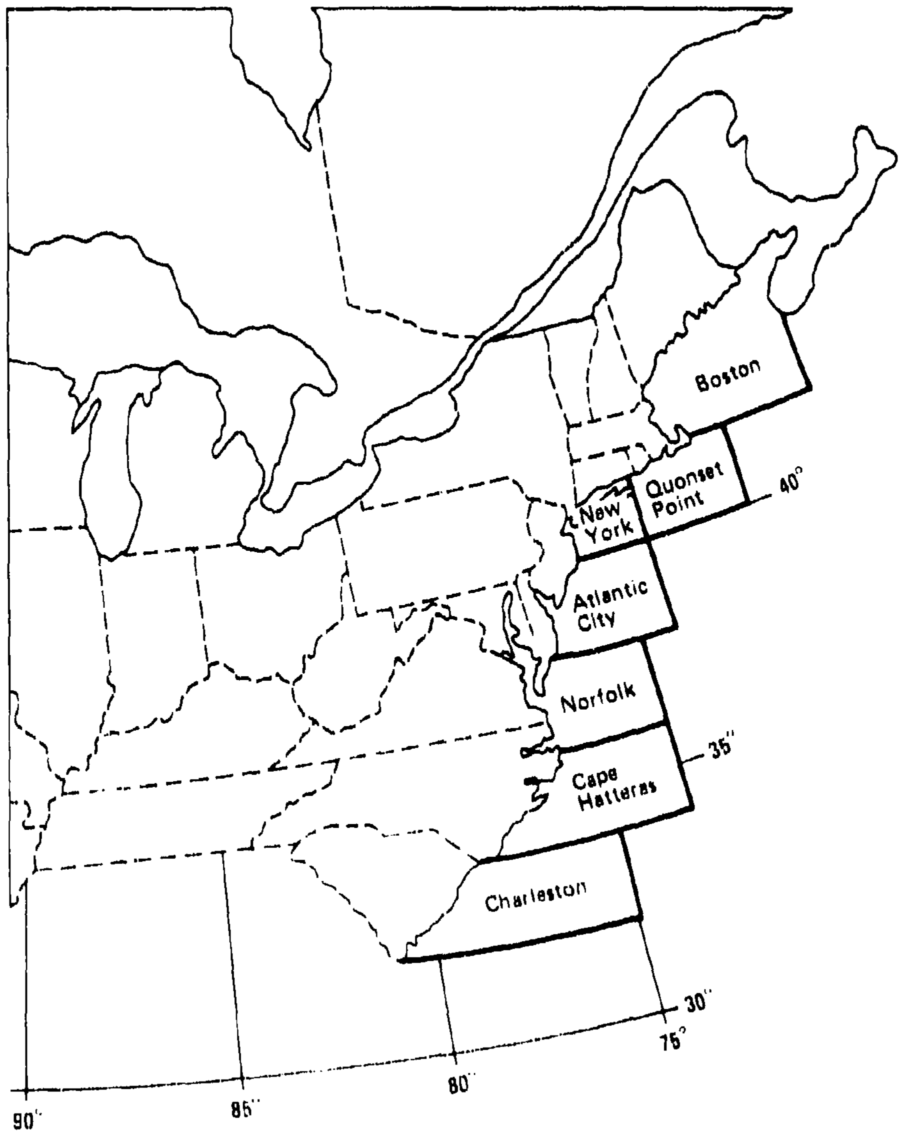


FIG. I-1-1: 1st, 3rd, AND 5th DISTRICT COASTAL MARINE AREAS

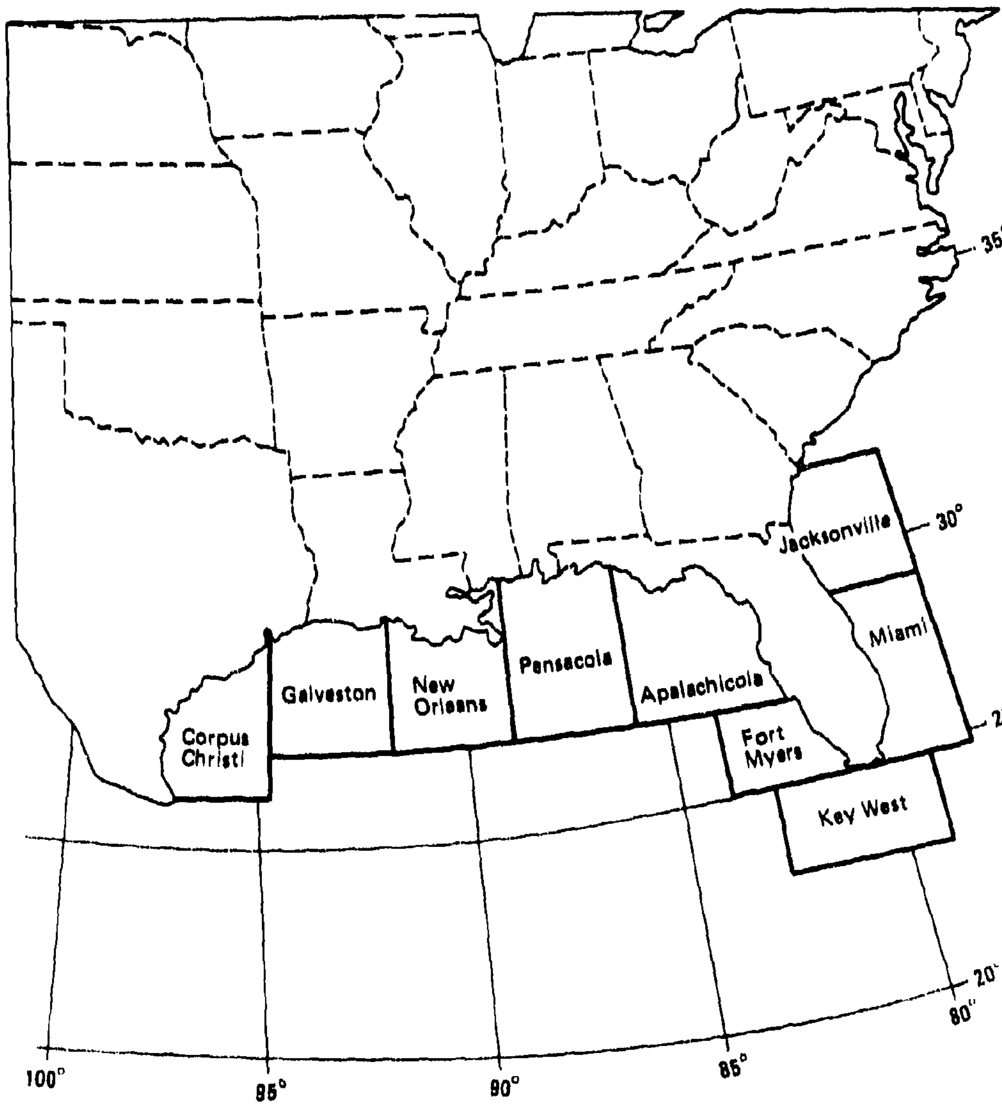


FIG. I-1-2: 7th, AND 8th DISTRICT COASTAL MARINE AREAS

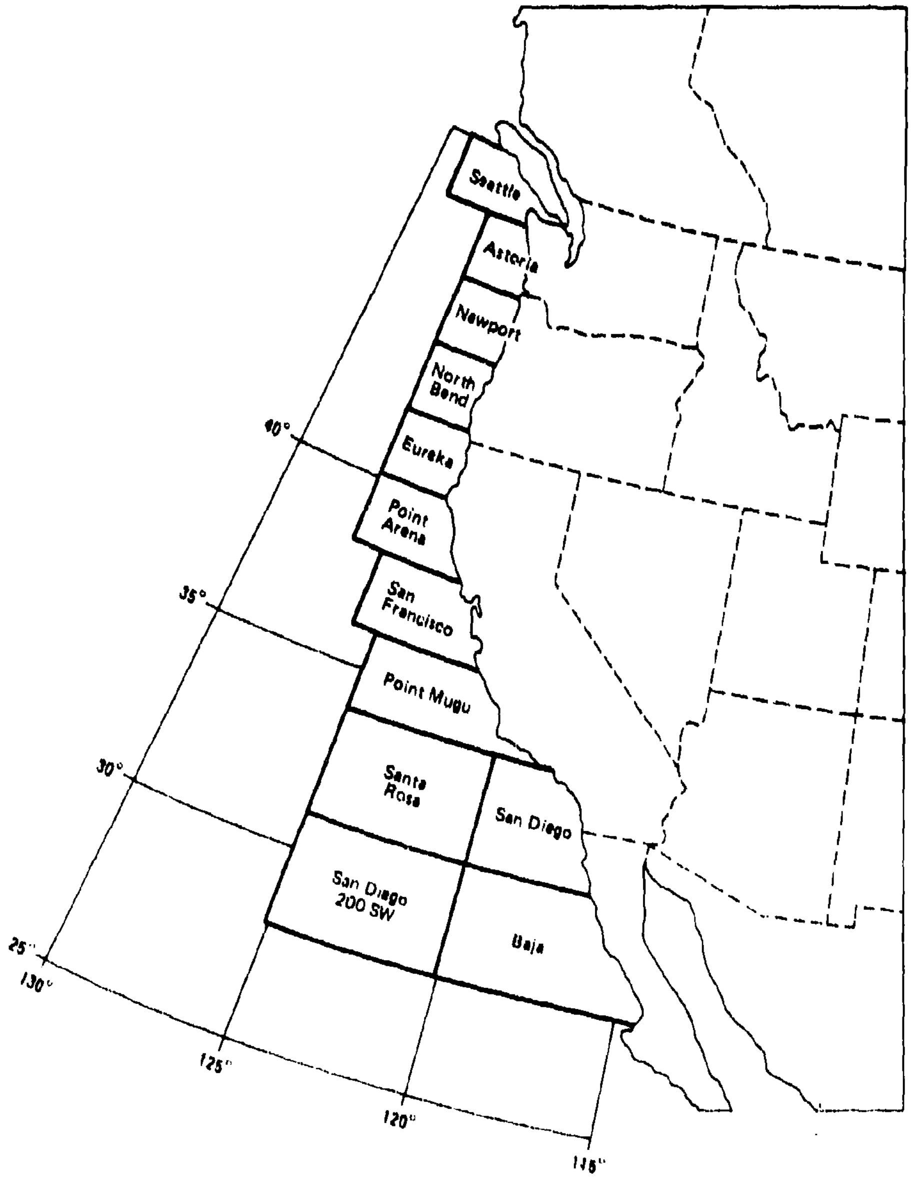


FIG. I-1-3: 11th, 12th, AND 13th DISTRICT COASTAL MARINE AREAS

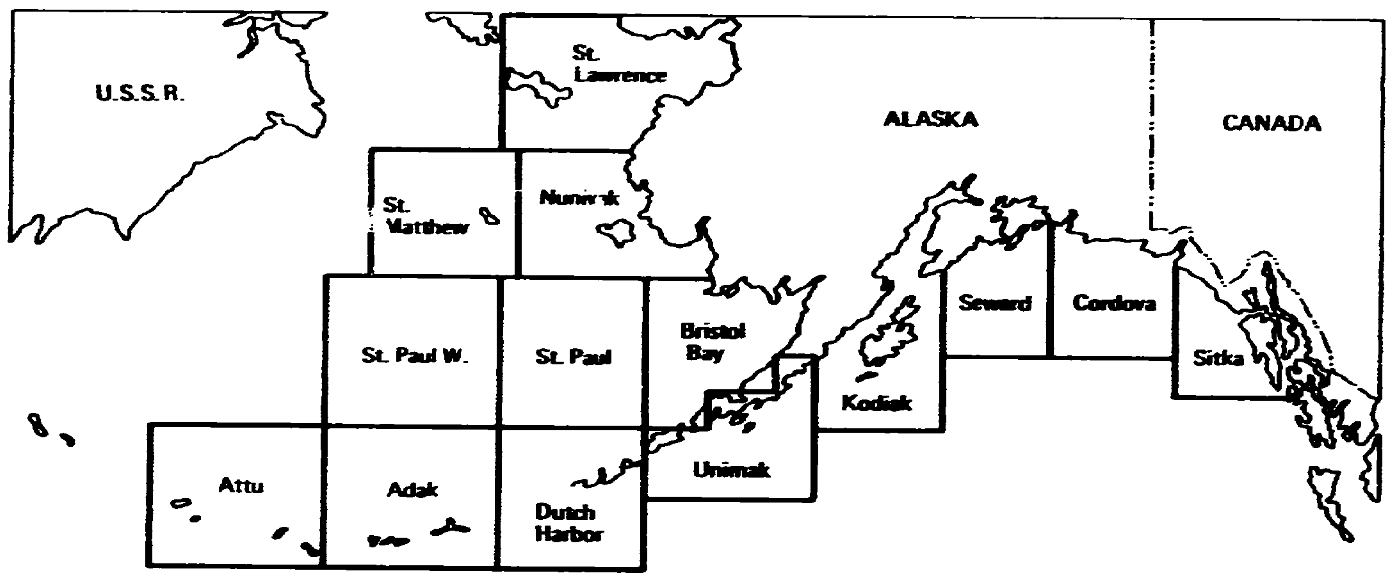
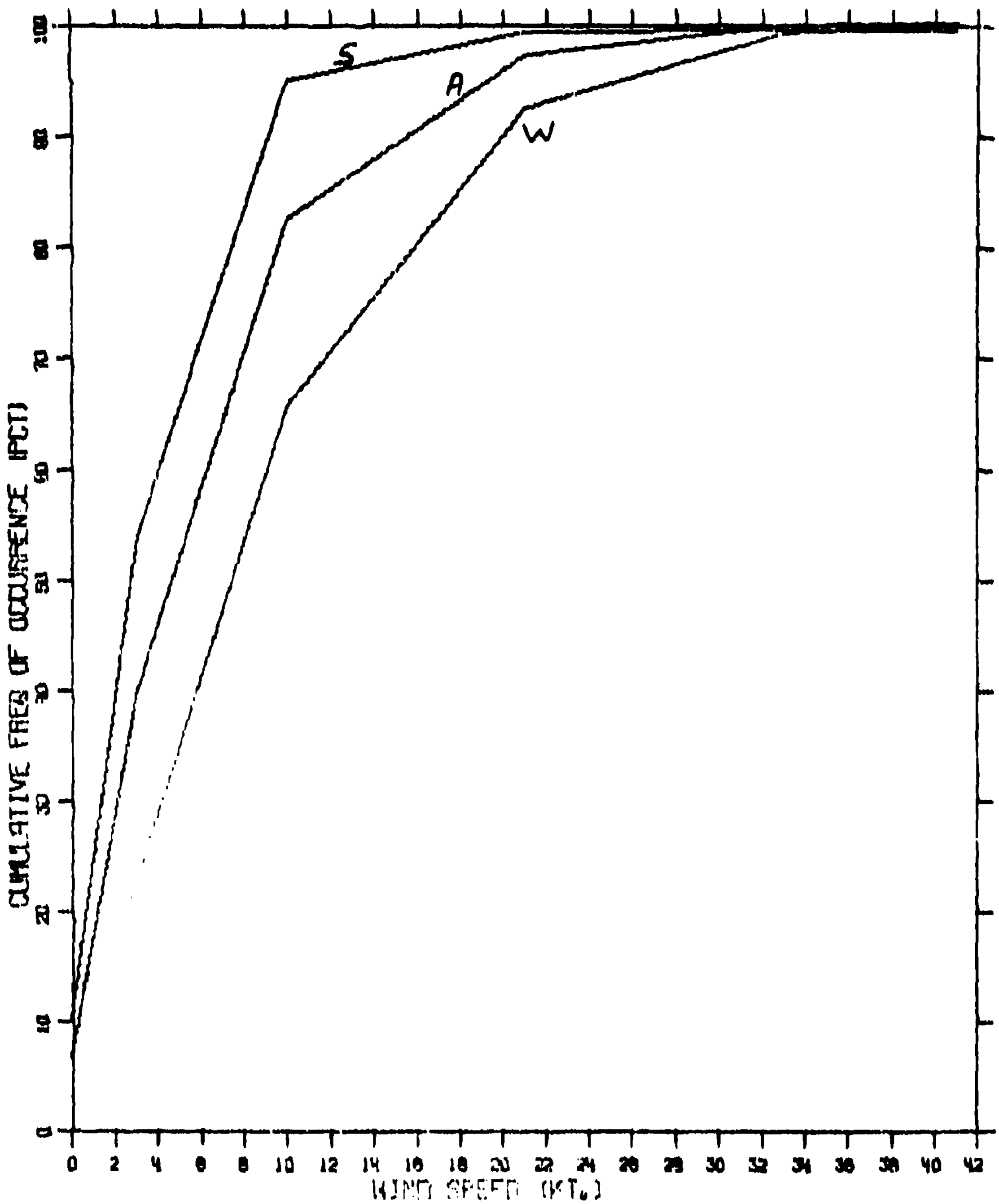


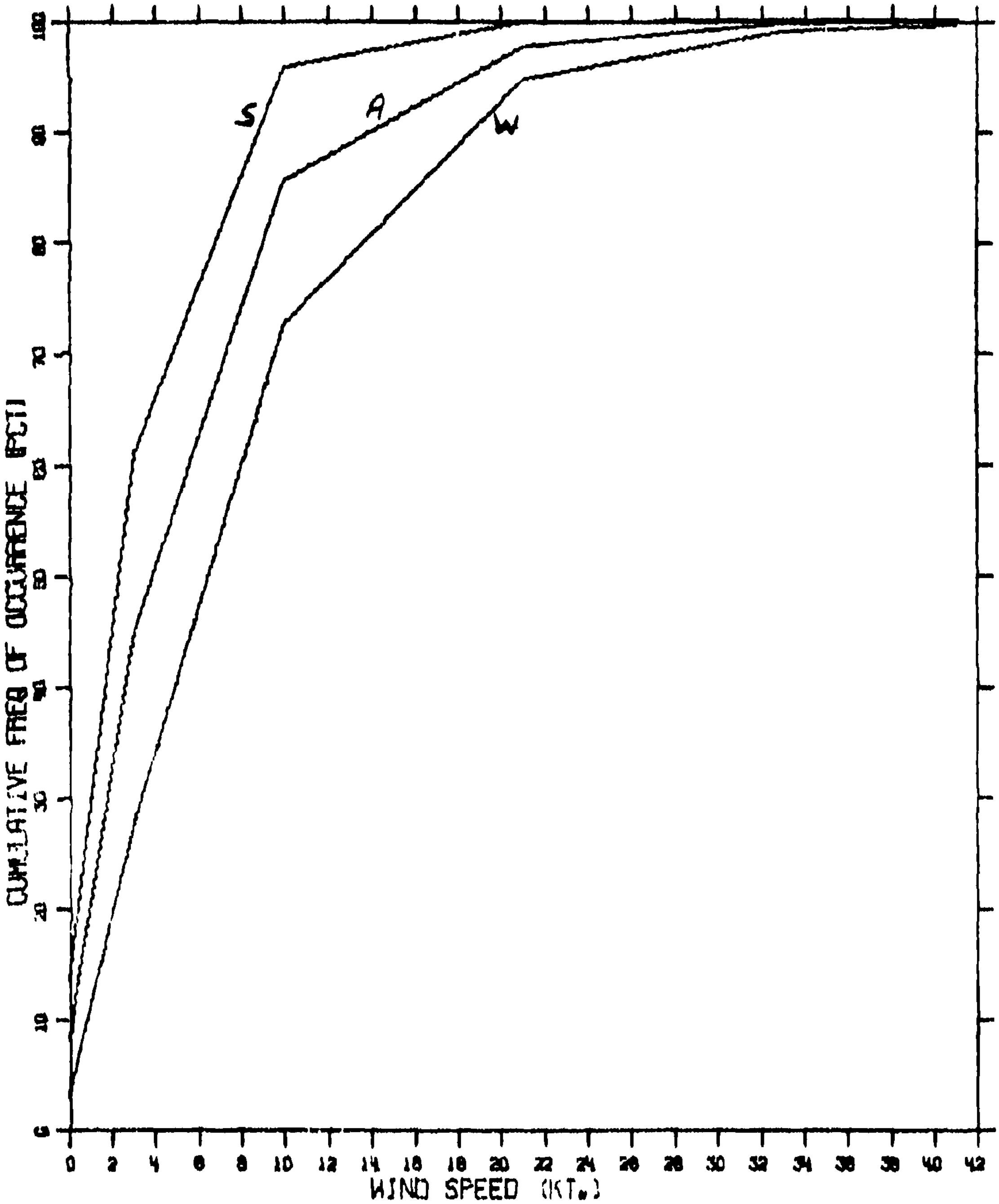
FIG. I-1-4: ALASKA COASTAL MARINE AREAS (17th DISTRICT)

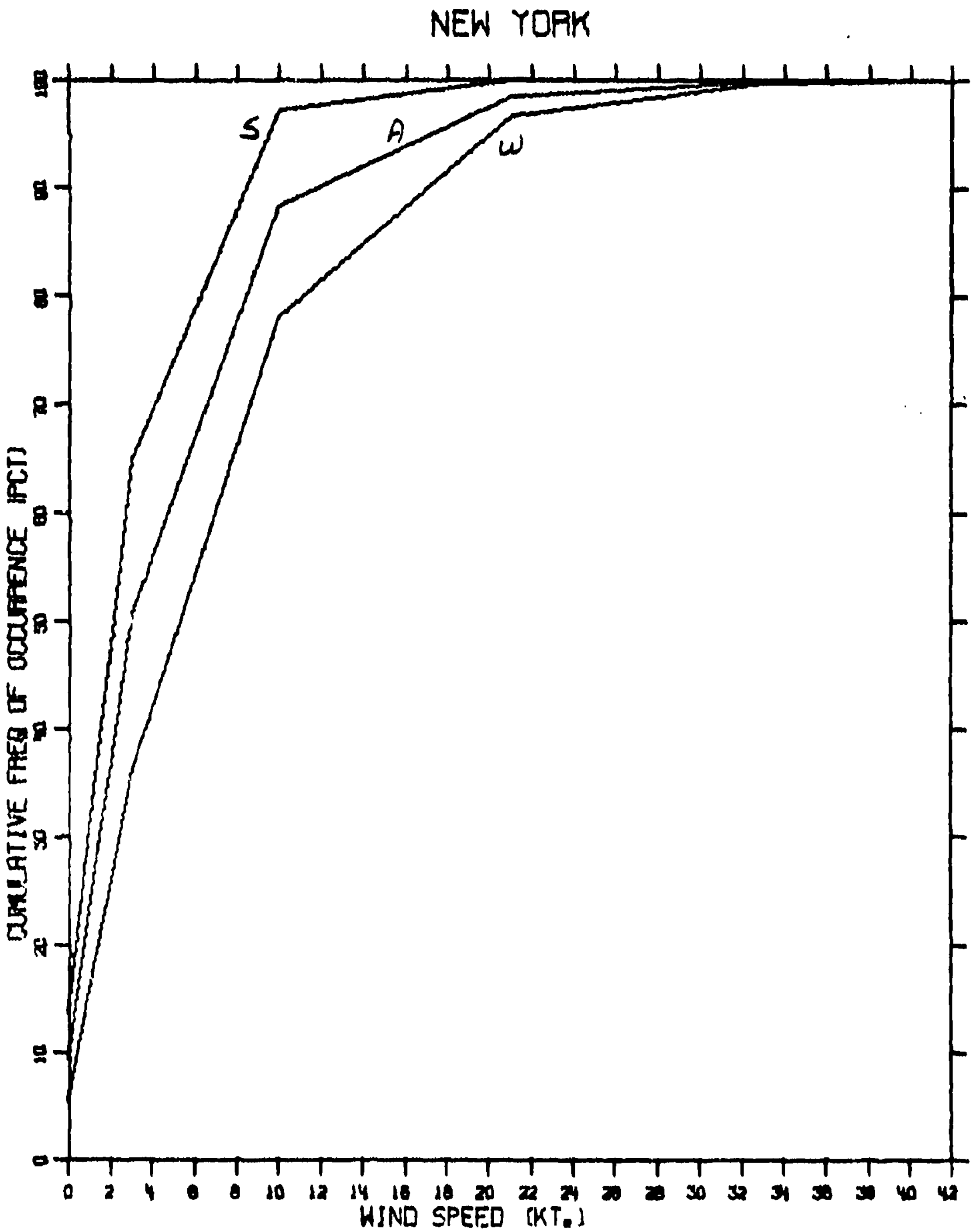
BOSTON



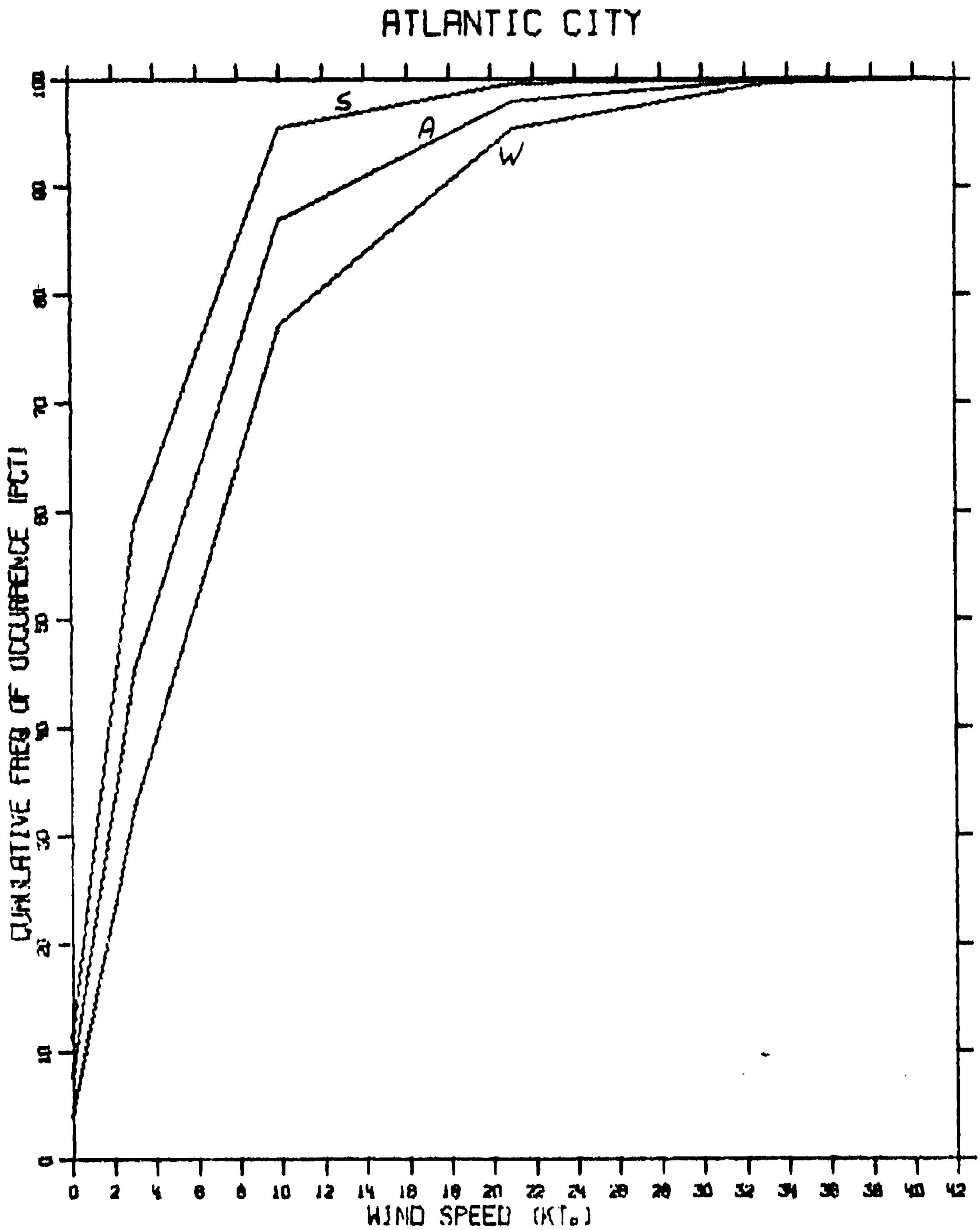
S
A
W
CUMULATIVE FREQ OF OCCURRENCE (PCT)
WIND SPEED (KT.)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42

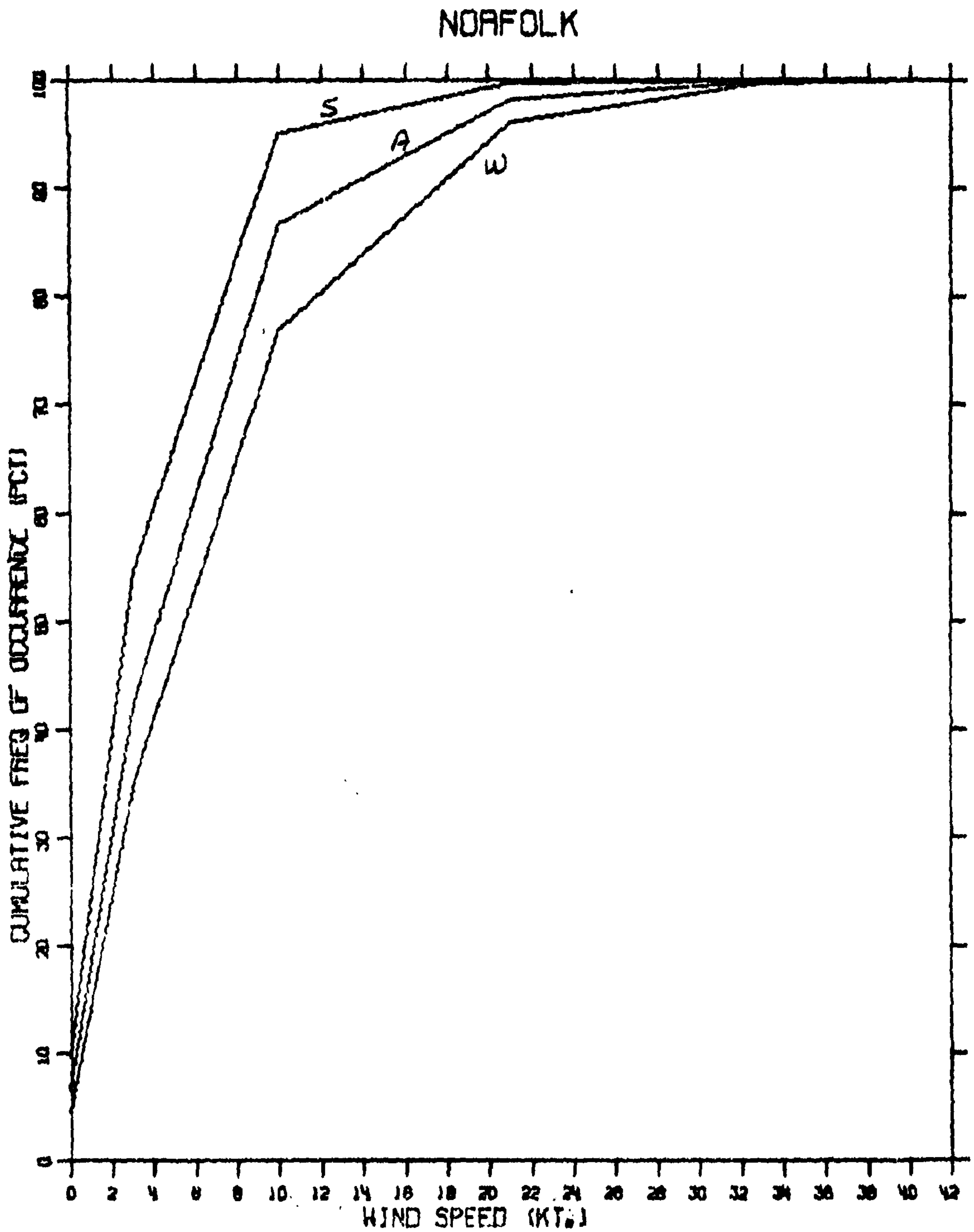
QUONSET POINT





NEW YORK
S
A
W
CUMULATIVE FREQ OF OCCURRENCE (PCT)
WIND SPEED (KT.)
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42
0 10 20 30 40 50 60 70 80 90 100


ATLANTIC CITY
CUMULATIVE FREQ OF OCCURRENCE (PCT)
WIND SPEED (KT.)
S
A
W
0
10
20
30
40
50
60
70
80
90
100
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42


NORFOLK
CUMULATIVE FREQ OF OCCURRENCE (PCT)
WIND SPEED (KT.)
S
A
W
0
10
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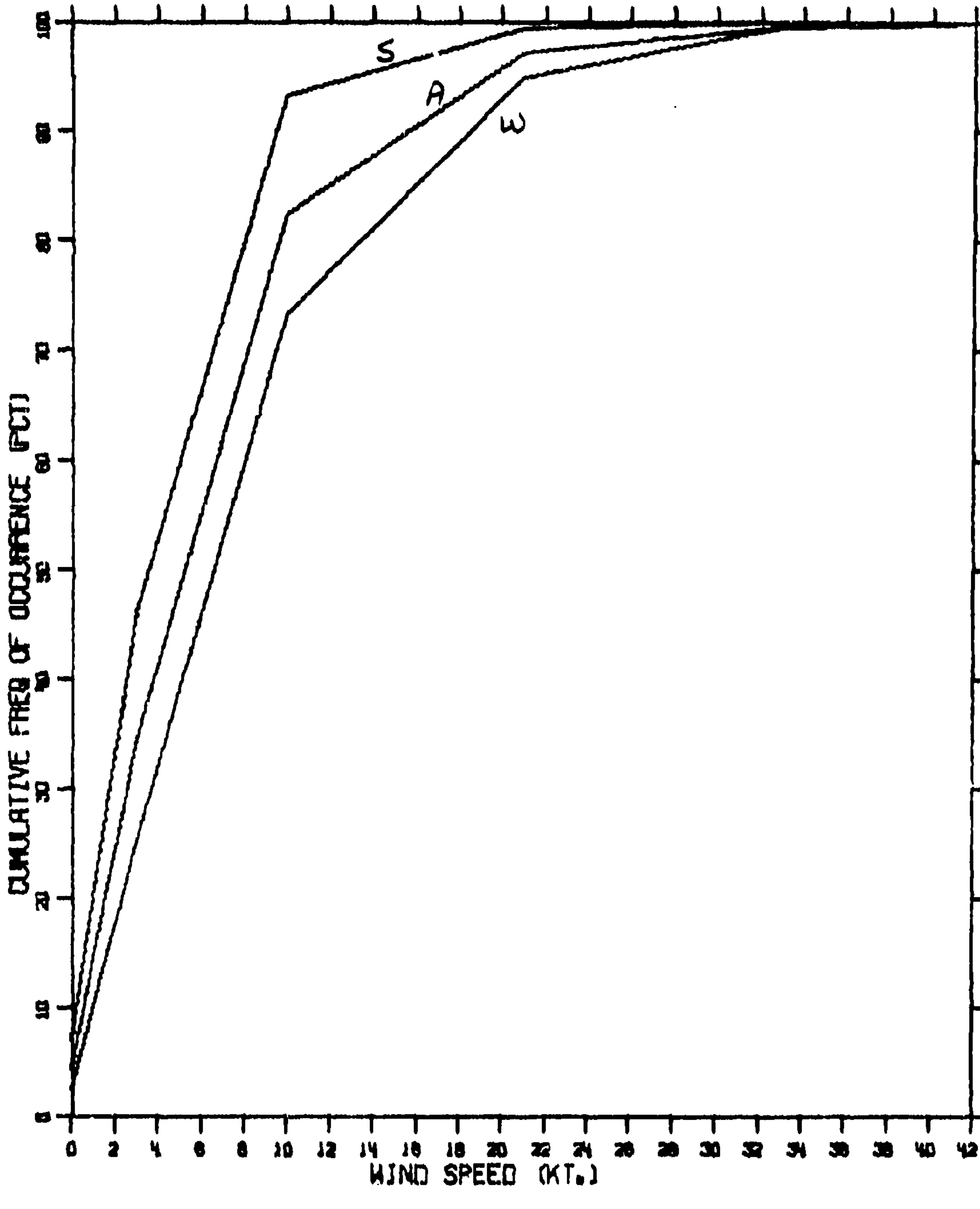
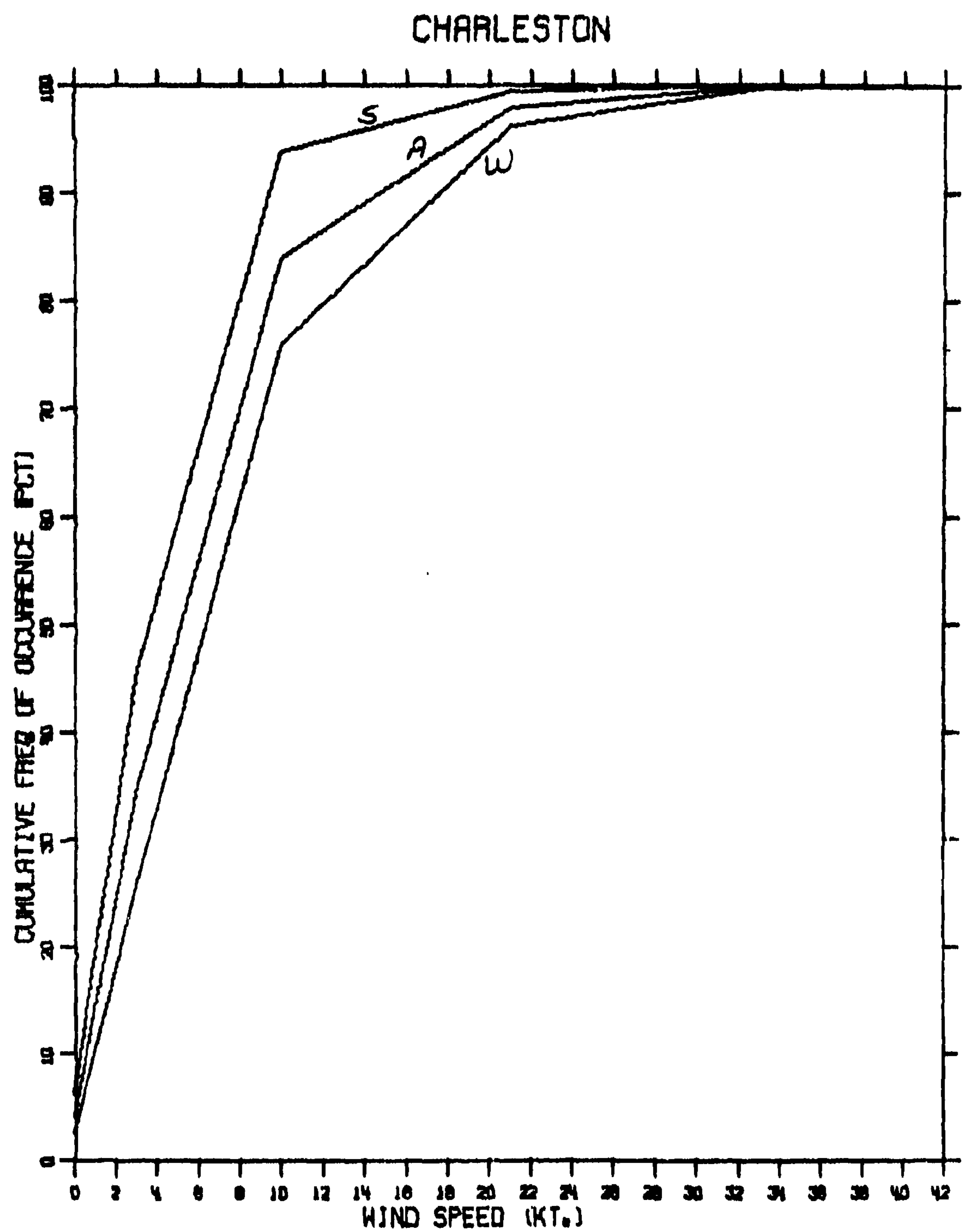
50
60
70
80
90
100
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42

CAPE HATTERAS





CHARLESTON
S
A
W
CUMULATIVE FREQ OF OCCURRENCE (PCT)
0
2
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6
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18
20
22
24
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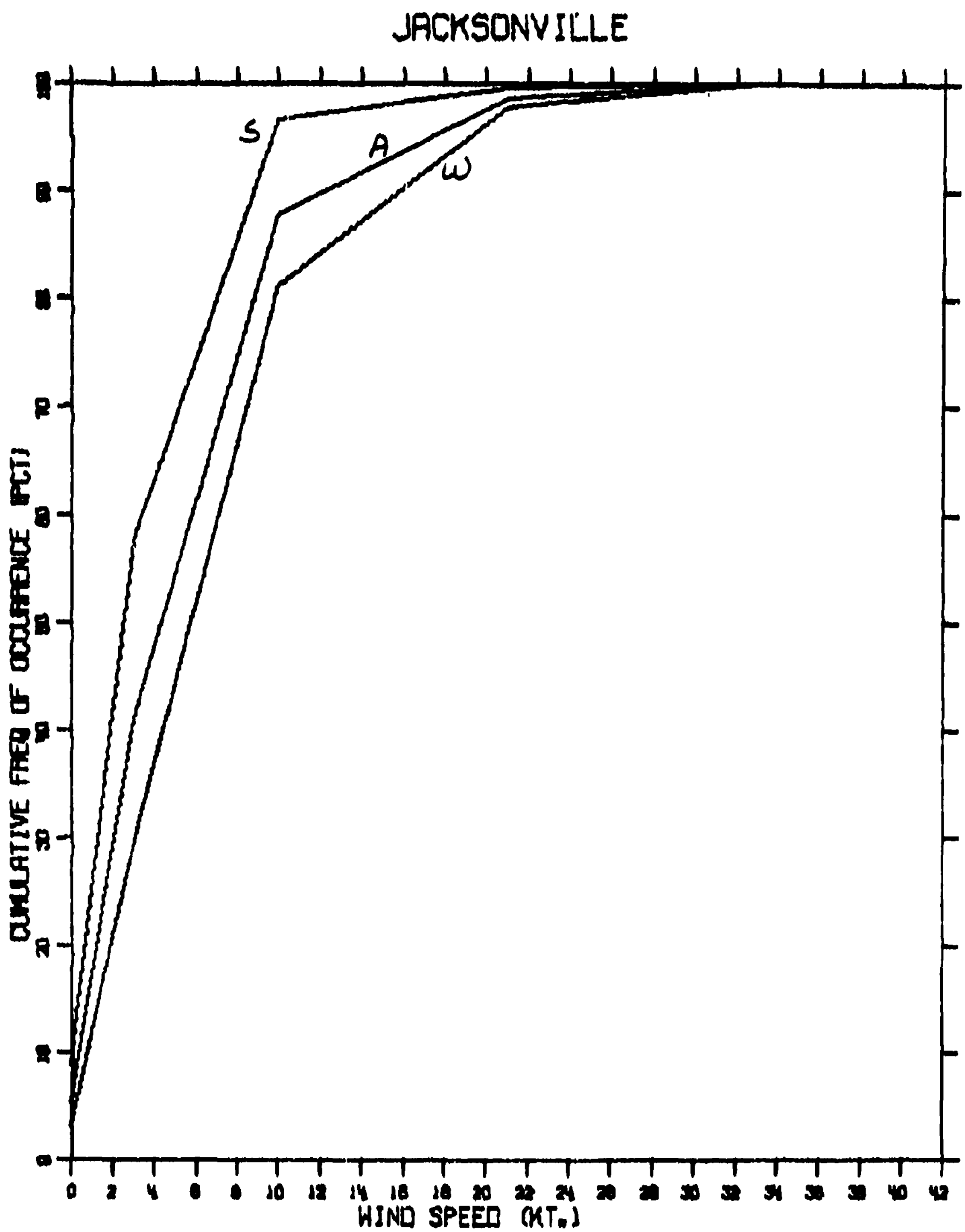
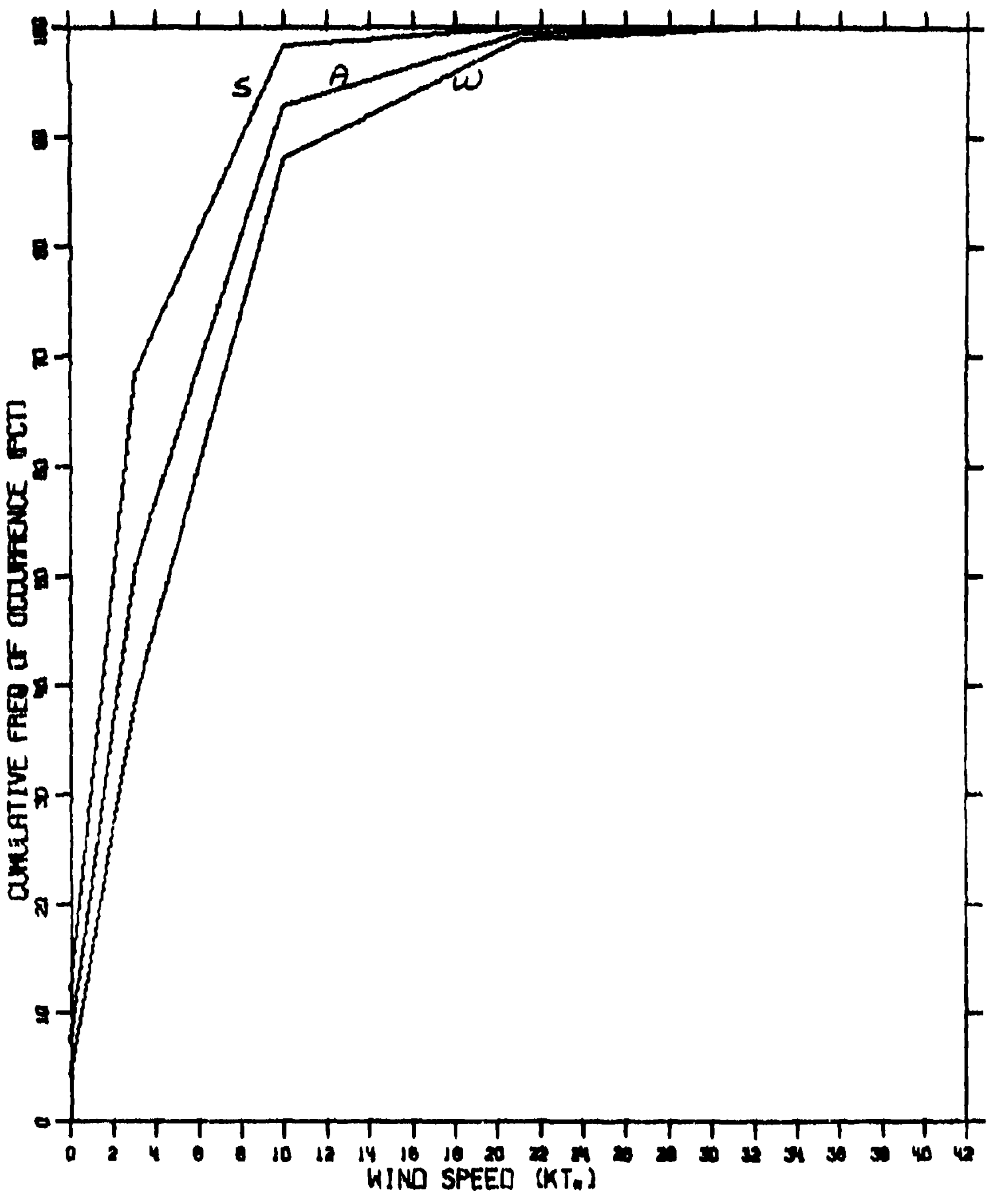
28
30
32
34
36
38
40
42
WIND SPEED (KT.)


JACKSONVILLE
S
A
W
CUMULATIVE FREQ OF OCCURRENCE (PCT)
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42
WIND SPEED (KT.)

MIAMI


S
A
W
CUMULATIVE FREQ OF OCCURRENCE (PCT)
WIND SPEED (KTS)
0
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32
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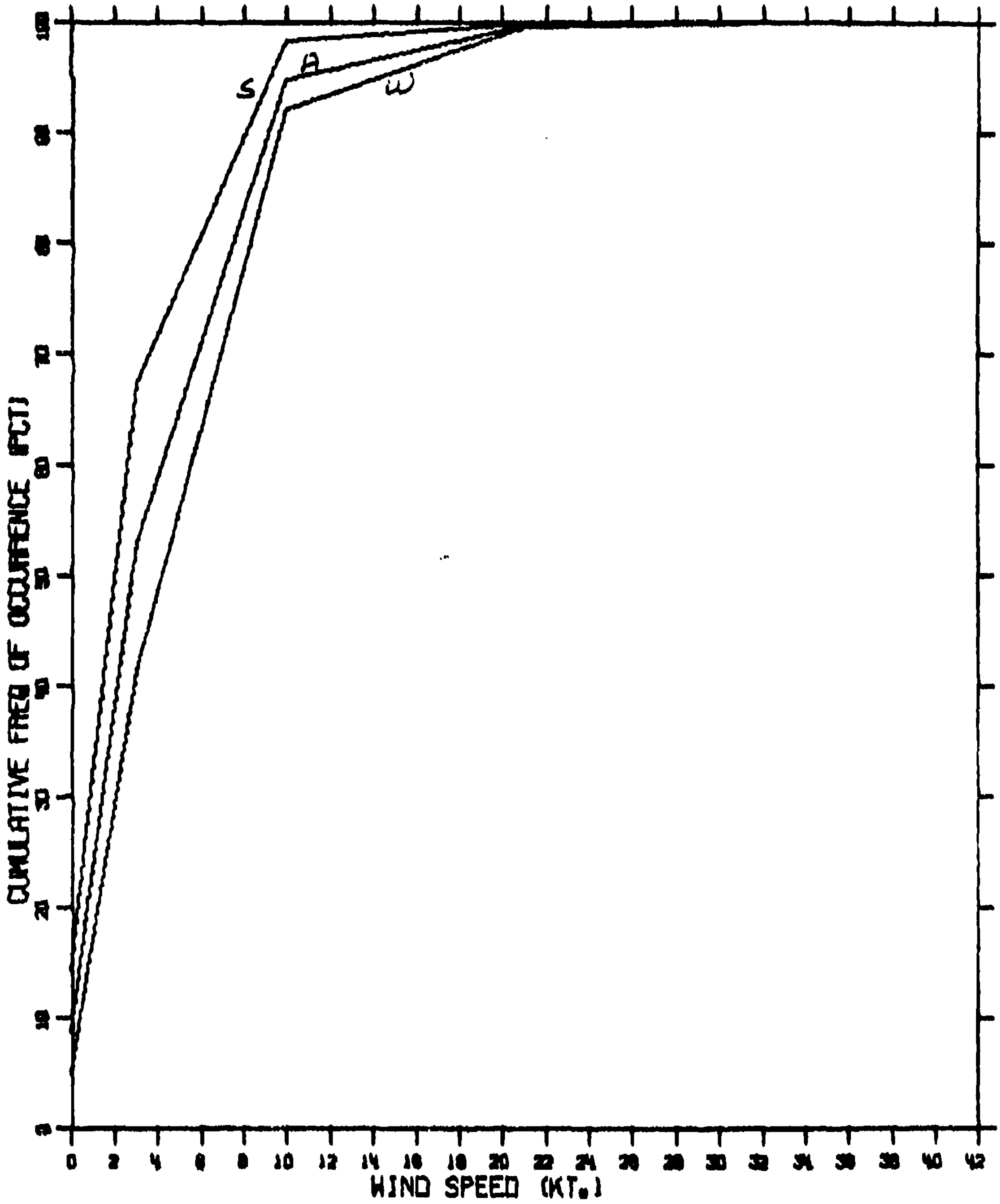
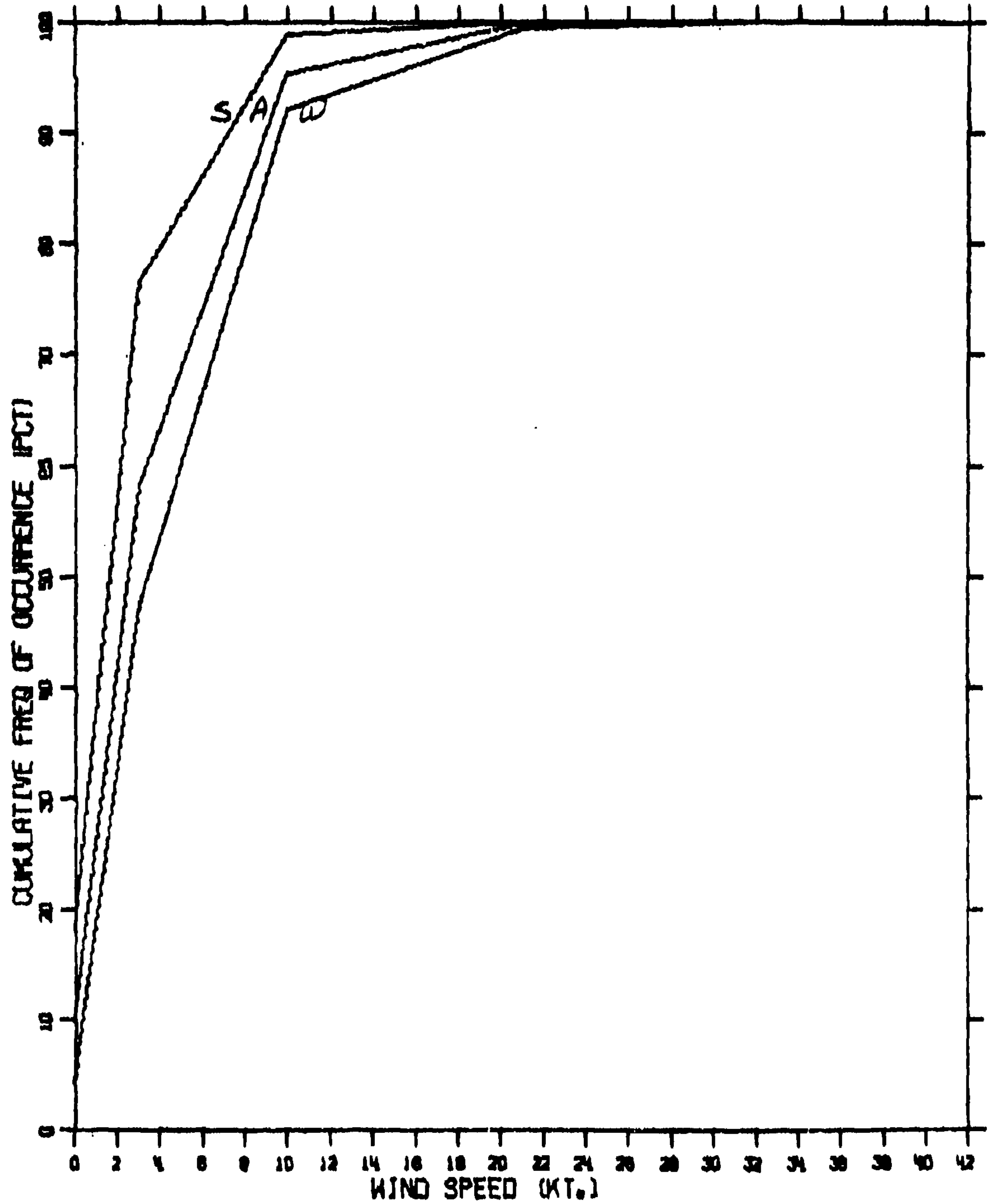
40
42

KEY WEST


CUMULATIVE FREQ OF OCCURRENCE (PCT)
WIND SPEED (KT.)
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42
S
A
W

FORT MYERS



S
A
W
CUMULATIVE FREQ OF OCCURRENCE (PCT)
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34
36
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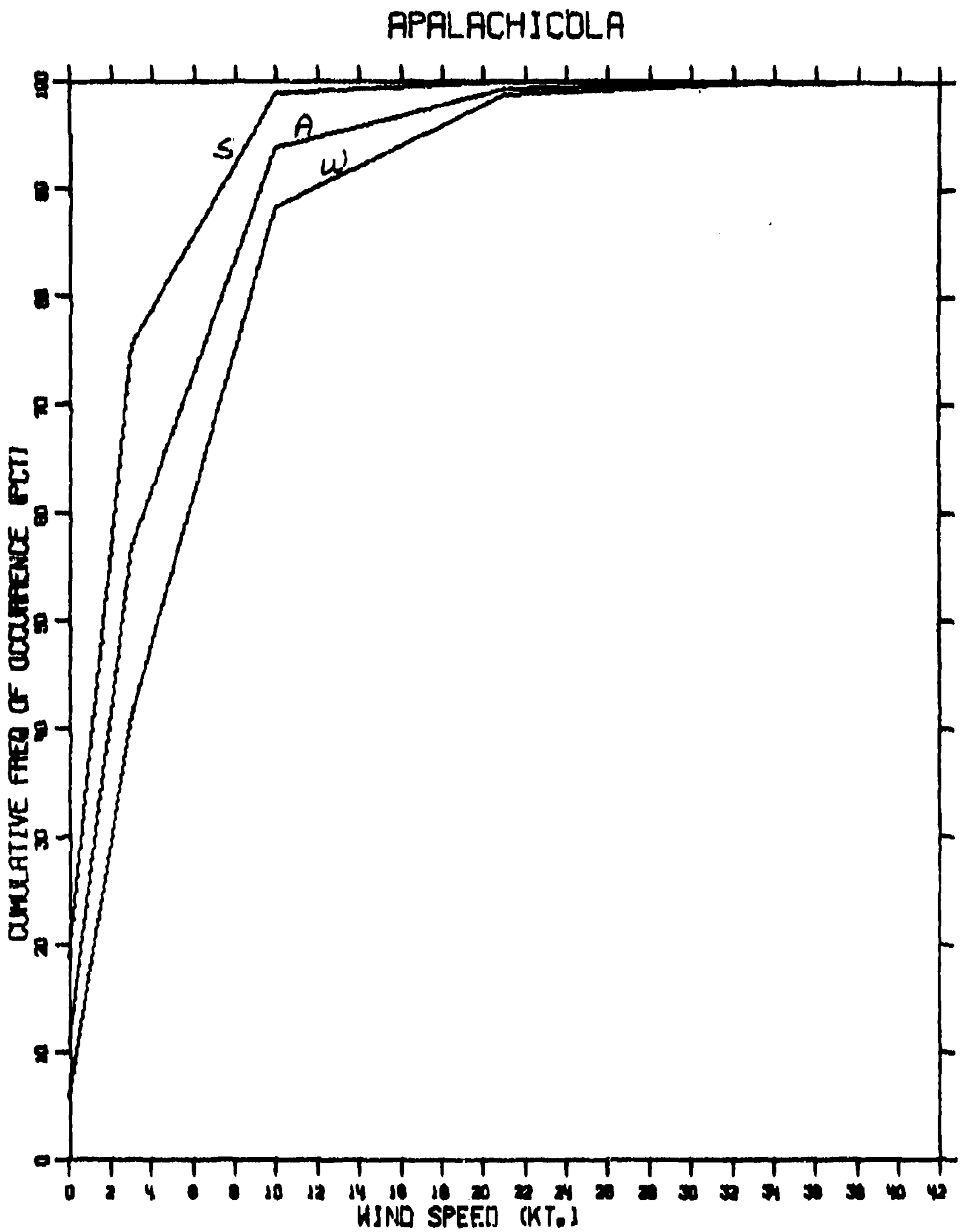
42
WIND SPEED (KT.)



APALACHICOLA
S
A
W
CUMULATIVE FREQ OF OCCURRENCE (PCT)
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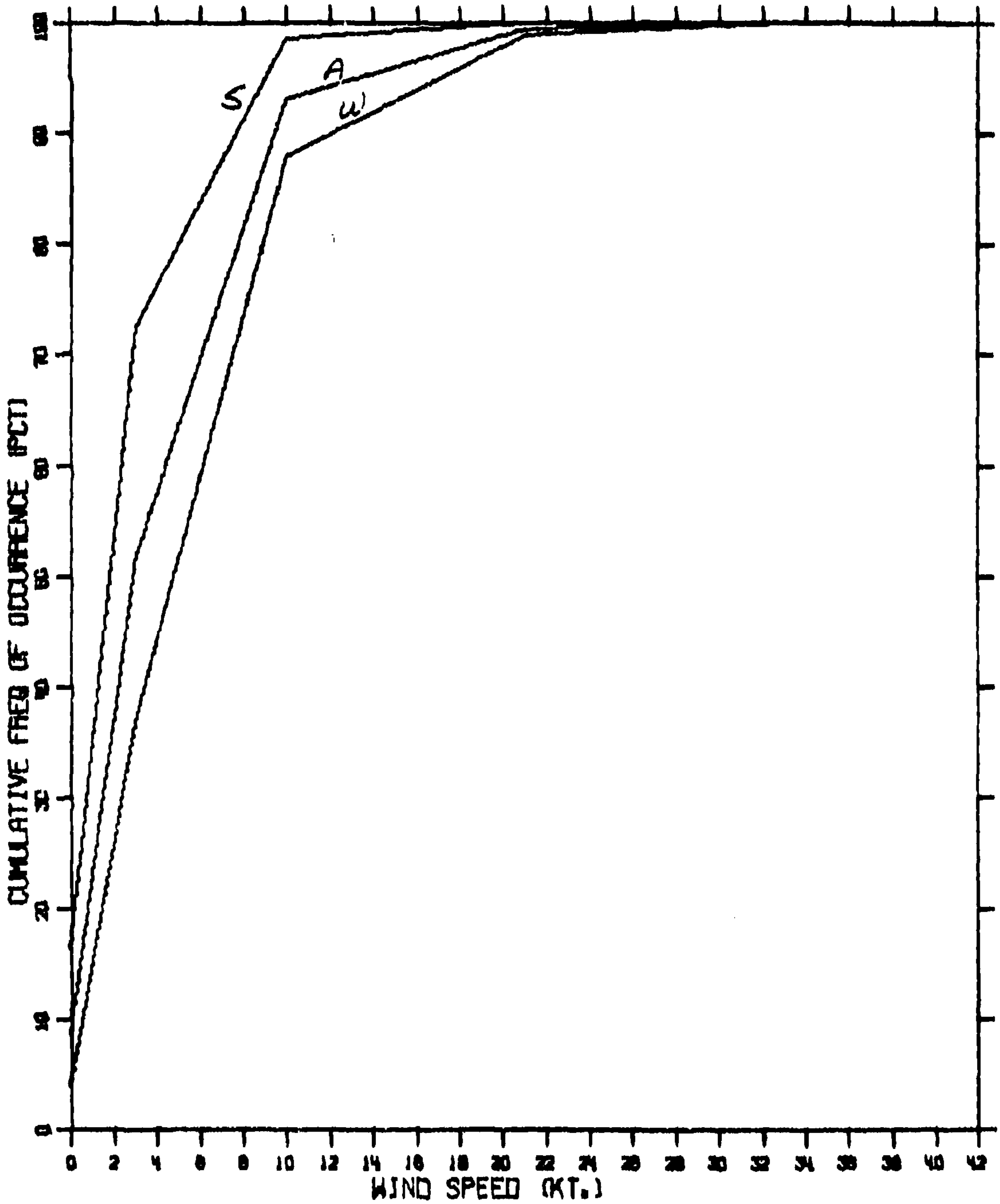
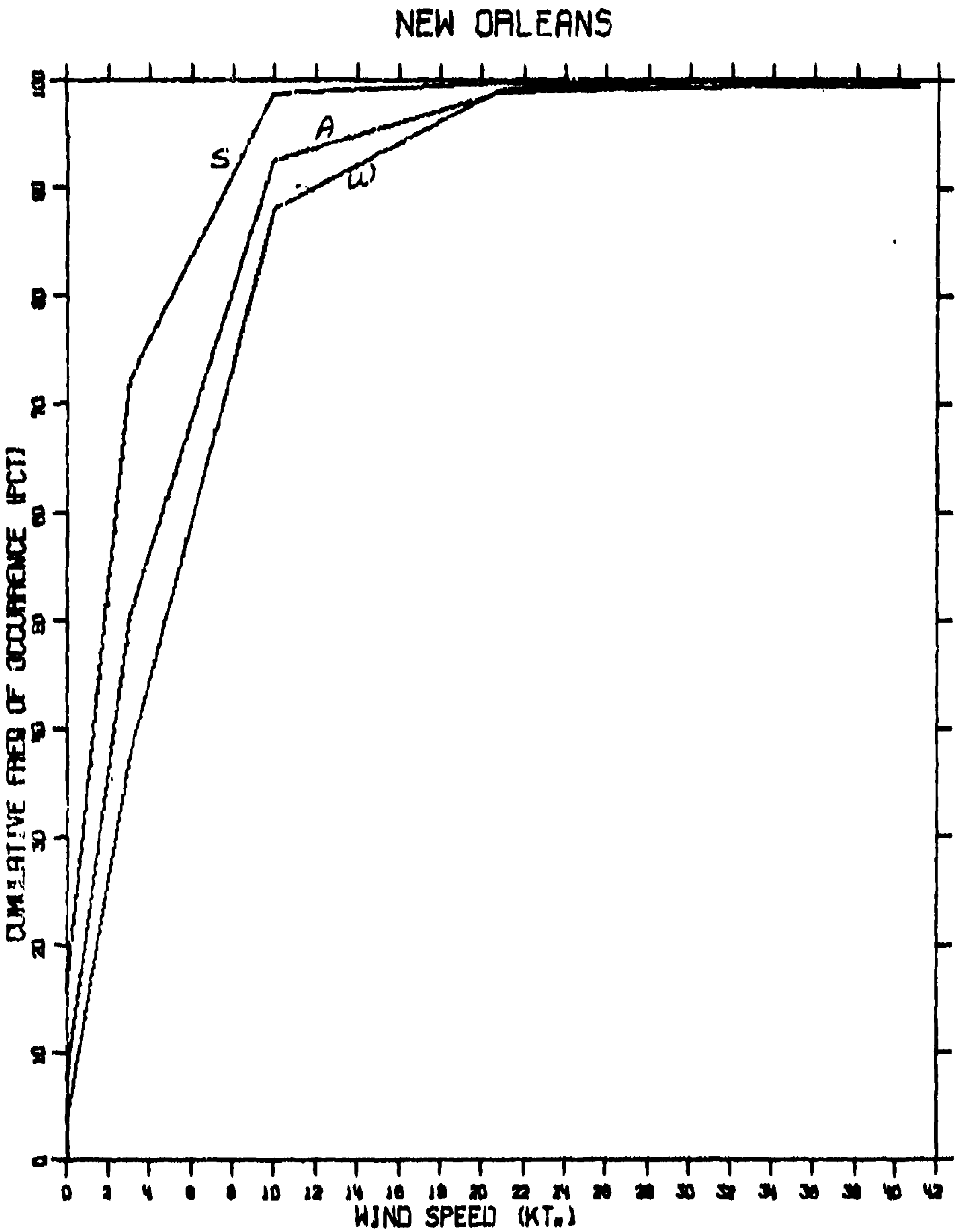
42
WIND SPEED (KT.)

PENSACOLA




NEW ORLEANS
S
A
W
CUMULATIVE FREQ OF OCCURRENCE (PCT)
WIND SPEED (KTS)
0
10
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50
60
70
80
90
100
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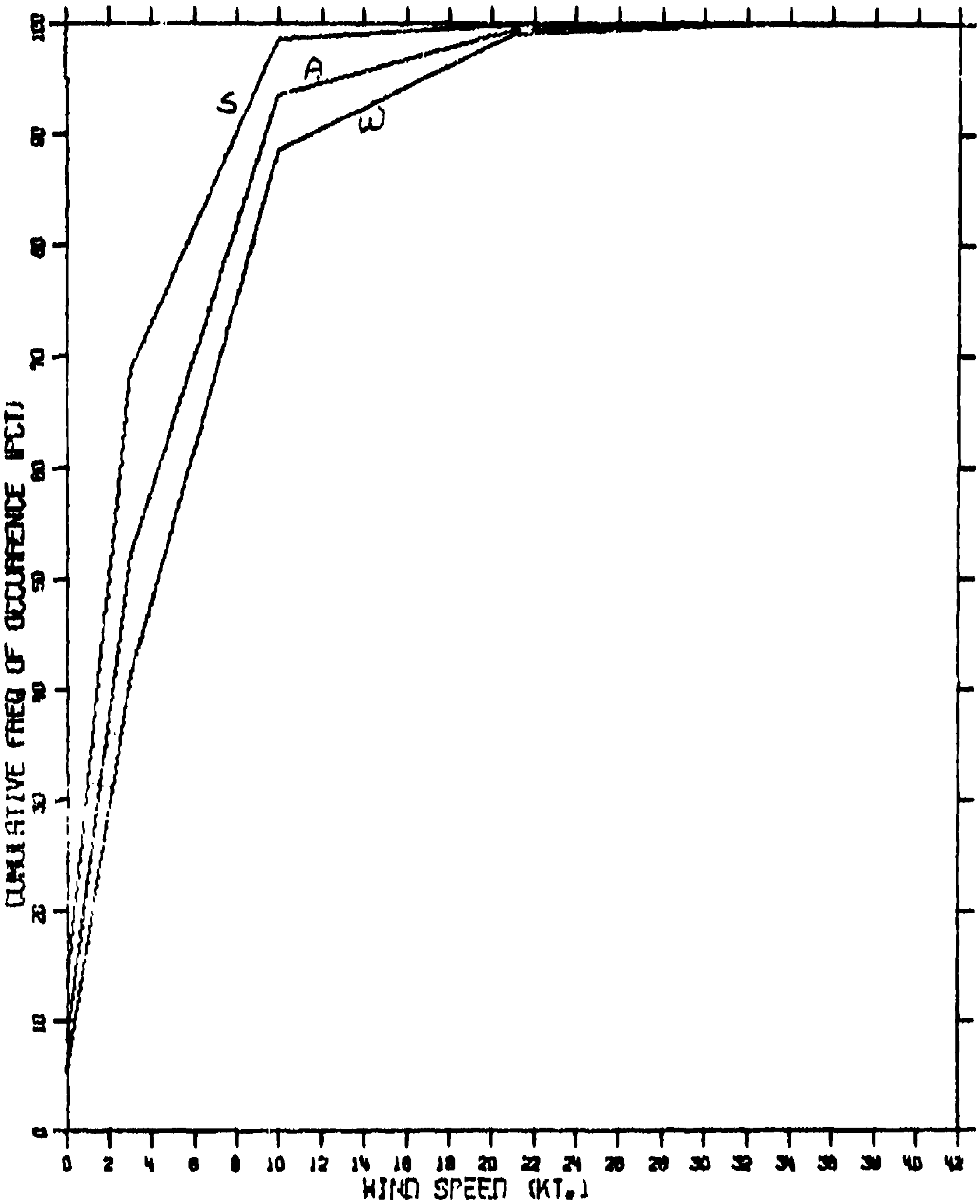
GALVESTON



CUMULATIVE FREQ OF OCCURRENCE (PCT)
WIND SPEED (KT.)
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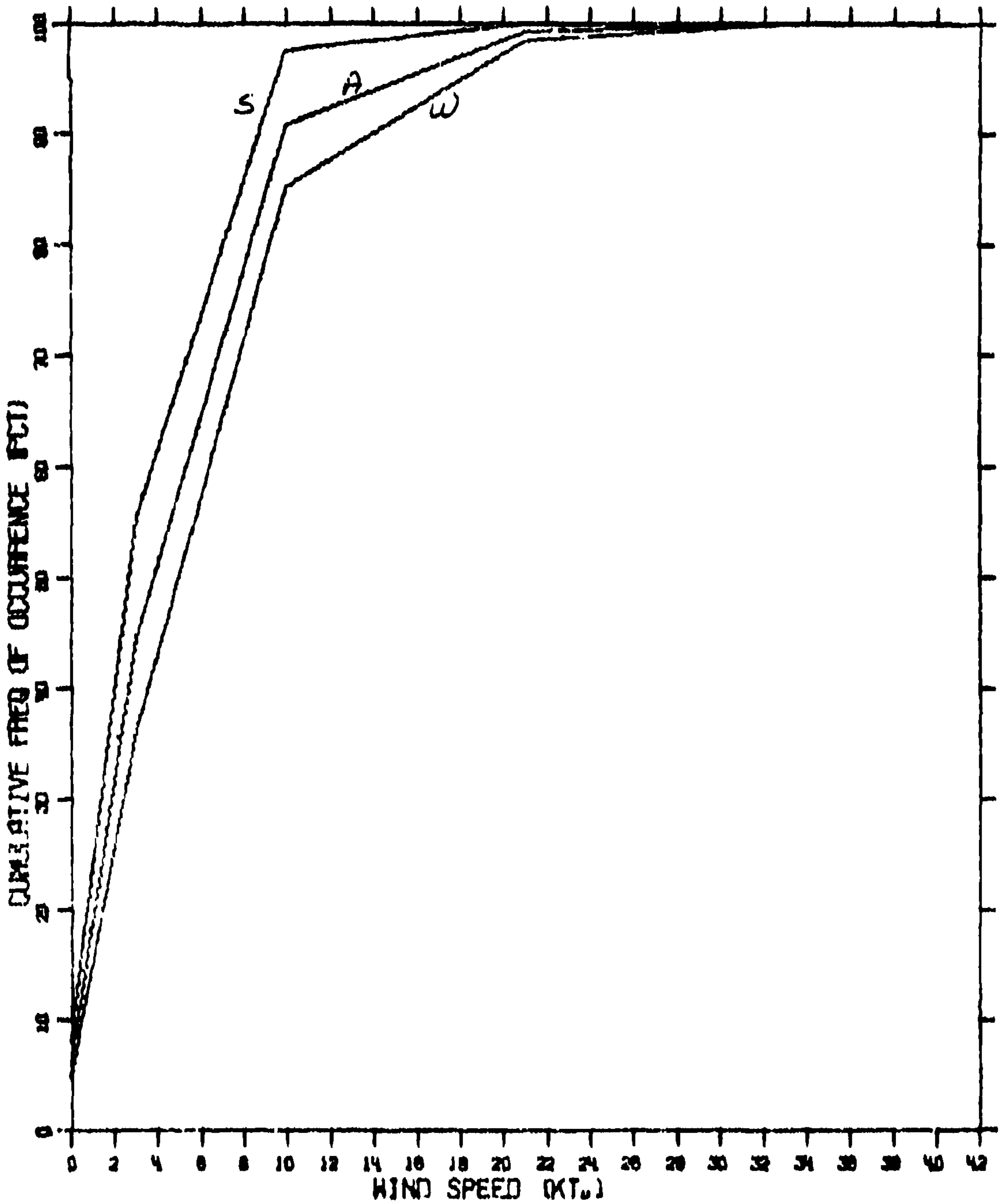
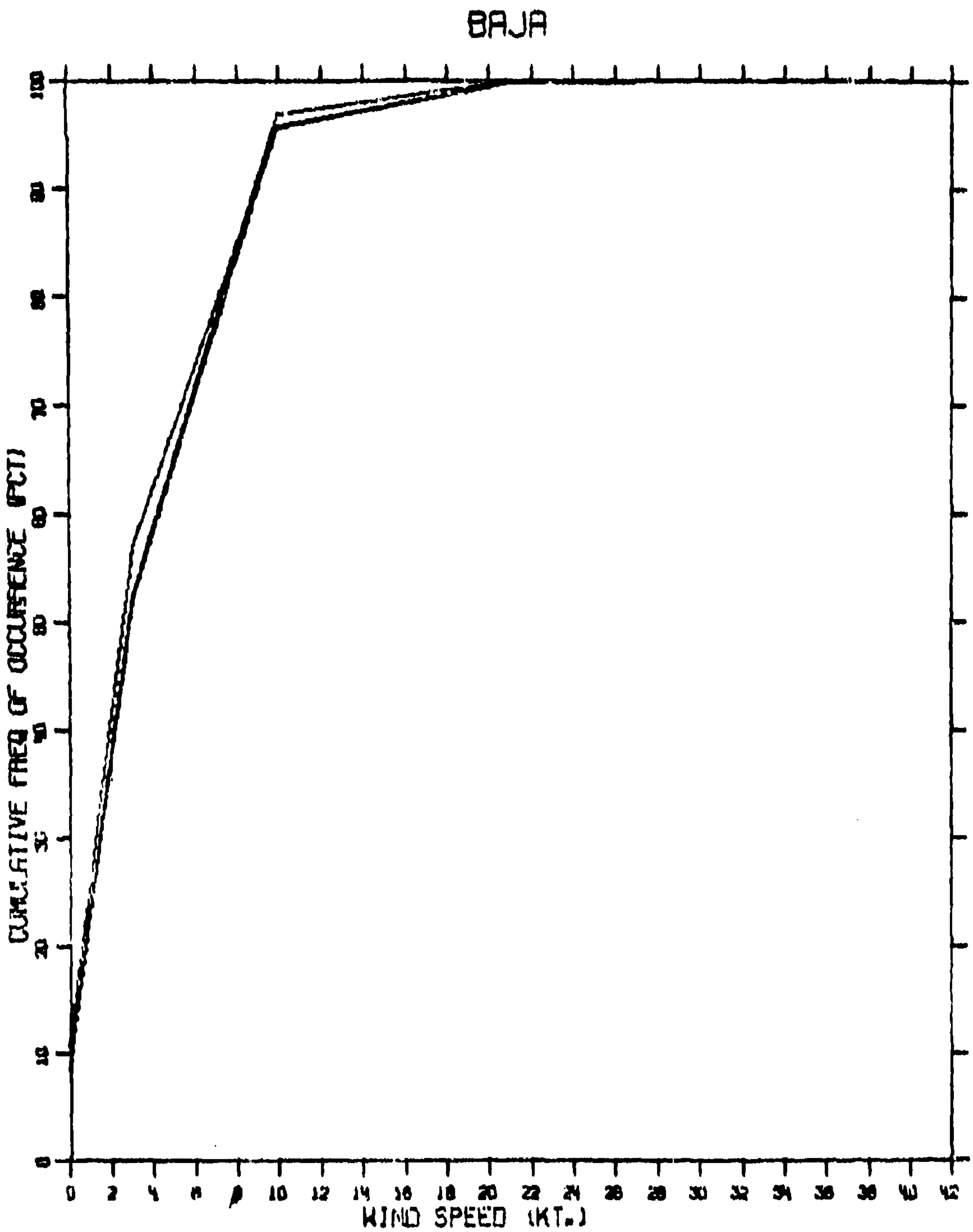
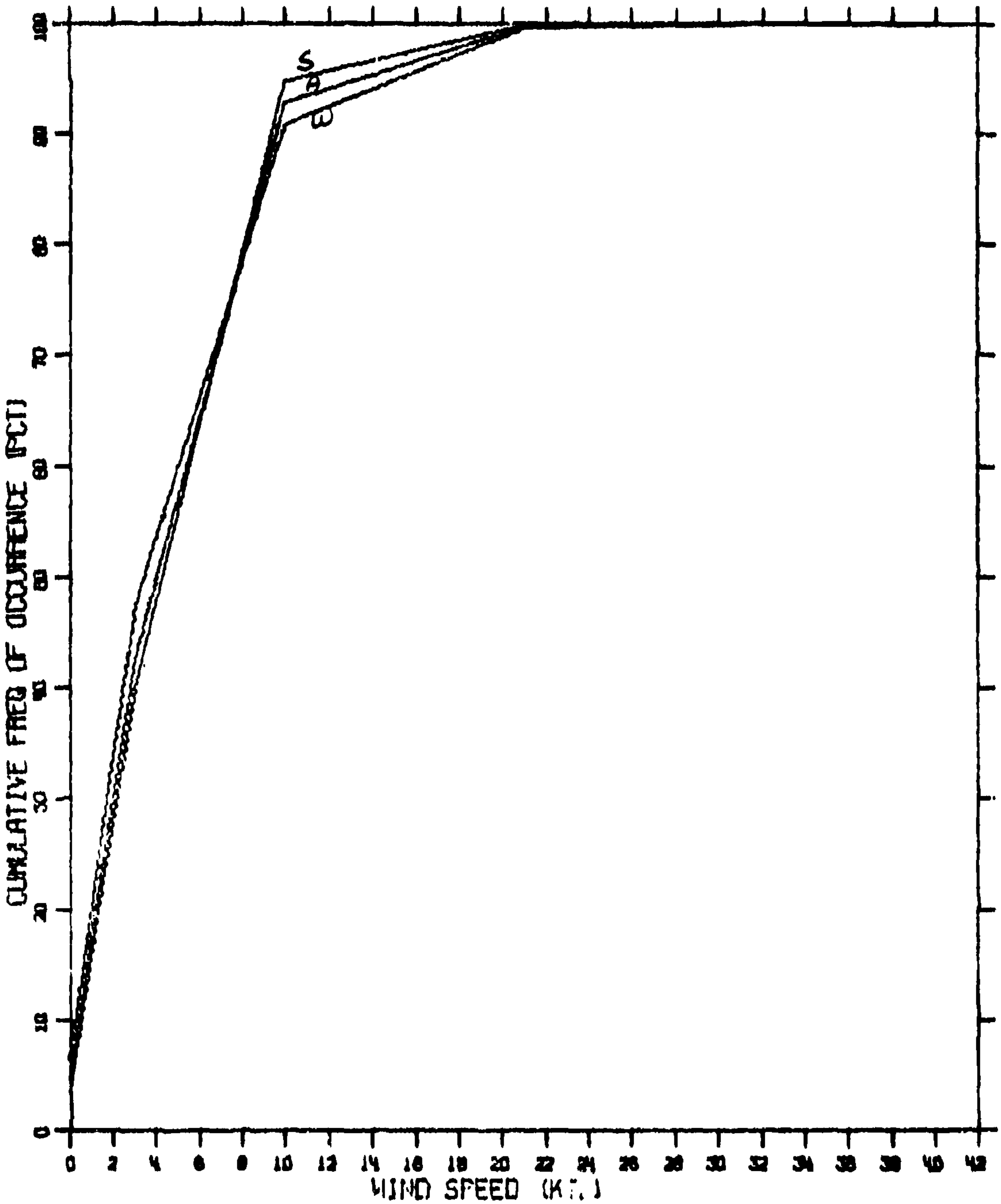
CORPUS CHRISTI

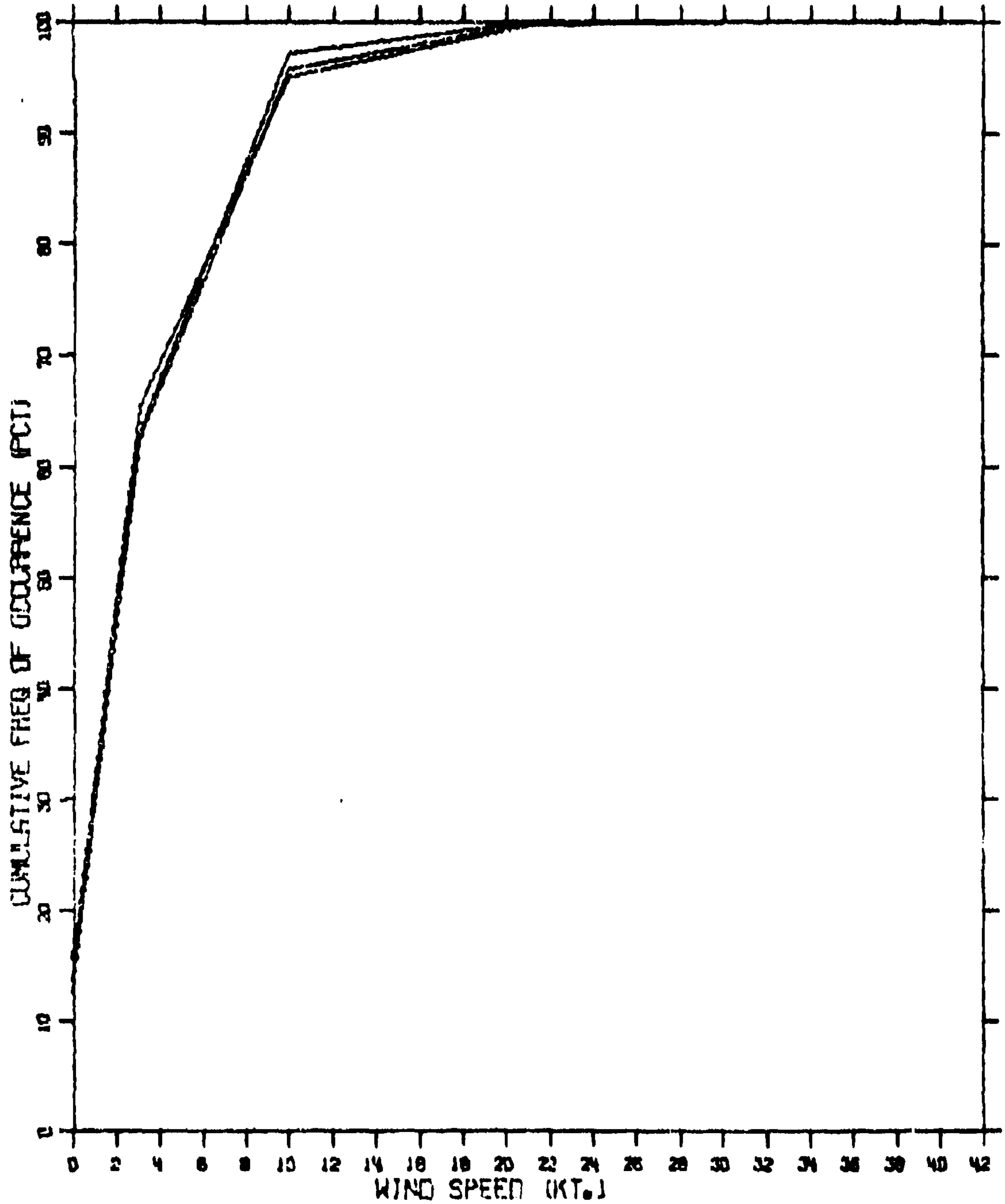



BAJA
CUMULATIVE FREQ OF OCCURRENCE (PCT)
WIND SPEED (KT.)

SAN DIEGO 200SW



SAN DIEGO



CUMULATIVE FREQ OF OCCURRENCE (PCT)
WIND SPEED (KT.)
0
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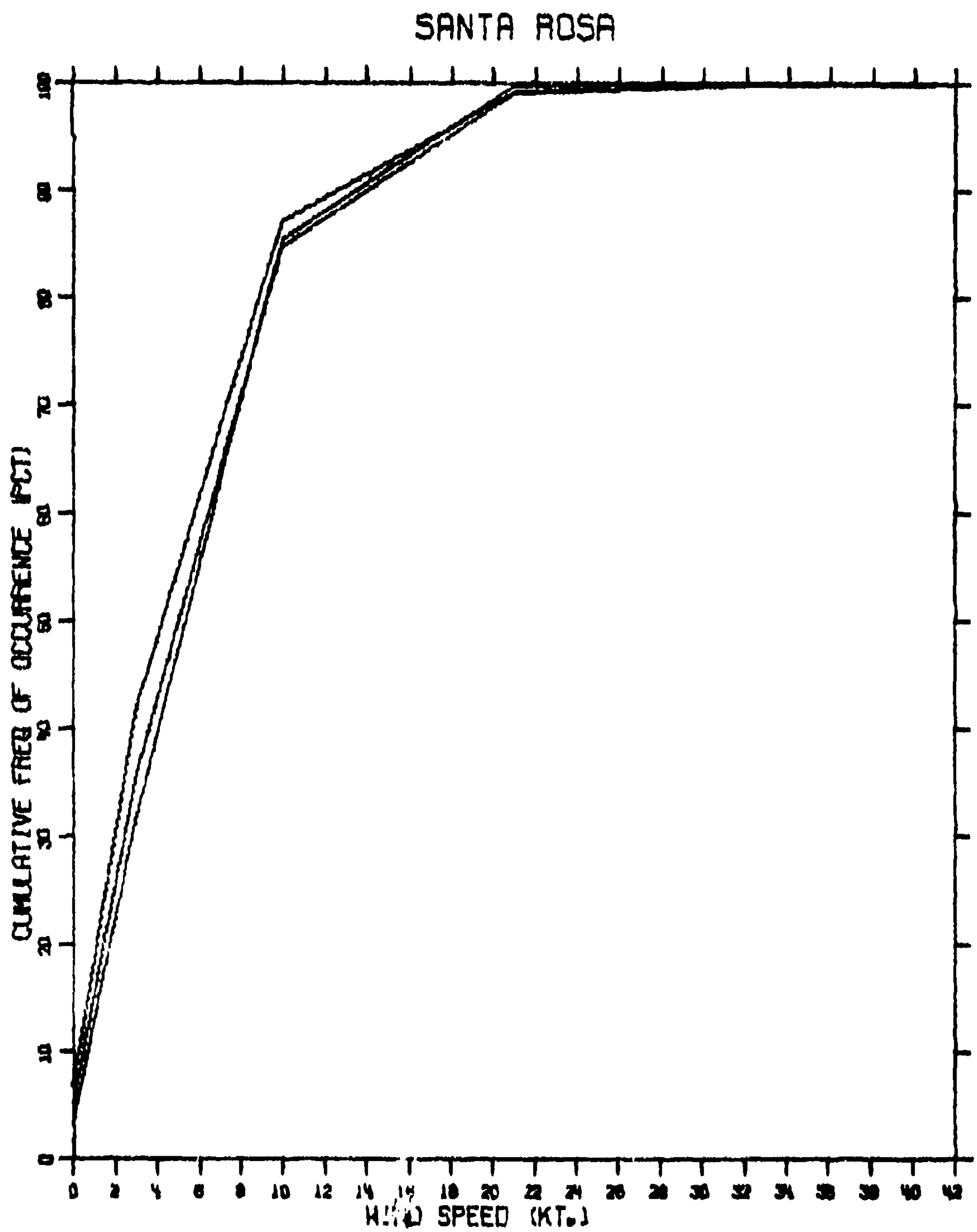
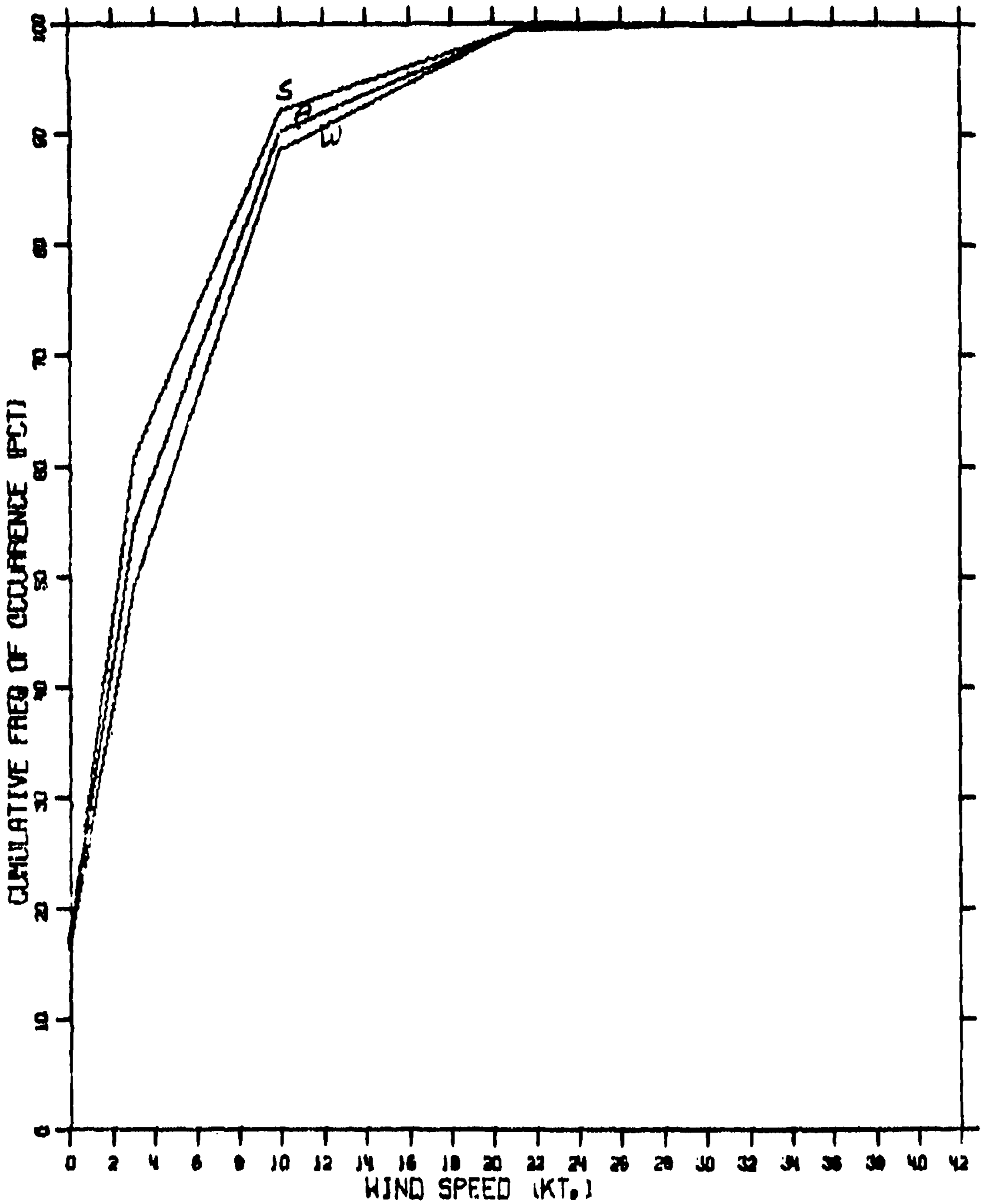
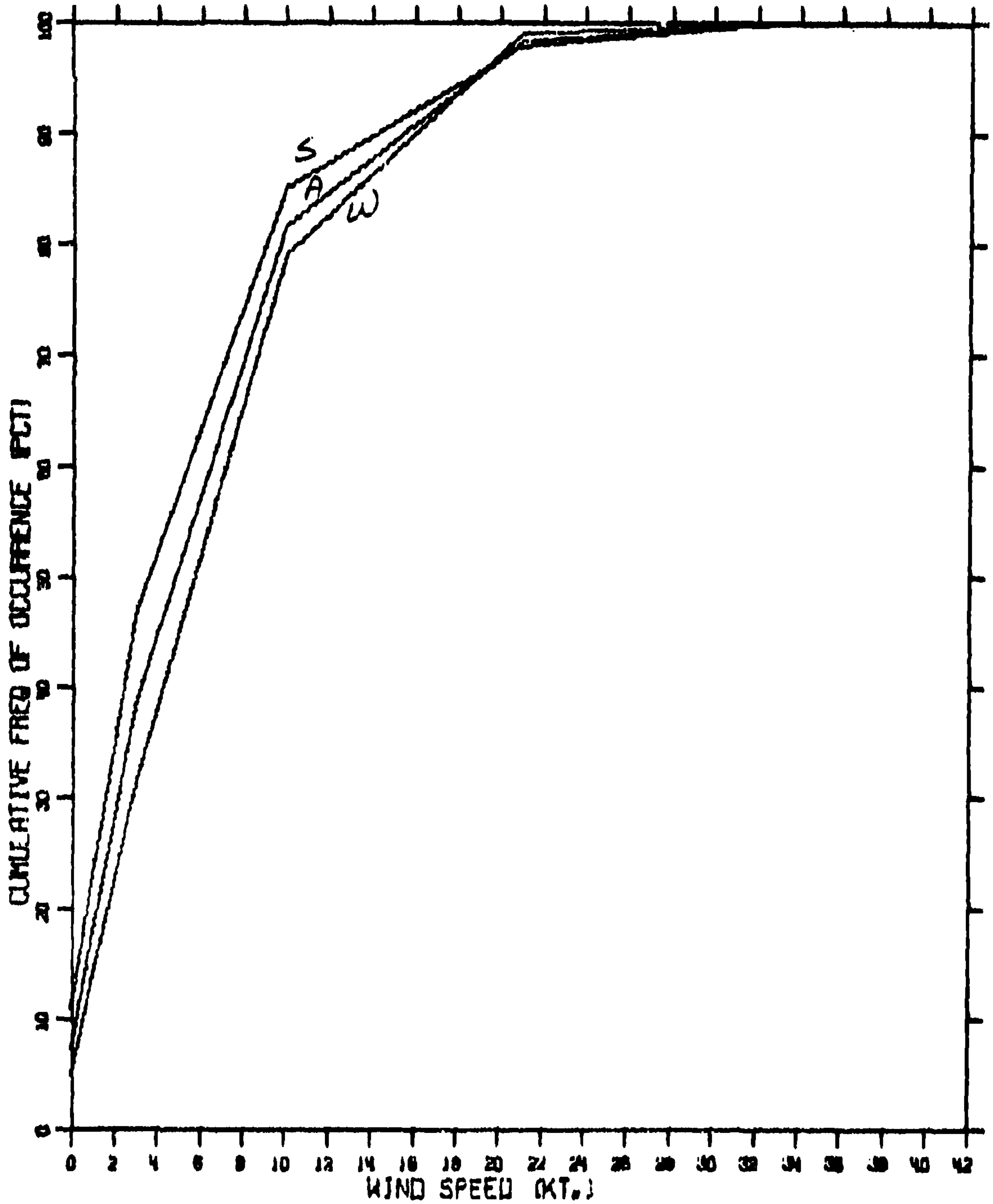

SANTA ROSA
CUMULATIVE FREQ OF OCCURRENCE (PCT)
WIND SPEED (KT.)

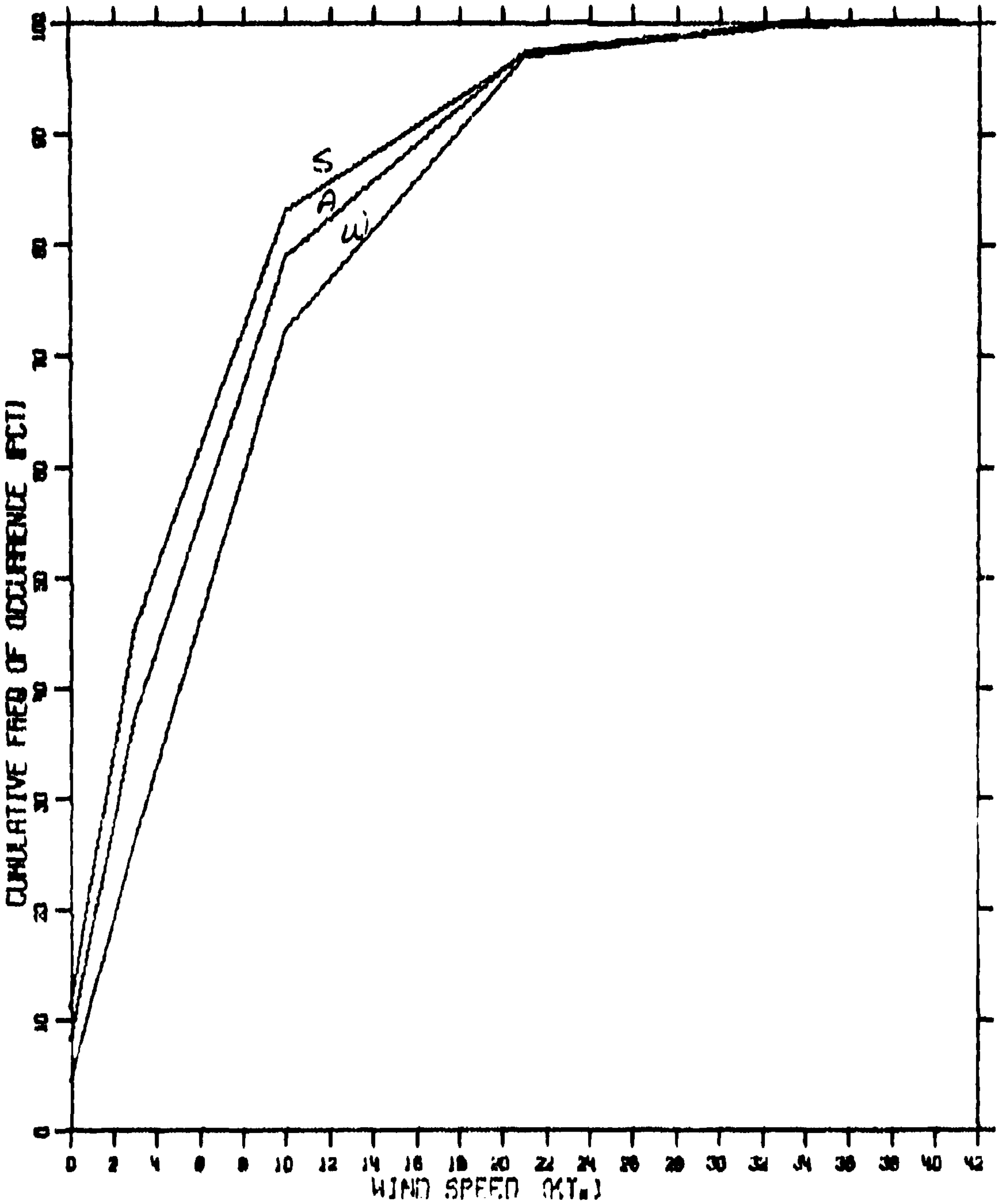
POINT MUGU


S
A
W
CUMULATIVE FREQ OF OCCURRENCE (PCT)
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42
WIND SPEED (KT.)

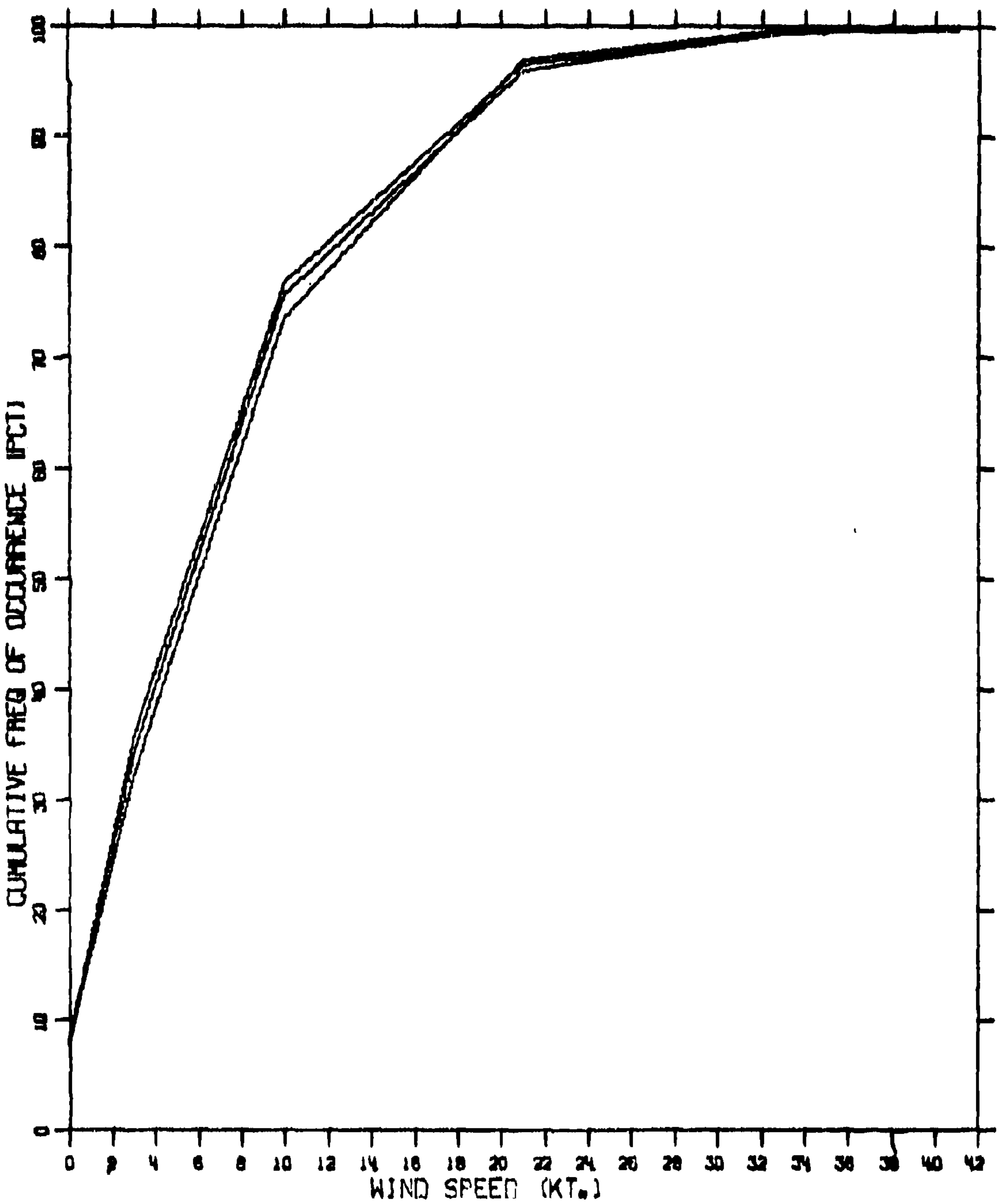
SAN FRANCISCO



POINT ARENA

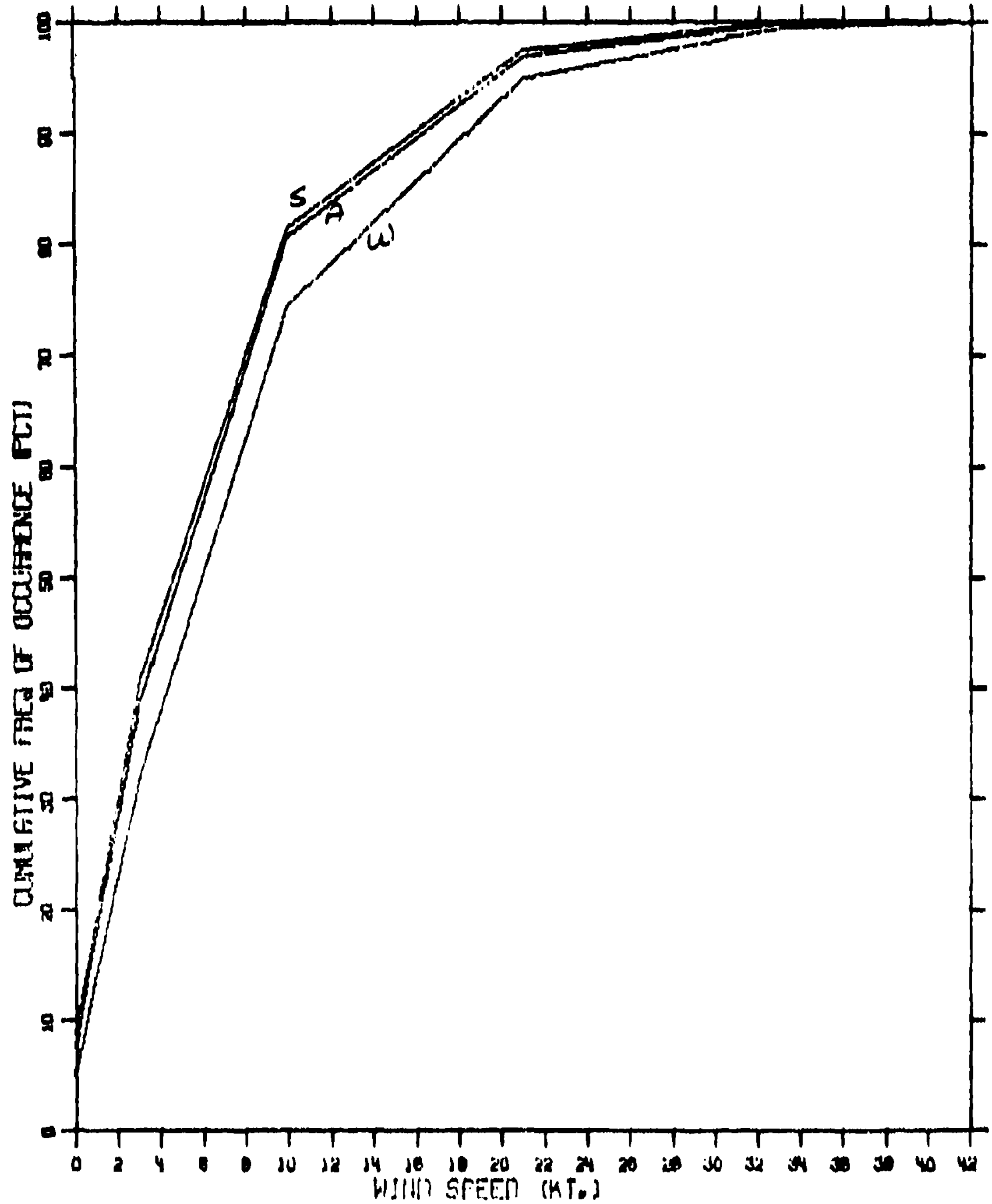


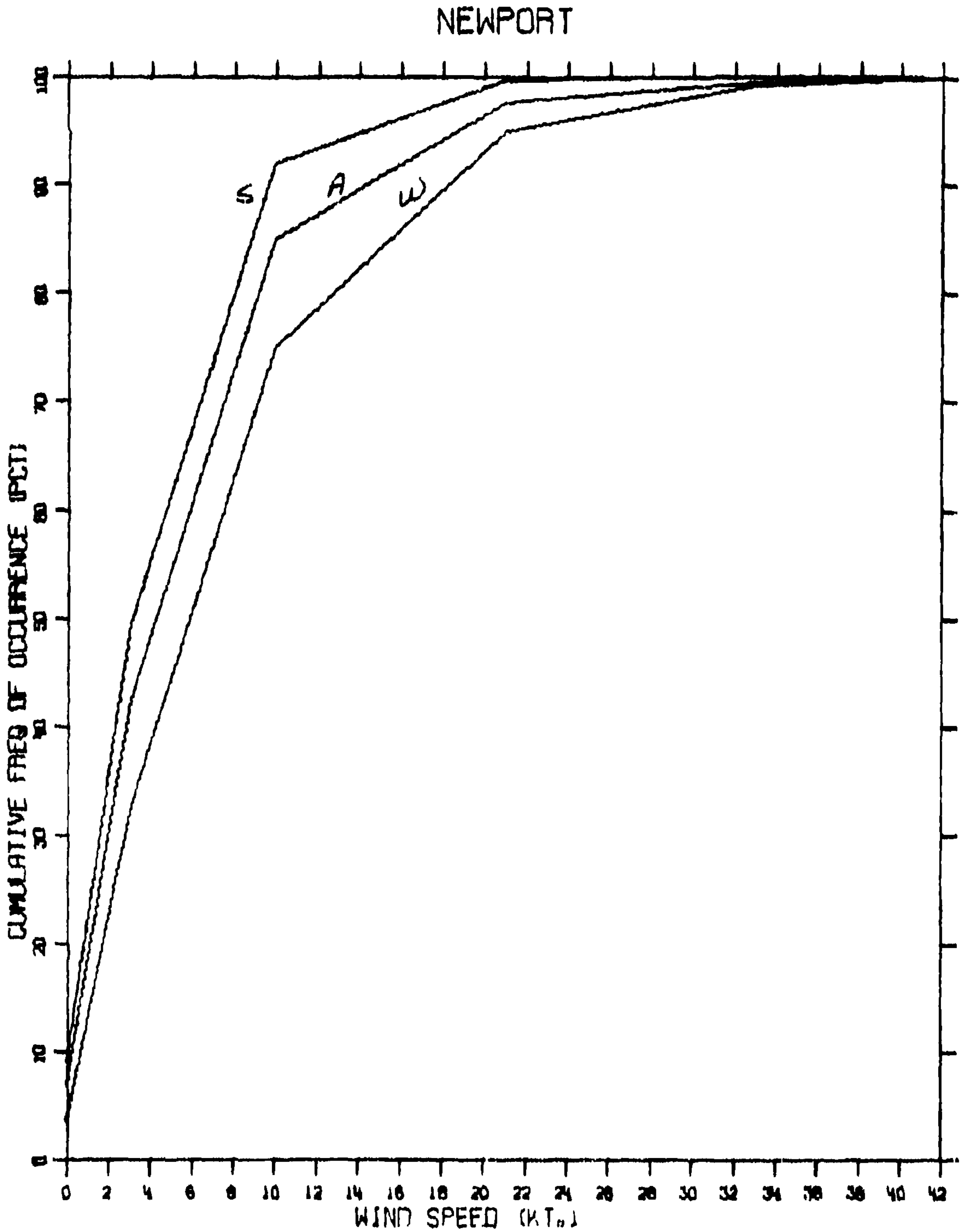
EUREKA

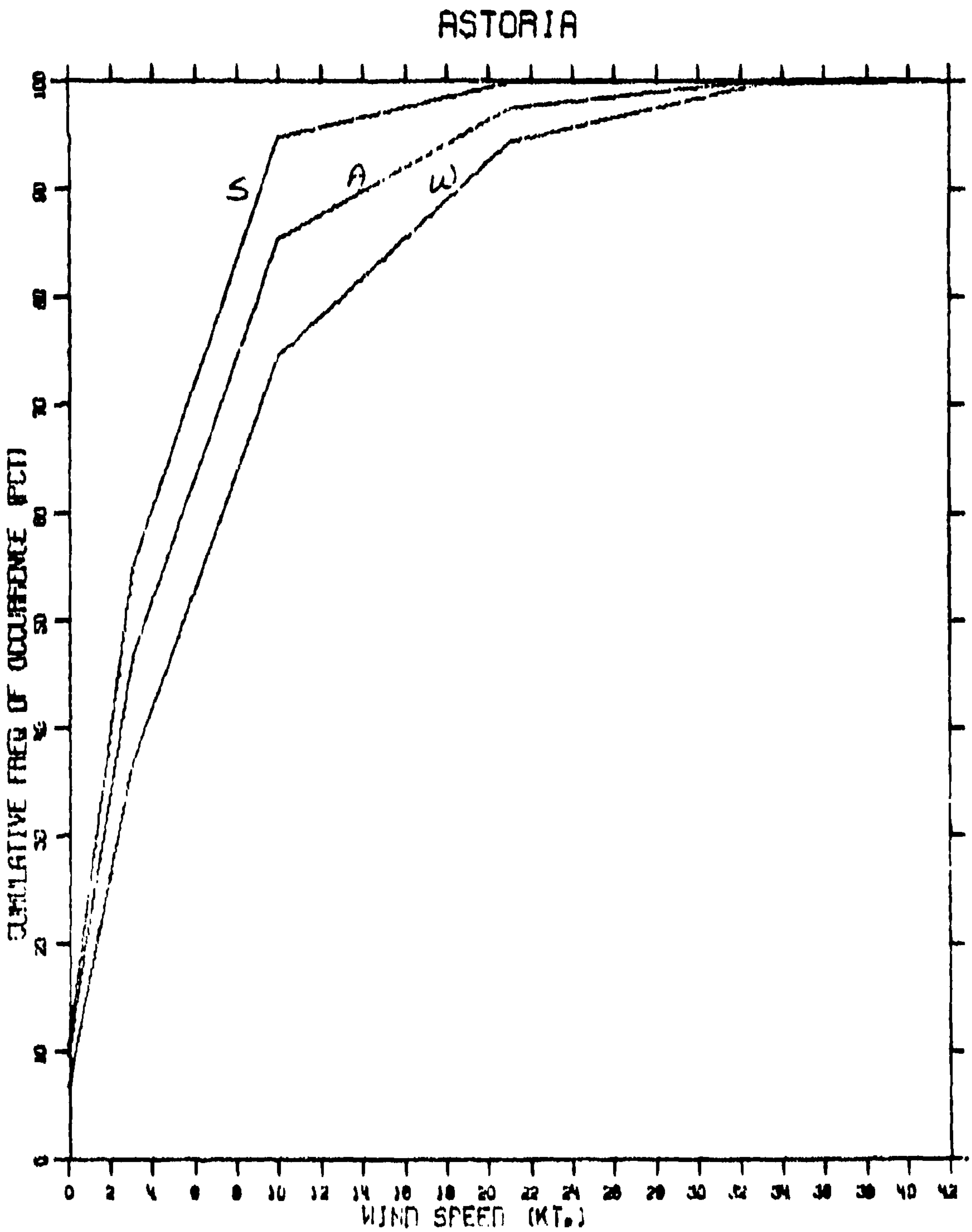


CUMULATIVE FREQ OF OCCURRENCE (PCT)
0
10
20
30
40
50
60
70
80
90
100
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42
WIND SPEED (KT.)

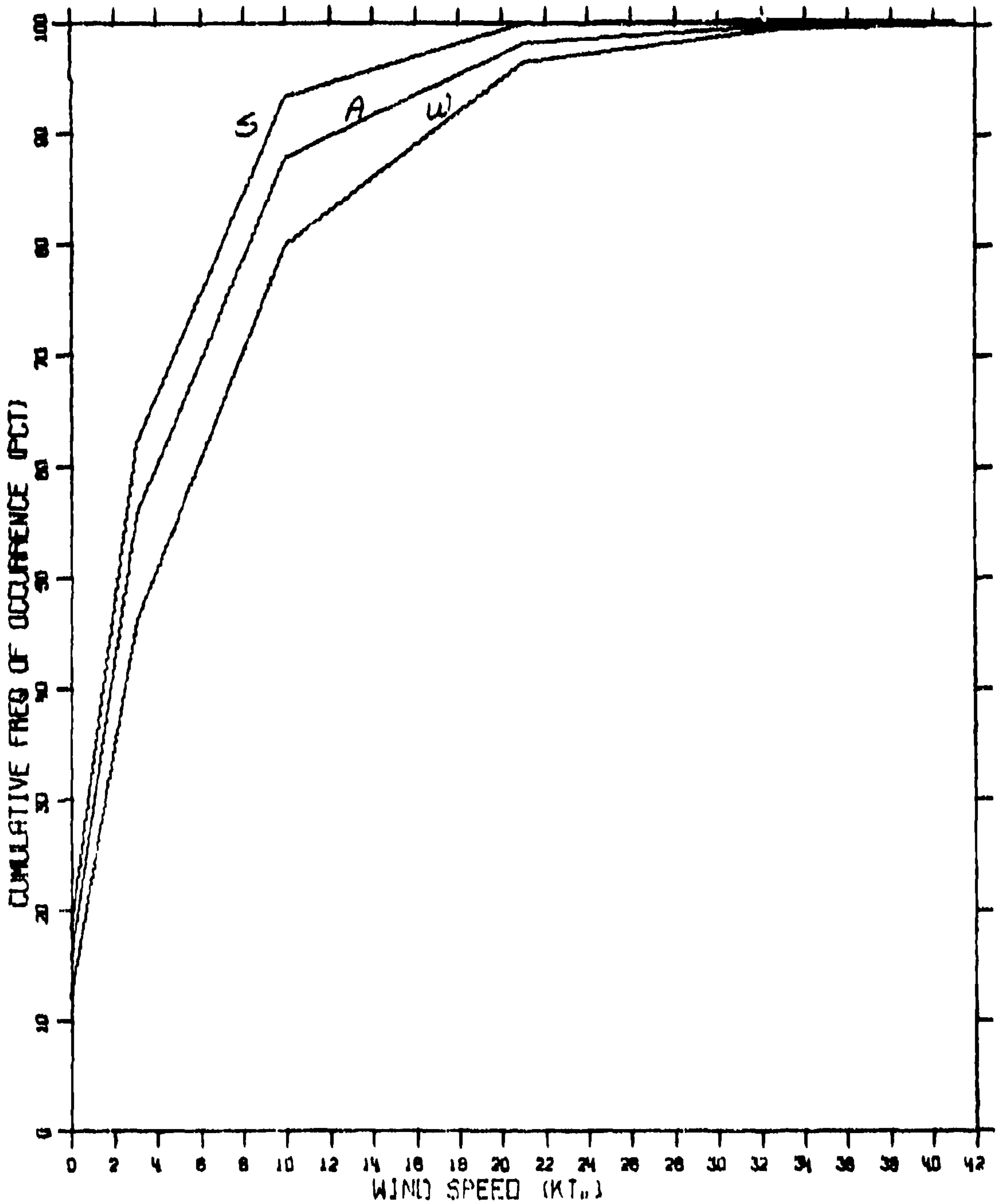
NORTH BEND




NEWPORT
CUMULATIVE FREQ OF OCCURRENCE (PCT)
WIND SPEED (KTS)
S
A
W


ASTORIA
CUMULATIVE FREQ OF OCCURRENCE (PCT)
100
90
80
70
60
50
40
30
20
10
0
S
A
W
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42
WIND SPEED (KT.)

SEATTLE



CUMULATIVE FREQ OF OCCURRENCE (PCT)
WIND SPEED (KT.)
S
A
W
0
10
20
30
40
50
60
70
80
90
100
0
2
4
6
8
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12
14
16
18
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22
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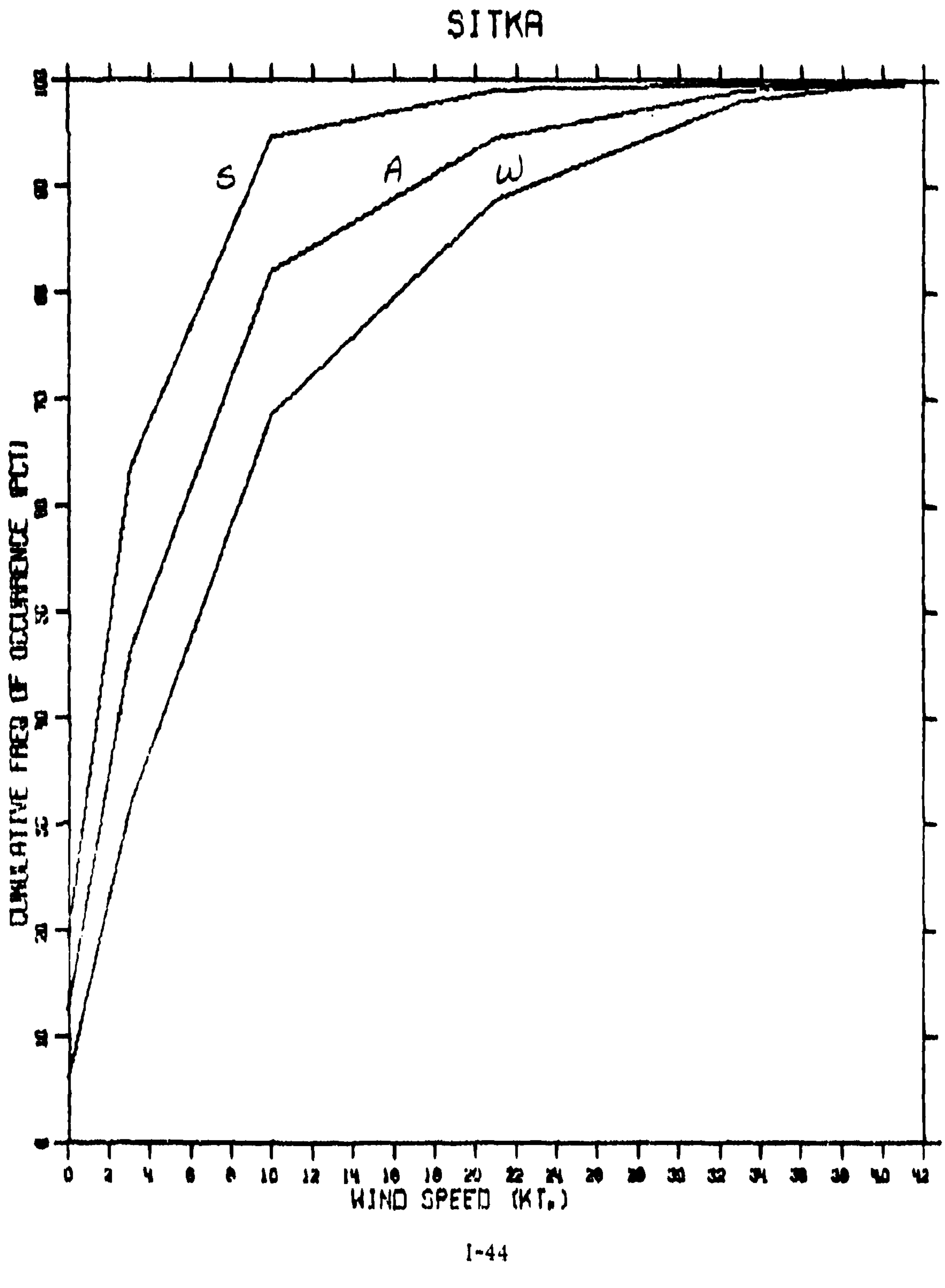
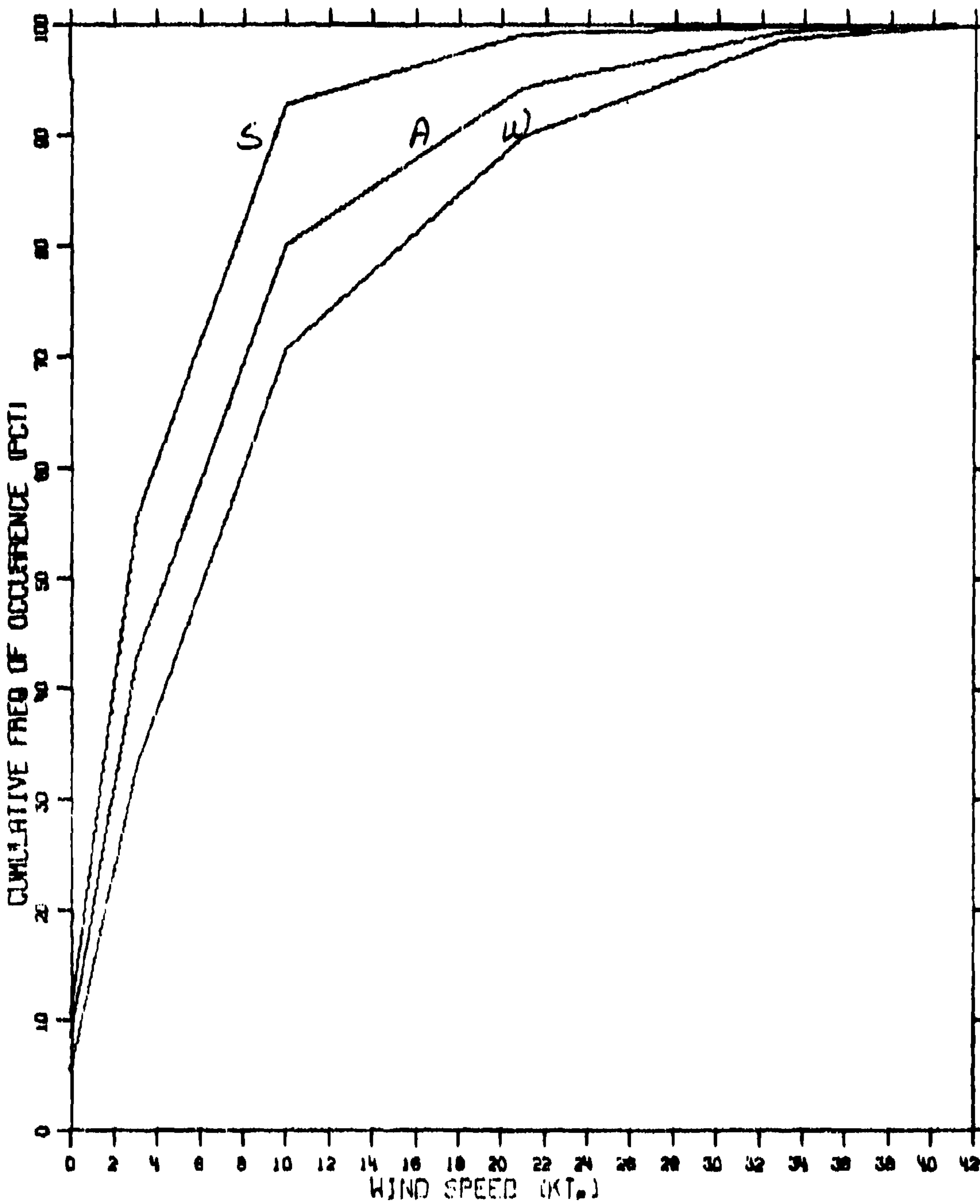
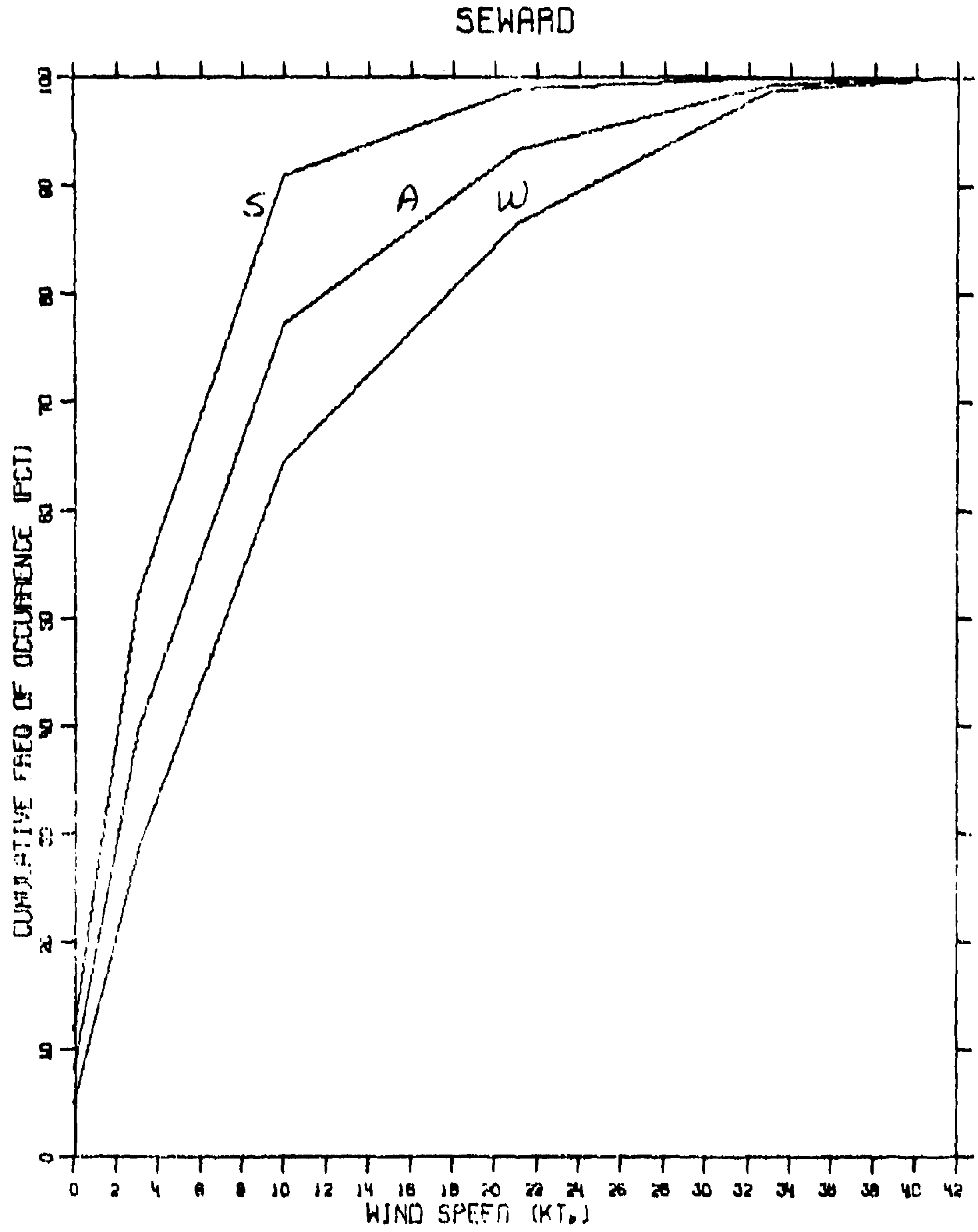
34
36
38
40
42



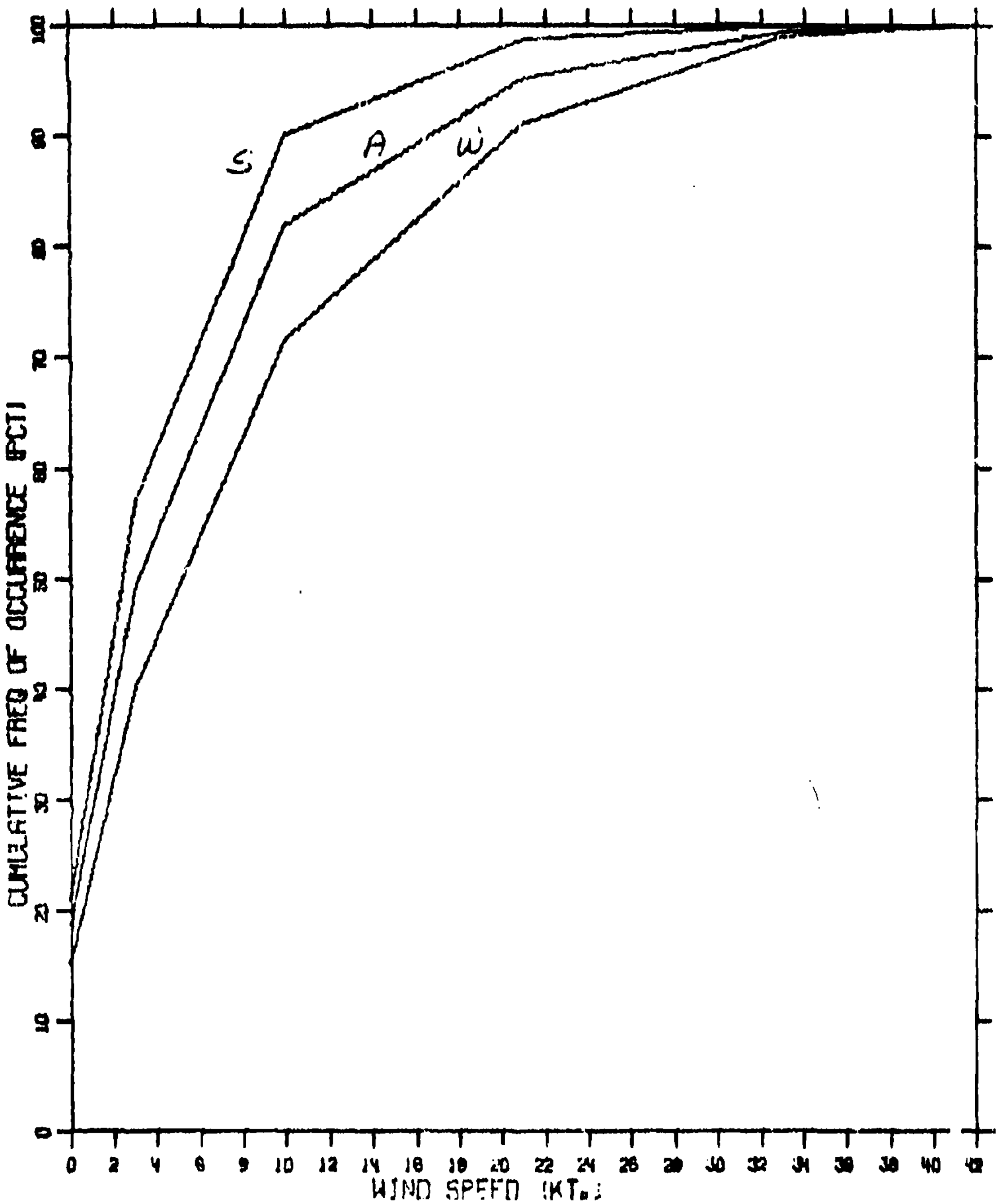
SITKA
S
A
W
CUMULATIVE FREQ OF OCCURRENCE (PCT)
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42
WIND SPEED (KT.)

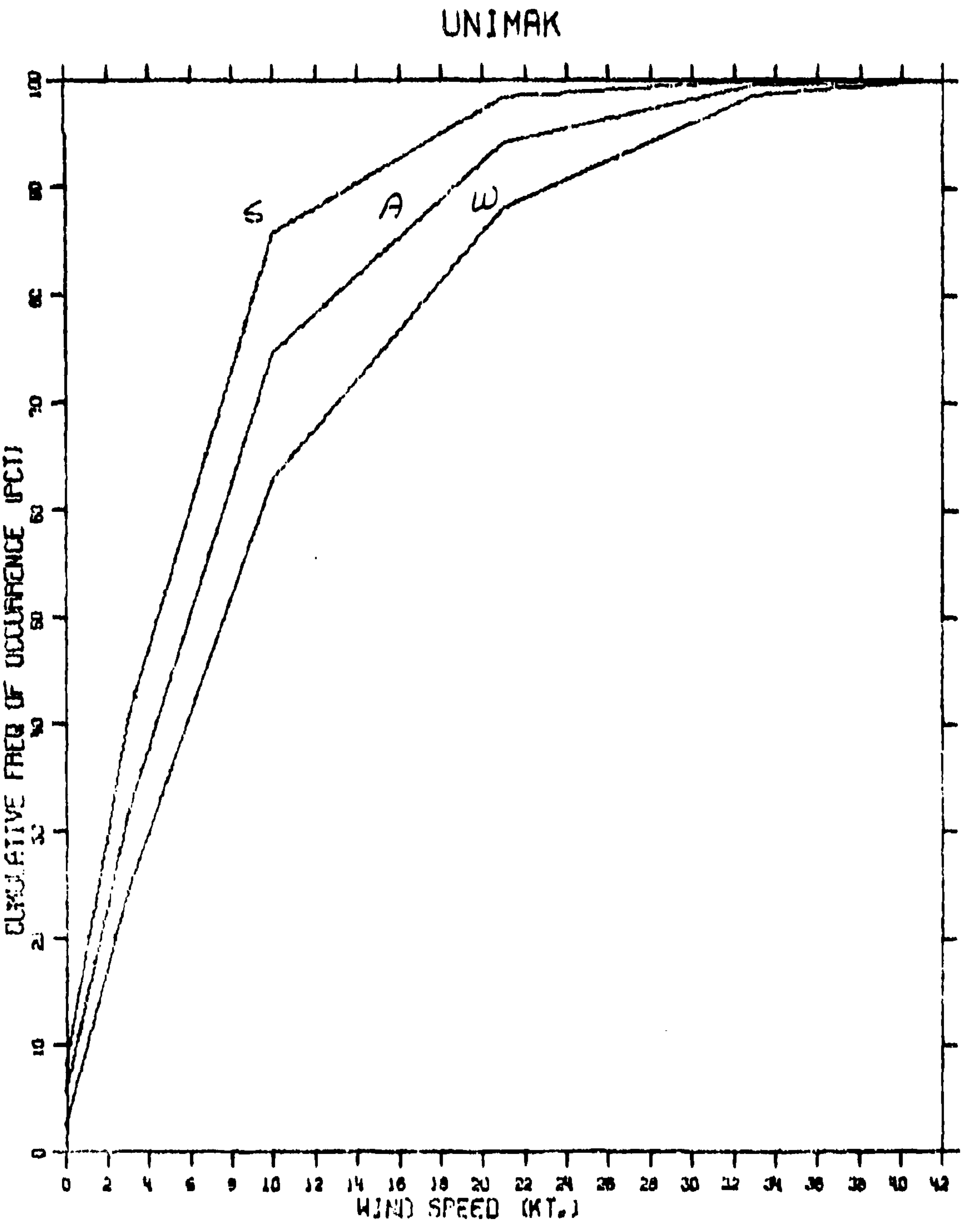
CORDOVA




SEWARD
CUMULATIVE FREQ OF OCCURRENCE (PCT)
WIND SPEED (KT.)
S
A
W
0
10
20
30
40
50
60
70
80
90
100
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42

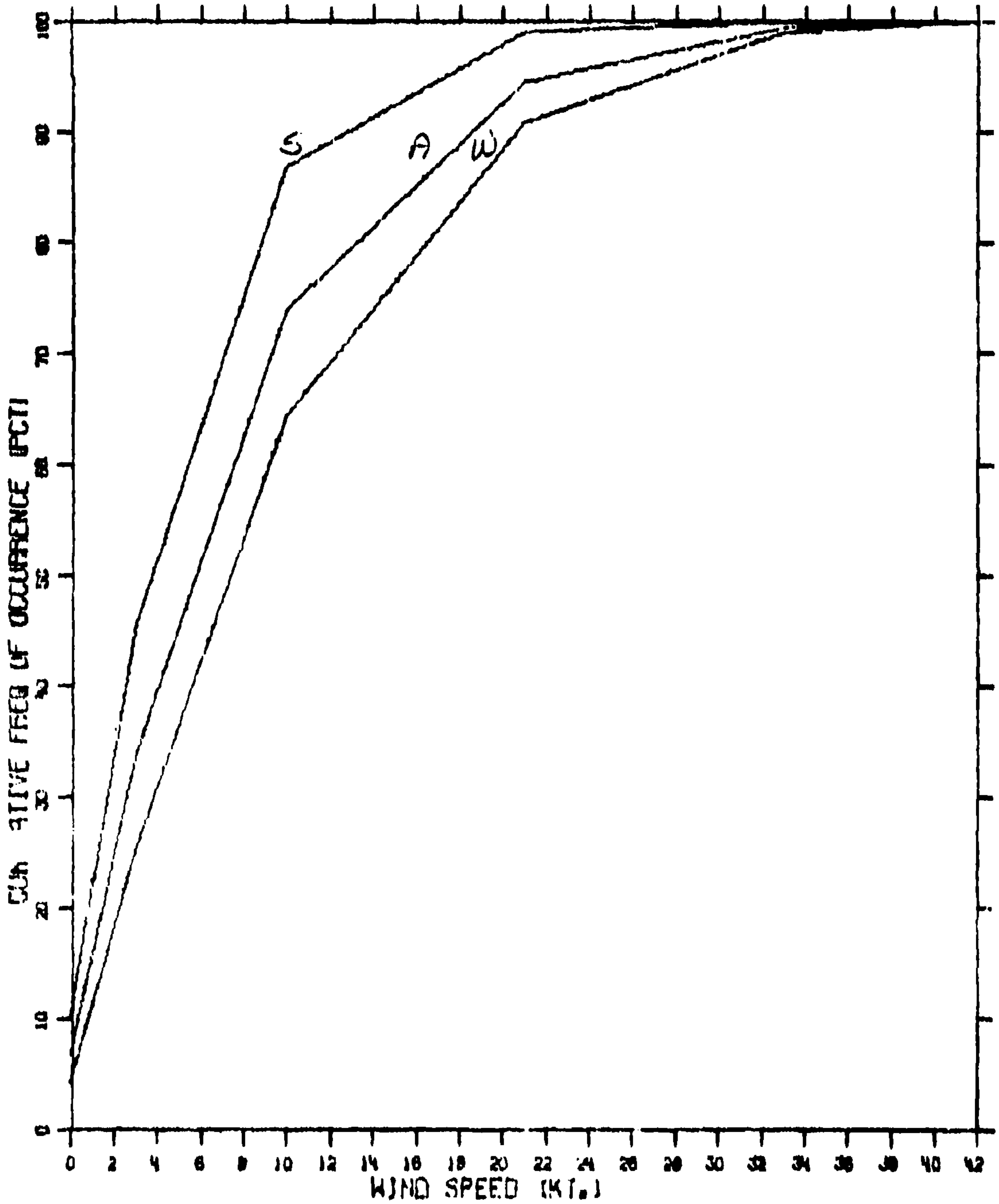
KODIAK

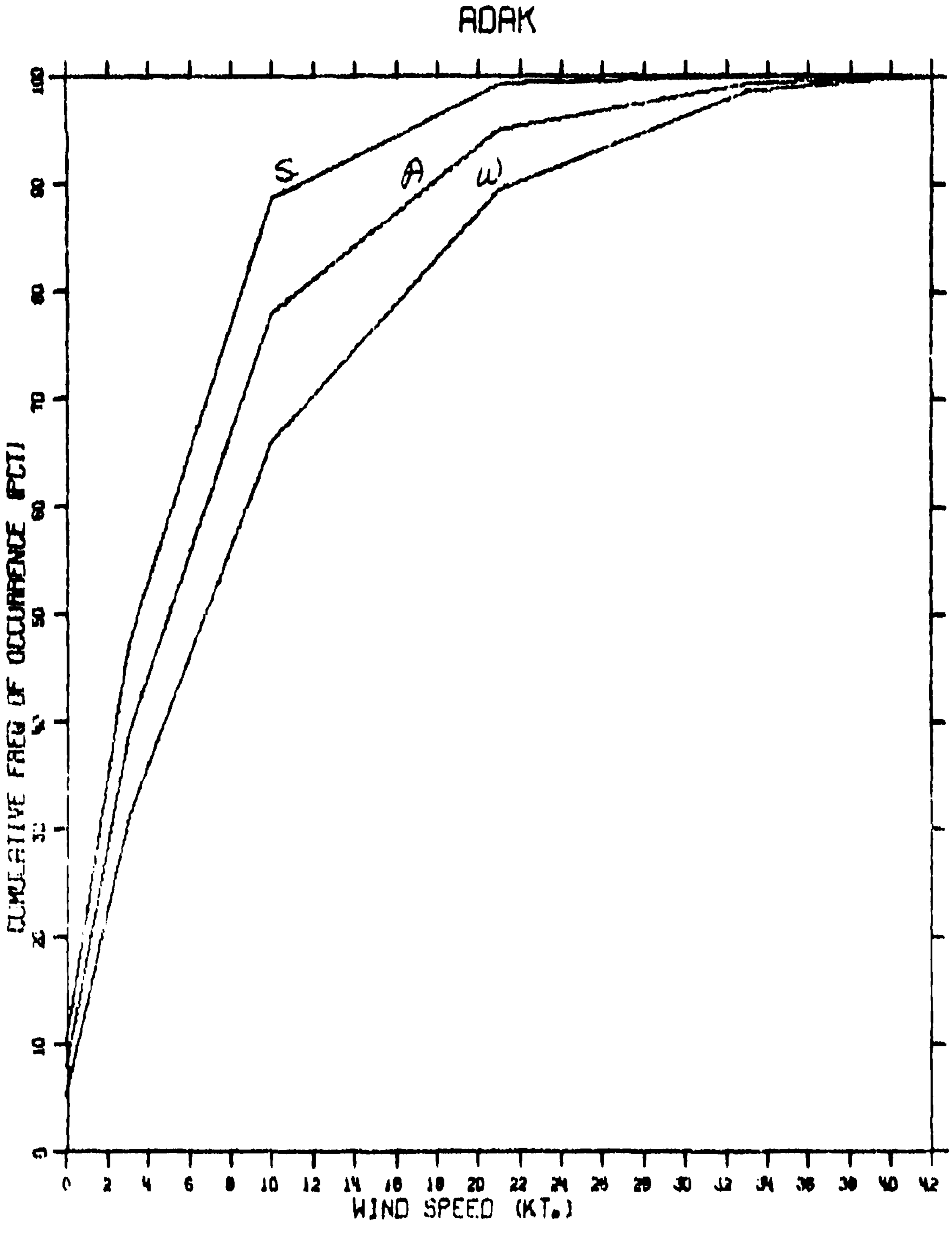




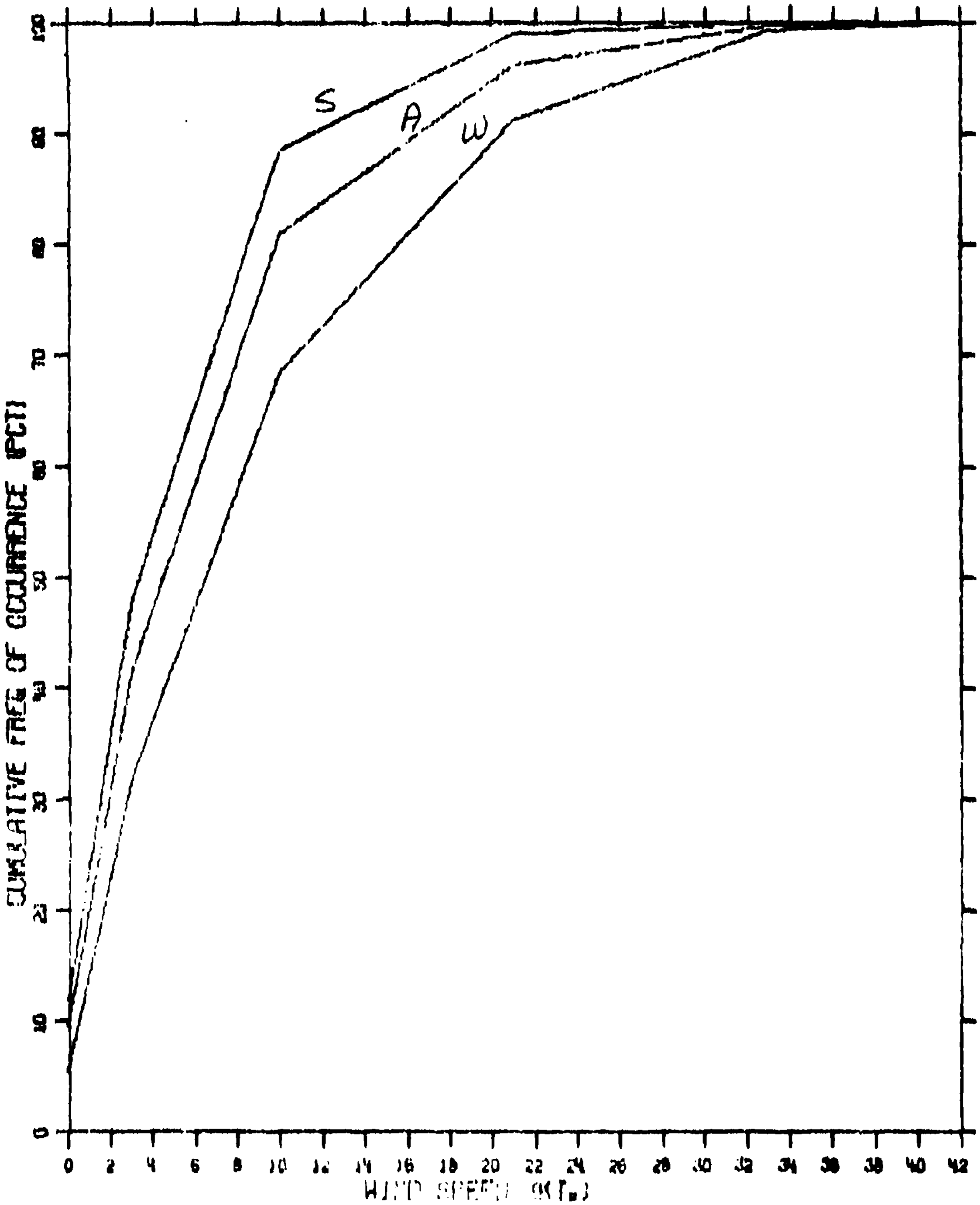
UNIMAK
CUMULATIVE FREQ OF OCCURRENCE (PCT)
WIND SPEED (KT.)
S
A
W

DUTCH HARBOR



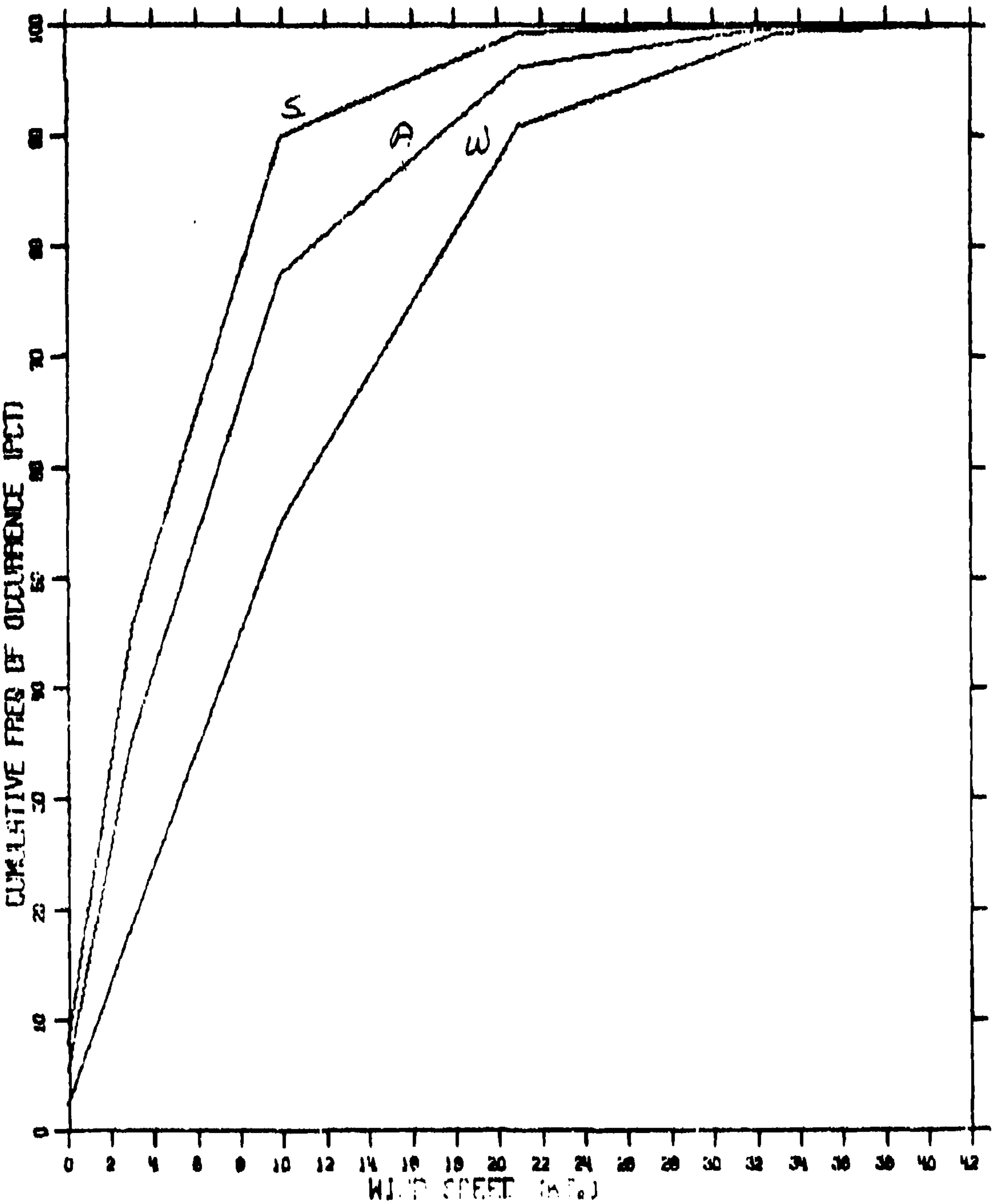

ADAK
S
A
W
CUMULATIVE FREQ OF OCCURRENCE (PCT)
WIND SPEED (KT.)

ATTU



S
A
W
CUMULATIVE FREQ OF OCCURRENCE (PCT)
0
10
20
30
40
50
60
70
80
90
100
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42
WIND SPEED (KTS)

ST. PAUL 180W



S
A
W
0
2
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6
8
10
12
14
16
18
20
22
24
26
28
30
32
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36
38
40
42
0
10
20
30
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50
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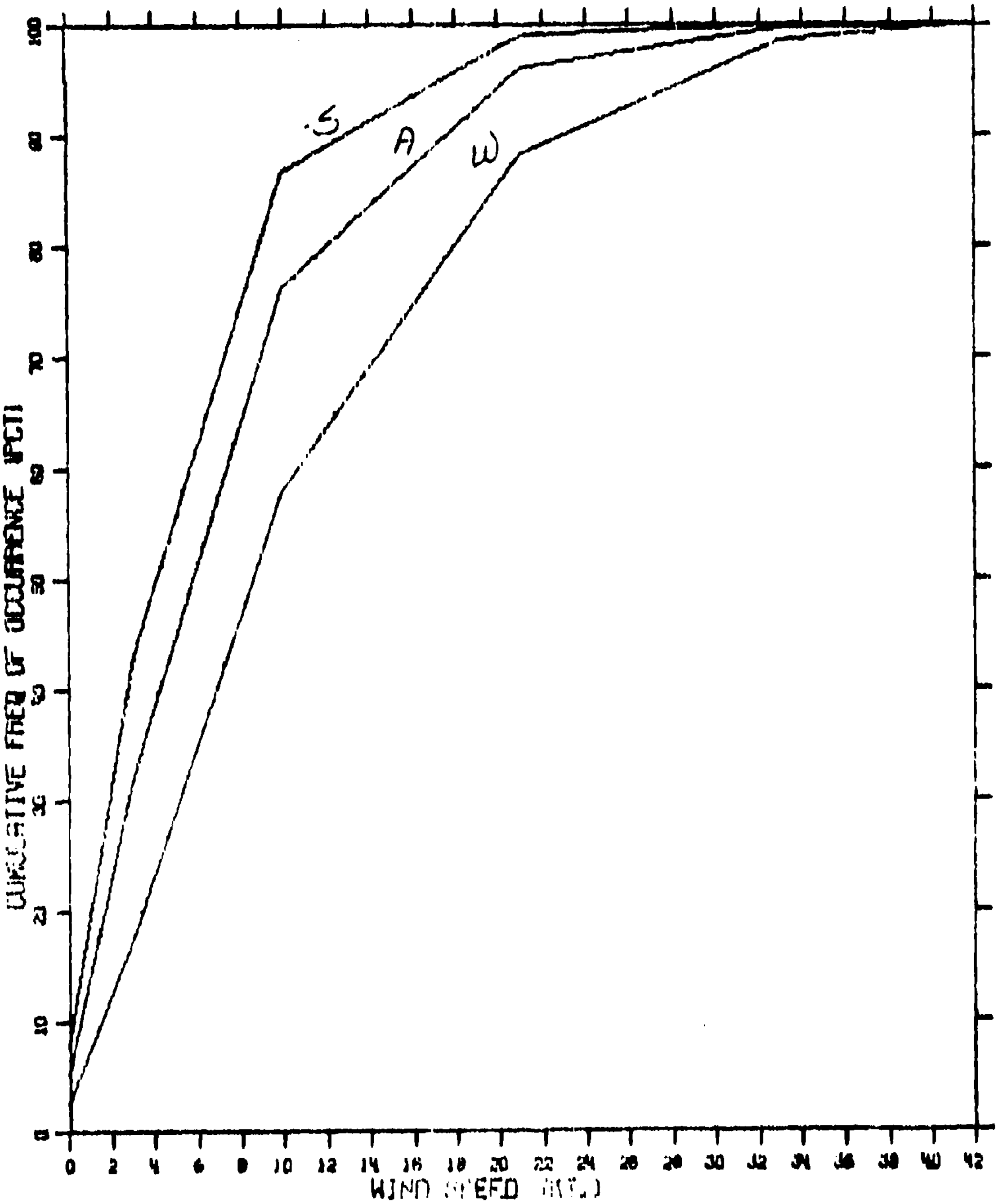
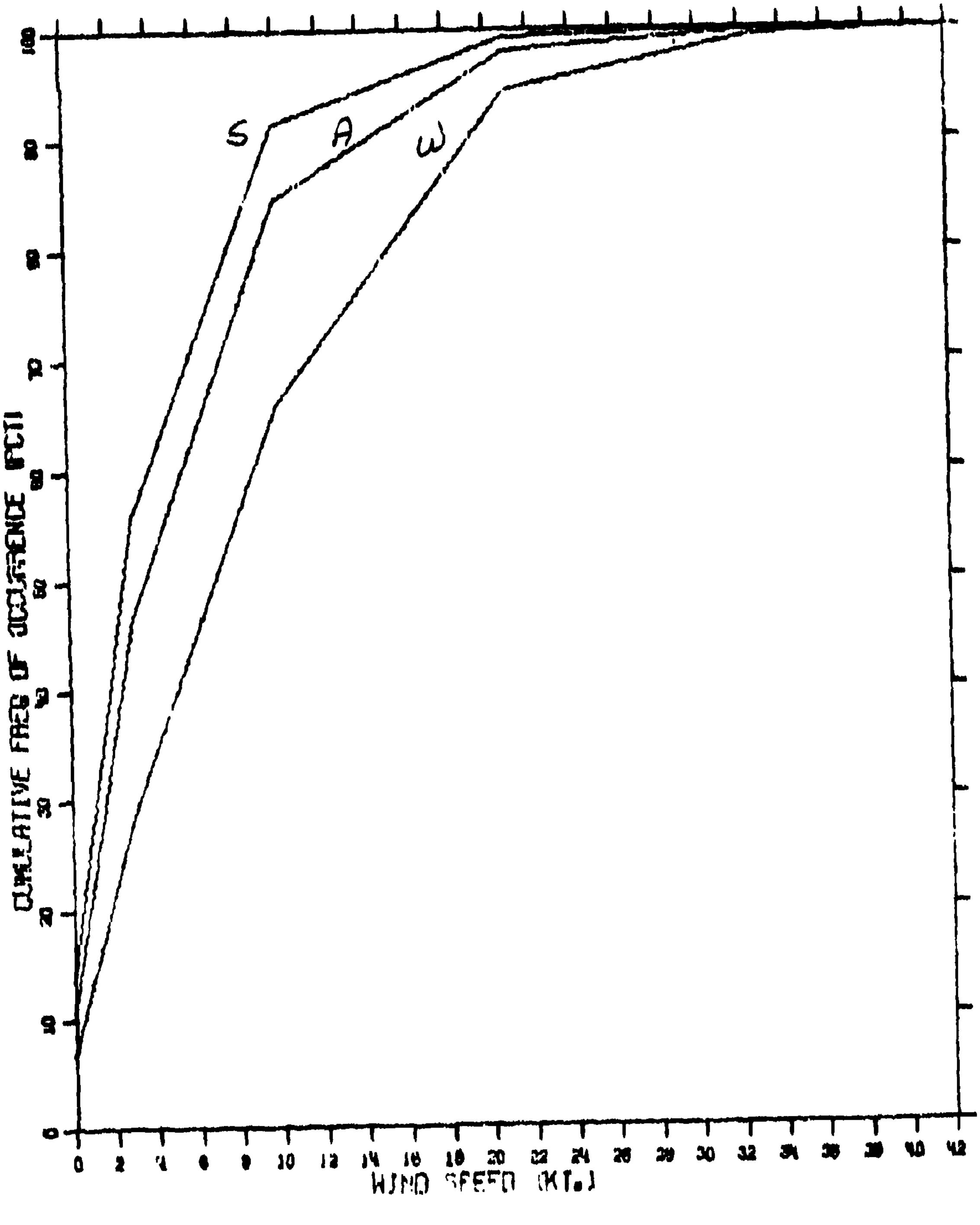
70
80
90
100

ST. PAUL



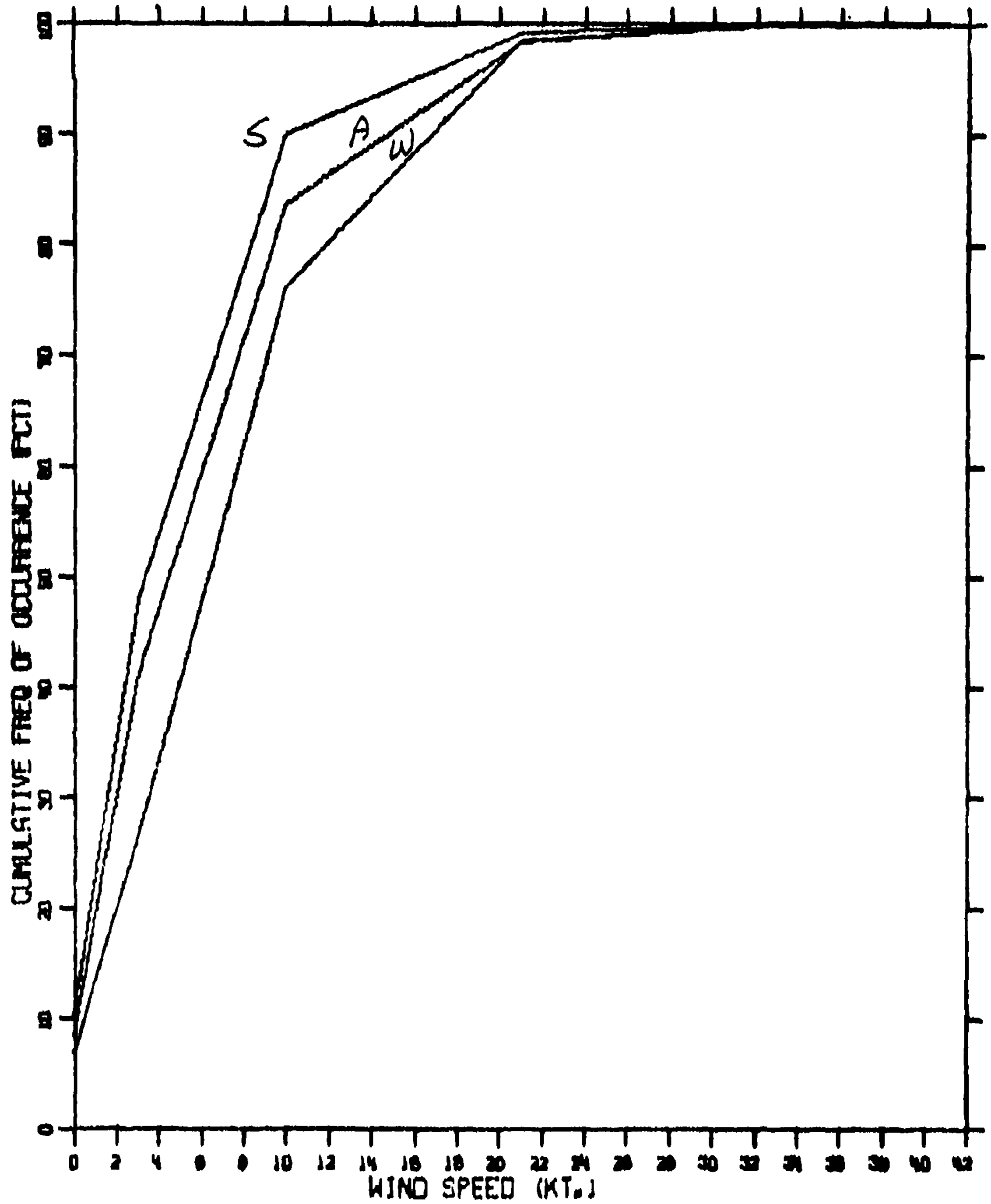
S
A
W
CUMULATIVE FREQ OF OCCURRENCE (PCT)
WIND SPEED (KTS)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42

BRISTOL BAY

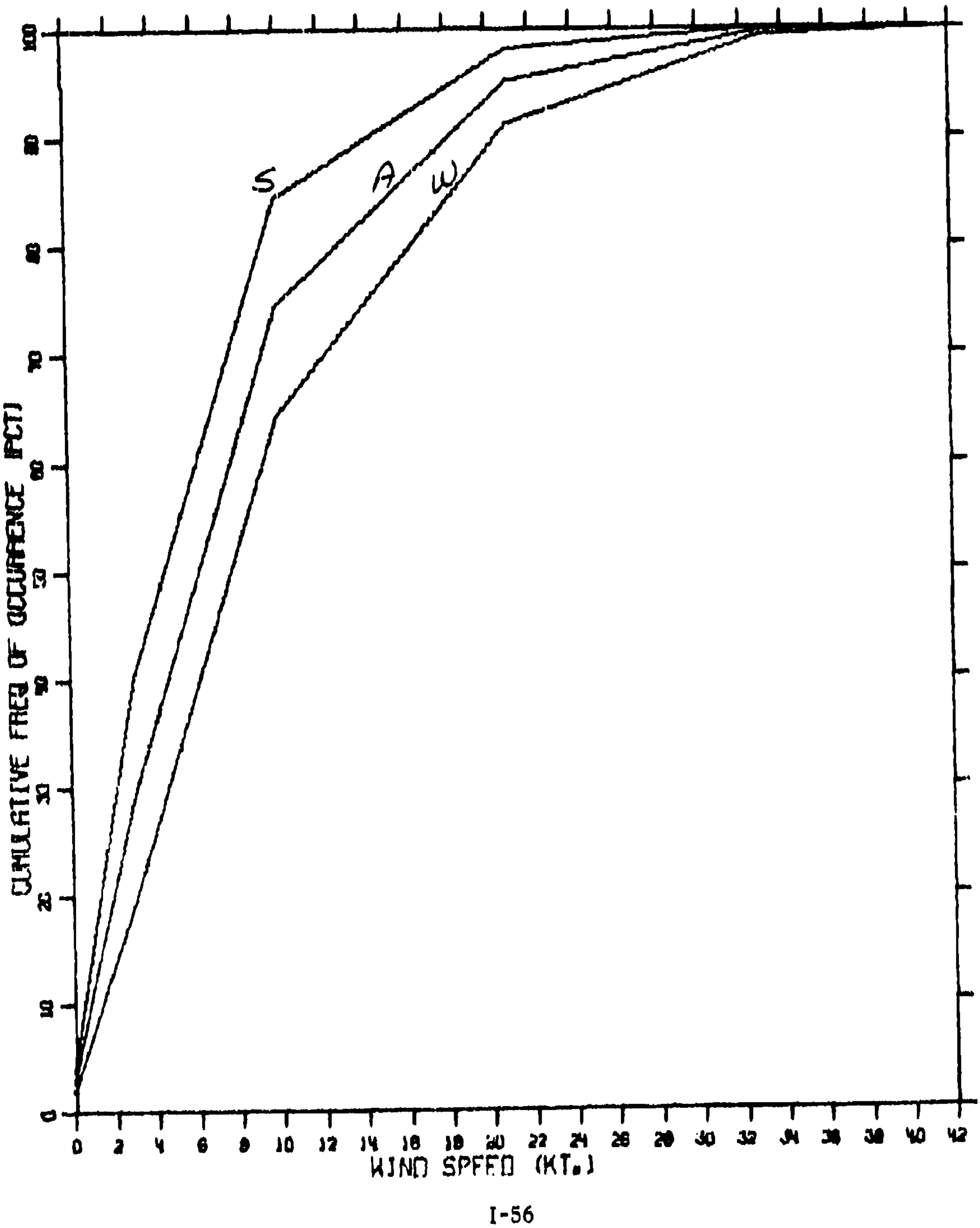


S
A
W
CUMULATIVE FREQ OF OCCURRENCE (PCT)
0
10
20
30
40
50
60
70
80
90
100
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42
WIND SPEED (KT.)

NUNIVAK

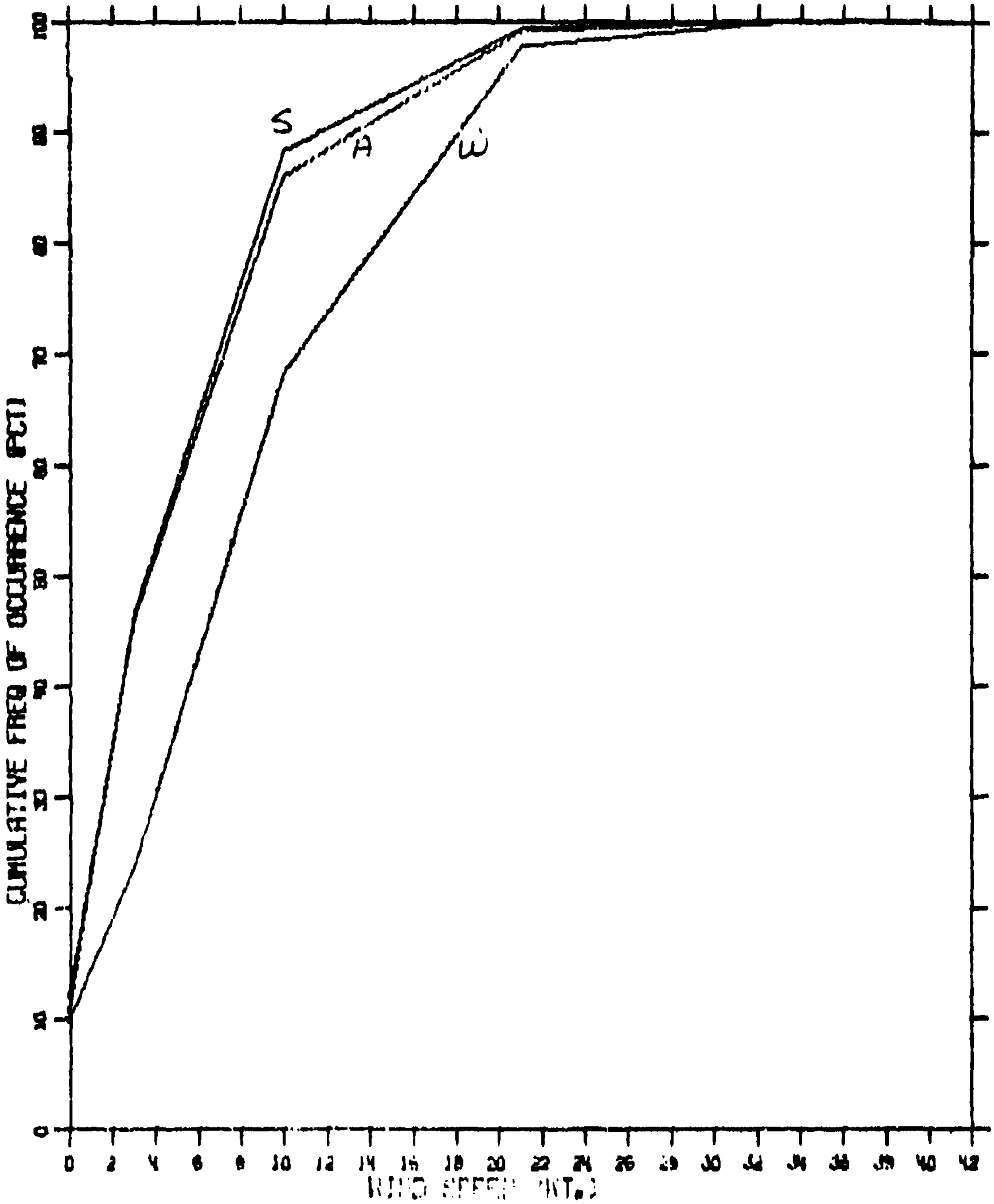

S
A
W
CUMULATIVE FREQ OF OCCURRENCE (PCT)
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42
WIND SPEED (KT.)

ST. MATTHEW



S
A
W
CUMULATIVE FREQ OF OCCURRENCE (PCT)
WIND SPEED (KT.)
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42

ST. LAWRENCE



ANNEX I-2

HIGH ALTITUDE WIND DISTRIBUTIONS FOR SELECTED U.S. COASTAL AREAS

This annex presents wind distributions at various altitudes for selected U.S. coastal areas. Figures I-2-1 and I-2-2 show the locations of these areas.

Data for these distributions were obtained from the Winds Aloft Summary published by the Air Weather Service. The summaries are prepared from winds aloft observations taken by pibal, rocket and/or rawin methods by month for a period of 10-20 years.

A simple computer model was developed to accumulate the monthly data and plot it as cumulative frequency of occurrence versus wind speed (in knots). Figure I-2-3 shows the 90th percentile distribution for all of the areas. Points on this figure and on individual plots are labeled "W" for winter months (December, January, February), "Sp" for Spring (March, April, May), "S" for Summer (June, July, August), and "F" for Fall (September, October, November).

Individual plots have altitudes labeled in either meters or millibars. For convenience to the reader, these have been converted to feet at standard atmosphere and are shown in parentheses at the top of each plot.

FIG. I-2-1: LOCATIONS OF WEATHER STATIONS PROVIDING WIND DISTRIBUTION DATA

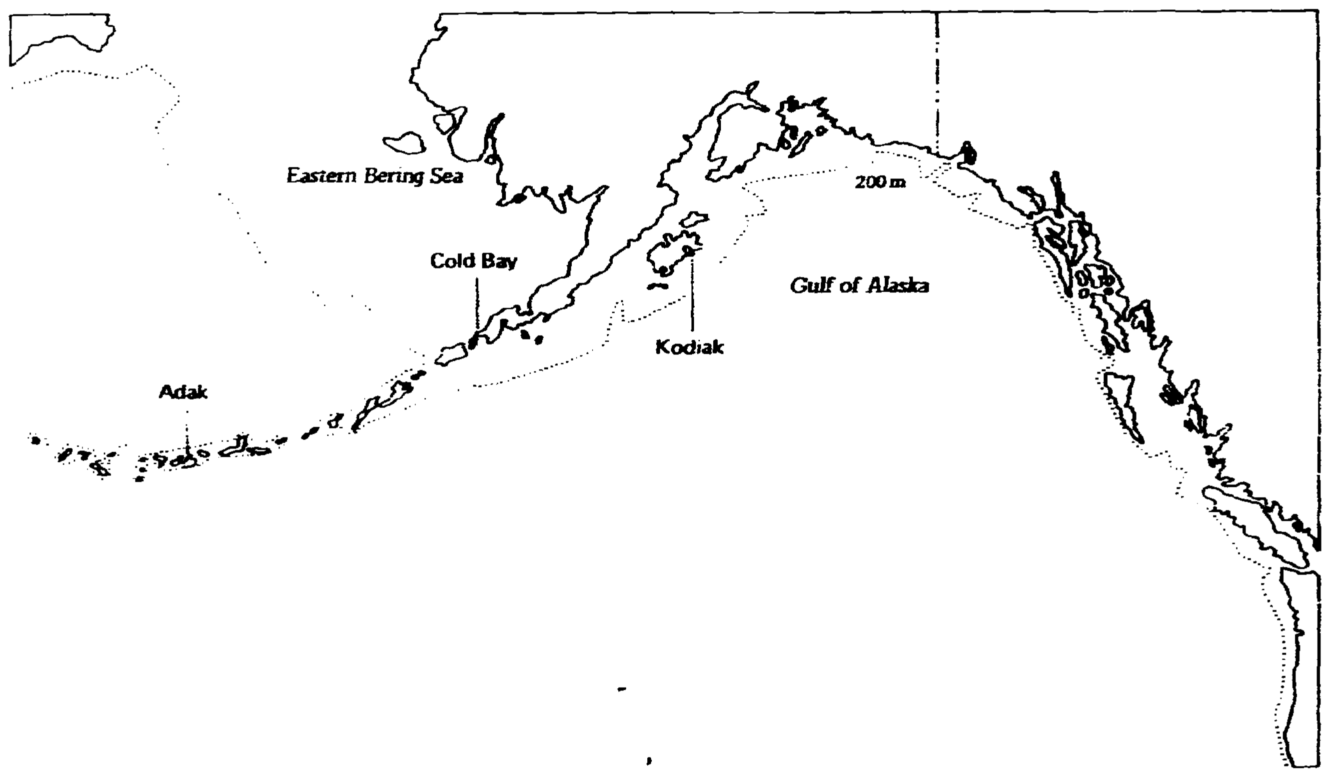


FIG. I-2-2: ALASKAN WEATHER STATIONS PROVIDING WIND DISTRIBUTION DATA

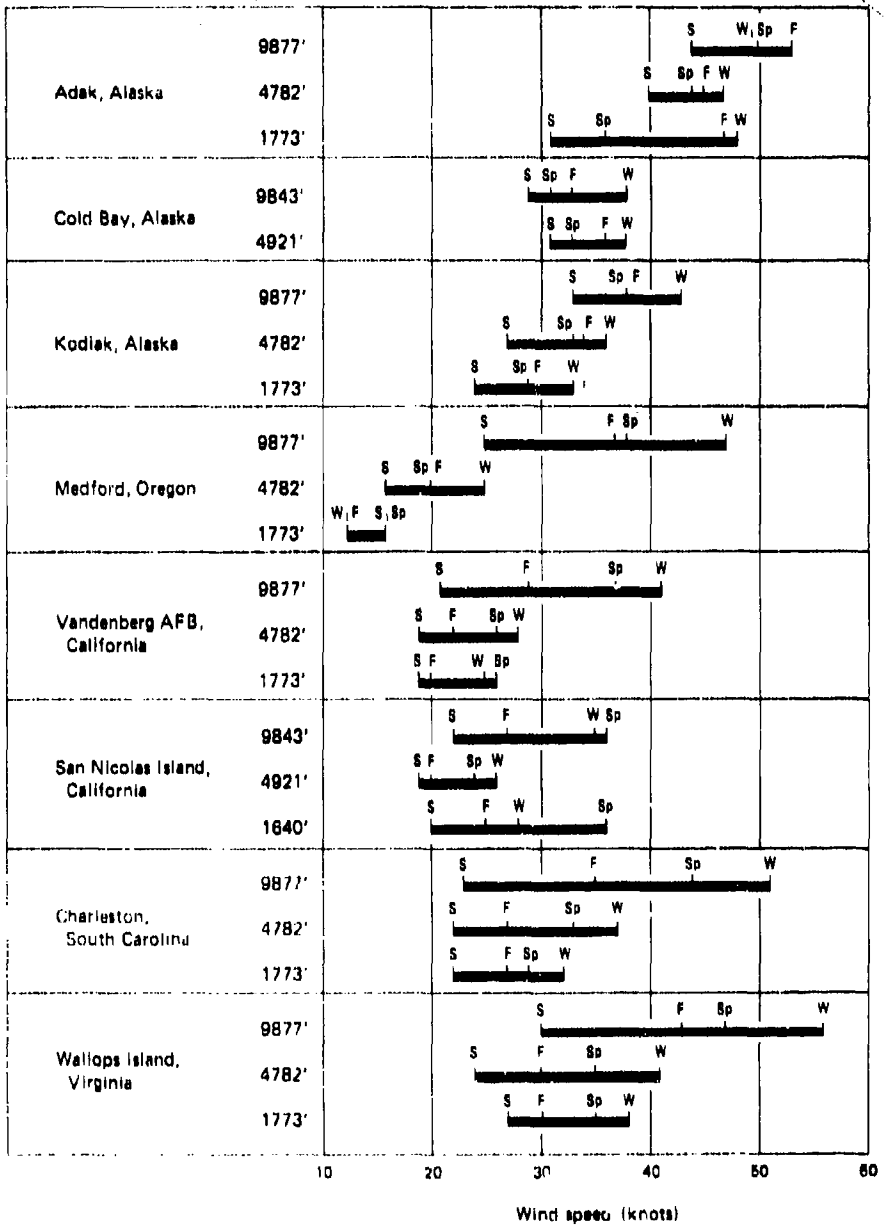
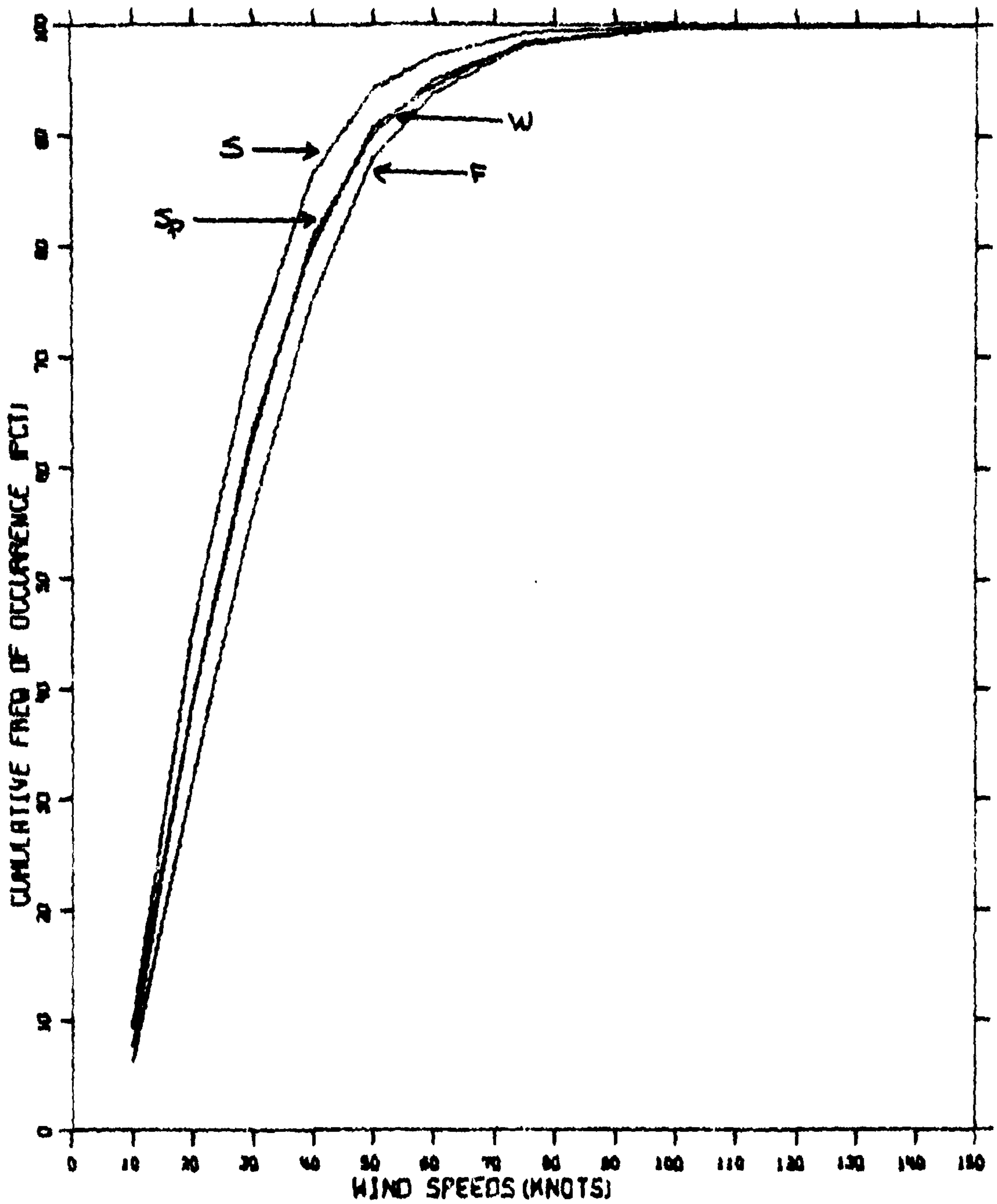
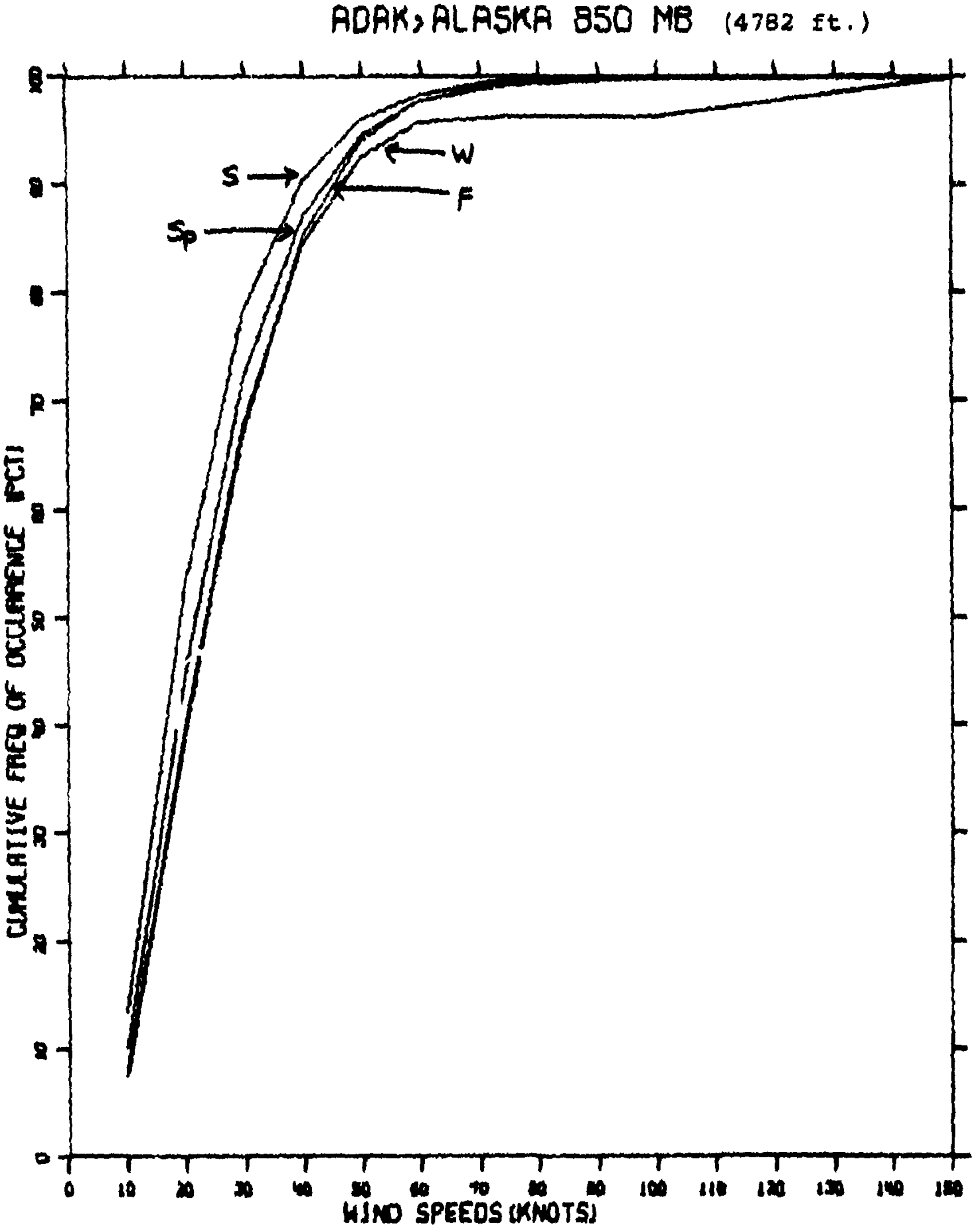


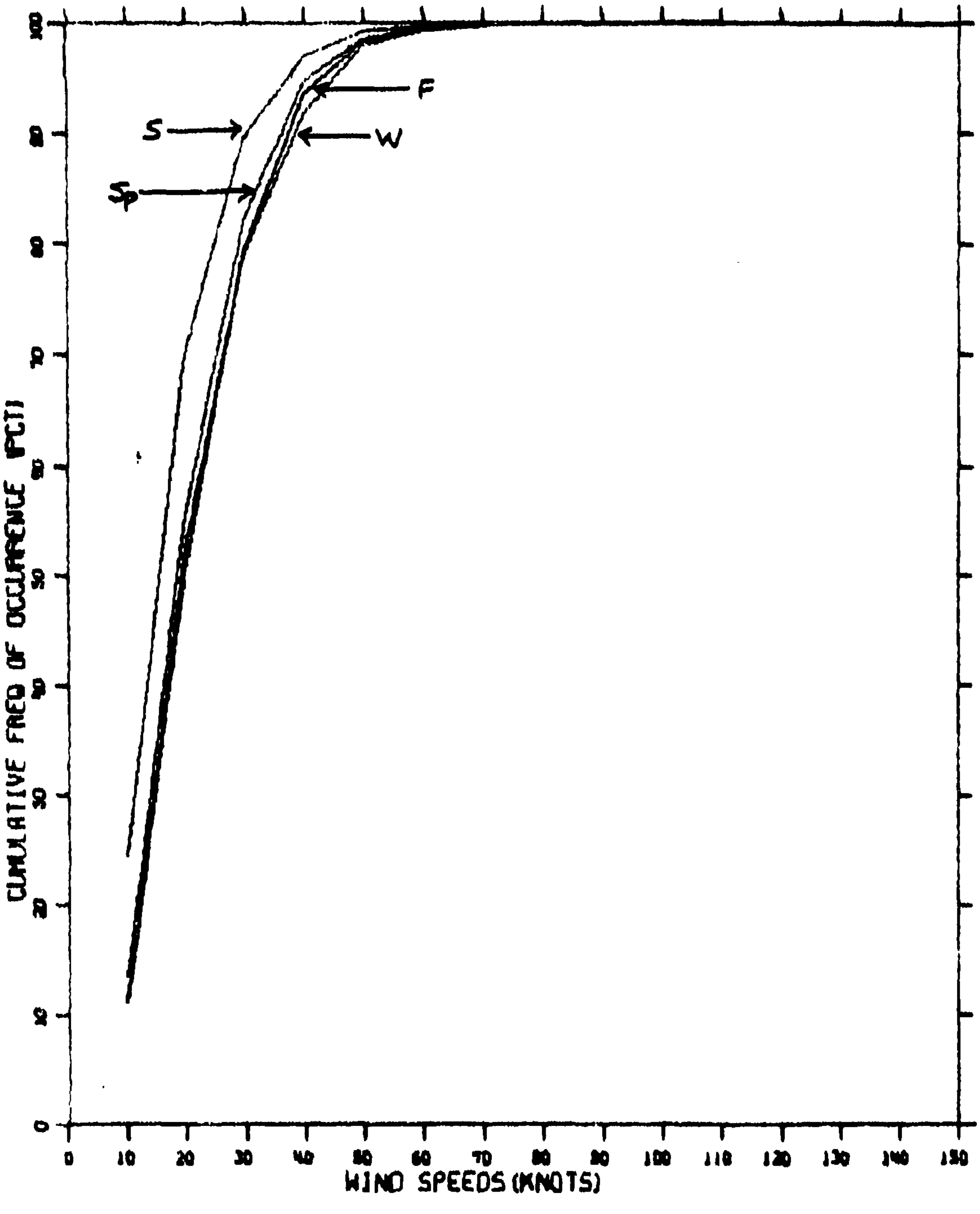
FIG. I-2-3: 90th PERCENTILE DISTRIBUTION

ADAK, ALASKA 700 MB (9877 ft.)

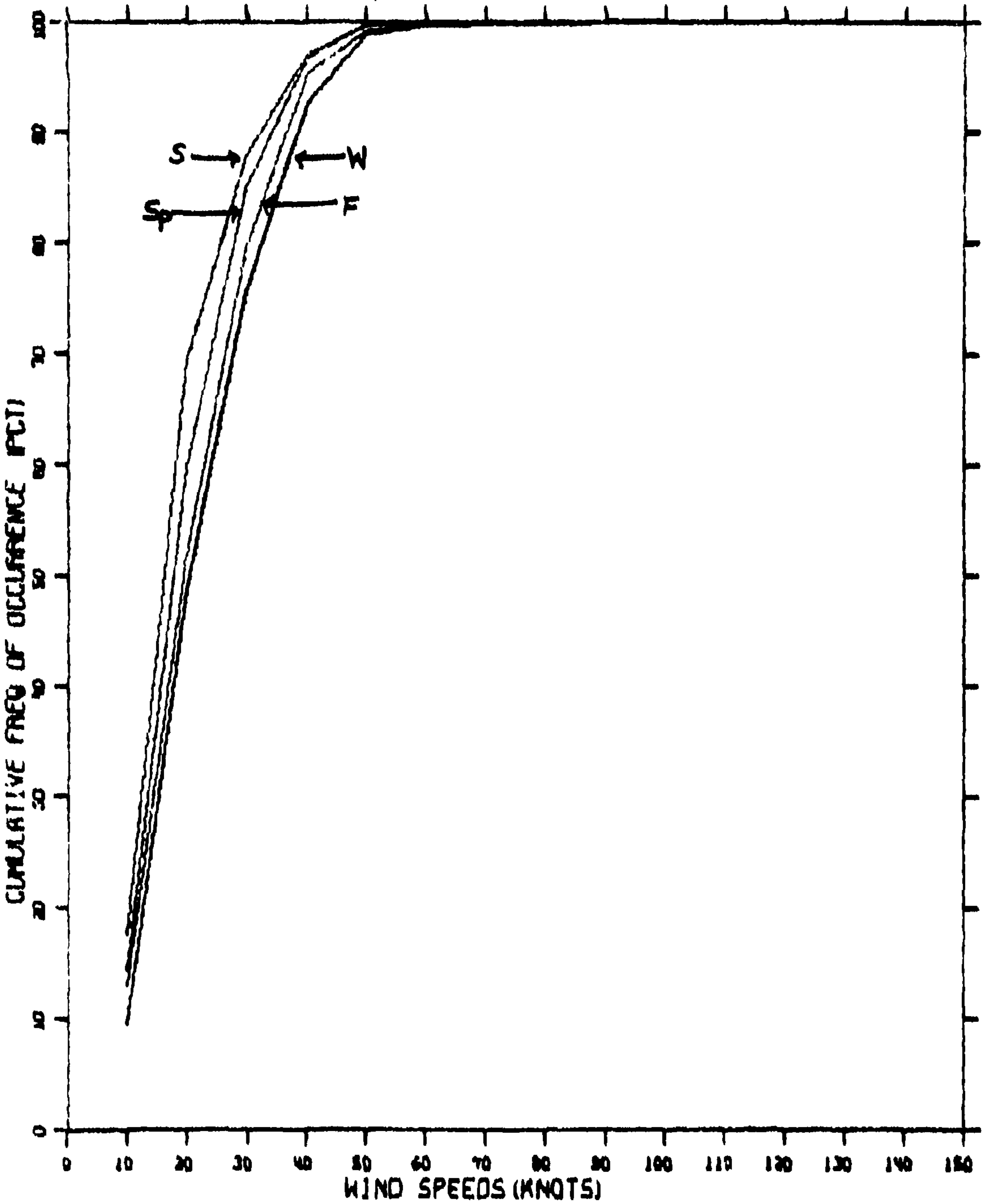



ADAK, ALASKA 850 MB (4782 ft.)
S
Sp
W
F
CUMULATIVE FREQ OF OCCURRENCE (PCT)
WIND SPEEDS (KNOTS)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150

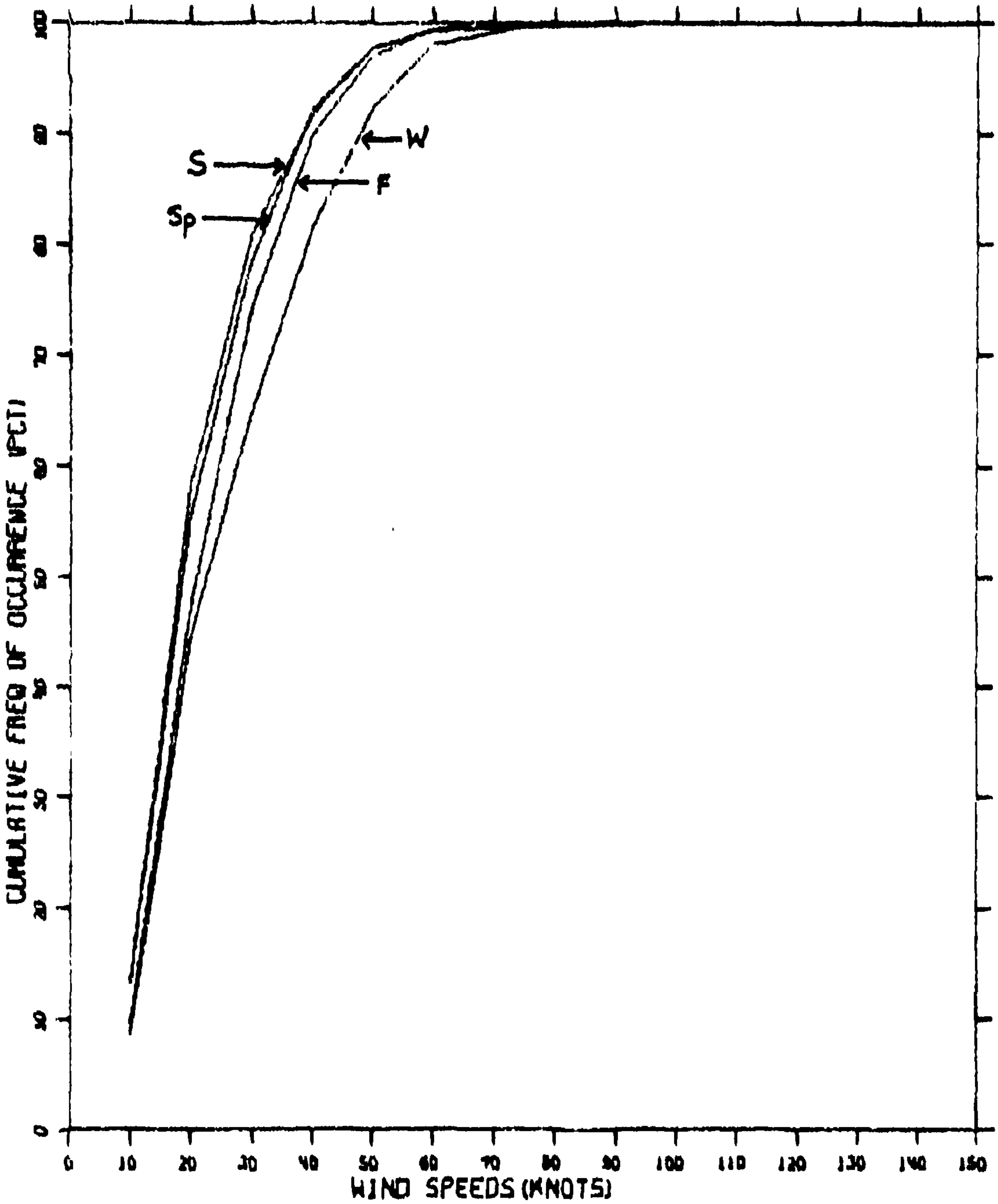
ADAK, ALASKA 950 MB (1773 ft.)



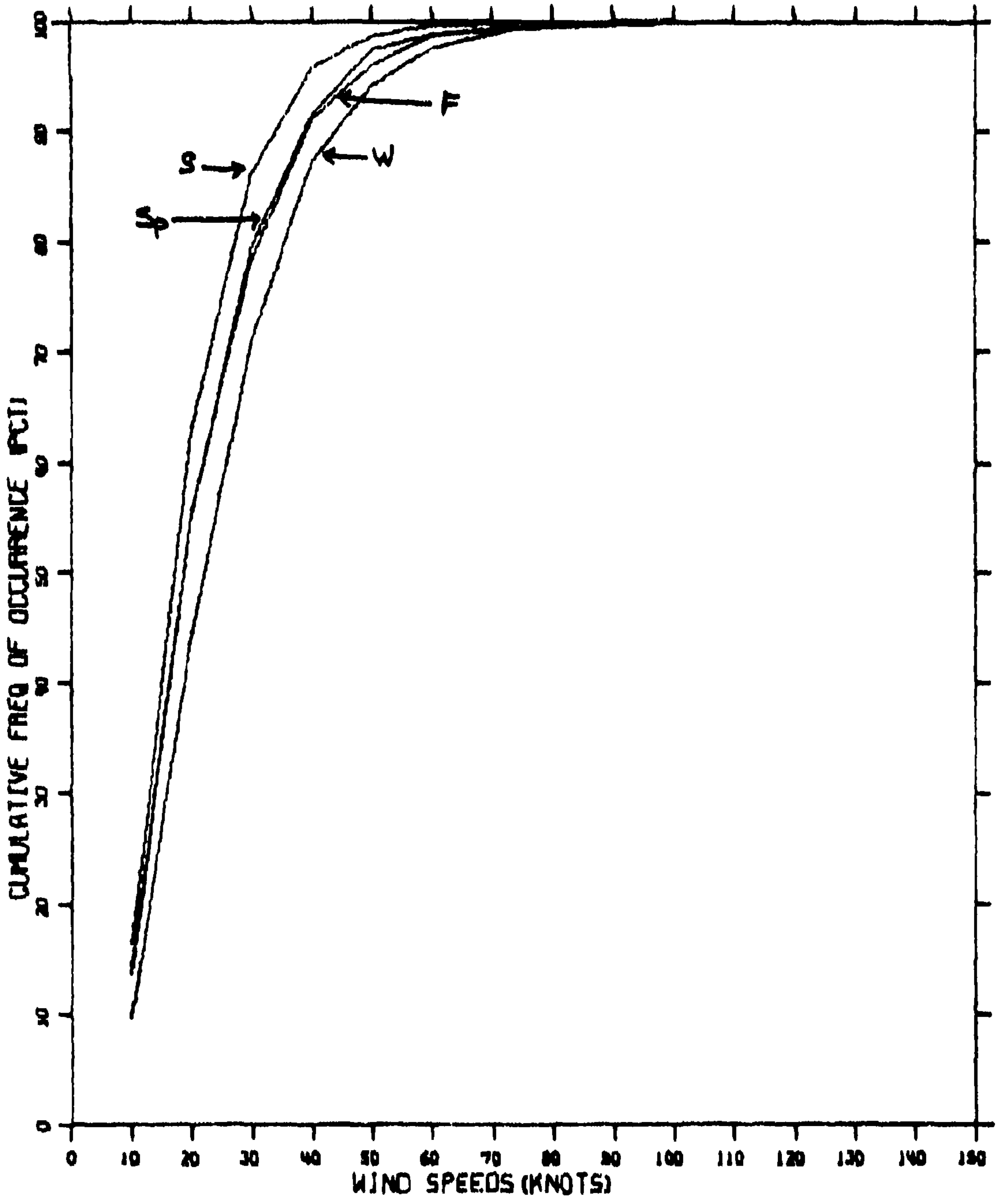
COLD BAY, ALASKA 1500 M (4921 ft.)



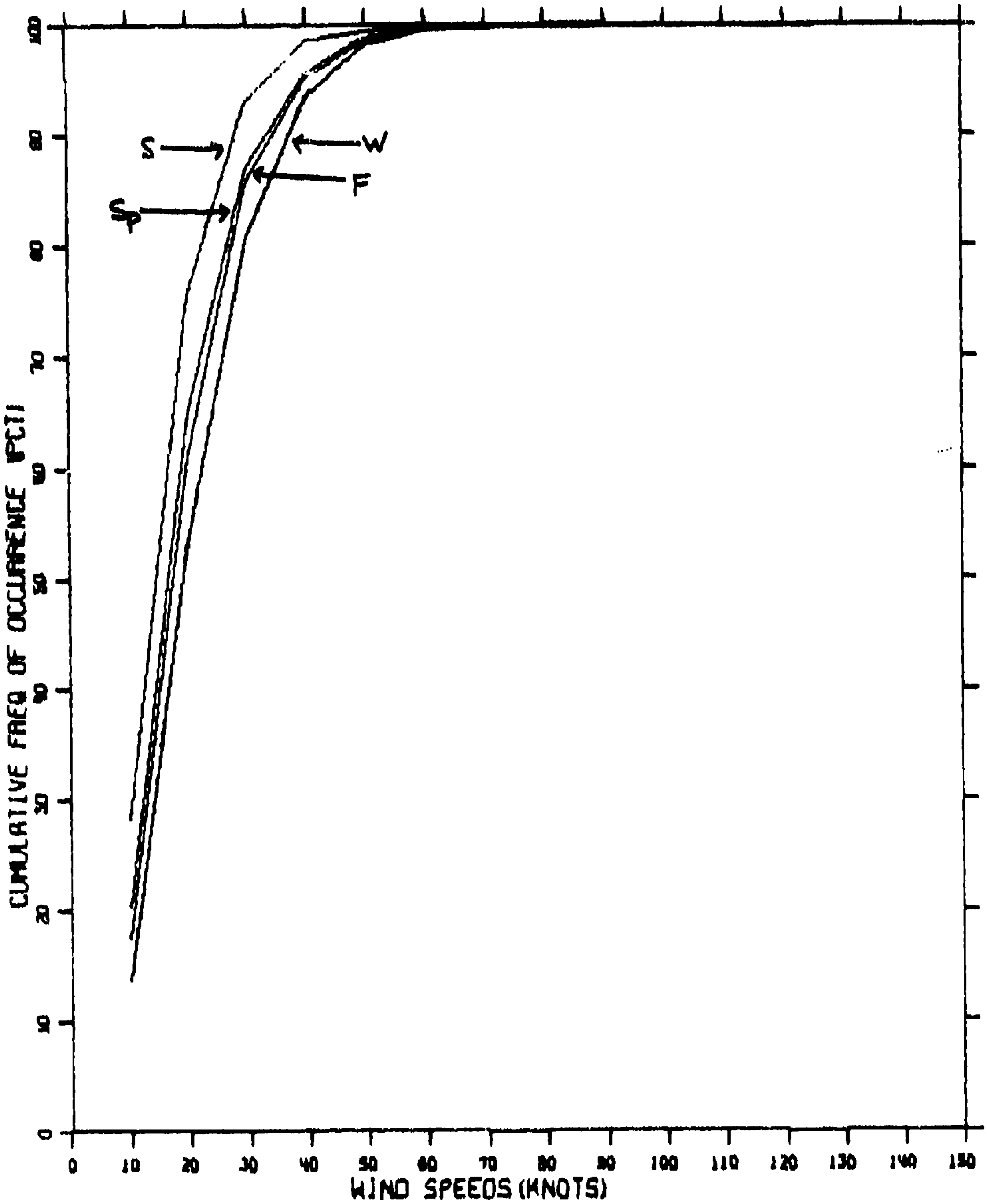
COLD BAY, ALASKA 3000 M (9843 ft.)



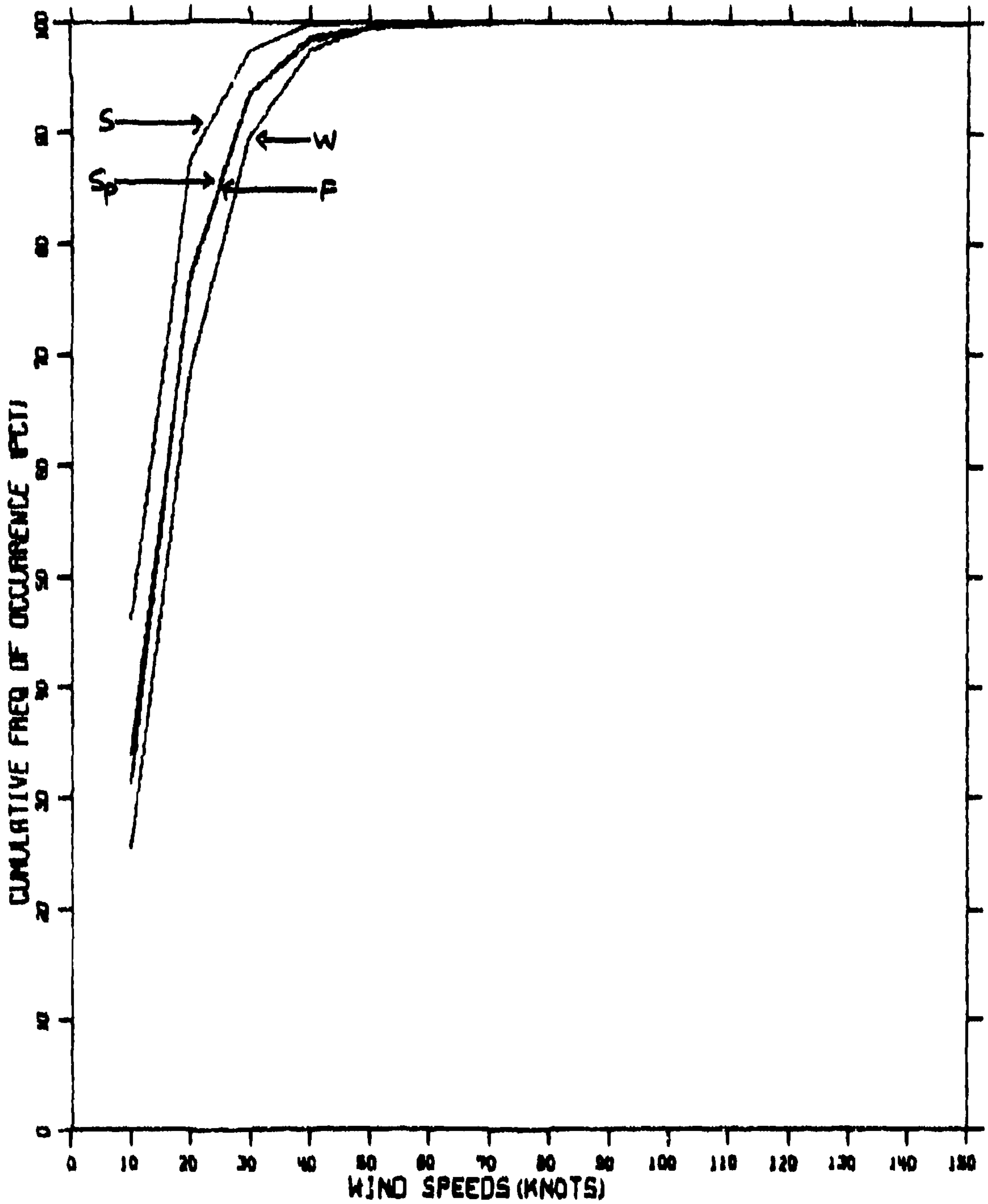
KODIAK, ALASKA 700 MB (9877 ft.)

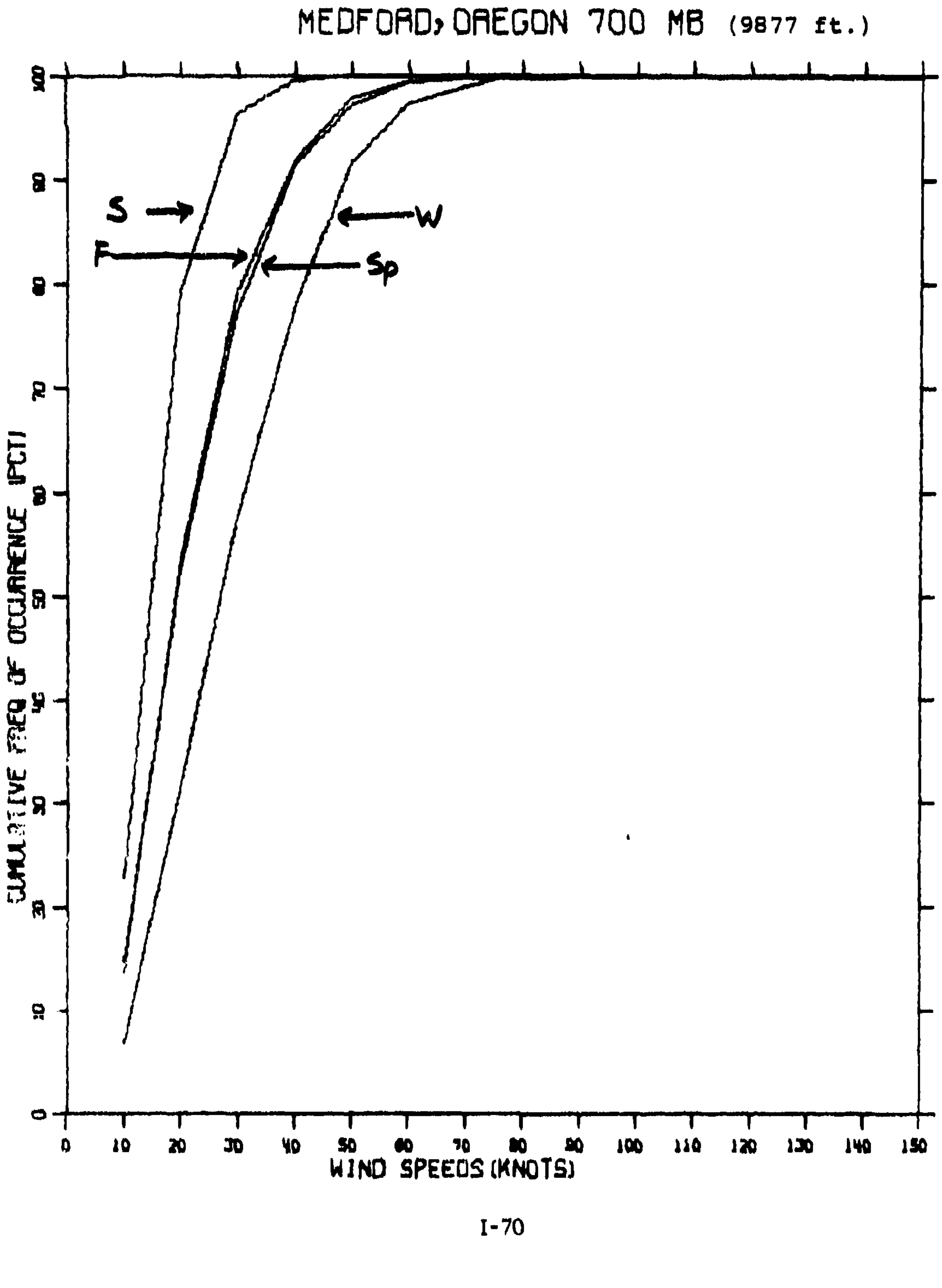


KODIAK, ALASKA 850 MB (4782 ft.)

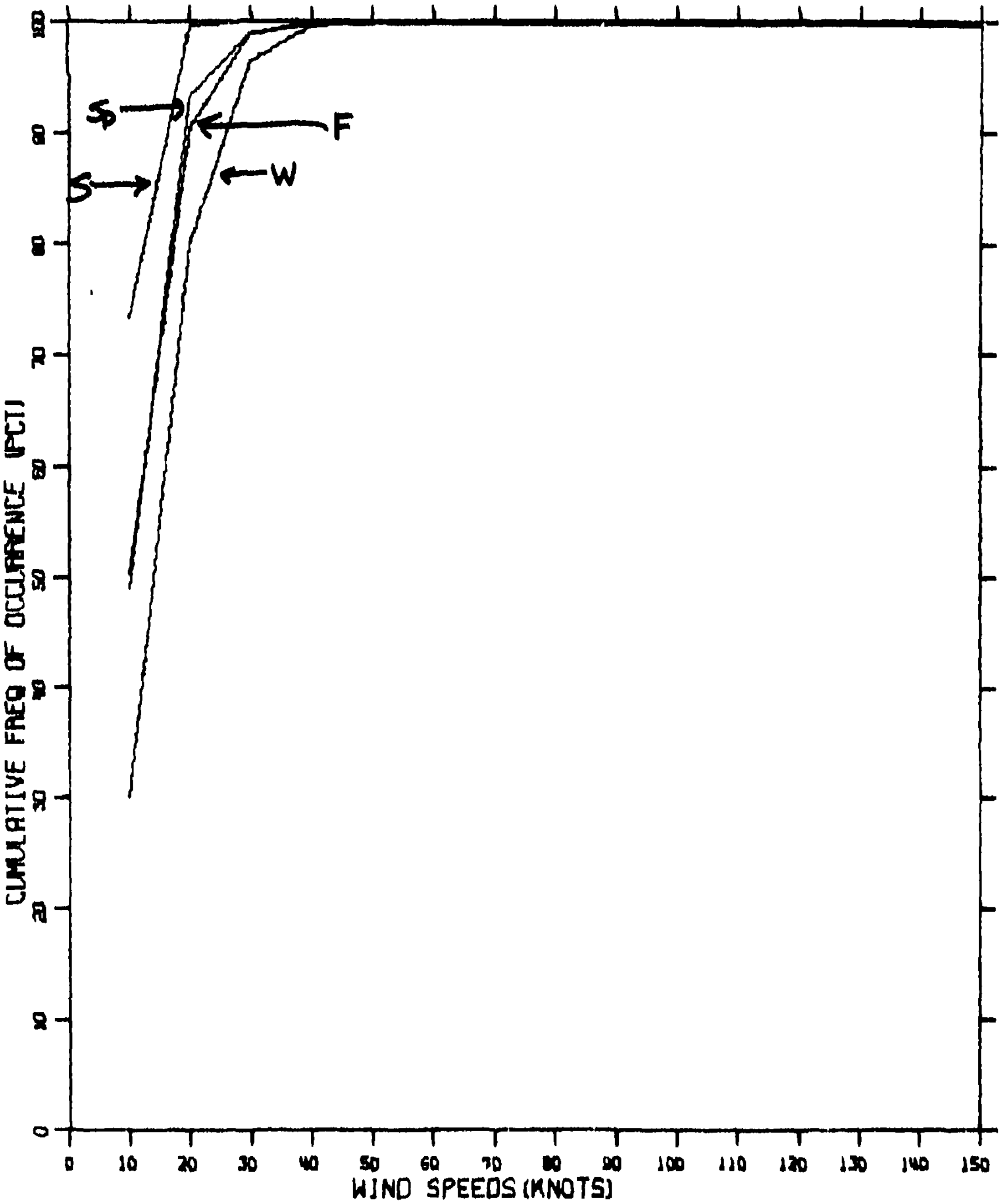


KODIAK, ALASKA 950 MB (1773 ft.)

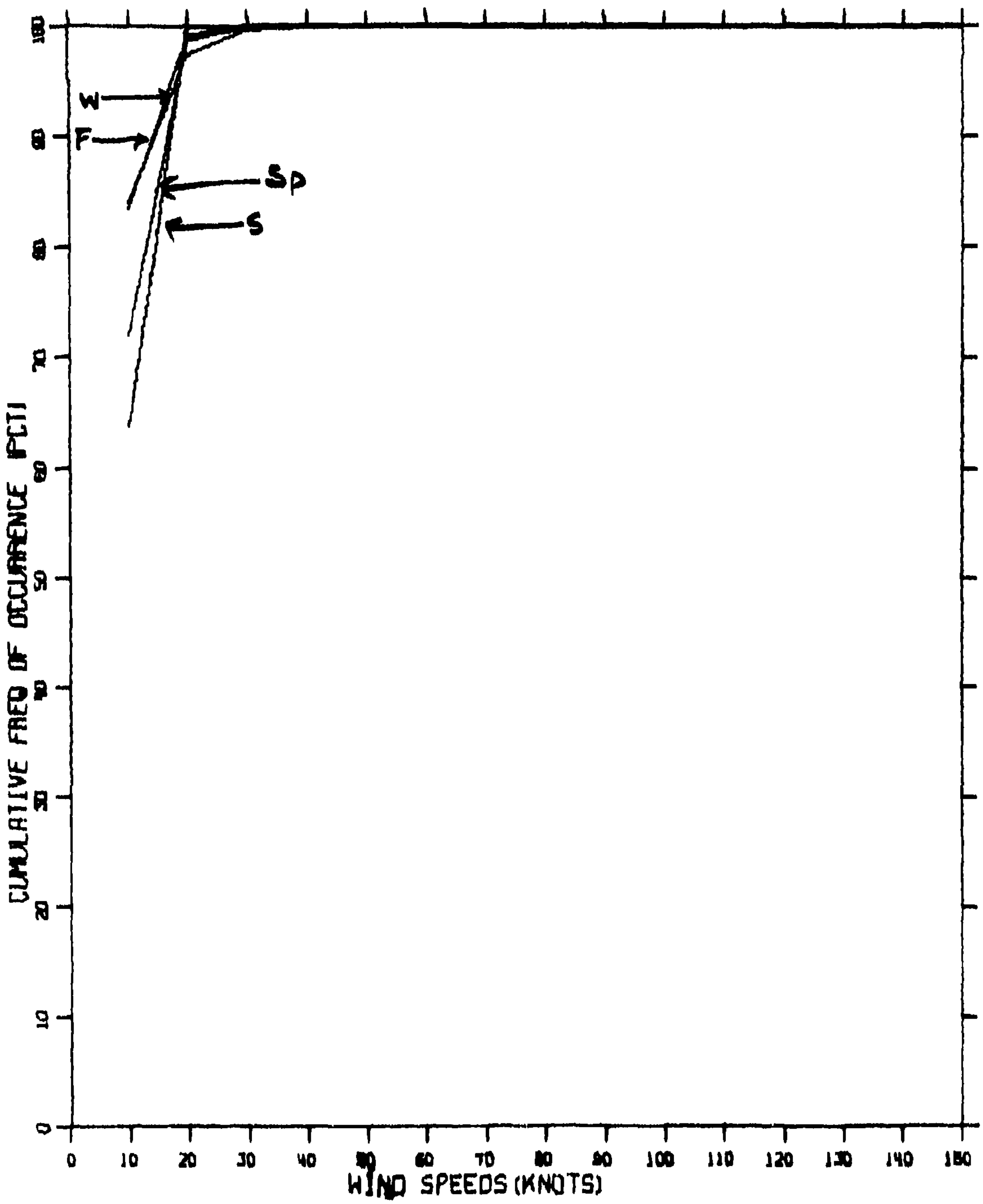



MEDFORD, OREGON 700 MB (9877 ft.)
S
F
W
Sp
CUMULATIVE FREQ OF OCCURRENCE (PCT)
0
10
20
30
40
50
60
70
80
90
100
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
WIND SPEEDS (KNOTS)

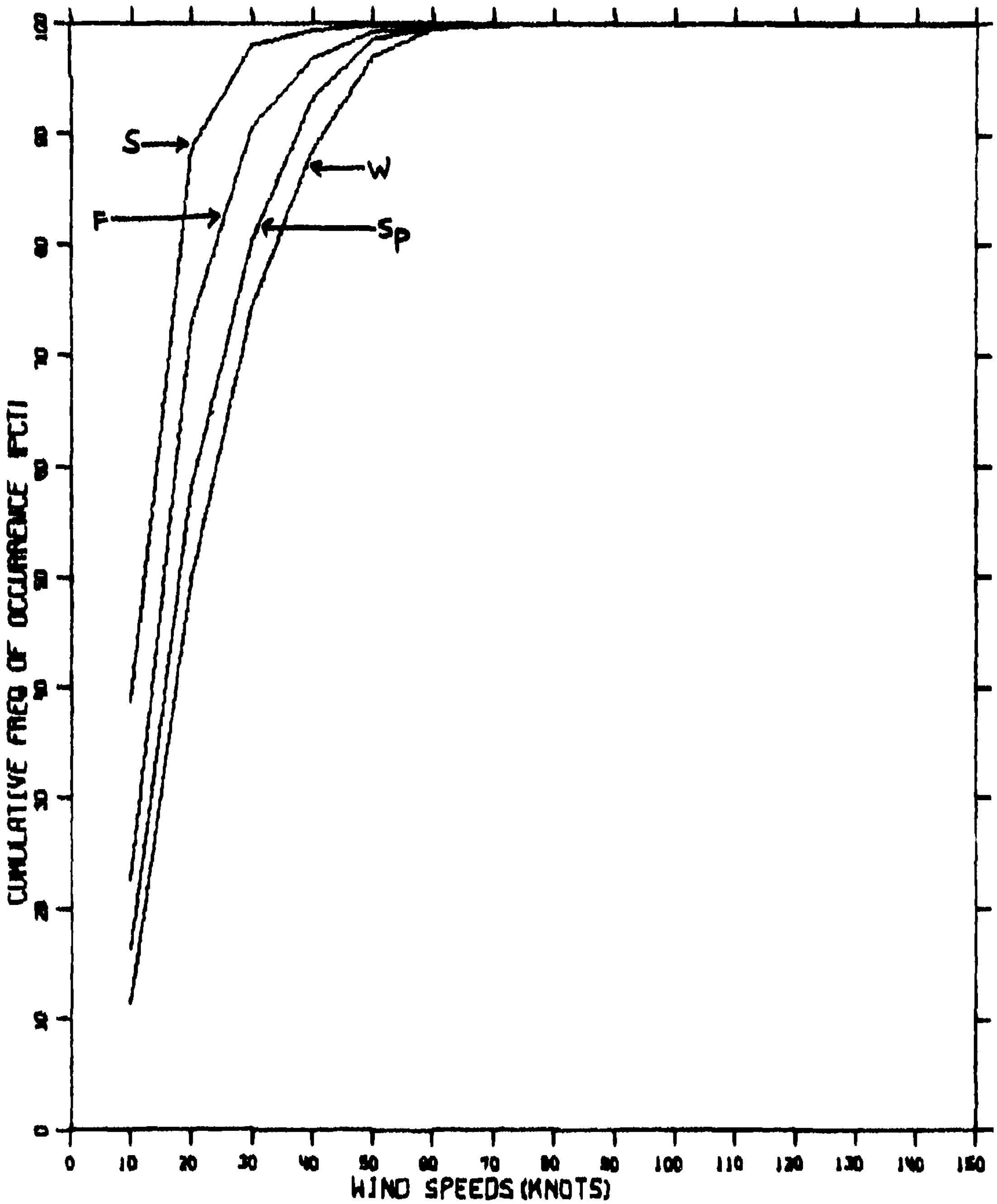
MEDFORD, OREGON 850 MB (4782 ft.)

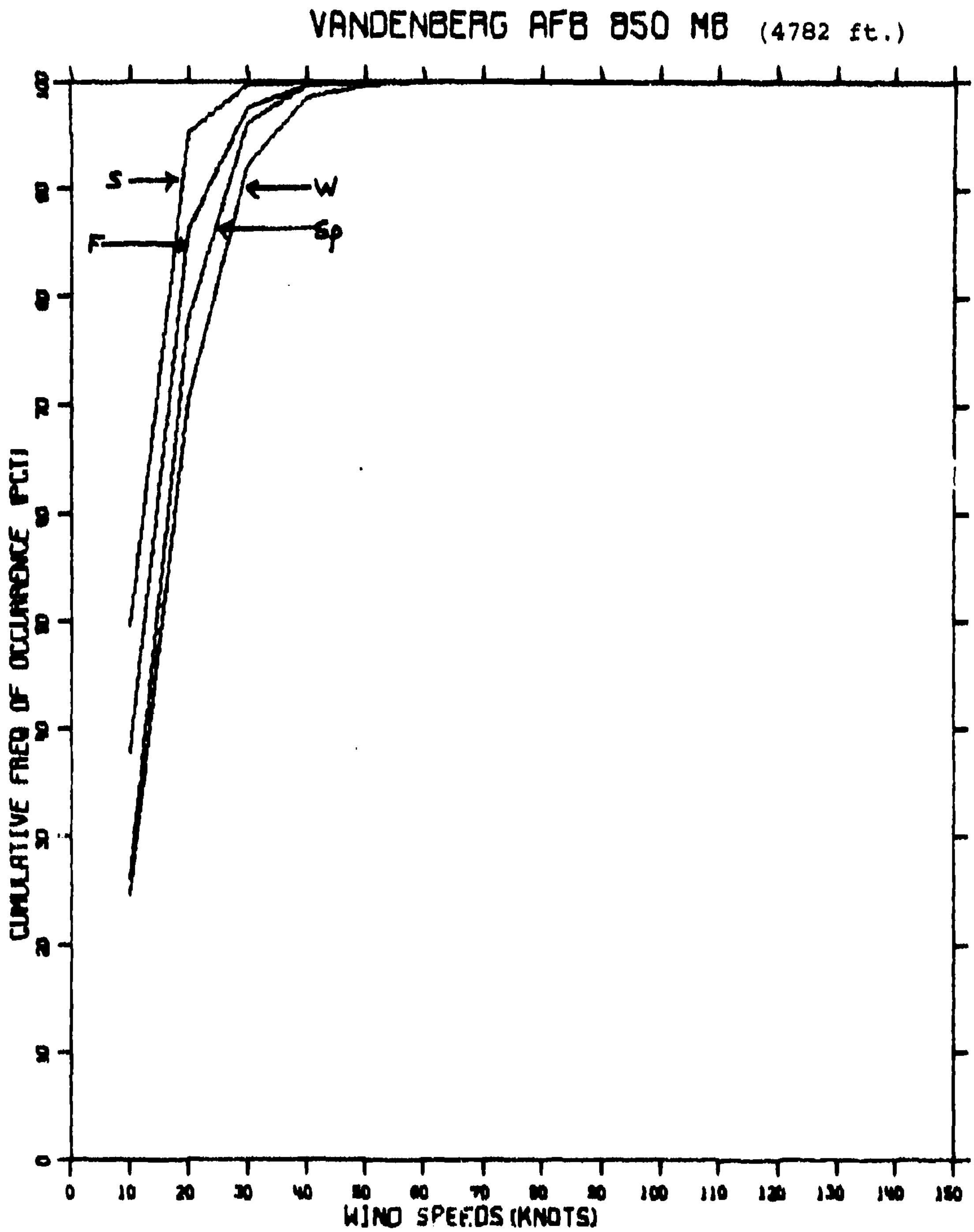


MEDFORD, OREGON 950 MB (1773 ft.)

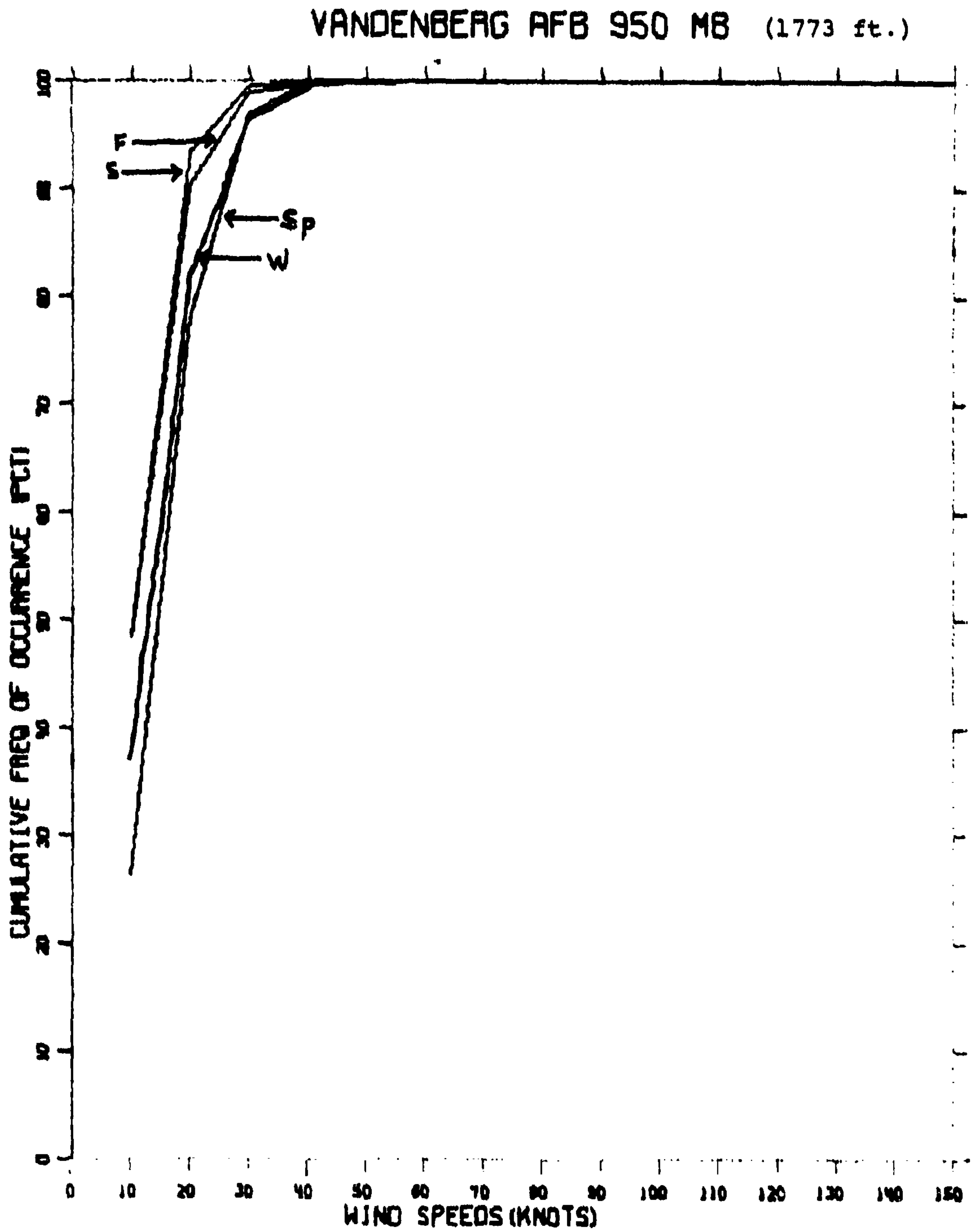


VANDENBERG AFB 700 MB (9877 ft.)





VANDENBERG AFB 850 MB (4782 ft.)
CUMULATIVE FREQ OF OCCURRENCE (PCT)
WIND SPEEDS (KNOTS)
S
W
F
Sp
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150



VANDENBERG AFB 950 MB (1773 ft.)
CUMULATIVE FREQ OF OCCURRENCE (PCT)
WIND SPEEDS (KNOTS)
F
S
Sp
W
0
10
20
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70
80
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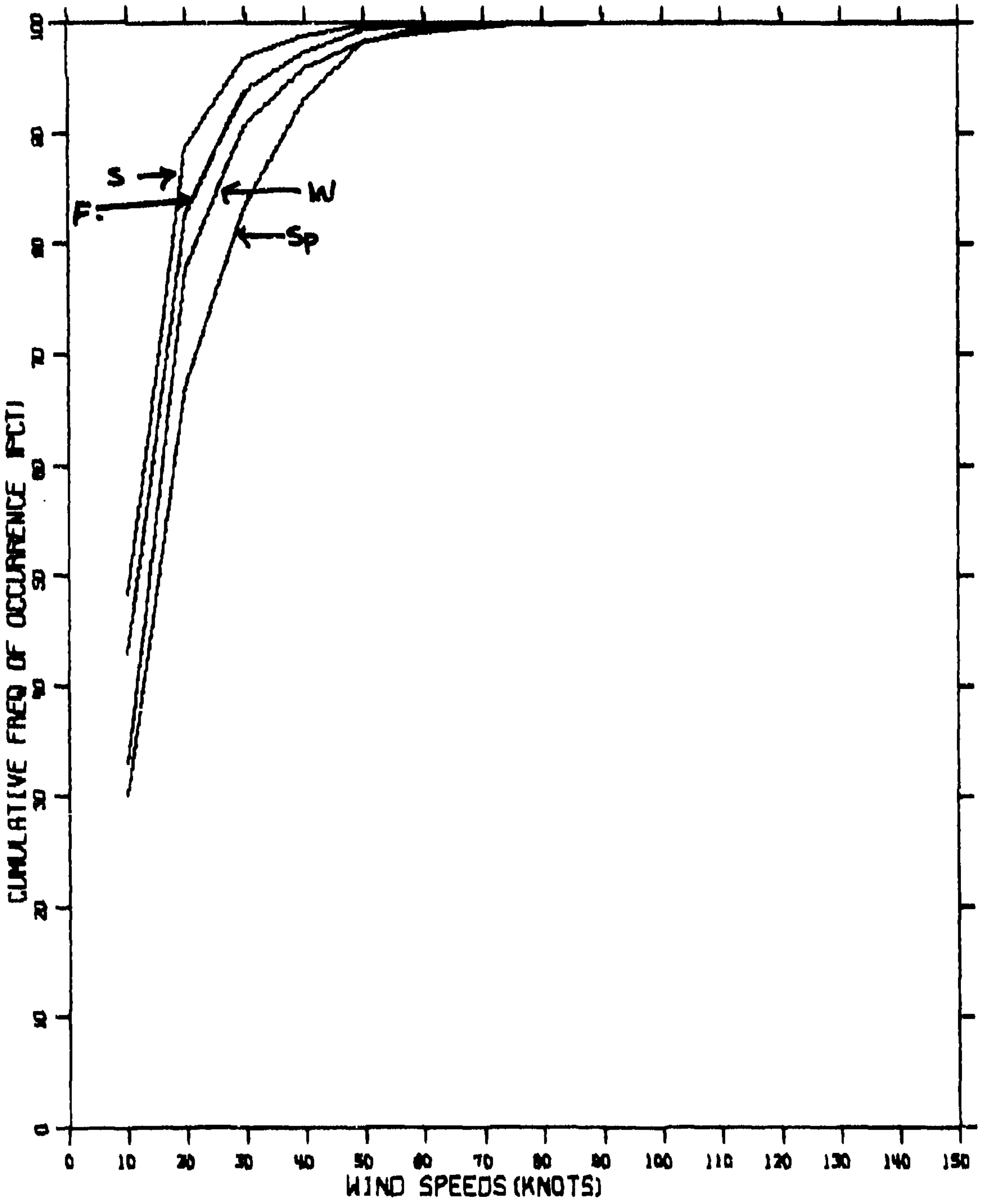
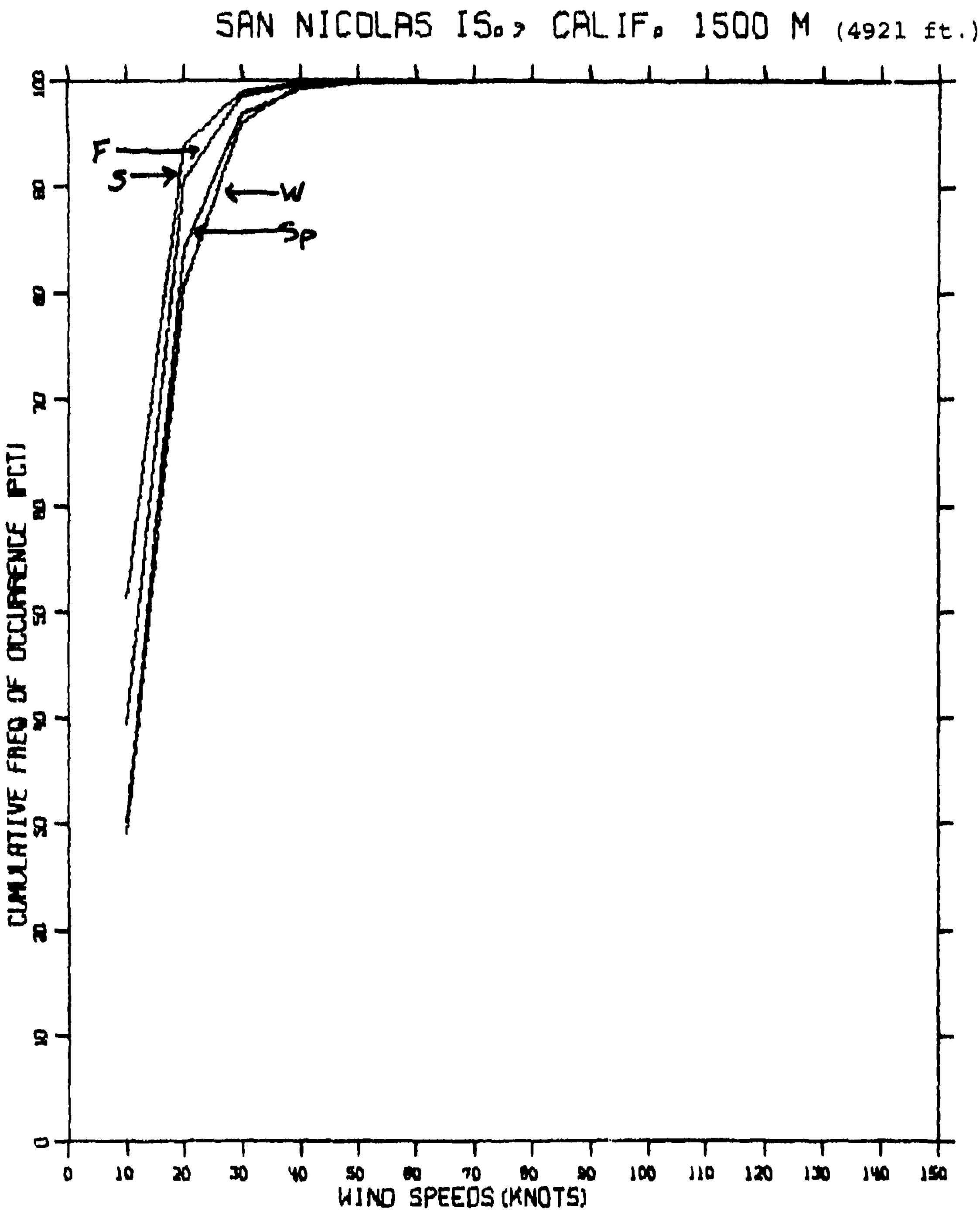
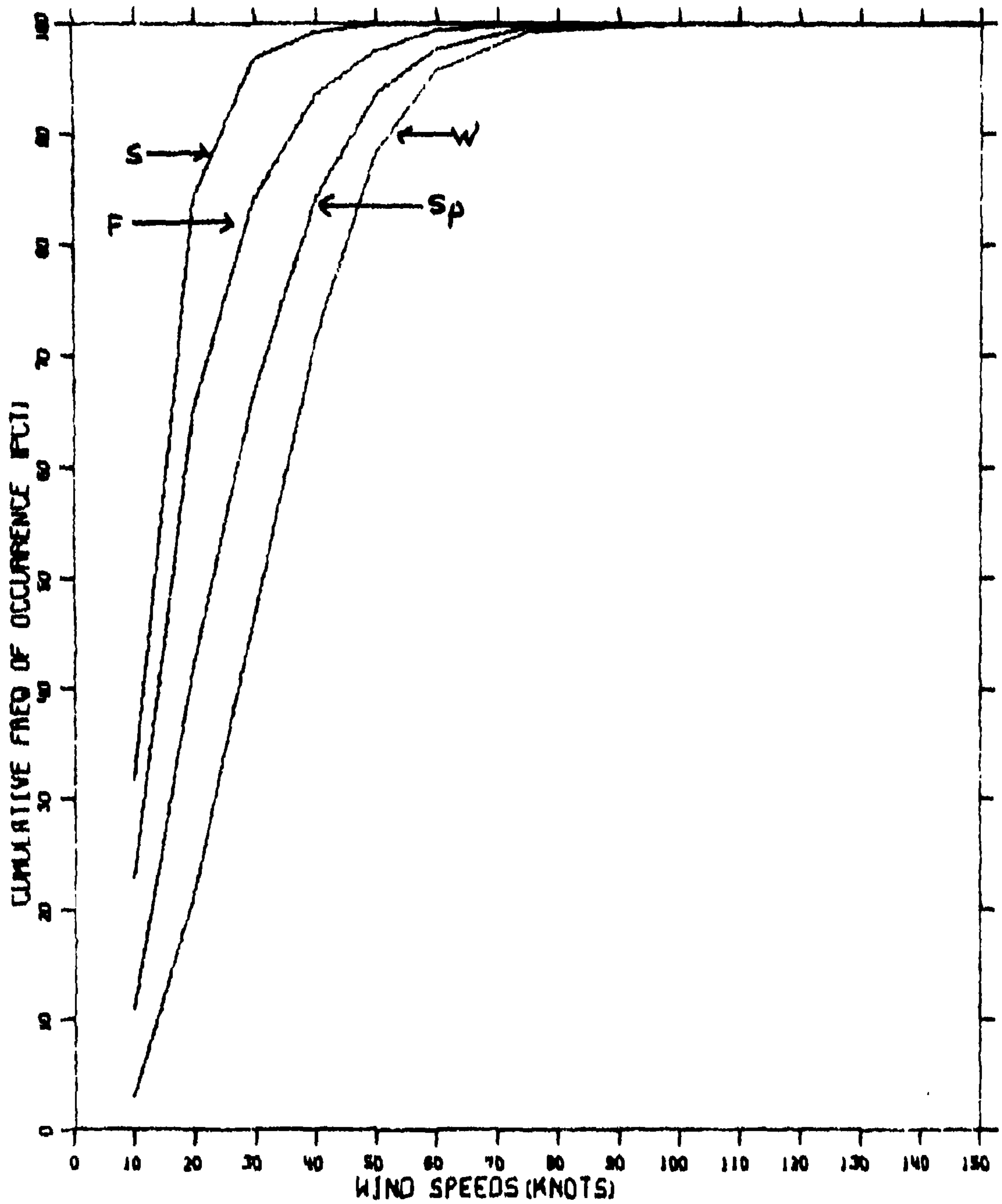
100
110
120
130
140
150

SAN NICOLAS IS., CALIF. 500 M (1640 ft.)

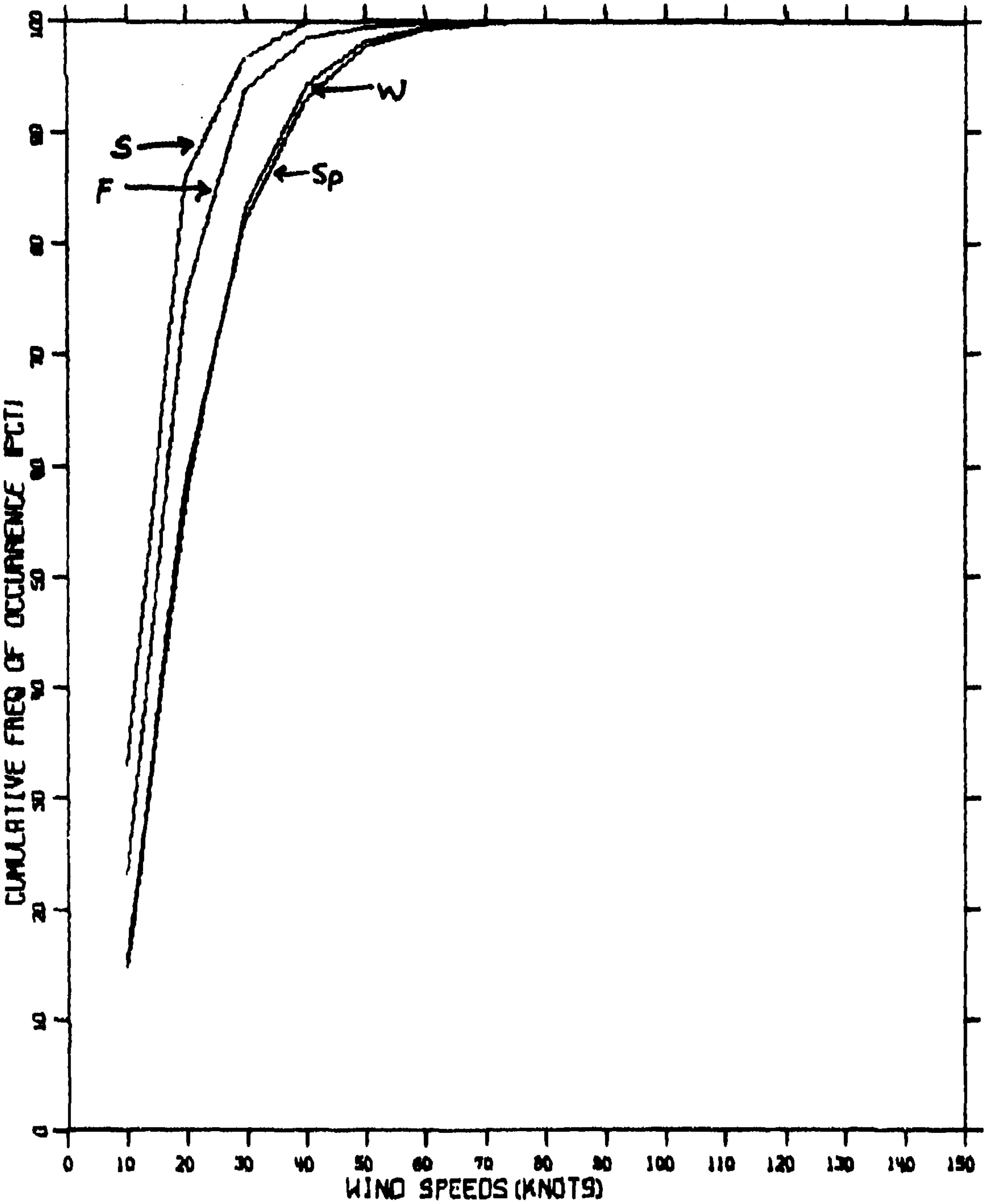


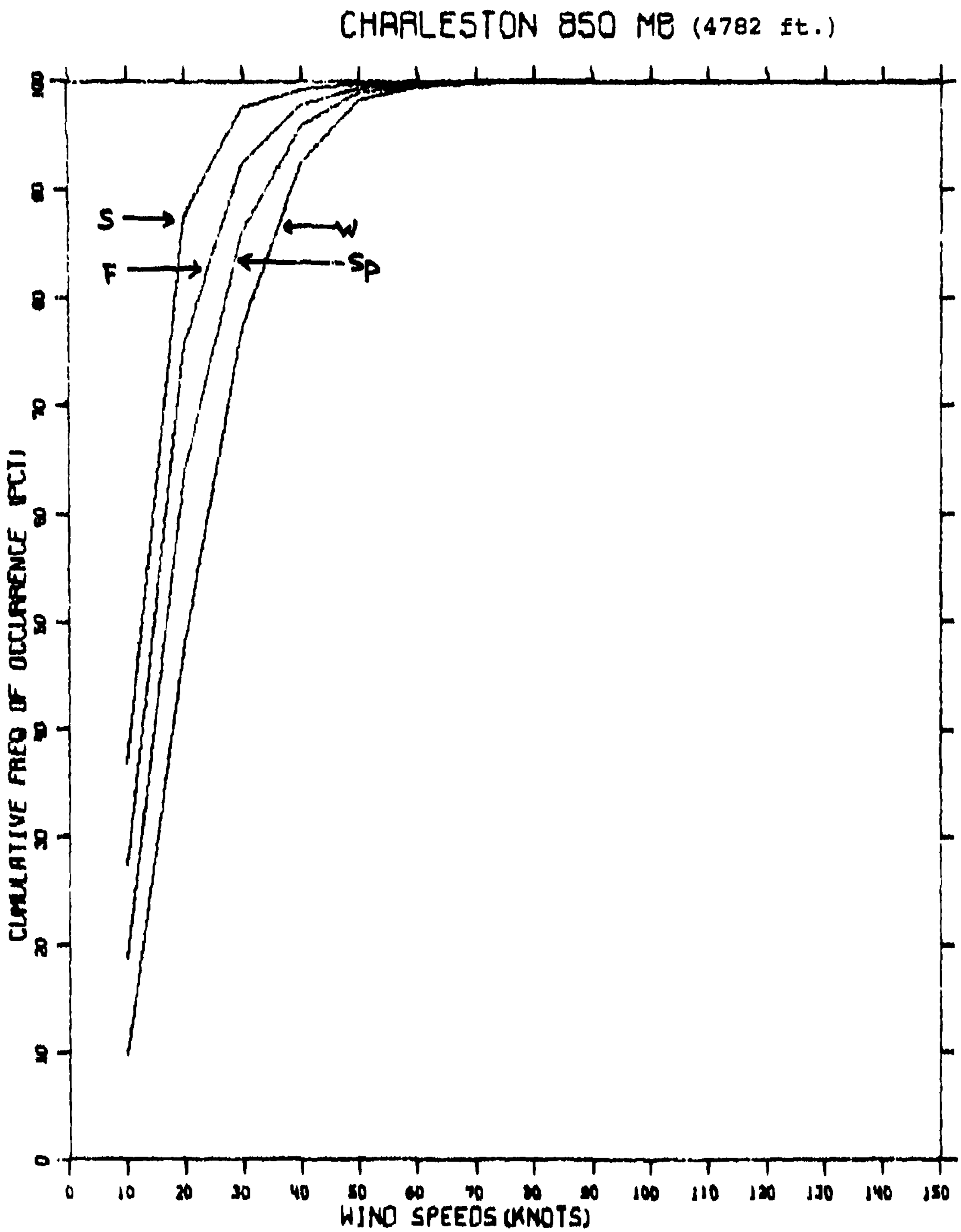

SAN NICOLAS IS., CALIF. 1500 M (4921 ft.)
CUMULATIVE FREQ OF OCCURRENCE (PCT)
WIND SPEEDS (KNOTS)
F
S
W
Sp
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150

CHARLESTON 700 MB (9877 ft.)

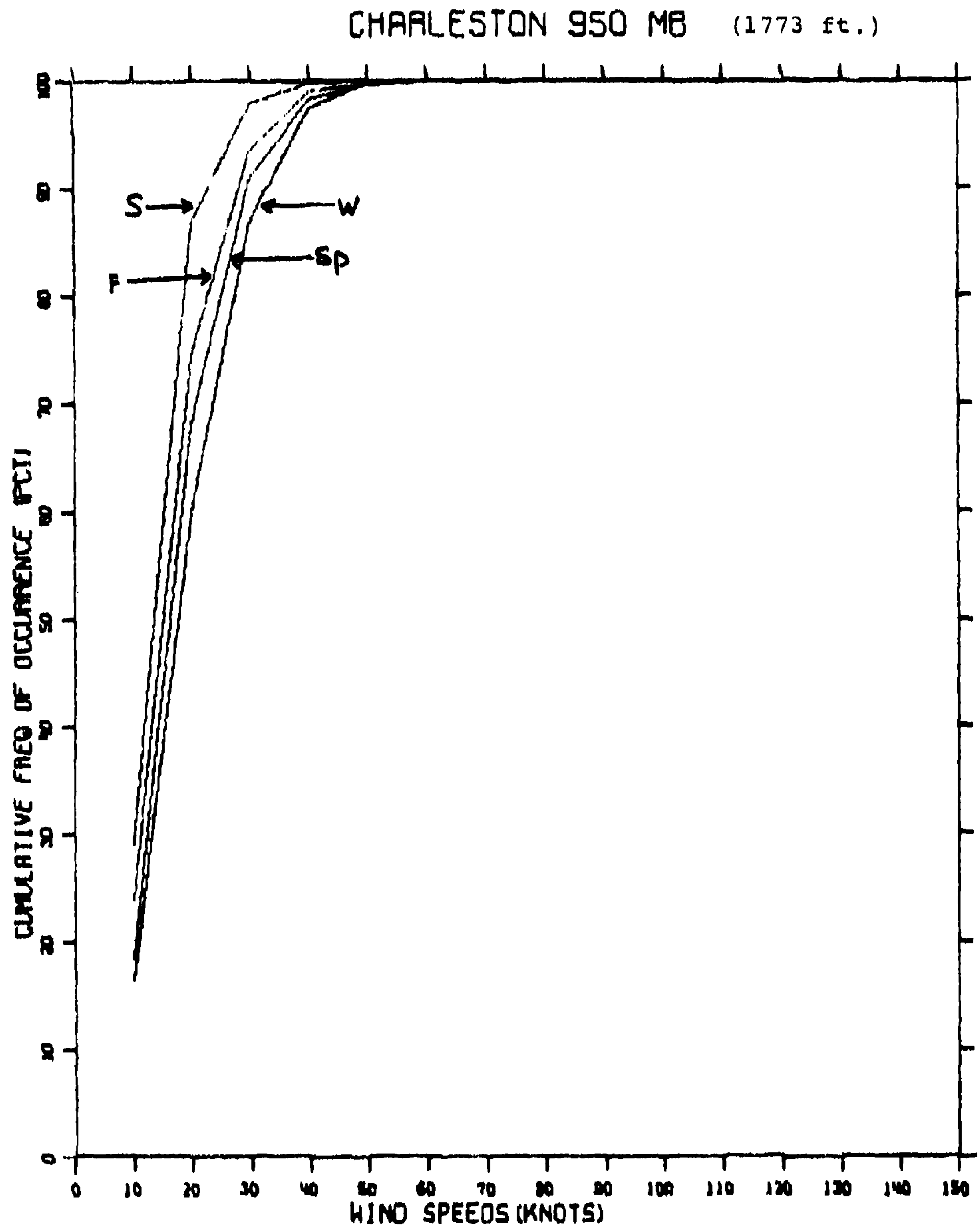


SAN NICOLAS IS., CALIF. 3000 M (9843 ft.)

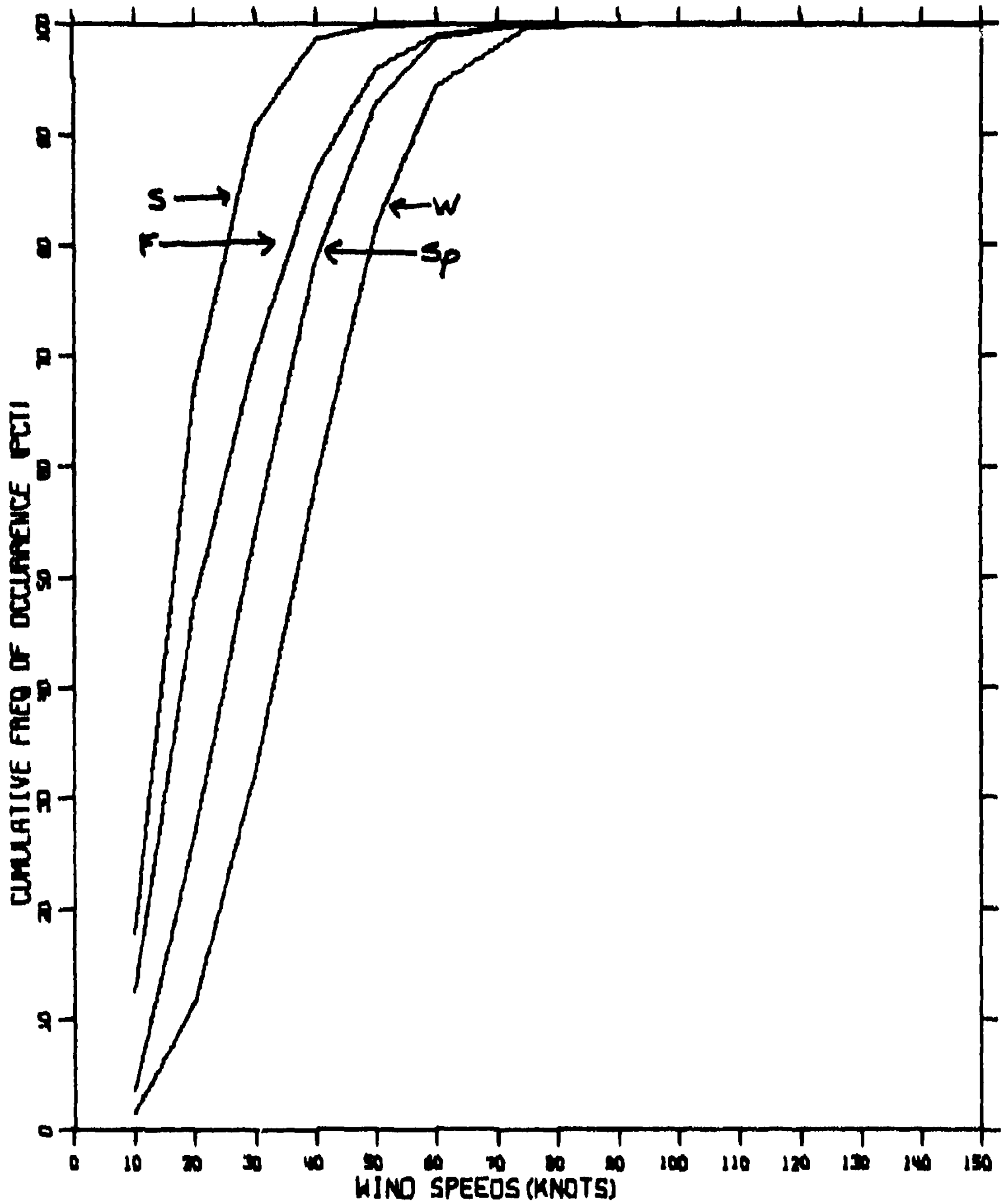




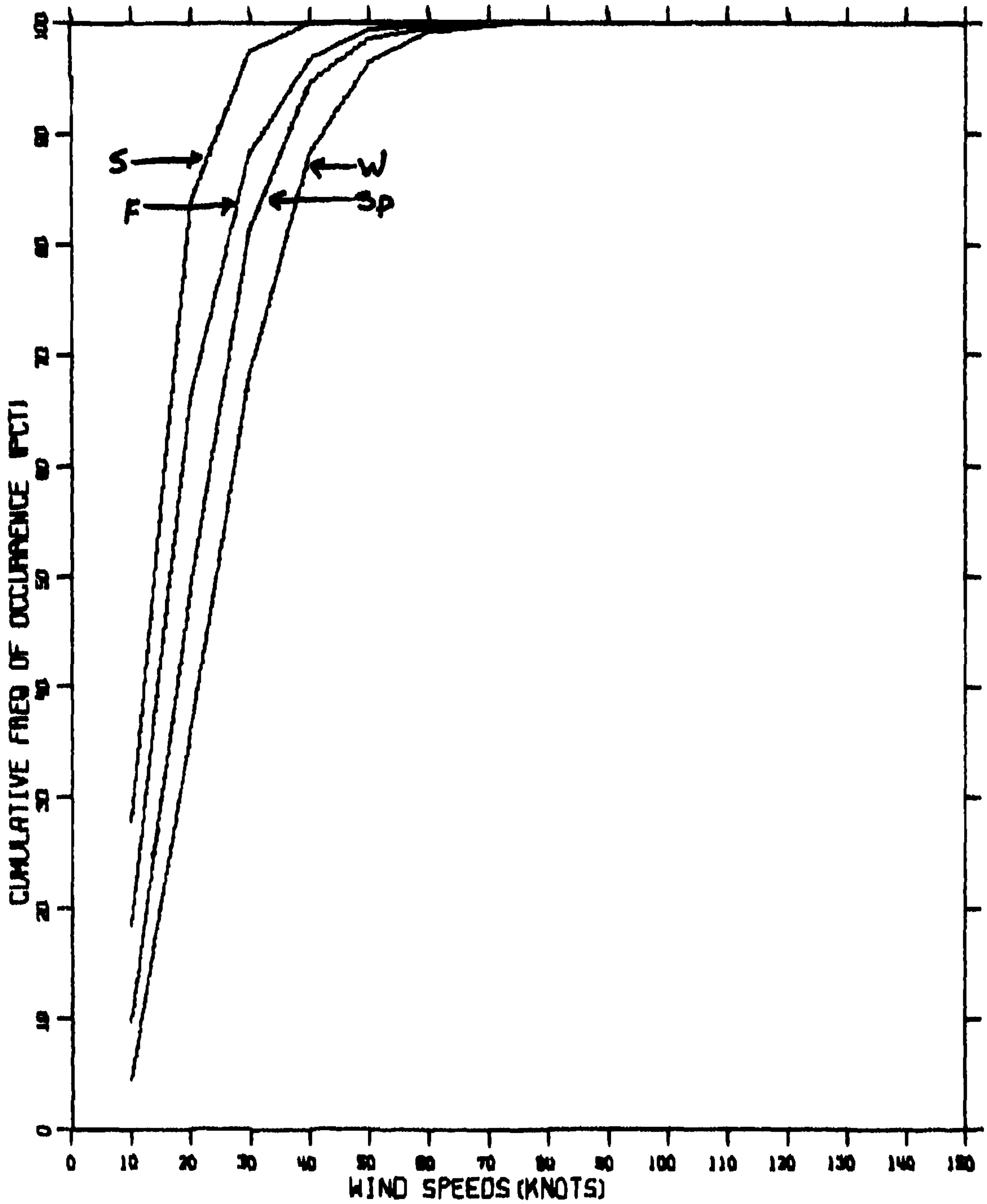
CHARLESTON 850 MB (4782 ft.)
S
F
W
Sp
CUMULATIVE FREQ OF OCCURRENCE (PCT)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
WIND SPEEDS (KNOTS)


CHARLESTON 950 MB (1773 ft.)
S
W
Sp
F
CUMULATIVE FREQ OF OCCURRENCE (PCT)
WIND SPEEDS (KNOTS)

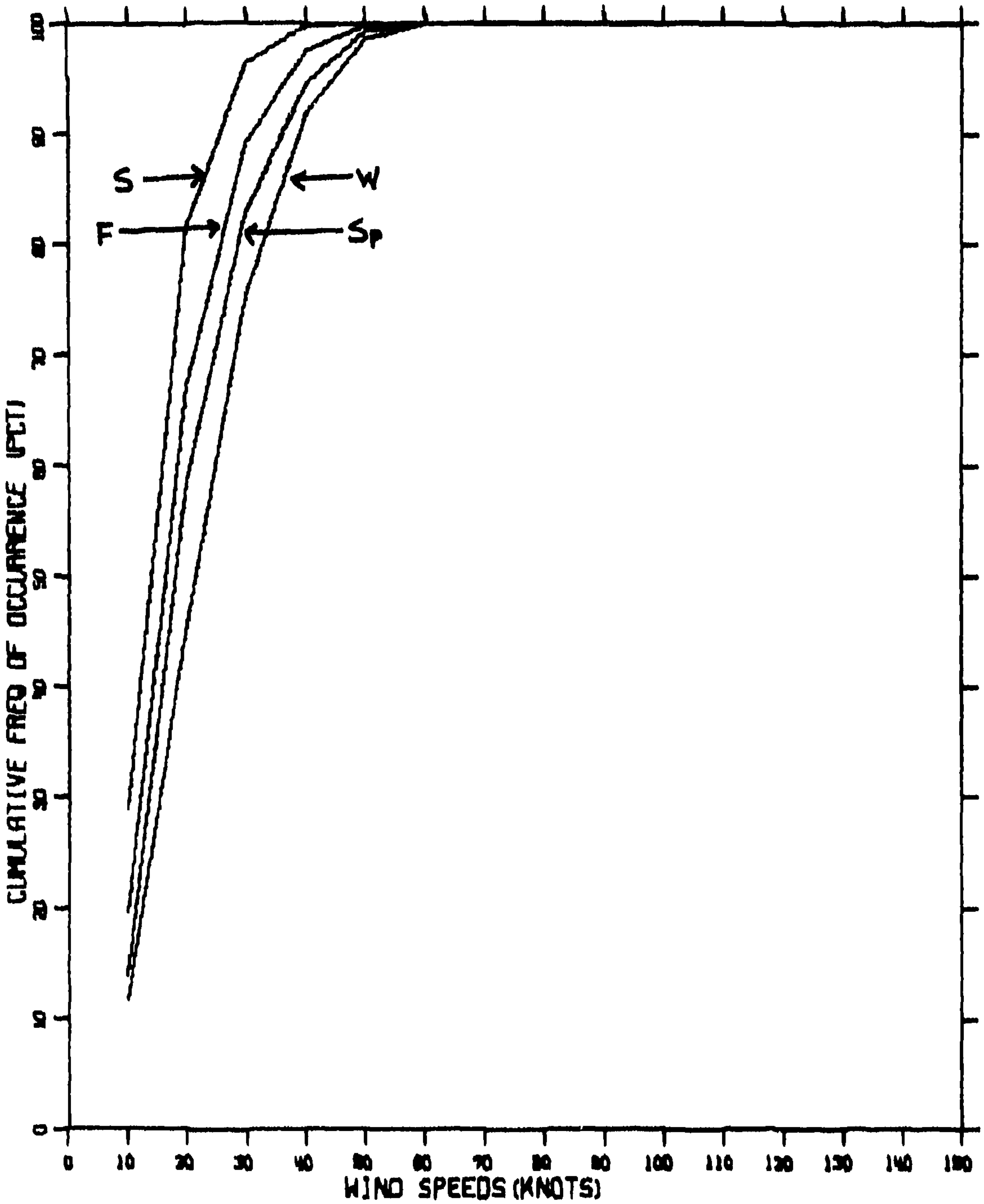
WALLOPS IS., VA. 700 MB (9877 ft.)



WALLOPS IS., VA. 850 MB (4782 ft.)



WALLOPS IS., VA. 950 MB (1773 ft.)



APPENDIX J

TIME-ON-STATION FRACTIONS AND EFFECTIVE SPEEDS

INTRODUCTION

Formulas are developed here for airship and other vehicle fractional time on station and effective speed for patrol and trail tasks performed at a distance, D, from base. In the first of these tasks, the effectiveness measure depends on the effective speed, defined as the miles on station per flight hour. For the trail tasks the effectiveness measure is hours on station per flight hour, or fractional time on station.

AIRSHIPS

Airship speeds for transit to station, v_T, are based on obtaining the maximum hours on station per flight hour. It will be shown that the optimum transit speed, v_{TOP}, is given by

$$v_{TOP} = \begin{cases} v_M & a_M \leq 0.43 \\ .6\, v_M \left(\frac{1}{a_M}\right)^{0.6} & , a_M \geq 0.43 \end{cases}$$

where v_M is the maximum sustained speed, and $a_M = 2D/R_M$ is a nondimensional transit distance parameter, with R_M equal to the range at maximum cruise speed, v_M.

Effective speed is maximized when the cruise speed on station, v_C, is equal to the optimum transit speed. Thus, we have

$$v_{COP} = v_{TOP}$$

Two cases are considered for patrol tasks involving target investigation depending on the assumption ma le concerning investigation time delays. A simple model is developed initially for the case of no time delays. This model also applies to gross surveillance tasks, measured by square miles on station per flight hour since the only change is the inclusion of a constant factor, W , called the detection "sweepwidth." The model is later extended to include the effects of an average time delay per investigation of τ hours.

Time-on-station fractions in patrol tasks are based initially on a simple cubic fuel rate law. Results are then extended to the case of a general power law that applies when heaviness is small.

A more general fuel rate formula is developed for both patrol and trail tasks where the heaviness variations are significant and variable speeds may be employed on station to obtain aerodynamic lift at constant angle of attack. The general fuel rate formula is approximated to obtain average fuel rates in both cases.

Endurance formulas and time-on-station fractions are then developed for both patrol and trail tasks. The patrol task at constant speed is treated simply in two phases -- heavy and buoyant. The trail task requires a more involved treatment of various phases of the flight -- transit out, variable speed on station, constant speed on station at 30 knots, and transit inbound. Both transit phases may involve either buoyant or partially buoyant phases.

In the case of investigation tasks with time delays, the effectiveness depends on the average track distance between targets, d, which depends on the target density, ρ. In this appendix, d is treated as a general parameter; in volume I, results are presented for two cases of low and high target density, defined by d values of 200 and 2 miles, respectively. The corresponding τ values associated with these cases are 0.1 and 0.01 hours, respectively.

No Investigation Delay

The optimization of effective speed is treated in two stages. In the first stage, the cruise speed on station is assumed to have a general fixed value, and transit speed is varied to maximize the time-on-station fraction, f_S. In the second stage, the cruise speed is varied to maximize the effective speed, v_E, given by

$$v_E = \frac{v_C t_C}{t_C + t_T} = v_C f_S \tag{J-1}$$

where

$$t_C = \text{time on station (hrs.)}$$
$$t_T = \text{time in transit} = \frac{2D}{v_T} \text{(hrs.)} \tag{J-2}$$

and

$$f_S = \frac{t_C}{t_C + t_T} = \frac{1}{1 + \frac{t_T}{t_C}} \quad . \tag{J-3}$$

The time on station is determined using the following equation for the available fuel W_F, in gallons

$$W_F = \dot{W}_T\, t_T + \dot{W}_C t_C = \dot{W}_C \frac{R_C}{v_C} = \dot{W}_M \frac{R_M}{v_M} \qquad \text{(J-4)}$$

where

$\dot{W}_T$ = transit fuel consumption rate (gal./hr.)

$\dot{W}_C$ = on-station fuel consumption rate (gal./hr.)

R_C = range at speed v_C (miles)

$\dot{W}_M$ = fuel consumption rate at speed v_M (gal./hr.) .

Inserting the relation (J-2) into equation (J-4), we obtain the ratio of on-station time to transit time,

$$\frac{t_T}{t_C} = \left(\frac{2D}{v_T}\right) \frac{1}{\dfrac{\left(W_F - \dot{W}_T \dfrac{2D}{v_T}\right)}{\dot{W}_C}} \quad . \qquad \text{(J-5)}$$

Using the relations,

$$\frac{2D}{v_T\, W_F} = \frac{2D}{R_M} \; \frac{R_M}{v_T\, W_F} = a_M \; \frac{R_M}{v_T\, W_F} = \frac{a_M\, v_M}{\dot{W}_M\, v_T} \qquad \text{(J-6)}$$

we obtain

$$\frac{t_T}{t_C} = \frac{a_M(\dot{W}_C/\dot{W}_M)}{x_T - a_M(\dot{W}_T/\dot{W}_M)} \qquad \text{(J-7)}$$

where

$X_T = v_T/v_M$.

Using equation (J-7), the time-on-station fraction is given by

$$f_S = \frac{1}{1 + \dfrac{a_M(\dot{W}_C/\dot{W}_M)}{x_T - a_M(\dot{W}_T/\dot{W}_M)}} \quad . \qquad \text{(J-8)}$$

When the transit and cruise speeds are both equal to the maximum speed, v_M, we find the simple result,

$$f_S = \frac{1}{1 + \dfrac{a_M}{1-a_M}} = 1 - a_M \quad . \qquad \text{(J-9)}$$

The time-on-station fraction is obviously at its maximum when the ratio t_C/t_T is a maximum. Physically, we are maximizing the product of transit speed and fuel available for the on-station part of the flight. To the extent that the fuel rate on station is independent of the transit phase, the optimization is valid for both patrol and trail tasks. When the airship heaviness is large some dependence effects occur. Differentiating the inverse of equation (J-7) we obtain the condition

$$\frac{d}{dx_T}\left(\frac{t_C}{t_T}\right) = \frac{\dot{W}_M}{a_M \dot{W}_C} \frac{d}{dx_T}\left(X_T - a_M \frac{\dot{W}_T}{\dot{W}_M}\right) = 0 \quad , \qquad \text{(J-10)}$$

so that,

$$\frac{d\dot{W}_T}{dx_T} = \frac{\dot{W}_M}{a_M} \qquad \text{(J-11)}$$

Using relation (J-6), equation (J-11) may be written in the alternative form

$$\frac{d\dot{W}_T}{dv_T} = \frac{W_F}{2D} \qquad \text{(J-12)}$$

which is also directly evident by inspection of equation (J-5).

Cubic Law Fuel Rate

For the purposes of illustration, we will first apply the above condition to the case of the simple cubic law for the fuel consumption rate

$$\dot{W}_T(x_T) = \dot{W}_M x_T^3 \quad . \tag{J-13}$$

Using the approximate form (J-13) for the fuel consumption rate, and the condition (J-11), we obtain the following result for the optimum transit speed ratio, x_{TOP},

$$x_{TOP} = \frac{1}{\sqrt{3a_M}} \tag{J-14}$$

or

$$v_{TOP} = \frac{v_M}{\sqrt{3a_M}} \quad . \tag{J-15}$$

Using relations (J-6), (J-13), and (J-14) we see that the optimum fractional time on station is obtained when the fuel burned in transit, W_{FT}, is one-third the total fuel available, W_F.

$$W_{FT} = \left(\frac{2D}{v_{TOP}}\right) \dot{W}_{TOP} = \left(\frac{2D}{v_{TOP}}\right)\left(\frac{\dot{W}_M}{3a_M}\right)\left(\frac{v_{TOP}}{v_M}\right) = \frac{W_F}{3} \quad . \tag{J-16}$$

When a_M is less than one-third, the optimum transit speed is clearly constrained by the maximum speed, so that we have, in general,

$$v_{TOP} = \begin{cases} v_M & a_M \leq 1/3 \\ \dfrac{v_M}{\sqrt{3a_M}} & a_M \leq 1/3 \quad . \end{cases} \tag{J-17}$$

The optimum transit speed ratio (v_{TOP}/v_M) is shown graphically in figure J-1 for three airships of varying range.

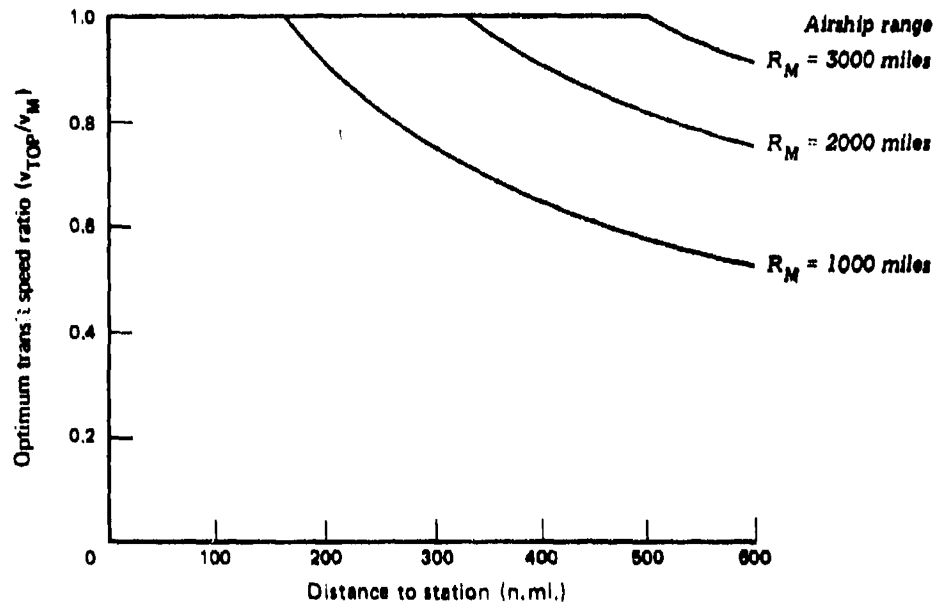


FIG. J-1: OPTIMUM TRANSIT SPEED RATIO vs. DISTANCE TO STATION

When relation (J-17) is inserted in equation (J-8), the time-on-station fraction is given by f_S =

$$\frac{1}{1+\frac{a_M(\dot{W}_C/\dot{W}_M)}{1-a_M}} = \frac{1}{1+\frac{a_M x_C^3}{1-a_M}} = \frac{1-a_M}{1-a_M(1-x_C^3)} \quad , a_M \leq 1/3 \quad \text{(J-18)}$$

$$f_S = \frac{1}{1+\frac{(3a_M)^{3/2}}{2}(\dot{W}_C/\dot{W}_M} = \frac{1}{1+\frac{(3a_M)^{3/2}}{2} x_c^3} = \frac{1}{1+C_M x_c^3} \quad , a_M \geq 1/3 \quad \text{(J-19)}$$

where

$$x_C = v_C/v_M$$

$$2C_M = (3a_M)^{3/2}$$

and

$$\dot{W}_C = \dot{W}_M x_C^3 \quad .$$

When $a_M \geq 1/3$, the effective speed is obtained using equation (J-19)

$$v_E = v_C f_S = v_M x_C f_S = v_M \frac{x_C}{1 + C_M x_C^3} \quad . \qquad \text{(J-20)}$$

The maximum effective speed is found by differentiating equation (J-20):

$$\frac{dv_E}{dx_C} = v_M \frac{1+C_M x_C^3 - 3C_M x_C^3}{(1+C_M x_C^3)^2} = 0 \qquad \text{(J-21)}$$

which yields the optimum cruise speed ratio:

$$x_{COP} = \frac{v_{COP}}{v_M} = \frac{1}{(2C_M)^{1/3}} = \frac{1}{\sqrt{3a_M}} \;, \; a_M \leq 1/3 \qquad \text{(J-22)}$$

where

v_{COP} = optimum cruise speed on station.

Comparing this result with equation (J-14) we find

$$v_{COP} = v_{TOP} = \frac{v_M}{\sqrt{3a_M}} \;, \qquad a_M \leq 1/3 \qquad \text{(J-23)}$$

for $a_M \leq 1/3$. Inserting the relation (J-22) into equation (J-19) we also see that the optimum time-on-station fraction, f_{SOP}, is constant:

$$f_{SOP} = \frac{2}{3} \;, \qquad a_M \geq 1/3 \; . \qquad \text{(J-24)}$$

The optimal effective speed in this case is given by

$$v_{EOP} = \frac{2}{3} \frac{v_M}{\sqrt{3a_M}} \;, \qquad a_M \geq 1/3 \; . \qquad \text{(J-25)}$$

Comparing equations (J-18) and (J-19), and using the result in equation (J-22) shows that the optimum is constrained to $x_C = 1$, when $a_M \le 1/3$. Thus

$$v_{COP} = v_{TOP} = v_M \ , \qquad a_M \le 1/3$$

$$f_{SOP} = 1 - a_M \ , \qquad a_M \le 1/3 \qquad \text{(J-26)}$$

and

$$v_{EOP} = v_M (1 - a_M) \ , \qquad a_M \le 1/3 \qquad \text{(J-27)}$$

The above result is illustrated graphically in figure J-2 for an airship with $v_M = 110$ knots and $R_M = 1{,}000$ miles. The time-on-station fraction for three cases is shown in the lower half of the figure as a function of distance to station; effective speed is shown in the upper half. The optimal case is indicated by solid lines.

When both the transit and on-station speeds are equal to the maximum speed of 110 knots the time-on-station fraction and the effective speed decrease linearly to zero at one-half the maximum range at 110 knots speed ($a_M = 1.0$). This case is illustrated by dash-dot lines.

When the on-station speed is constant at 110 knots (corresponding to $x_C = 1$, or $v_C = v_M = 110$ knots) and the transit speed is optimal (variable), the time-on-station fraction decreases linearly for distances less than one-third of $R_M/2$, ($a_M = 1/3$), and inversely as given by equation (J-19) (with $x_C = 1$) for greater distances:

$$f_S = \begin{cases} 1 - a_M & , \ a_M \le 1/3 \\ \dfrac{1}{1 + \dfrac{(3a_M)^{3/2}}{2}} & , \ a_M \ge 1/3 \end{cases}$$

The effective speed in this case is equal to the above f_S times $v_M = 110$ knots.

This intermediate case is illustrated by the dashed lines in figure J-2. The effective speed for this case is less than the optimal value. At 500 miles station distance, the optimal effective speed is about 40 percent above the effective speed in the case of constant cruise speed on station at maximum speed.

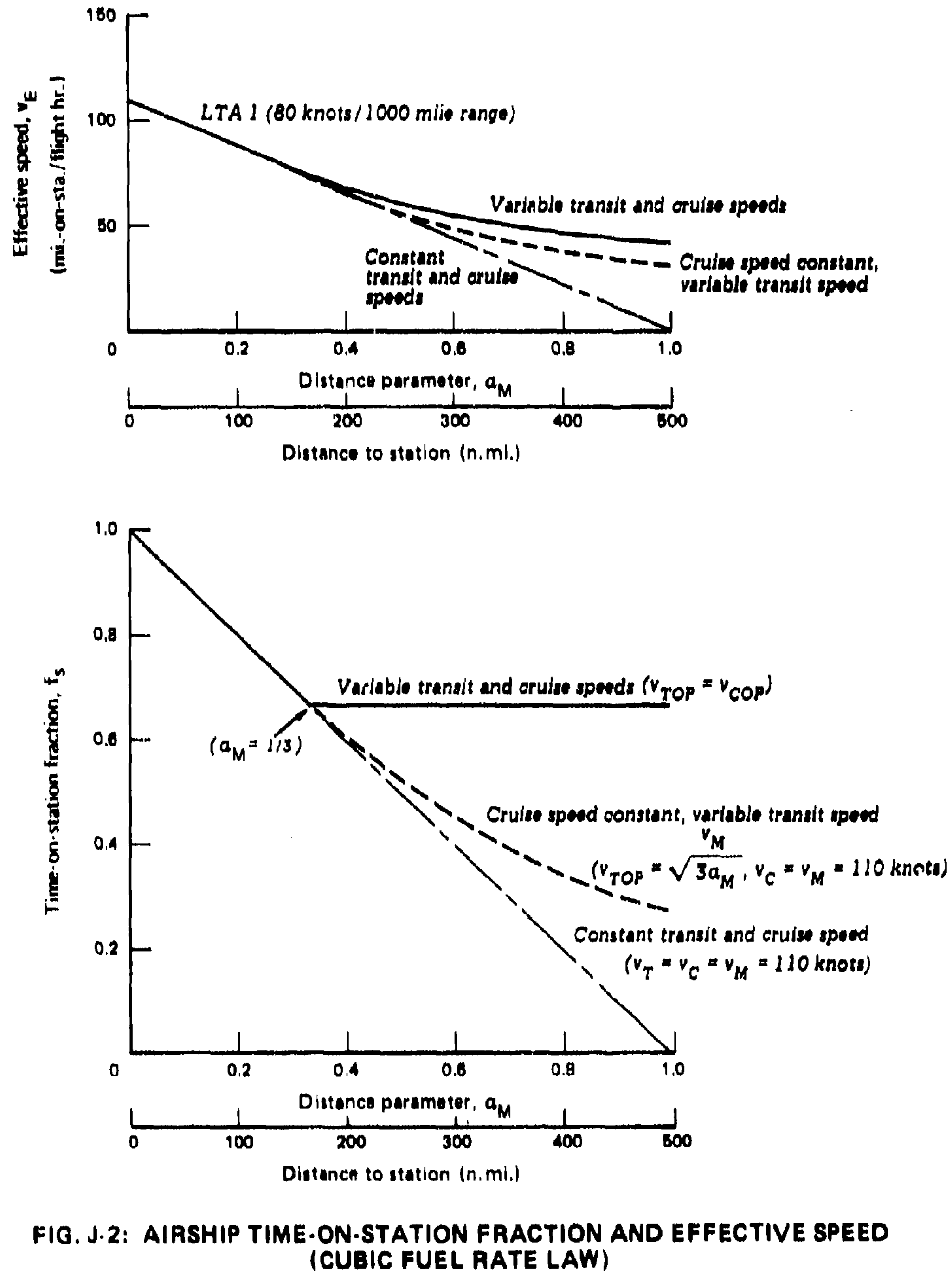


FIG. J-2: AIRSHIP TIME-ON-STATION FRACTION AND EFFECTIVE SPEED (CUBIC FUEL RATE LAW)

The endurance, t_F , in patrol tasks is obtained using the relation

$$t_F = t_T + t_C = t_T + f_S t_F \quad , \tag{J-28}$$

so that

$$t_F = \frac{t_T}{1-f_S} \quad . \tag{J-29}$$

Using equations (J-24) and (J-26) we find

$$t_F = \begin{cases} \dfrac{t_T}{a_M} & a_M \le 1/3 \\ 3t_T & a_M \ge 1/3 \end{cases} \tag{J-30}$$

which, using equation (J-17), becomes

$$t_F = \begin{cases} \dfrac{R_M}{v_M} = t_M & a_M \le 1/3 \\ \dfrac{R_M}{v_M} (3a_M)^{3/2} & a_M \ge 1/3 \quad . \end{cases} \tag{J-31}$$

Equation (J-31) is illustrated in figure J-3 for three airships that were found in volume I to provide the least cost per mile in patrol tasks for airship ranges of 1,000, 2,000, and 3,000 miles.

In the following section, the simple cubic fuel rate law is replaced by a more accurate fuel consumption rate formula.

General Fuel Rate Law (Zero Heaviness)

The simple cubic fuel rate law is a good approximation for airship speeds close to maximum speed. However, when the transit speeds are reduced for long distances to station, a more accurate fuel rate law is needed. A good approximation formula for determining optimal transit speeds is the following general power law formula:

$$\frac{\dot{W}(x_T)}{W_M} = C_0 + C_1 x_T^{\alpha} \tag{J-32}$$

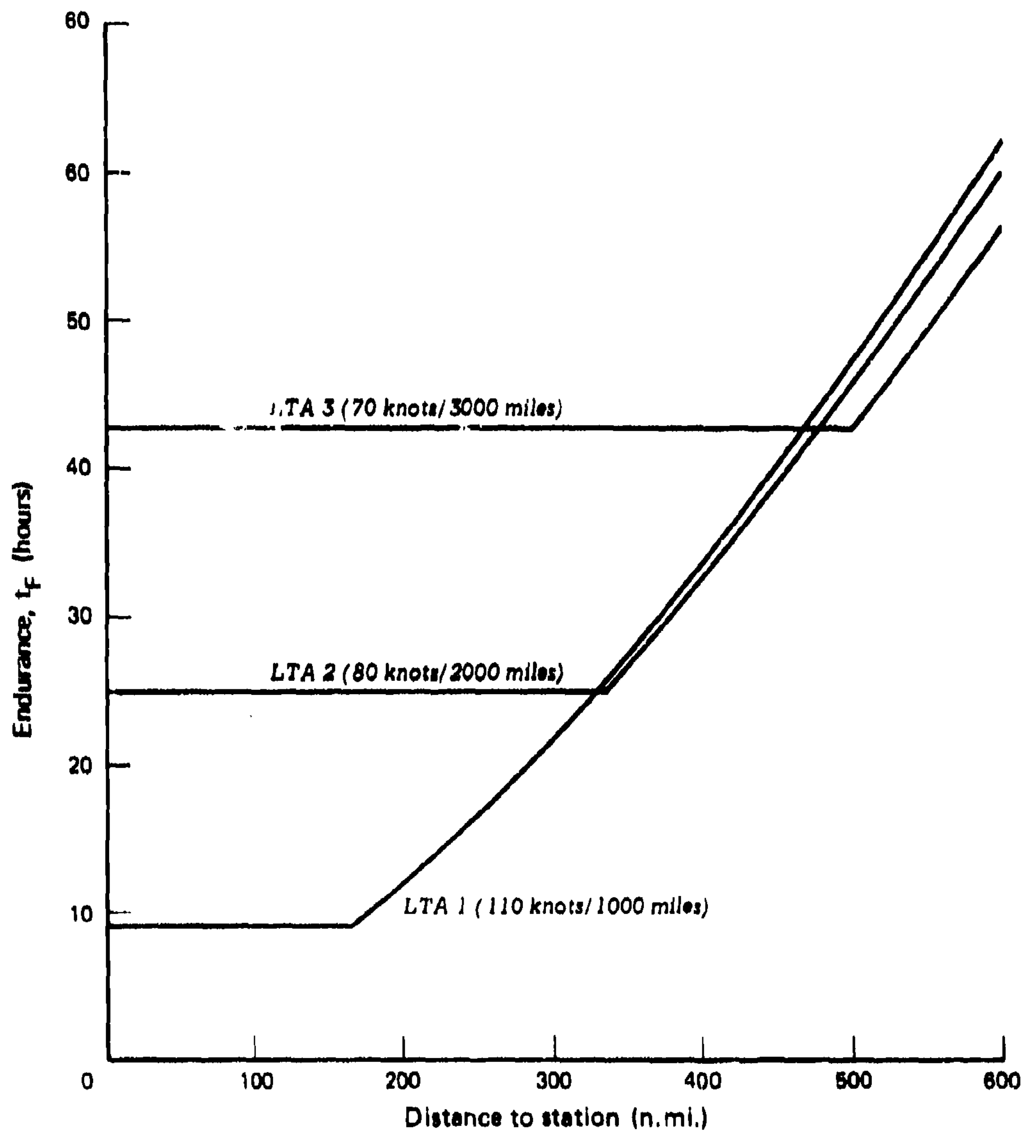


FIG. J-3: AIRSHIP ENDURANCE IN PATROL TASKS (CUBIC FUEL RATE LAW)

where the exponent α is about 2.67 for the airship speeds and ranges considered in this study. The coefficients C_0 and C_1 are equal to 0.11 and 0.89, respectively, for airships using turboprop propulsion systems. Formula (J-32) is shown in annex J-1 to be an excellent approximation for speeds down to about $0.6v_M$ when the airship heaviness is low. For the purposes of transit speed optimization the assumption is made that heaviness effects can be neglected. It is considered that such an assumption is a good one for the purpose intended. However, for the purpose of determining on-station time fractions, the effect of heaviness on fuel rate will be considered in more detail in a later section of this appendix. Heaviness effects are most important in the case of trail tasks that involve very low speeds on station. For patrol tasks, use of formula (J-32) should provide a fair approximation for the on-station fractions.

Inserting formula (J-32) into equation (J-10) the optimum transit speed ratio is found to be

$$x_{TOP} = \left(\frac{1}{\alpha a_M C_1}\right)^{\frac{1}{\alpha-1}} = \left(\frac{1}{\alpha a_M}\right)^{\frac{1}{\alpha-1}} \left(\frac{1}{1-C_0}\right)^{\frac{1}{\alpha-1}}, \quad a_M \geq \frac{1}{\alpha C_1} \qquad \text{(J-33)}$$

which reduces to formula (J-14) when $\alpha = 3$ and $C_0 = 0$. When $\alpha = 2.67$ we get

$$x_{TOP} = .595 \left(\frac{1}{a_M}\right)^{0.6}, \qquad \alpha = 2.67 .$$

Thus, the following simple formula has been adopted:

$$x_{TOP} = \begin{cases} 1 & a_M \leq 0.43 \\ 0.6 \left(\frac{1}{a_M}\right)^{0.6} & a_M \geq 0.43 \end{cases} \qquad \text{(J-34)}$$

Formula (J-34) is employed later in making the more accurate calculations of on-station fractions for both patrol and trail tasks.

For the purposes of making approximate calculations of on-station fractions and effective speeds in patrol tasks we follow the previous approach used with the simple cubic law with x_{TOP} replaced by the general result found in equation (J-33).

When equation (J-33) is inserted into equation (J-8) the time-on-station fraction is given by

$$f_S = \frac{1}{1 + \dfrac{a_M(\dot{W}_C/\dot{W}_M)}{1-a_M}} \qquad a_M \le \frac{1}{\alpha C_1} \tag{J-35}$$

$$f_S = \frac{1}{1 + \dfrac{a_M(\dot{W}_C/\dot{W}_M)}{\left(\dfrac{\alpha-1}{\alpha}\right) x_{TOP} - a_M C_0}} \qquad a_M \ge \frac{1}{\alpha C_1} \quad . \tag{J-36}$$

The form of equation (J-36) indicates that the on-station fraction goes to zero at a distance determined by the condition

$$\left(\frac{\alpha-1}{\alpha}\right) x_{TOP} = a_M C_0 = \frac{2D}{R_M} C_0 \quad . \tag{J-37}$$

It can be shown that this distance is equal to one-half the maximum range possible, achieved at a speed ratio x_{MAX}, given by

$$x_{MAX} = \left(\frac{C_0}{(\alpha-1)\, C_1}\right)^{\frac{1}{\alpha}} \quad . \tag{J-38}$$

The corresponding maximum range, R_{MAX}, is given by the formula

$$R_{MAX} = \left(\frac{\alpha-1}{\alpha}\right) \frac{x_{MAX}}{C_0} R_M \quad . \tag{J-39}$$

Inserting equation (J-39) into equation (J-36) we get the alternative form

$$f_S = \frac{1}{1 + \dfrac{a_M(\dot{W}_C/\dot{W}_M)}{\left(\dfrac{\alpha-1}{\alpha}\right) x_{TOP} \left(1 - \dfrac{2D}{R_{MAX}} \dfrac{x_{MAX}}{x_{TOP}}\right)}} \quad , \quad a_M \ge \frac{1}{\alpha C_1} \tag{J-40}$$

which shows clearly the condition for zero on-station time ($x_{TOP} = x_{MAX}$, $2D = R_{MAX}$).

Using the general formula (J-32) for the fuel rate on station at speed $v_C = x_C v_M$ we have

$$\frac{\dot{W}_C}{\dot{W}_M} = C_0 + C_1 x_C^{\alpha} \quad . \tag{J-41}$$

Inserting formula (J-41) into equation (J-36) we obtain the result

$$f_S = \frac{1-a_M}{1-a_M(1-C_0)(1-x_C^{\alpha})} \quad , \quad a_M \leq \frac{1}{\alpha C_1} \tag{J-42}$$

$$f_S = \frac{1-\dfrac{a_M C_o}{x_{TOP}}\left(\dfrac{\alpha}{\alpha-1}\right)}{1+\dfrac{a_M C_1}{x_{TOP}}\left(\dfrac{\alpha}{\alpha-1}\right)x_C^{\alpha}} \quad , \quad a_M \geq \frac{1}{\alpha C_1} \quad . \tag{J-43}$$

Multiplying the above expressions by $x_C v_M$ gives the effective speed, v_E, which is then differentiated to obtain the optimum cruise speed ratio, x_{COP}, in the form

$$x_{COP} = \left(\frac{x_{TOP}}{\alpha a_M C_1}\right)^{\frac{1}{\alpha}} \quad a_M \geq \frac{1}{\alpha C_1} \quad . \tag{J-44}$$

Putting equation (J-33) in the form

$$x_{TOP}^{\alpha} = \frac{x_{TOP}}{\alpha a_M C_1} \quad ,$$

and inserting the result in (J-44) leads again to the same condition that was true for the cubic case:

$$x_{COP} = x_{TOP} \quad .$$

When $a_M \le 1/\alpha C_1$, it can be shown also that the optimum cruise speed ratio is constrained to unity. The optimum station time fraction becomes

$$f_{SOP} = \begin{cases} 1 - a_M & , \quad a_M \le \dfrac{1}{\alpha C_1} \\ \left(\dfrac{\alpha - 1}{\alpha}\right)\left[1 - \dfrac{C_0}{(\alpha-1)\, C_1} (\alpha a_M C_1)^{\frac{\alpha}{\alpha-1}}\right] & , \quad a_M \ge \dfrac{1}{\alpha C_1} \end{cases} \qquad \text{(J-45)}$$

The optimum effective speed is given by

$$v_{EOP} = v_{COP} f_{SOP} = x_{COP} f_{SOP} v_M \quad , \qquad \text{(J-46)}$$

where f_{SOP} is given by equation (J-45), and x_{COP} by equation (J-33), since $x_{COP} = x_{TOP}$.

The above two functions are presented graphically in figure J-4 for the case of a 110 knot/1,000 mile range airship (LTA 1). The cubic law results are shown as dashed lines for comparison with the results based on the more general fuel rate law. At 500 miles distance to station, the on-station fraction is 75 percent of the cubic law result; the effective speed is about 68 percent of the cubic law effective speed. For distances less than about 300 miles, the effective speeds are essentially the same for both fuel rate formulas. The results shown are based on the assumption that $\alpha = 2.67$.

Figure J-5 presents a graphic comparison of three airships over a larger range of station distances to demonstrate the form of equation (J-45) out to the limit where $f_{SOP} = 0$.

The maximum range for $\alpha = 2.67$ is $R_{MAX} = 2.14\ R_M$, so that $f_{SOP} = 0$ at a station distance of 1,070 miles for the 1,000 mile range airship. The corresponding speed ratio to obtain maximum range is $x_{MAX} = 0.38$.

In the next section the general fuel rate law is extended to include the effects of airship heaviness.

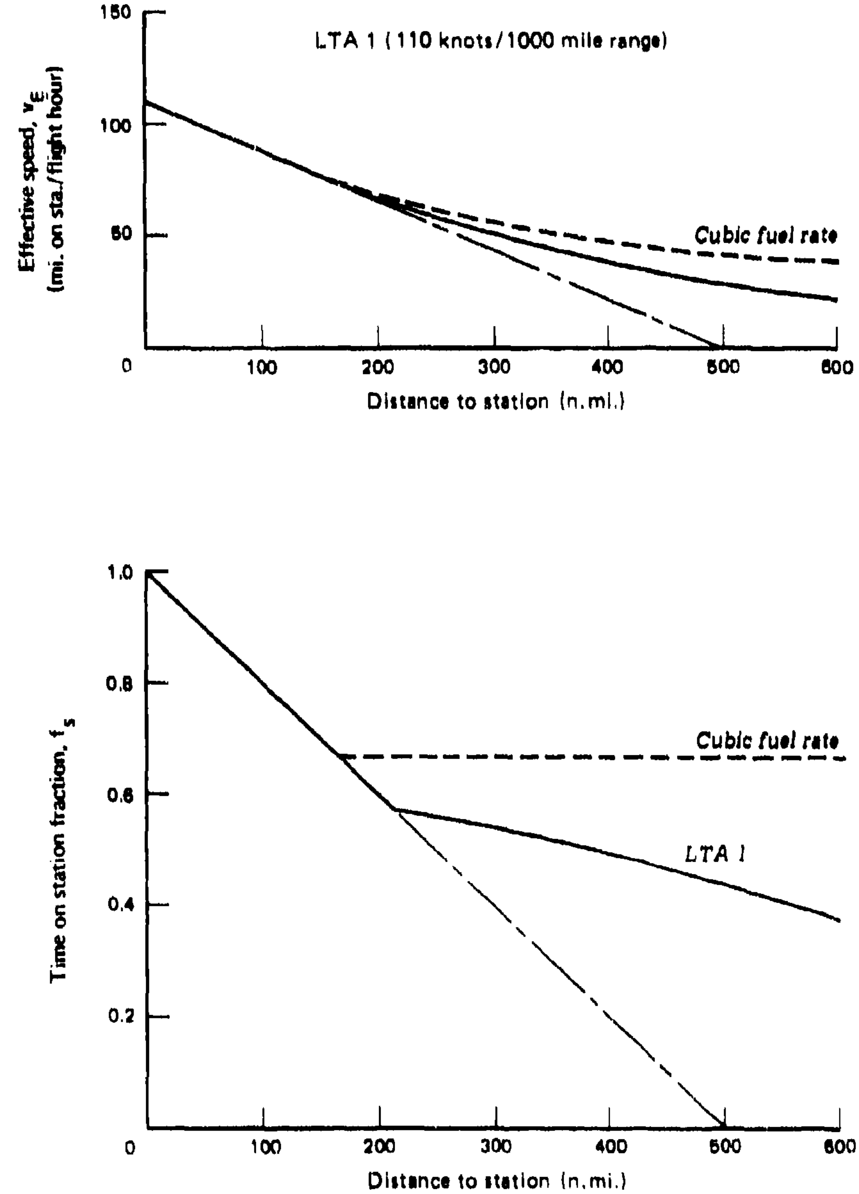


FIG. J-4: AIRSHIP TIME-ON-STATION FRACTION AND EFFECTIVE SPEED (GENERAL FUEL RATE LAW – ZERO HEAVINESS)

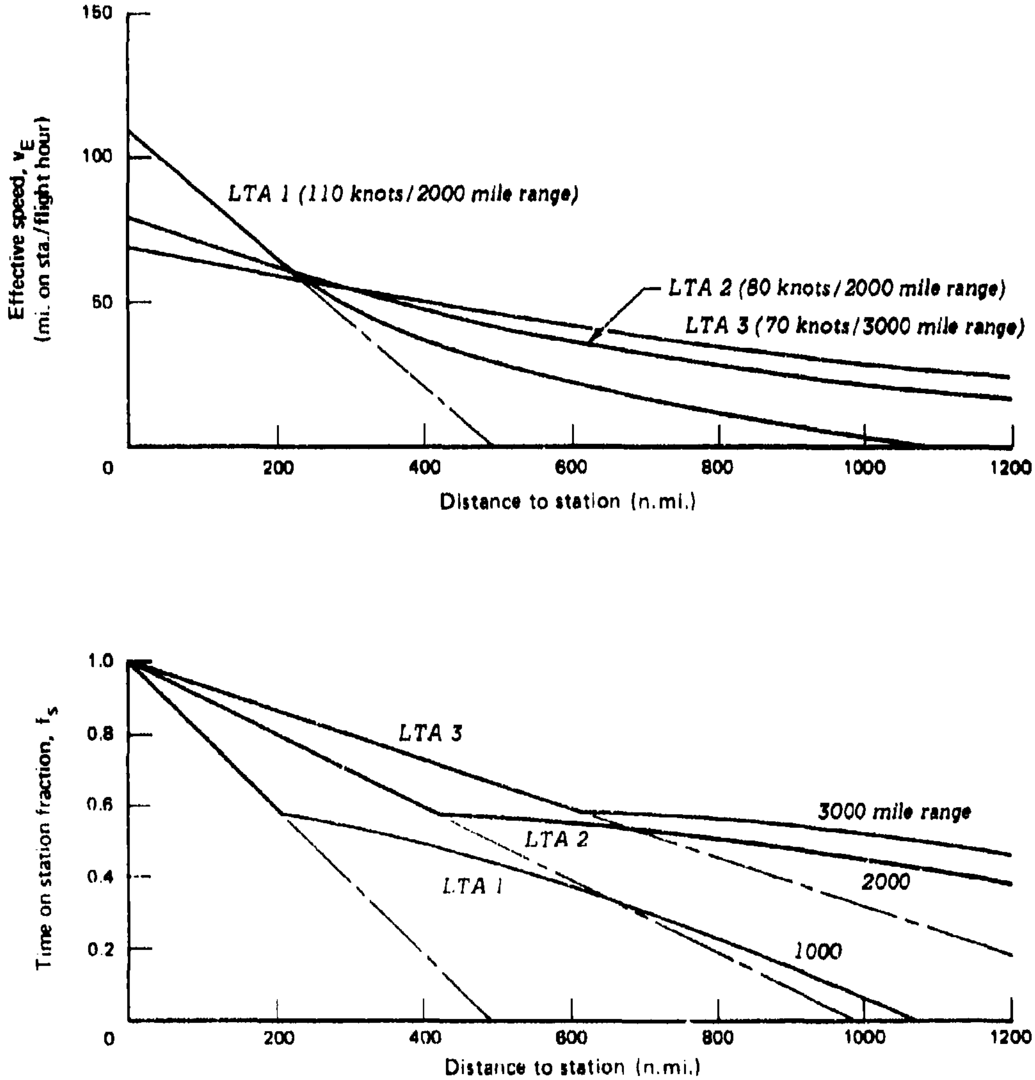


FIG. J-5: AIRSHIP TIME-ON-STATION FRACTION AND EFFECTIVE SPEED (GENERAL FUEL RATE LAW – ZERO HEAVINESS)

General Fuel Rate Law

The following general formula for the fuel consumption rate of semi-buoyant airships is developed in annex J-1:

$$\frac{\dot{W}(x,H)}{\dot{W}_M} = C_0 + \frac{C_1}{C_2} x^{2.43} \left(1+b_M \frac{H^2}{x^4}\right)^{1.2} \left[1+C_3 \frac{x^{.51}}{\left(1+\frac{b_M H^2}{x^4}\right)^{0.24}}\right] \quad \text{(J-47)}$$

where

x = speed ratio = v/v_M

H = heaviness; i.e., dynamic lift/static lift = L_D/L_S

$\dot{W}_M$ = initial fuel consumption rate at speed v_M and initial heaviness, H_0 , (gal./hr.)

The coefficients C_0 and C_1 are 0.11 and 0.89, as above, and the other coefficients are functions of the airship characteristics (maximum speed and volume) and altitudes (flight and limiting gas altitudes). When $x = 1$ and $H = H_0$, the fuel consumption rate is equal to $\dot{W}_M$. The initial fuel rate $\dot{W}_M$ is related to the design average fuel rate, $\dot{W}_{MAV}$, at speed v_M, as follows:

$$\dot{W}_M = \dot{W}_{MAV} \left(1 + \frac{3}{4} b_M H_0^2\right) .$$

Airship heaviness results in additional drag that varies as H^2/x^4. The term in brackets in equation (J-47) arises from the effects of propulsion efficiency changes with speed and heaviness. The speed variation to the 2.43 power represents the normal zero dynamic lift power term ($x^{2.86}$) modified by a propulsion efficiency factor ($1/x^{.43}$).

Equation (J-47) is presented graphically in figure J-6 to show the effects of speed and heaviness variations for a 100 knot airship with a volume of 500,000 cubic feet and a heaviness factor, $H_0 = 0.5$. The solid curves show the fuel rate ratio for constant heaviness, in increments of 0.1 from $H = 0$ to $H = H_0 = 0.5$. The dashed lines indicate the speed/heaviness relations for variable speed operations at constant angle of attack.

Since aerodynamic lift varies as the square of the speed, it can be shown that

$$v_1 = \frac{v}{100} = 1.089\, V^{\frac{1}{6}} \sqrt{H} \tag{J-48}$$

where v_1 is a dimensionless speed parameter equal to the speed in knots divided by 100, and the angle of attack, α , is constant at 10 degrees. The relation (J-48) is indicated in figure J-6 for $\alpha = 5$, 10, and 15 degrees. (See also equations J-1-10 and J-1-13.)

At 5 degrees attack angle the dashed curve is close to the zero heaviness curve. The 15 degree curve follows closely the minimum points on the fuel consumption curves. The 10 degree curve is also near the minimum points. The 10 degree attack angle represents a practical operational compromise between achieving reduced fuel consumption and not requiring excessive flight attitudes. When 10 degrees is considered the upper limit, the speed is constrained to remain above various limits that depend on the particular heaviness condition prevailing at a given time in the flight.

Initially, for example, the speed must exceed about 70 knots; to operate at 30 knots the heaviness must be less than 0.1. The reduced speeds required for optimum transits to large station distances are generally feasible for the airships considered in this study. For trailing operations, however, it is usually necessary to include a variable speed phase on station until the heaviness decreases to the point that 30 knot operations are possible at the 10 degree attack angle limit. Reduced speeds may also be desired when conducting investigations during patrol tasks. Estimation of the fuel conserved during target investigations with delays depends on the average fuel rates during variable speed operations.

Since the fuel rate also varies in constant speed operations, it is necessary to develop formulas for the average fuel rates of both variable and constant speed flight profiles. The constant speed case will be treated first.

<u>Average Fuel Rate - Constant Speed</u>

When speed, v , is constant, equation (J-47) takes the form

$$\frac{\dot{W}(H)}{\dot{W}_M} = C_0 + C_4 \left(1 + bH^2\right)^{1.2} \left[1 + \frac{C_5}{\left(1 + bH^2\right)^{.24}}\right] \tag{J-49}$$

where

$$b = \frac{1.13V^{0.71}}{v_1^4} ,$$

and the coefficients C_4 and C_5 depend on the constant speed parameter, $v_1 = v/100$.

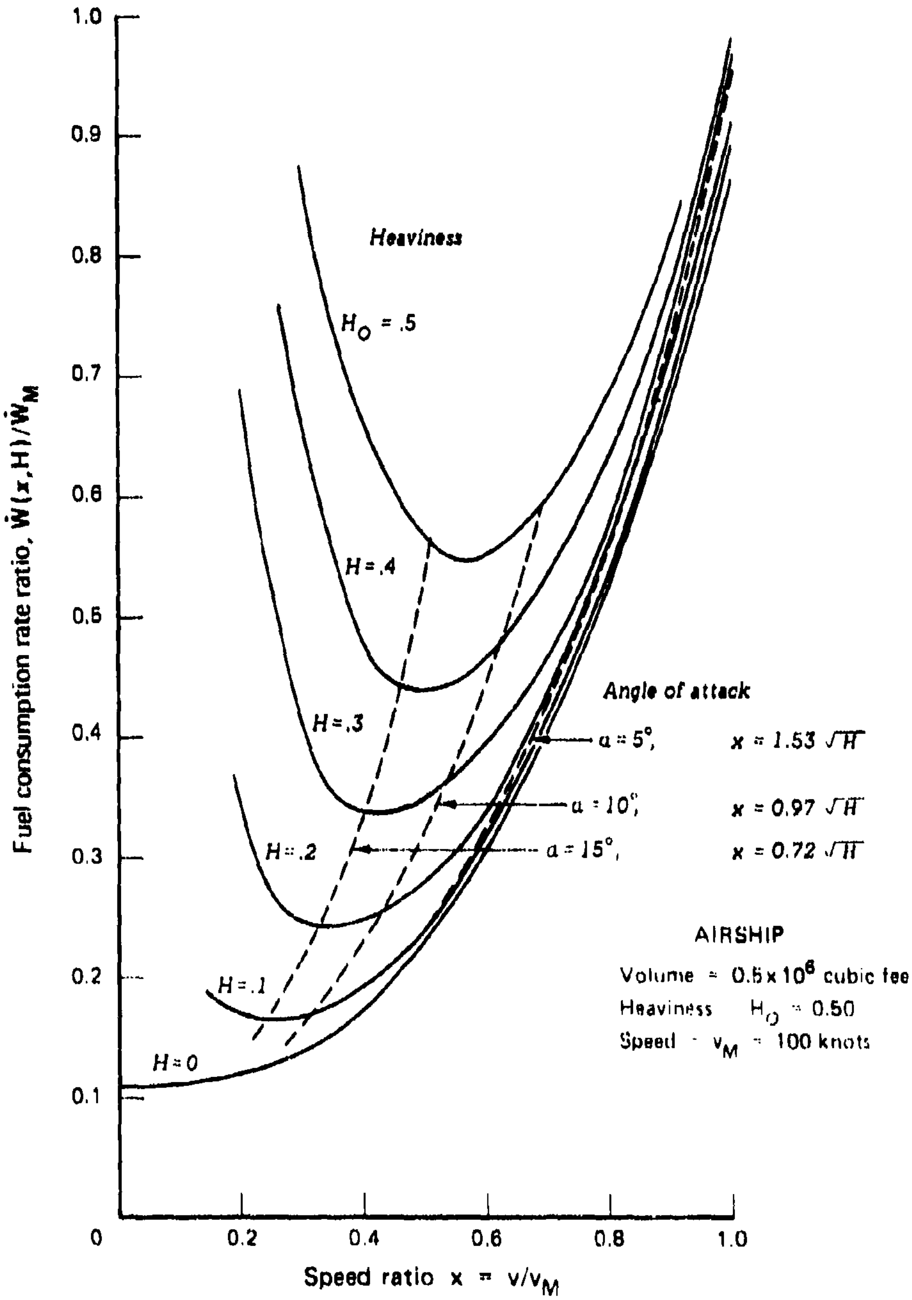


FIG. J-6: GENERAL FUEL RATE LAW

Since the term bH^2 is usually less than unity, equation (J-49) can be put in the approximate form

$$\frac{\dot{W}(H)}{\dot{W}_M} \doteq K(1 + b'H^2) \qquad \text{(J-50)}$$

where

$$K = C_0 + C_4(1 + C_5) \qquad \text{(J-51)}$$

$$b' = \frac{(1.2 + 0.96\,C_5)C_4}{K}\, b \quad . \qquad \text{(J-52)}$$

Since the fuel weight is equal to $L_S H$, we have the following equation for the rate of change of fuel weight, divided by $\dot{W}_M$,

$$\frac{L_S}{\dot{W}_M} \frac{dH}{dt} = -K(1 + b'H^2) \quad . \qquad \text{(J-53)}$$

Since fuel weights and rates enter as ratios it is convenient to express these quantities in gallons rather than pounds.

Integrating equation (J-53) between arbitrary initial and final heaviness states, H_i and H_f, respectively, we get

$$\frac{\dot{W}_{AV}}{\dot{W}_M} = \frac{L_S(H_i - H_f)}{\dot{W}_M t} = K \frac{(H_i - H_f)\sqrt{b'}}{(\tan^{-1}\sqrt{b'}H_i - \tan^{-1}\sqrt{b'}H_f)} \quad . \qquad \text{(J-54)}$$

Expanding the $\tan^{-1}$ terms we get the approximate relation

$$\frac{\dot{W}_{AV}}{\dot{W}_0} = \left[1 + \frac{b'}{3}(H_i^2 + H_i H_f + H_f^2) \right] \qquad \text{(J-55)}$$

where

$$\dot{W}_0 = K\dot{W}_M = \text{fuel rate at zero heaviness,} \qquad \text{(J-56)}$$

When the final heaviness is zero, equation (J-55) reduces to the simpler form

$$\frac{\dot{W}_{AV}}{\dot{W}_0} = 1 + \frac{b'}{3} H_i^2 \quad . \tag{J-57}$$

Average Fuel Rate - Variable Speed

When the attack angle is constant at 10 degrees, we have, from equation (J-48)

$$v_1^4 = 1.406V^{0.67}H^2 \quad .$$

Inserting this relation into equation (J-47) we obtain the result

$$\frac{\dot{W}}{\dot{W}_M} = C_0 + AH^{1.22}(1 + BH^{0.25}) \tag{J-58}$$

where A and B are functions of airship maximum speed and volume.

Equation (J-58) can be approximated by the expression

$$\frac{\dot{W}}{\dot{W}_M} = C_0 (1 + CH)^2 \tag{J-59}$$

where C is a parameter that was estimated by numerical integration of equation (J-58) and comparison of the result with the integration of equation (J-59).

Following the same approach as before, in the constant speed case, we construct the fuel rate differential equation

$$\frac{L_S}{\dot{W}_M} \frac{dH}{dt} = - \left[C_0 + AH^{1.22}(1 + BH^{0.25}) \right] \tag{J-60}$$

and obtain the average fuel rate

$$\frac{\dot{W}_{AV}}{\dot{W}_M} = \frac{L_S(H_i - H_f)}{\dot{W}_M t} = \frac{(H_i - H_f)}{\int_{H_f}^{H_i} \frac{dH}{C_0 + AH^{1.22}(1 + BH^{.25})}} \quad . \tag{J-61}$$

Following the same approach using the approximate formula (J-59) we have

$$\frac{L_S}{\dot{W}_M} \frac{dH}{dT} = -C_0 (1 + CH)^2 \quad , \tag{J-62}$$

so that

$$t = \frac{L_S}{\dot{W}_M C_0} \int_{H_F}^{H_i} \frac{dH}{(1 + CH)^2}$$

$$= \frac{L_S}{\dot{W}_M C_0} \frac{(H_i - H_f)}{(1 + CH_i)\ (1 + CH_f)} \quad . \tag{J-63}$$

Inserting this value of t in the expression for the average fuel rate ratio, we find

$$\frac{\dot{W}_{AV}}{\dot{W}_M} = \frac{L_S(H_i - H_f)}{\dot{W}_M t} = C_0 (1 + CH_i)\ (1 + CH_f) \quad . \tag{J-64}$$

When the final heaviness is zero we have

$$\frac{\dot{W}_{AV}}{C_0 \dot{W}_M} = 1 + CH \tag{J-65}$$

where $H = H_i$ is the initial heaviness.

The variable speed fuel rate parameter, C is thus the slope of the linear expression (J-65). The slopes were determined by fitting the approximate linear formula (J-65) to the exact results obtained using equation (J-61), as shown in figure J-7 for an airship range of 1,000 miles and speeds from 50 to 120 knots. The exact results are indicated by the series of dots in figure J-7. The linear approximations were adjusted to give the best fit to the exact results over the upper half of the heaviness values for each speed considered. Over the lower half of the heaviness values, the exact results fall slightly below the linear approximation, so that the effective C values would be smaller in the region of smaller heaviness values. In our application, the lower heaviness limit during the variable speed phase will be approximately 0.1, corresponding to a speed of 30 knots. It is thus appropriate to put less weight on the fit in the region of small heaviness.

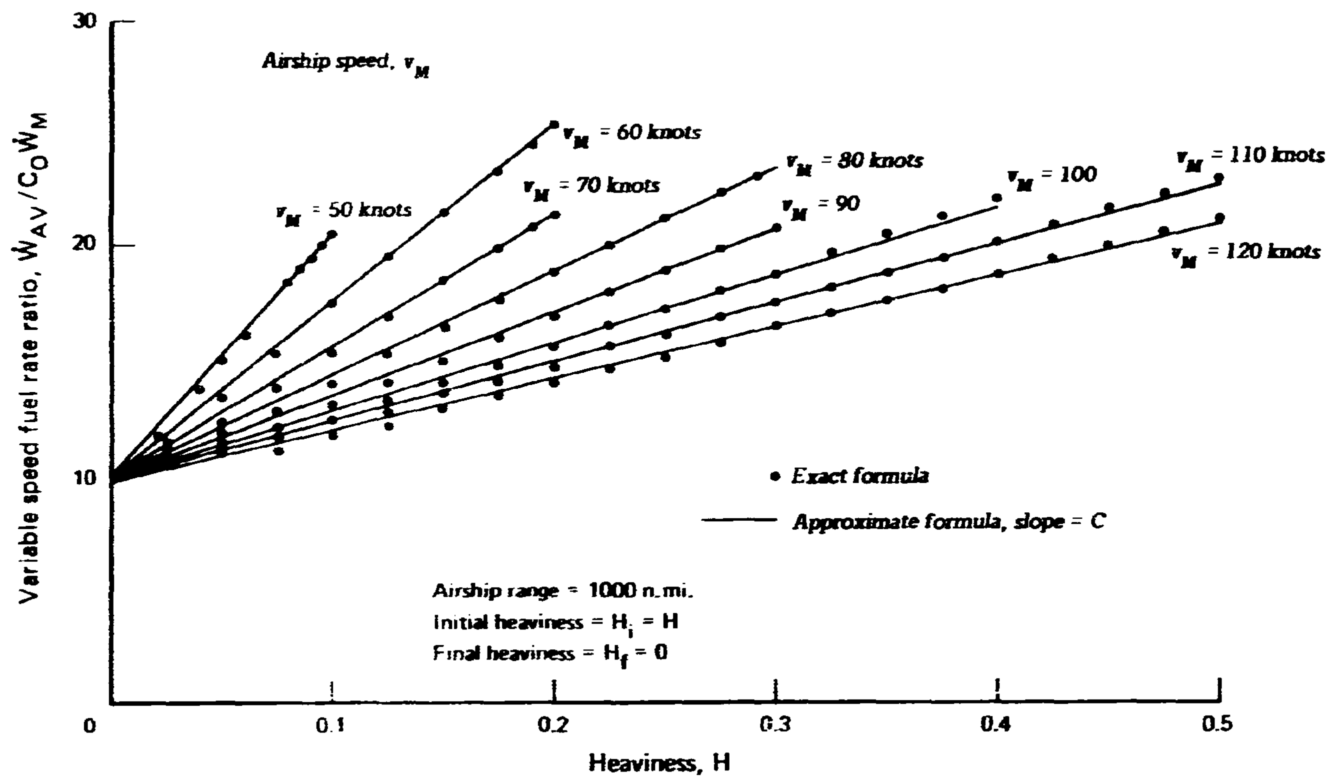


FIG. J-7: DETERMINATION OF VARIABLE SPEED FUEL RATE PARAMETER, C

The specific C values obtained are listed in table J-2-2 of annex J-2. The C values are also shown graphically as points in figure J-8, where the abscissa is airship volume. The dashed lines are rough fits of these points, connecting cases of the same airship maximum speed, v_M. The C values range from 2.37 at 110 knots to 12.81 at 50 knots. The variation with volume is greatest at the lower maximum speeds.

The variation of speed with time, $v_1(t)$, during a variable speed phase at constant angle of attack (α = 10 degrees) can be obtained using equations (J-48) and (J-64). Thus, we find

$$v_1(t) = 1.089V^{\frac{1}{6}} \sqrt{H_i - H_0 \frac{(\dot{W}_i t/L_D)}{1 + \left(\frac{CH_0}{1 + CH_i}\right) (\dot{W}_i t/L_D)}} \tag{J-66}$$

where H_i is the heaviness at the start of the variable speed phase, and $\dot{W}_i$ is the corresponding fuel rate given by

$$\dot{W}_i = C_0 \dot{W}_M (1 + CH_i)^2 = \left(\frac{1 + CH_i}{1 + CH_f}\right) \dot{W}_{AV} . \tag{J-67}$$

The limiting value of t in equation (J-66) occurs when the final heaviness and speed are zero; so that

$$\frac{\dot{W}_{AV} t_{MAX}}{L_D} = \frac{H_i}{H_0} \tag{J-68}$$

or alternatively,

$$\frac{\dot{W}_i t_{MAX}}{L_D} = \frac{H_i}{H_0} (1 + CH_i) \tag{J-69}$$

and

$$t_{MAX} = \frac{L_D H_i}{C_0 \dot{W}_M H_0 (1 + CH_i)} \tag{J-70}$$

which follows also from equation (J-63) when $H_f = 0$, since $L_D = L_S H_0$.

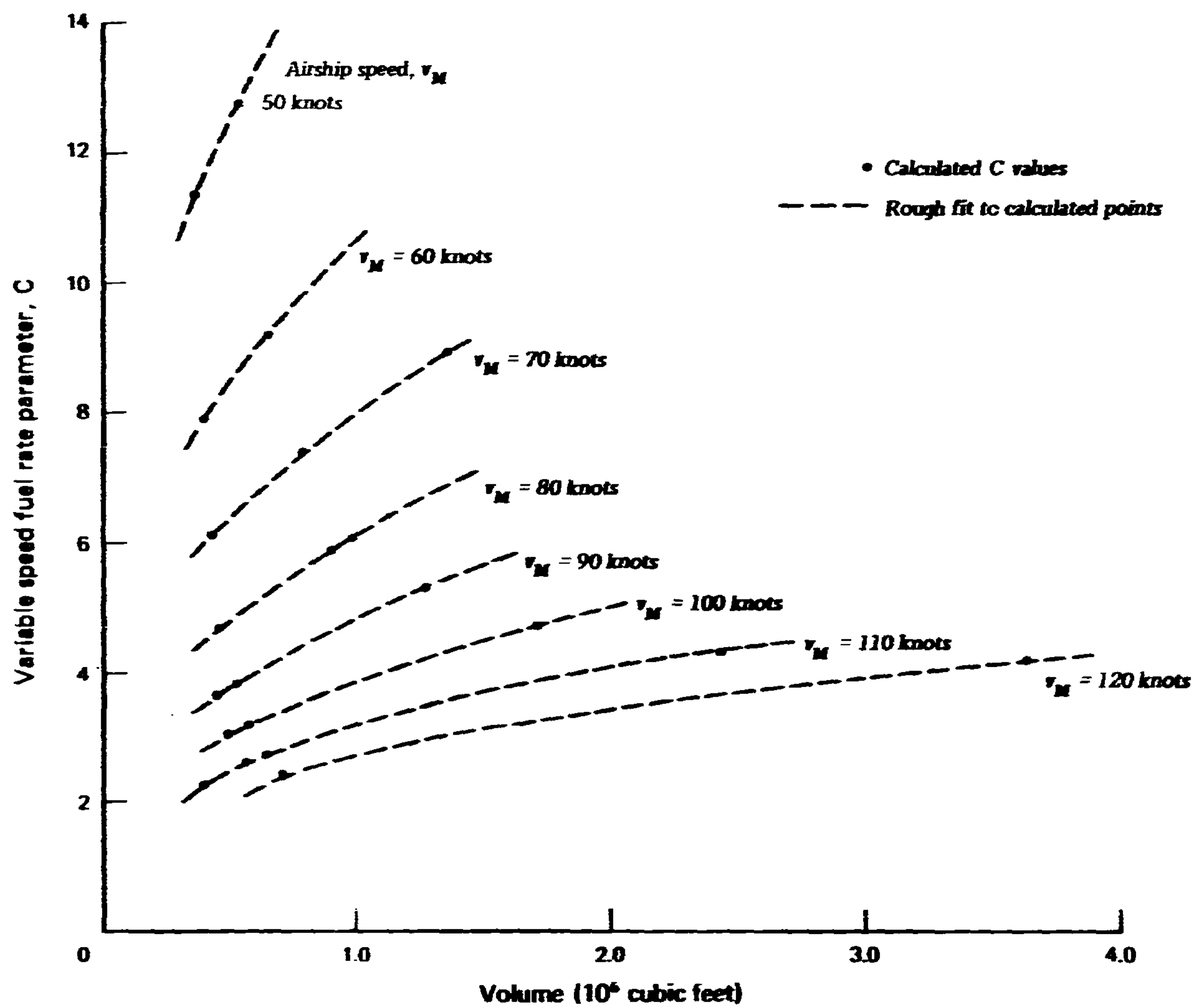


FIG. J-8: VARIABLE SPEED FUEL RATE PARAMETER, C

The average fuel rate formulas developed above for constant speed and variable speed phases will next be applied to the calculation of endurance. The constant speed case will be treated first.

Endurance In Patrol Tasks - Constant Speed

Endurance in constant speed patrol tasks, t_{FP}, is calculated as the sum of the heavy phase endurance, t_H, and the buoyant phase endurance, t_0.

$$t_{FP} = t_H + t_0 \quad . \tag{J-71}$$

The fuel available for each phase depends on the total fuel available and the initial heaviness, H_0. The total fuel available is assumed to be 90 percent of the total fuel carried, allowing 10 percent for reserve. The total fuel weight is the sum of the buoyant fuel weight, W_{FO}, and the aerodynamic lift, L_D. The available buoyant fuel, Δ_F, is thus given by

$$\begin{aligned} \Delta_F &= 0.9\,(L_D + W_{F0}) - L_D \\ &= 0.9\,W_{F0} - 0.1\,L_D \quad . \end{aligned} \tag{J-72}$$

In most cases $\Delta_F > 0$, so that

$$t_0 = \frac{\Delta_F}{\dot{W}_0} \tag{J-73}$$

where $\dot{W}_0 = K\dot{W}_M$, and $K = C_0 + C_4\,(1 + C_5)$ according to equation (J-51).

The endurance during the heavy phase is calculated by dividing the fuel available during the heavy phase by the average fuel rate given in equation (J-57); with $H_1 = H_0$,

$$t_H = \frac{L_D}{\dot{W}_0\,(1 + \frac{b'}{3}\,H_0^2)} \quad . \tag{J-74}$$

Adding equations (J-73) and (J-74), we obtain the total endurance

$$t_{FP} = \frac{L_D}{\dot{W}_0\,(1 + \frac{b'}{3}\,H_0^2)} + \frac{\Delta_F}{\dot{W}_0} \quad . \tag{J-75}$$

In the event that the buoyant fuel weight is negative, $\Delta_F < 0$, the entire flight is made in a heavy condition. The available fuel is then $L_D - \Delta_F$, so that the final heaviness is given by

$$H_f = \frac{\Delta_F}{L_S} = \frac{\Delta_F}{L_D} H_0 \quad . \tag{J-76}$$

In this case, the endurance is calculated using equation (J-55) with $H_i = H_0$ and H_f given by equation (J-76). We thus find

$$t_{FP} = \frac{L_D - \Delta_D}{\dot{W}_0 \left[1 + \frac{b'}{3} \left(1 + \frac{\Delta_F}{L_D} + \left(\frac{\Delta_F}{L_D}\right)^2 \right) H_0^2 \right]} \quad . \tag{J-77}$$

The time-on-station fraction in patrol tasks, f_{SP}, is determined using equation (J-77) and the relation

$$f_{SP} = \frac{t_{FP} - t_T}{t_{FP}} = 1 - \frac{t_T}{t_{FP}} \tag{J-78}$$

where $t_T = 2D/v_T$ is the total time in transit.

The effective speed is obtained using equation (J-78):

$$v_E = f_{SP} v_T \tag{J-79}$$

where v_T is the optimal speed given in equation (J-34).

Endurance In Trail Tasks - Variable Speed

The objective in trail tasks is to operate on station at speeds as close to 30 knots as possible. When the initial heaviness on station, H_i, exceeds the allowable heaviness at 30 knots, H_{30}, a period of variable speed operations is required until a heaviness of H_{30} is reached. At that point, a constant speed of 30 knots can be maintained while heaviness is decreased to some final value, H_f, before leaving station. If $H_f = 0$

before leaving station, a period of operations at 30 knots at zero heaviness is possible. If the initial heaviness on station is less than H_{30} , no variable speed phase is necessary, the on-station period is at a constant speed of 30 knots. In the latter case, the flight is conducted at two speeds -- the transit speed and the trail speed of 30 knots.

To categorize the various heaviness conditions we express them as fractions of the initial heaviness, H_0 . Thus, we define

$$f_{H1} = \frac{H_1}{H_0}$$

$$f_{H2} = \frac{H_f}{H_0}$$

$$f_{H30} = \frac{H_{30}}{H_0} \quad . \tag{J-80}$$

The first two fractions are calculated by solving for the fuel consumed during the outbound and inbound transits. The third fraction is determined using the heaviness-speed condition for constant angle of attack with the speed set equal to 30 knots. Thus, using equation (J-48) we have

$$H_{30} = \frac{0.076}{V^{1/3}} \tag{J-81}$$

and

$$f_{H30} = \frac{0.076}{V^{1/3} H_0} \quad . \tag{J-82}$$

When the volume is close to 500,000 cubic feet, H_{30} is about 0.1, and

$$f_{H30} = \frac{0.1}{H_0} \quad . \tag{J-83}$$

The initial heaviness fraction, f_{H1} , is found by solving the fuel weight equation

$$L_S(H_0 - H_1) = \dot{W}_{AV} t \tag{J-84}$$

where t is the outbound transit time, D/v_T. Using equation (J-55) for the average fuel rate at constant transit speed, v_T, we have

$$L_S (1 - f_{H1}) H_0 = \dot{W}_0 t \left[1 + \frac{b'}{3} \left(1 + f_{H1} + f_{H1}^2\right) H_0^2\right] . \qquad \text{(J-85)}$$

Rearranging this quadratic in f_{H1} yields,

$$\left(\frac{b'}{3} H_0^2\right) f_{H1}^2 + \left(\frac{b'}{3} H_0^2 + \frac{L_D}{\dot{W}_0 t}\right) f_{H1} + \left(1 + \frac{b'}{3} H_0^2 - \frac{L_D}{\dot{W}_0 t}\right) = 0 . \qquad \text{(J-86)}$$

Letting

$$a_0 = \frac{1}{3} b' H_0^2$$

$$b_0 = \frac{\dot{W}_0 t}{L_D}$$

equation (J-86) takes the form

$$a_0 f_{H1}^2 + \left(a_0 + \frac{1}{b_0}\right) f_{H1} + \left(1 + a_0 - \frac{1}{b_0}\right) = 0 . \qquad \text{(J-87)}$$

A convenient approximate solution that is sufficiently accurate for our purposes, is easily found to be given by

$$f_{H1} = 1 - b_0 \left[1 + 3a_0 (1 - \frac{2}{3} b_0)\right] . \qquad \text{(J-88)}$$

The final heaviness fraction, f_{H2}, is found by solving the fuel weight equation

$$L_S H_f = \dot{W}_{AV} (t - t_0) \qquad \text{(J-89)}$$

where t is the inbound transit time, D/v_T, and t_0 is the time at zero heaviness, given by equation (J-73). Using equation (J-57) for the average fuel rate, with H_1 equal to H_f, equation (J-89) becomes

$$L_D f_{H2} = \dot{W}_0 \left(1 + \frac{b'}{3} f_{H2}^2 H_0^2\right) \left(t - \frac{\Delta_F}{\dot{W}_0}\right) . \qquad \text{(J-90)}$$

Rearranging, we have

$$\left(\frac{b'}{3} H_0^2\right) f_{H2}^2 - \left(\frac{L_D}{\dot{W}_0 t - \Delta_F}\right) f_{H2} + 1 = 0 \quad . \qquad (J\text{-}91)$$

Equation (J-91) can be solved approximately as follows:

$$f_{H2} = \left(\frac{\dot{W}_0 t - \Delta_F}{L_D}\right) \left[1 + \frac{b'}{3} \left(\frac{\dot{W}_0 t - \Delta_F}{L_D}\right)^2 H_0^2 \right] \quad . \qquad (J\text{-}92)$$

For trail tasks the flight endurance, t_{FT} , is calculated as the sum of the endurance on station, t_C , and the total transit time, t_T

$$t_{FT} = t_C + t_T \qquad (J\text{-}93)$$

where $t_T = 2D/v_T$.

The endurance on station, t_C , is calculated in various ways depending on the relationships of f_{H1} and f_{H2} and f_{H2} to f_{H30} . The endurance on station is subdivided into various factors, as indicated in the following matrix:

Endurance On-Station Factors

	$f_{H2} > f_{H30}$	$f_{H30} > f_{H2} > 0$	$f_{H2} < 0$
$f_{H1} > f_{H30}$	t_V	$t'_V + t'_{H30}$	$t'_V + t'''_{H30} + t_{030}$
$f_{H1} < f_{H30}$		t_{H30}	$t''_{H30} + t_{030}$

where

$$t_V = \frac{\left(f_{H1} - f_{H2}\right) L_D}{C_0 \dot{W}_M \left(1 + Cf_{H1} H_0\right) \left(1 + CF_{H2} H_0\right)} \qquad (J\text{-}94)$$

$$t'_V = \frac{\left(f_{H1} - f_{H30}\right) L_D}{C_0 \dot{W}_M \left(1 + Cf_{H1}H_0\right) \left(1 + Cf_{H30}H_0\right)} \qquad (J\text{-}95)$$

$$t_{H30} = \frac{\left(f_{H1} - f_{H2}\right) L_D}{\dot{W}_{030} \left[1 + \frac{b'_{30}}{3} \left(f_{H1}^2 + f_{H1}f_{H2} + f_{H2}^2\right) H_0^2\right]} \qquad (J\text{-}96)$$

$$t'_{H30} = \frac{\left(f_{H30} - f_{H2}\right) L_D}{\dot{W}_{030} \left[1 + \frac{b'_{30}}{3} \left(f_{H30}^2 + f_{H30}f_{H2} + f_{H2}^2\right) H_0^2\right]} \qquad (J\text{-}97)$$

$$t''_{H30} = \frac{f_{H1} L_D}{\dot{W}_{030} \left(1 + \frac{b'_{30}}{3} f_{H1}^2\right)} \qquad (J\text{-}98)$$

$$t'''_{H30} = \frac{f_{H30} L_D}{\dot{W}_{030} \left(1 + \frac{b'_{30}}{3} f_{H30}^2 H_0^2\right)} \qquad (J\text{-}99$$

$$t_{030} = \frac{\Delta_F - \dot{W}_0 t}{\dot{W}_{030}} \qquad (J\text{-}100)$$

and b'_{30} and W_{030} are given by equations (J-52) and (J-56), respectively, with the airship at 30 knots, rather than the transit speed v_T.

Equation (J-94) for the time at variable speed, t_V, is based on equation (J-64) with $H_i = f_{H1}H_0$ and $H_f = f_{H2}H_0$. Equation (J-95) for t'_V is obtained from equation (J-94) with f_{H2} replaced by f_{H30}.

Equation (J-96) for the time while heavy at 30 knots constant speed is obtained from equation (J-55) with $H_i = f_{H1}H_0$ and $H_f = f_{H2}H_0$, $\dot{W}_0 = \dot{W}_{030}$ and $b' = b'_{30}$. Equations (J-97) to (J-100) are based on equation (J-96) with the following substitutions:

equation (J-97) $f_{H1} = f_{H30}$

equation (J-98) $f_{H2} = 0$

equation (J-99) $f_{H1} = f_{H30}$ and $f_{H2} = 0$.

Equation (J-100) for the buoyant time at 30 knots, t_{030} , is based on the buoyant fuel remaining after subtracting the fuel required for the inbound transit, $\dot{W}_0 t$, where $t = D/v_T$.

On-station fractions in trail tasks, f_{ST} , are obtained using the relation

$$f_{ST} = \frac{t_C}{t_{FT}}$$

with the on-station endurance calculated as indicated in the above matrix using equations (J-94) to (J-100).

Figure J-9 is a graphic presentation of the time-on-station fractions in patrol and trail tasks as a function of distance to station. Results are shown for a 110 knot/1,000 mile range airship.

The patrol and trail on-station fractions, f_{SP} and f_{ST} , are used also in the following section to determine the effects on endurance of speed change during investigations with delays.

Patrol Tasks with Investigation Delays

When investigation delays are included the effectiveness measure of concern is targets investigated per flight hour, which is proportional to track miles on station per flight hour. Track miles is a measure of distance covered when proceeding directly from one target to the next closest target. One effect of delays is to reduce the effective cruise speed on station by the factor

$$1 - f_L = \frac{t_d}{t_d + \tau} = \frac{1}{1 + \tau/t_d} \qquad \text{(J-101)}$$

where f_L is the fraction of on-station time spent in investigation, τ is the delay time, and t_d is the time to travel an average distance between targets equal to d. Thus $t_d = d/v_C$, when v_C is assumed to be equal to the optimum speed on station ($v_C = v_{COP} = v_{TOP}$) determined for the case of no investigation delay. Relation (J-101) may be rearranged to give f_L directly,

$$f_L = \frac{\tau/t_d}{1 + \tau/t_d} = \frac{kv_C}{1 + kv_C} \tag{J-102}$$

where

$$k = \tau/d \quad .$$

In this appendix, k is treated as a general delay parameter, including the delay time and target density, since the average distance d is related inversely to the square root of the target density. In volume I, low density is associated with an average distance between targets of 200 miles and average delay times of 0.1 hour, so that $k = 0.1/200 = 0.0005$; high density is associated with an average distance of 2 miles and average delay times of 0.01 hours, so that $k = 0.01/2 \sim 0.005$.

The effective speed made good along the track connecting the investigated targets is given by $(1 - f_L)v_C$. The effective speed for the mission is thus:

$$v_E = (1 - f_L)v_C f_{SP} \quad . \tag{J-103}$$

Equation (J-103) omits a secondary effect that enters in the case of airships, or other vehicles capable of operating at reduced speeds during the investigation delay periods. The use of slow speeds during investigation periods can lead to more effective investigations, but no attempt is made here to quantify such effects. The effect of the slow speeds on the average fuel rate, and hence the endurance and time-on-station fraction, can be estimated, however.

For very short delay times, decelerations and acceleration effects might make it difficult to achieve such reduction in fuel rates. However, the situation would be different if the delay time is an average of many small delays plus a few much larger delays, where accelerations could be ignored. It is assumed here that the high target density case does correspond with such a situation of many short plus a few long delay times.

Delay periods are assumed to be distributed in a random uniform manner throughout the on-station period. Speeds employed during delay periods are assumed to be the same as if the airship were conducting trail operations, i.e., as close to 30 knots as possible, constrained by the prevailing heaviness condition.

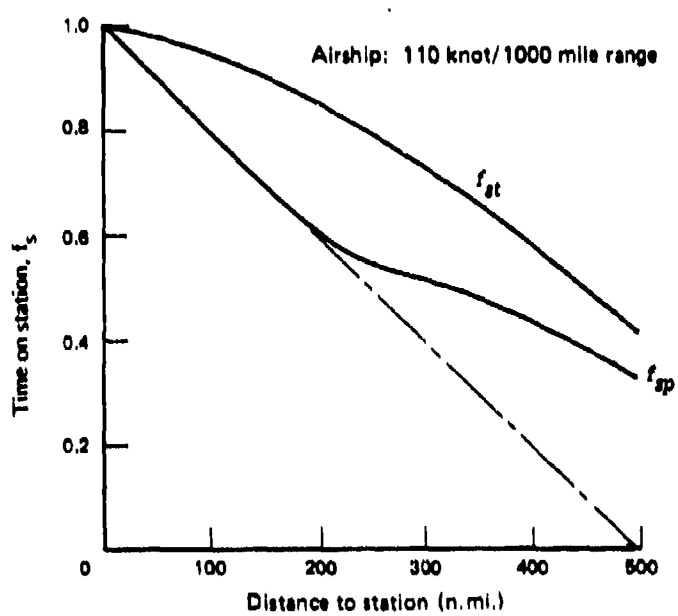


FIG. J-9: TIME ON STATION FRACTIONS FOR PATROL AND TRAIL TASKS

With the above assumptions, the average fuel rate on station, $\dot{W}_{AVS}$, can be approximated as follows:

$$\dot{W}_{AVS} = (1 - f_L)\,\dot{W}_{SP} + f_L\,\dot{W}_{ST}\ , \qquad \text{(J-104)}$$

where $\dot{W}_{SP}$ and $\dot{W}_{ST}$ are the average fuel rates on station for patrol and trail tasks, respectively. Equation (J-104) can be rewritten in the form

$$\begin{aligned} \dot{W}_{AVS} &= \left(1 - f_L + f_L \frac{\dot{W}_{ST}}{\dot{W}_{SP}}\right) \dot{W}_{SP} \\ &= \left[1 - f_L\,(1 - f_F)\right] \dot{W}_{SP} \end{aligned} \qquad \text{(J-105)}$$

where $$f_F = \frac{\dot{W}_{ST}}{\dot{W}_{SP}} \tag{J-106}$$

The time-on-station fraction for patrol tasks with investigation delays, f'_{SP}, can be expressed in terms of the average fuel rate on station, $\dot{W}_{AVS}$, as follows:

$$f'_{SP} = \frac{1}{1 + \frac{t_T}{t'_{CP}}} = \frac{1}{1 + \frac{t_T \dot{W}_{AVS}}{W_{FS}}} \tag{J-107}$$

where t'_{CP} is the endurance on station in patrol tasks with delays, and W_{FS} is the fuel available on station.

Inserting equation (J-105) into equation (J-107) we obtain the result

$$\begin{aligned} f'_{SP} &= \frac{1}{1 + \frac{t_T \dot{W}_{SP}}{W_{FS}} \left[1 - f_L(1 - f_F)\right]} \\ &= \frac{1}{1 + \frac{t_T}{t_{CP}} \left[1 - f_L\,(1 - f_F)\right]} \end{aligned} \tag{J-108}$$

where t_{CP} is the on-station patrol endurance with no delays.

Since f_{SP}, by definition, is given by

$$f_{SP} = \frac{1}{1 + \frac{t_T}{t_{CP}}}, \tag{J-109}$$

then

$$\frac{t_T}{t_{CP}} = \frac{1 - f_{SP}}{f_{SP}} \tag{J-110}$$

and

$$f'_{SP} = \frac{1}{1 + \frac{(1 - f_{SP})}{f_{SP}} \left[1 - f_L (1 - f_F) \right]}$$

$$= \frac{f_{SP}}{1 - f_L (1 - f_F)(1 - f_{SP})} \quad . \qquad \text{(J-111)}$$

Equation (J-111) can be simplified by developing an alternative expression for the product in the denominator.

Since the fuel available on station, W_{FS} , is the same for both patrol and trail tasks, the fuel rate ratio, f_F , can be expressed as the ratio of the on-station patrol and trail endurance times, t_{CP} and t_{CT} , respectively. Thus, we have the relation

$$f_F = \frac{\dot{W}_{ST}}{\dot{W}_{SP}} = \frac{t_{CP}}{t_{CT}} \quad . \qquad \text{(J-112)}$$

Using relation (J-110) and its counterpart for trail tasks we obtain the on-station endurance time ratio, t_{CP}/t_{CT} , so that equation (J-112) becomes

$$\frac{t_{CT}}{t_T} = \frac{f_{ST}}{1 - f_{ST}} \qquad \text{(J-113)}$$

$$f_F = \frac{t_{CP}}{t_{CT}} = \left(\frac{f_{SP}}{1 - f_{SP}} \right) \left(\frac{1 - f_{ST}}{f_{ST}} \right) \quad . \qquad \text{(J-114)}$$

Rearranging equation (J-114) we get the desired product:

$$(1 - f_F)(1 - f_{SP}) = 1 - f_{SP} - \frac{f_{SP}}{f_{ST}} (1 - f_{ST})$$

$$= 1 - \frac{f_{SP}}{f_{ST}} \quad . \qquad \text{(J-115)}$$

Inserting equation (J-115) into equation (J-111) yields the result

$$f'_{SP} = \frac{1}{1 - f_L\left(1 - \frac{f_{SP}}{f_{ST}}\right)} f_{SP} \quad \text{(J-116)}$$

The effective speed with delays, v'_E, is given by equation (J-103) with f_{SP} replaced by f'_{SP}.

$$v'_E = (1 - f_L)\, v_C f'_{SP} \quad \text{(J-117)}$$

$$= \frac{1 - f_L}{1 - f_L\left(1 - \frac{f_{SP}}{f_{ST}}\right)} v_C f_{SP}$$

$$= \frac{1 - f_L}{1 - f_L\left(1 - \frac{f_{SP}}{f_{ST}}\right)} v_E \quad \text{(J-118)}$$

where v_E is the effective speed without delays.

The endurance of patrol tasks with delays, t'_{FP}, is derived using the time-on-station fraction calculated using equation (J-116):

$$t'_{FP} = \frac{2t}{1 - f'_{SP}} \quad \text{(J-119)}$$

where $t = D/v_T$.

Equation (J-119) is used in turn to obtain the average fuel rate with delays:

$$\dot{W}'_{AVP} = \frac{L_D + \Delta_F}{t'_{FP}} \quad \text{(J-120)}$$

OTHER VEHICLES

Formulas for the time-on-station fractions and effective speeds of other vehicles are developed in this section. In the case of patrol tasks, such as surveillance and investigation, the transit and on-station speeds are specified in volume I. For trail tasks, however, it is necessary to calculate the optimum transit speeds for the hydrofoil (Flagstaff II) and the large cutter (WHEC-378). The results for investigation tasks with no delay can be applied also to gross surveillance tasks, because the measures of effectiveness differ only in the sweepwidth factor. Investigation tasks with time delays differ from the no delay case only in the effective speeds on station; the time-on-station fractions are the same in both cases because all vehicles are assumed to operate at constant on-station speeds.

Investigation Tasks

The time-on-station fractions for patrol tasks are based on the following form of equations (J-4) and (J-5), giving the ratio of time on station to transit time:

$$\frac{t_C}{t_T} = \frac{R_C v_T}{2Dv_C} - \frac{\dot{W}_T}{\dot{W}_C} \qquad \text{(J-121)}$$

where the C and T subscripts denote on station and transit values, respectively, and D is distance to station.

The ranges R_C and R_T, at on-station and transit speeds v_C and v_T, respectively, are related by the fuel weight equation:

$$W_F = \frac{R_C}{v_C} \dot{W}_C = \frac{R_T}{v_T} \dot{W}_T \, .$$

Thus, we have:

$$\frac{R_C}{R_T} = \frac{v_C \dot{W}_T}{v_T \dot{W}_C} \qquad \text{(J-122)}$$

Inserting (J-122) into equation (J-121), the time-on-station fraction takes the form

$$f_S = \cfrac{1}{1 + \cfrac{1}{\cfrac{\dot{W}_T}{\dot{W}_C}\left(\cfrac{R_T}{2D} - 1\right)}} \qquad \text{(J-123)}$$

and

$$f_S = 1 - \frac{\frac{\dot{W}_C}{\dot{W}_T}\ \frac{2D}{R_T}}{1 - \left(1 - \frac{\dot{W}_C}{\dot{W}_T}\right) \frac{2D}{R_T}} , \qquad \text{(J-124)}$$

which reduces to the simple form

$$f_S = 1 - \frac{2D}{R_T} \qquad \text{(J-125)}$$

when the transit and on-station fuel consumption rates are equal.

The only vehicle for which $\dot{W}_C$ is not equal to $\dot{W}_T$ is the HC-130 aircraft. In this case, the low altitude fuel consumption rate exceeds the high altitude transit fuel rate, despite the lower speed employed at low altitude. The fuel rate ratio is determined using table 5 of the Hydrofoil Study.

$$\frac{\dot{W}_C}{\dot{W}_T} = \frac{5,200 \text{ lbs./hr.}}{4,500 \text{ lbs./hr.}} = 1.156 \quad .$$

The same reference was used to calculate R_T for the HC-130. Data in table 5 was used to obtain a fuel load estimate of about 62,000 pounds. Allowing a reserve of 14 percent, the available fuel is 53,320 pounds. Endurance and range at 290 knots transit speed are thus, 11.84 hours and 3,437 miles, respectively.

Maximum transit range for the MRS aircraft was based on an endurance of 4.5 hours at 375 knots (R_T = 1,688 miles).

Other vehicle speed and range characteristics used in calculating time-on-station fractions are shown in the following table.

TABLE J-1

OTHER VEHICLE CHARACTERISTICS

Vehicle	v_T transit speed (knots)	v_C On-station speed (knots)	R_T Range at transit speed (miles)
HC-130	290	210	3,437
MRS	375	230	1,688
HH-X	125	125	530
HH-3	126	126	720
Flagstaff II	45	48	1,000
WMEC-210	18	18	2,700
HEC-MEC	18	18	3,000
WHEC-378	29	29	3,000

Figure J-10 presents the time-on-station fractions for the above vehicles as a function of distance. The airships are shown for comparison purposes.

Effective speeds shown in the upper part of figure J-10 were calculated using the definition

$$v_E = v_C f_S \quad . \tag{J-126}$$

When time delays are involved the effective speeds are given by

$$v_E = (1 - f_L) v_C f_S = \frac{v_C f_S}{1 + k v_C} \tag{J-127}$$

where

$$k = \frac{\tau}{d}$$

and

τ = time delay (hours)

d = average distance between targets

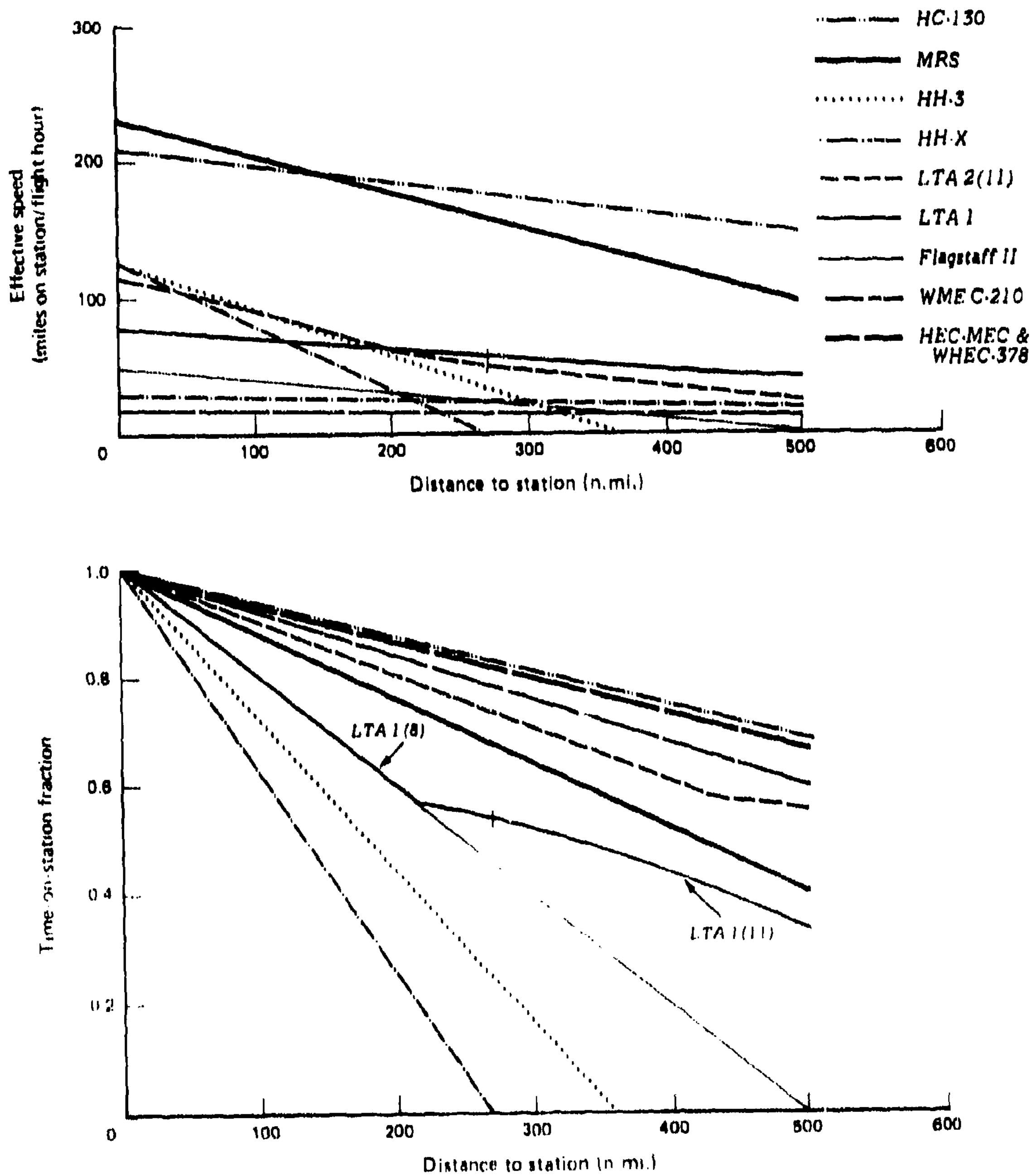


FIG. J-10: VEHICLE TIME ON STATION AND EFFECTIVE SPEED

Trail Tasks

On-station speeds in trail tasks are based on the assumption of a 15 knot target.

Fixed wing aircraft and helicopters are assumed to fly at low altitude at the same speeds as in investigation tasks.

Two of the conventional cutters (WMEC-210 and HEC-MEC) would also employ the same speeds as in investigation tasks. The higher speed WHEC-378, however, was assumed to operate at about 19 knots, with the fuel consumption rate reduced from 2,514 gallons per hour to only 334 gallons per hour.

The hydrofoil was assumed to employ a mixed propulsion mode to make good an average speed of 18 knots; assuming 45 knots foilborne and 10 knots hullborne, the hullborne fraction was 77 percent, with an average fuel rate of 82.6 gallons per hour (based on table 5 of the Hydrofoil Study).

Except for the higher speed cutter and Flagstaff II, the time-on-station fractions are the same in trail tasks and investigation tasks.

Time-on-station fractions for WHEC-378 were calculated using equation (J-124) with an assumed transit speed of 29 knots. The fuel rate ratio $\dot{W}_C/\dot{W}_T$ was 334/2,514 = 0.133.

For the hydrofoil, the time-on-station fraction was calculated under the assumption that the transit would be made using a mix of hullborne and foilborne operations. Assuming a foilborne fraction during transit equal to f_H, the average transit speed and fuel consumption rate are given by

$$\bar{v}_T = v_H f_H + v_F (1 - f_H) = v_F - (v_F - v_H) f_H \qquad \text{(J-128)}$$

$$\bar{\dot{W}}_T = \dot{W}_H f_H + \dot{W}_F (1 - f_H) = \dot{W}_F - (\dot{W}_F - \dot{W}_H) f_H \qquad \text{(J-129)}$$

where the H and F subscripts denote hullborne and foilborne values, respectively.

Using equation (J-5) for the time-on-station fraction, the on station/transit time ratio is given by

$$\frac{t_C}{t_T} = \left(\frac{W_F}{2D}\right) \frac{\bar{v}_T}{\dot{W}_C} - \frac{\bar{\dot{W}}_T}{\dot{W}_C} \qquad \text{(J-130)}$$

where W_F is the available fuel (W_F = 5,000 gallons for Flagstaff II).

Inserting the average values from equations (J-128) and (J-129) into equation (J-130) we obtain the result

$$\frac{t_C}{t_T} = \frac{1}{\dot{W}_C}\left[\left(\frac{W_F}{2D} v_F - \dot{W}_F\right) + \left(\dot{W}_F - \dot{W}_H - \frac{v_F - v_H}{2D} W_F\right) f_H\right] . \qquad \text{(J-131)}$$

The coefficient of f_H is negative when

$$2D < \frac{\left(v_F - v_H\right) W_F}{\left(\dot{W}_F - \dot{W}_H\right)} . \qquad \text{(J-132)}$$

When $v_F = 45$ knots and $v_H = 10$ knots, $\dot{W}_F = 225$ gallons per hour and $\dot{W}_H = 40$ gallons per hour. Thus, the inequality becomes

$$2D < 946 \text{ miles.}$$

When the coefficient of f_H is negative, the t_C/t_T ratio is maximized by the condition, $f_H = 0$, and (J-131) becomes

$$\frac{t_C}{t_T} = \frac{1}{\dot{W}_C}\left(\frac{W_F}{2D} v_F - \dot{W}_F\right) = \frac{\dot{W}_F}{\dot{W}_C}\left(\frac{W_F}{2D} \frac{v_F}{\dot{W}_F} - 1\right). \qquad \text{(J-133)}$$

For greater values of D , the coefficient of f_H is positive, and t_C/t_T is maximized by the condition $f_H = 1$. In this case, equation (J-131) becomes

$$\frac{t_C}{t_T} = \frac{1}{\dot{W}_C}\left[\left(\frac{W_F}{2D} v_F - \dot{W}_F\right) + \dot{W}_F - \dot{W}_H - \frac{(v_F - v_H)}{2D} W_F\right] \qquad \text{(J-134)}$$

$$= \frac{1}{\dot{W}_C}\left(\frac{W_F}{2D} v_H - \dot{W}_H\right) .$$

For the particular conditions assumed here, the time-on-station fraction is given by

$$f_S = \frac{1}{1 + 0.37\left(\frac{2D}{1,000-2D}\right)} \quad , \quad 2D < 946 \qquad \text{(J-135)}$$

$$f_S = \frac{1}{1 + 2.07\left(\frac{2D}{1,250-2D}\right)} \quad , \quad 2D > 946 \quad . \qquad \text{(J-136)}$$

The time-on-station fractions for all vehicles in the trail task are shown graphically in figure J-11.

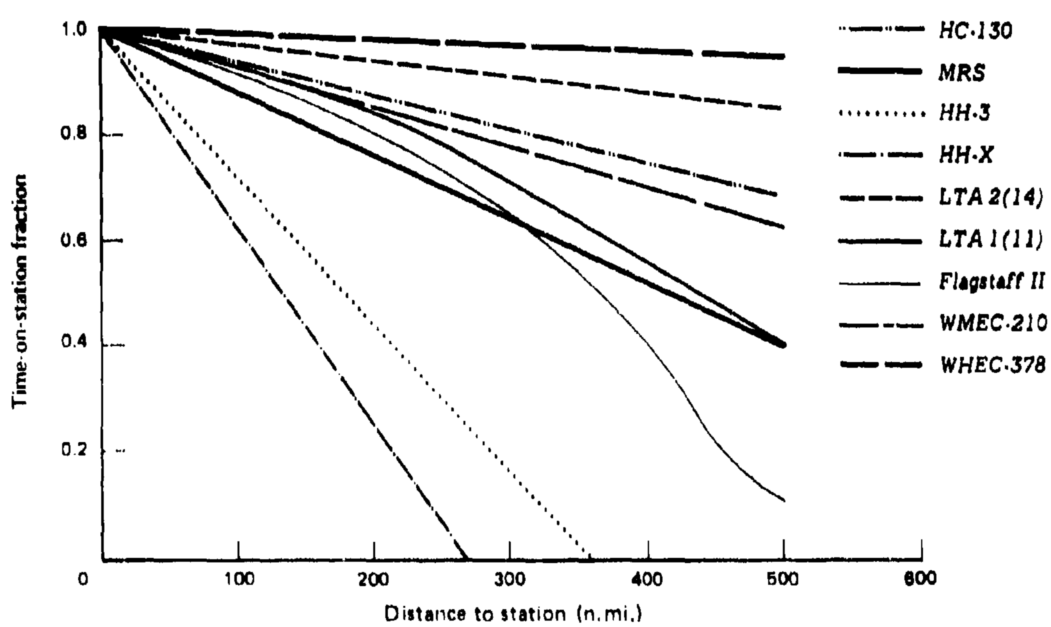


FIG. J-11: TIME-ON-STATION FRACTIONS FOR TRAIL TASKS

ANNEX J-1

GENERAL FUEL RATE FORMULA FOR SEMI-BUOYANT AIRSHIPS

A general fuel consumption rate formula for semi-buoyant nonrigid airships is developed in this annex. Approximate forms of formulas presented in volume III are used to estimate the dependence of the required horsepower on airship speed, volume, heaviness, and altitude. The zero heaviness power relation is modified to include the effect of additional drag associated with dynamic lift and propulsion efficiency variations with speed and volume. The specific fuel consumption rate is based on the formula presented in volume III for turboprop propulsion systems. The general formula is simplified for the case of zero heaviness.

SPECIFIC FUEL CONSUMPTION RATE

The fuel consumption rate, $\dot{W}$, is given by

$$\dot{W} = P\sigma_F \qquad \text{(J-1-1)}$$

where P = required horsepower at speed v

σ_F = specific fuel consumption rate (pounds/horsepower hour) .

The specific fuel consumption rate is a function of the power ratio, P/P_{CM}, where P_{CM} is the required power for maximum sustained cruise speed, v_M. In the case of turboprop propulsion systems, we use formula (223) of volume III for the specific fuel consumption rate ratio,

$$\frac{\sigma_F}{\sigma_R} = 0.11 \left(\frac{P_{CM}}{P}\right) + 0.89 \qquad \text{(J-1-2)}$$

where

σ_R = reference specific fuel rate at speed v_M.

A formula for σ_R is presented in volume III. Since here we are concerned only with fuel rate ratios, the reference rate is not needed.

Combining formulas (J-1-1) and (J-1-2) we obtain the result:

$$\frac{\dot{W}}{\dot{W}_{CM}} = 0.11 + 0.89\left(\frac{P}{P_{CM}}\right) \qquad \text{(J-1-3)}$$

where $\dot{W}_{CM}$ is the fuel rate at speed v_M.

Formulas for the power ratio, P/P_{CM}, will be developed in the following sections.

POWER RATIO

The power ratio can be expressed in the following form:

$$\frac{P}{P_{CM}} = \left(\frac{\eta_{CM}}{\eta}\right)\left(\frac{P_0 + \Delta P_0}{P_{CMO} + \Delta P_{CMO}}\right) \qquad \text{(J-1-4)}$$

where

η = propulsion efficiency at speed v

η_{CM} = propulsion efficiency at speed v_M

P_0 = zero heaviness power at speed v

P_{CM0} = zero heaviness power at speed v_M

ΔP_0 = power increase at speed v and heaviness H

ΔP_{CMO} = power increase at speed v_M and heaviness H_0

The heaviness, H, is defined as the ratio of dynamic lift, L_D, to static lift, L_S. The static lift is also referred to frequently as the gross weight, W_G. The heaviness, H_0, is the initial heaviness of the airship at the start of the flight.

Relation (J-1-4) can be put in the form of a triple product

$$\frac{P}{P_{CM}} = \left(\frac{\eta_{CM}}{\eta}\right)\left(\frac{P_0}{P_{CMO}}\right)\left(\frac{1 + \Delta P_0/P_0}{1 + \Delta P_{CMO}/P_{CMO}}\right) \qquad \text{(J-1-5)}$$

where the three factors show the effects of propulsion efficiency, zero-lift (heaviness) power, and heaviness power, respectively.

Each of these factors will be treated separately in the following sections, starting with the zero-heaviness factor and ending with the propulsion efficiency factor.

Zero Heaviness Power Ratio

The zero heaviness, or zero dynamic lift, power required for a nonrigid airship of volume, V, at speed, v, and altitude, z, varies as follows:

$$P_0 \sim C_{D0} \rho_z v^3 V^{2/3} \tag{J-1-6}$$

where

C_{D0} = zero-lift drag coefficient

ρ_z = air density at altitude z .

The drag coefficient, C_{D0}, is proportional to a skin drag coefficient, C_f, that varies approximately as the inverse 1/7 power of the Reynolds number, R_e. The Reynolds number is defined by the relation

$$R_e = \frac{v\ell}{\nu}$$

where ℓ is the vehicle length and ν is the kinematic viscosity.

Since $\ell \sim V^{1/3}$, the power relation (J-1-6) can be further refined as follows:

$$P_0 \sim \rho_z \, v^{2.86} V^{0.62} \quad . \tag{J-1-7}$$

Using the relation (J-1-7), the zero heaviness power ratio is given by

$$\frac{P_0}{P_{CMO}} = \left(\frac{v}{v_M}\right)^{2.86} = \left(\frac{v_1}{v_{M1}}\right)^{2.86} = x^{2.86} \tag{J-1-8}$$

where x is the speed ratio, v_1/v_{M1} . The volume does not enter because the power ratio applies to a particular vehicle of fixed volume.

Heaviness Power Factor

A conventional airship flying at an angle of attack α generates dynamic lift that varies as follows:

$$L_D \sim C_L \sigma_z v^2 V^{2/3} \qquad (J\text{-}1\text{-}9)$$

where the lift coefficient C_L varies quadratically with α. The lift coefficient varies from 0.06 at 5 degrees to 0.15 at 10 degrees. Using these two values we get the following equation for the lift coefficient:

$$C_L = 0.009\alpha(1 + 0.067\alpha) \ . \qquad (J\text{-}1\text{-}10)$$

This relation applies to the case of zero elevator setting. It is shown in volume III that a linear relation results for trimmed elevator settings.

Static lift, on the other hand, varies directly with volume and air density as follows:

$$L_S \sim \sigma_h V, \qquad (J\text{-}1\text{-}11)$$

where σ_h is the air density ratio at the gas, or pressure, altitude h.

From relations (J-1-9) and (J-1-11) we obtain the relation for the heaviness:

$$H = \frac{L_D}{L_S} \sim \frac{C_L \sigma_z v^2}{\sigma_h V^{1/3}} \ . \qquad (J\text{-}1\text{-}12)$$

In terms of the dimensionless speed and volume parameters, $v_1 = v/100$ and $V_1 = V/10^6$, it can be shown that

$$H = 5.46 C_L \frac{\sigma_z v_1^2}{\sigma_h V_1^{1/3}} \ . \qquad (J\text{-}1\text{-}13)$$

The induced drag, D_L, due to the dynamic lift, varies directly as the dynamic pressure $q = 1/2\ \rho v^2$ and the surface area $S \sim V^{2/3}$, so that we have

$$D_L \sim C_{DL} \sigma_z v^2 V^{2/3} \ , \qquad (J\text{-}1\text{-}14)$$

where C_{DL} is the induced drag coefficient that is frequently approximated by the formula

$$C_{DL} = 0.9C_L^2 \quad . \qquad \text{(J-1-15)}$$

More accurate expressions for C_{DL} are developed in volume III. The simple formula (J-1-15) is found to be a good approximation for lift coefficients less than about 0.2.

Combining relations (J-1-13), (J-1-14), and (J-1-15) we obtain the following relation for the drag due to dynamic lift:

$$D_L \sim \frac{\sigma_h V^{4/3}}{\sigma_z v^2} H^2 \quad . \qquad \text{(J-1-16)}$$

Multiplying relation (J-1-16) by the speed v, we get the relation for the additional cruise horsepower, ΔP_0, required as a result of induced drag:

$$\Delta P_0 \sim \frac{\sigma_h^2 V^{4/3}}{\sigma_z v} H^2 \quad . \qquad \text{(J-1-17)}$$

Dividing by relation (J-1-7) we finally get the ratio

$$\frac{\Delta P_0}{P_0} \sim \frac{\sigma_h 2\ V^{0.71}}{\sigma_z^2 v^{3.86}} H^2 \qquad \text{(J-1-18)}$$

so that

$$1 + \frac{\Delta P_0}{P_0} = 1 + bH^2 \quad . \qquad \text{(J-1-19)}$$

The b coefficient in equation (J-1-19) depends on the particular value assumed for the zero-lift drag coefficient. The result we use here is

$$b = 1.20 \frac{\sigma_h^2 V_1^{0.71}}{\sigma_z^2 v_1^{3.86}} \qquad \text{(J-1-20)}$$

which agrees within 10 percent with the similar relation presented in volume III. We simplify relation (J-1-20) by setting the speed exponent equal to 4 and insert the appropriate values of the density ratios for z = 2,000 feet ($\sigma_z = 0.945$) and h = 3,000 feet

(σ_h = 0.917) to obtain

$$b = 1.13 \frac{V_1^{0.71}}{v_1^4} \quad . \qquad \text{(J-1-21)}$$

When equation (J-1-19) is applied to the case of maximum speed v_M and initial heaviness H_0 we get the result:

$$1 + \frac{\Delta P_{CMO}}{P_{CMO}} = 1 + b_M H_0^2 \quad , \qquad \text{(J-1-22)}$$

where

$$b_M = 1.13 \frac{V_1^{0.71}}{v_{M1}^4} = b, x^4 \quad , \qquad \text{(J-1-23)}$$

and v_{M1} is the dimensionless speed parameter $v_M/100$.

Combining (J-1-19) and (J-1-23) we get finally the desired heaviness power factor:

$$\frac{1 + \frac{\Delta P_0}{P_0}}{1 + \frac{\Delta P_{CMO}}{P_{CMO}}} = \frac{1 + bH^2}{1 + b_M H_0^2} \quad . \qquad \text{(J-1-24)}$$

Propulsion Efficiency Factor

Formulas are derived in chapter 5 of volume III for propeller efficiency as a function of the effective speed-power coefficient

$$C_{SP}^* = V \left(\frac{P(0.0787 + 0.0394\, B^{\frac{1}{3}}\, \alpha_P^{\frac{2}{3}} C_{LA}^{\frac{3}{2}})}{C_{LA} P^* n^2} \right)^{0.2} \qquad \text{(J-1-25)}$$

where

B = number of blades

α_p = activity factor (weighted blade width)

C_{LA} = average lift coefficient

P^* = power in foot-pounds/second

= 550P (in horsepower)

n = propeller revolutions per second .

When

$B = 4$

$\alpha_p = 100$

$C_{LA} = 0.3$

the effective speed power coefficient reduces to the usual speed power coefficient, C_{SP}, defined by the relation

$$C^*_{SP} = C_{SP} = v \left(\frac{\rho}{P^* n^2} \right)^{0.2} \quad . \qquad \text{(J-1-26)}$$

The propeller revolution rate will be set equal to 15 revolutions per second in accordance with volume III, where it is pointed out that 15 rps gives a reasonable approximation to an overall airship vehicle optimum for many concepts. With this value for n, and assuming flight altitude z = 2,000 feet, relation (J-1-26) becomes

$$C_{SP} = 4.77 \frac{v_1}{P^{0.2}} \quad , \qquad \text{(J-1-27)}$$

where P is the power in horsepower. It should be noted that the power here is for a single engine.

The propeller efficiency, η, is expressed as a function of C^*_{SP} and the propeller blade angle β in equation (168) of volume III as follows:

$$\eta_{EMX} C_{SP}/\eta = (0.40 + 0.017\beta^{1.2}) \left[1 + (11.46 C^*_{SP}/\beta)^3 \right] \qquad \text{(J-1-28)}$$

where η_{EMX} is the envelope maximum efficiency. For the particular values of β, α_P, and C_{LA} assumed here, $\eta_{EMX} = 0.91$, in accordance with equation (163) of volume III.

The optimum blade angle, β_{OPT}, is given by equation (166) of volume III:

$$\beta_{OPT} = 15.5C^*_{SP} \quad . \tag{J-1-29}$$

Inserting this optimum value in equation (J-1-28) we find,

$$\frac{\eta}{\eta_{EMX}} = \frac{C^*_{SP}}{0.56 + 0.64\ C^{*\,1.2}_{SP}} \quad . \tag{J-1-30}$$

Since $C^*_{SP} = C_{SP}$ for the particular propeller assumed here, equation (J-1-30) may be evaluated using relation (J-1-27) for C_{SP} as follows:

$$\frac{\eta}{\eta_{EMX}} = \frac{4.77\ v_1/P^{0.2}}{0.56(1 + 1.14(4.77)^{1.2}v_1^{\ 1.2}/P^{0.24})} \tag{J-1-31}$$

$$= \frac{8.52\ v_1/P^{0.2}}{1 + 7.43v_1^{\ 1.2}/P^{0.24}} \quad . \tag{J-1-32}$$

Since the power, P is inversely proportional to η, an exact solution for η would involve a complex iteration. In view of the fact that η is a slowly varying function that appears in terms with relatively low exponents, it should be possible to obtain a good approximate solution by ignoring the η dependence of the P terms in equation (J-1-32).

To obtain an approximate solution of equation (J-1-32) we will relate P to the power required at 100 knots cruise speed, P_{100}. Using only the second and third power factors in equation (J-1-5), and the relations (J-1-8) and (J-1-24), we have

$$\frac{P}{P_{100}} = v_1^{\ 2.86}\ \frac{(1 + bH^2)}{(1 + b_{100}H_0^{\ 2})} \tag{J-1-33}$$

where $b_{100} = 1.13V_1^{\ 0.71}$, from equation (J-1-23).

The single engine power required at 100 knots, P_{100}, was determined using the technical model results obtained for the basic and extended family of airships. These results for seven airships, of 100 knots maximum cruise speed, with volumes ranging from 0.74 to 4.71 million cubic feet were fitted approximately by the relation

$$P_{100} = \left(\frac{V_1}{.49}\right)^{0.67} 1{,}000$$

$$= 1{,}613V_1^{0.67} \quad . \qquad \text{(J-1-34)}$$

Inserting relation (J-1-34) into equation (J-1-33), and putting the result into equation (J-1-30), we find

$$\frac{\eta}{\eta_{EMX}} = \left(\frac{1.94}{v_1^{0.13}}\right) \frac{v_1^{0.43}(1+b_{100}H_0^2)^{0.20}/(1+bH^2)^{0.20}}{1+1.26v_1^{0.51}(1+b_{100}H_0^2)^{0.24}/V_1^{0.16}(1+bH^2)^{0.24}} \quad . \qquad \text{(J-1-35)}$$

Since both terms involving $b_{100}H_0^2$ are approximately unity, we can further simplify equation (J-1-35) to obtain

$$\frac{\eta}{\eta_{EMX}} = \left(\frac{1.94}{v_1^{0.13}}\right) \frac{v_1^{0.43}/(1 + bH^2)^{0.2}}{1 + 1.26\, v_1^{0.51}/V_1^{0.16}(1 + bH^2)^{0.24}} \quad . \qquad \text{(J-1-36)}$$

Using equation (J-1-36) evaluated at the two speeds, v_1 and v_{M1}, we obtain the propulsion efficiency factor

$$\frac{\eta_{CM}}{\eta} = \left(\frac{v_{M1}}{v_1}\right)^{0.43} \left(\frac{1 + bH^2}{1 + b_M H_0^2}\right)^{0.2} \left[\frac{1+1.26v_1^{0.51}/V_1^{0.16}(1+bH^2)^{0.24}}{1+1.26v_{M1}^{0.51}/V_1^{0.16}(1+b_M H_0^2)^{0.24}}\right]$$

$$= \left(\frac{1}{x}\right)^{0.43} \left(\frac{1 + bH^2}{1 + b_M H_0^2}\right)^{0.2} \left[\frac{1+C_3 x^{0.51}/(1+bH^2)^{0.24}}{1+C_3/(1+b_M H_0^2)^{0.24}}\right] \qquad \text{(J-1-37)}$$

where $C_3 = 1.26v_{M1}^{0.51}/V_1^{0.16}$. (J-1-38)

FINAL POWER RATIO RESULT

With the above result, we are now in a position to combine the three power factors making up the power ratio, P/P_{CM}.

Combining equations (J-1-8), (J-1-24), and (J-1-37) the final power ratio result is obtained in the form

$$\frac{P}{P_{CM}} = x^{2.43}\left(\frac{1+bH^2}{1+b_M H_0^2}\right)^{1.2}\left[\frac{1+C_3 x^{0.51}/(1+bH^2)^{0.24}}{1+C_3/(1+b_M H_0^2)^{0.24}}\right] \qquad \text{(J-1-39)}$$

which becomes, using relation (J-1-23):

$$\frac{P}{P_{CM}} = \frac{1}{C_2}\, x^{2.43}\left(1+b_M\frac{H^2}{x^4}\right)^{1.2}\left[1+C_3\frac{x^{0.51}}{\left(1+b_M\frac{H^2}{x^4}\right)^{0.24}}\right] \qquad \text{(J-1-40)}$$

where

$$C_2 = (1+b_M H_0^2)^{1.2}\left[1+C_3/(1+b_M H_0^2)^{0.24}\right] . \qquad \text{(J-1-41)}$$

FINAL FUEL RATE FORMULA

Inserting equation (J-1-41) into equation (J-1-3) we obtained the final fuel rate ratio formula

$$\frac{\dot{W}(x,H)}{W_{CM}} = C_0 + \frac{C_1}{C_2}\, x^{2.43}\left(1+b_M\frac{H^2}{x^4}\right)^{1.2}\left[1+C_3\frac{x^{0.51}}{\left(1+b_M\frac{H^2}{x^4}\right)^{0.24}}\right] \qquad \text{(J-1-42)}$$

where $C_0 = 0.11$ and $C_1 = 0.89$.

The fuel rate at maximum cruise speed, $\dot{W}_{CM}$, in equation (J-1-42) should be interpreted as the initial maximum fuel rate, $\dot{W}_M$, at speed v_M and initial heaviness, H_0.

When the speed ratio x is constant, it can be shown that equation (J-1-42) can be approximated in the form

$$\frac{\dot{W}}{\dot{W}_M} = K(1 + b' H^2) \qquad \text{(J-1-43)}$$

where $K = C_0 + C_4(1 + C_5)$.

When H is zero, equation (J-1-42) becomes

$$C_4 = .89 \left(\frac{v_1}{v_{M1}}\right)^{2.43} \frac{1}{\left(1 + b_M H_0^2\right)^{1.2}} \cdot \frac{1}{\left[1 + \frac{C_5/x^{.51}}{\left(1 + b_M H_0^2\right)^{.24}}\right]}$$

$$C_5 = \frac{1.26}{V_1^{0.16}} v_1^{0.51}$$

$$\frac{\dot{W}(x,0)}{\dot{W}_M} = C_0 + \frac{C_1}{C_2} x^{2.43} (1 + C_3 x^{0.51}) \ . \qquad \text{(J-1-44)}$$

When $x > 0.6$, equation (J-1-44) can be approximated as follows:

$$\frac{\dot{W}(x,0)}{\dot{W}_M} = C_0 + C_1 x^{\alpha}$$

where α is about 2.67 for the airships considered in this study.

LIST OF SYMBOLS

v	=	speed (knots)
v_M	=	maximum sustained speed (knots)
v_1	=	$v/100$ = dimensionless speed parameter
v_{M1}	=	$v_{M1}/100$ = dimensionless maximum speed parameter
x	=	$v/v_m = v_1/v_{M1}$ = speed ratio
H	=	Heaviness = dynamic lift/static lift = L_D/L_S
H_0	=	initial heaviness
$\dot{W}_M$	=	initial fuel consumption rate at speed v_M (gal./hr.)
V	=	volume (cu.ft.)
V_1	=	$V/10^6$ = dimensionless volume parameter
b_M	=	$1.13 V_1^{0.71}/v_{M1}^{4} = b x^{4}$
C_0	=	0.11
C_1	=	0.89

$$C_2 = (1 + b_M H_0^2)^{1.2} \left[1 + \frac{C_3}{\left(1 + b_M H_0^2\right)^{.24}}\right]$$

$$C_3 = 1.26\, v_{M1}^{0.51}/V_1^{0.16}$$

$$C_4 = .89 \left(\frac{v_1}{v_{M1}}\right)^{2.43} \frac{1}{\left(1 + b_M H_0^2\right)^{1.2}} \frac{1}{\left[1 + \frac{C_5}{x^{.51}} / \left(1 + b_M H_0^2\right)^{.24}\right]}$$

$$C_5 = \frac{1.26}{V_1^{0.16}} v_1^{.51}$$

$$K = C_0 + C_4 (1 + C_5)$$

ANNEX J-2

LTA COST-EFFECTIVENESS MODEL INPUTS AND OUTPUTS

This annex lists the inputs and outputs for the computer model that was employed to make the cost-effectiveness calculations for semi-buoyant airships.

Table J-2-1 presents a matrix of all the airships considered in the study according to speed, range, and aircrew. The basic LTA family is indicated by Xs and the extended family by 0s. The particular airships for which cost-effectiveness calculations were made are noted by □s.

Table J-2-2 presents the input values for 20 of the 22 airships considered in the cost-effectiveness analysis.

The results of the analysis are presented in tables J-2-3 to J-2-22. The effectiveness and cost outputs and cost-effectiveness measures are presented as a function of distance to station, at 100-mile intervals.

INPUTS

v_M = maximum cruise speed (knots)

R_M = range (miles)

V = volume (millions of cubic feet)

H_0 = initial heaviness

L_D = dynamic lift (gallons)

W_{F0} = buoyant fuel (gallons) = W_{62} (gallons)

W_{MAV} = average fuel rate at maximum speed (gallons/hour)

C = variable speed fuel rate parameter

$F = fuel cost ($/hour)

$C = total cost ($/hour)

W = sweepwidth (miles)

OUTPUTS

Effectiveness and Cost

t_{FP} = endurance in patrol tasks (hours)

t_{FT} = endurance in trail tasks (hours)

f_{SP} = time-on-station fraction in patrol tasks

f_{ST} = time-on-station fraction in trail tasks

v_E = effective speed (knots) = $f_{SP}v_T$

$\dot{W}_{AVP}$ = average fuel rate in patrol tasks (gallons/hour) = $\frac{L_D + \Delta_F}{t_{FP}}$

$\dot{W}_{AVT}$ = average fuel rate in trail tasks (gallons/hour) = $\frac{L_D + \Delta_F}{t_{FT}}$

$\$C_P$ = total hourly cost in patrol tasks ($/hour)

$$= \$C - \left(1 - \frac{\dot{W}_{AVP}}{\dot{W}_{MAV}}\right)\$F$$

$\$C_T$ = total hourly cost in trail tasks ($/hour)

$$= \$C - \left(1 - \frac{\dot{W}_{AVT}}{\dot{W}_{MAV}}\right)\$F$$

Cost-Effectiveness Measures

I_{P1} = miles on-station per cost (mi. on sta./$1,000)

I_{P2} = square miles on-station per cost (sq.mi. on sta./$1,000)

= WI_{P1}

I_T = hours on-station per cost (hours/$1,000) = $(f_{ST}/\$C_T)\ 1,000$

Energy Efficiency Measures

I_{FP1} = miles on-station per gallon (mi.on sta./gal.)

$= v_E/\dot{W}_{AVP}$

I_{FP2} = square miles on-station per gallon (sq.mi.on sta./gal.)

$= WI_{FP1}$

I_{FT} = hours on station per 1,000 gallons (hrs.on sta./1,000 gal.)

$= (f_{ST}/\dot{W}_{AVT})\ 1,000$

TABLE J-2-1

KEY TO BASIC AND EXTENDED LTA FAMILY CASES

Speed/Range (Kts./mi.)	Crew size 8	Crew size 11	Crew size 14	
50/1000		x	[o]	
2000			[x]	
3000			x	
60/1000		x	[o]	
2000		x	[o]	
3000			x	
70/1000		x	[o]	
2000		x	[o]	
3000			[x]	LTA 3 (14)
80/1000		x	[o]	
2000		[x] LTA 2 (11)	[o]	
3000			x	
90/1000	x	[o]	[o]	
2000		x	[o]	
3000		x		
100/1000	x	[o]	[o]	
2000		x	[o]	
3000		x		
110/1000	[x] LTA 1 (8)	[o]	[o]	
2000		x	[o]	
3000		x		
120/1000	x		o	
2000		x	o	
3000		x		

KEY

x = Basic LTA family
o = Trail task extensions
□ = LTA cost-effectiveness model runs

TABLE J-2-2

LTA COST/EFFECTIVENESS MODEL INPUTS

Speed/Range/Crew (Kts-mi-no.)	V Volume (10^6 cu. ft.)	H_O Initial Heaviness	L_D Dynamic Lift (gal.)	W_{FO} Buoyant fuel (gal.)	$\dot{W}_{MAV}$ Average fuel rate (gal./hr.)	C Fuel rate parameter	$F Fuel cost ($/hr.)	$C Total cost ($/hr.)
110/1000/8 (LTA 1 (8))	.411	.53	2030	135	215	2.37	88	715
110/1000/11 (LTA 1 (11))	.511	.46	2333	270	258	2.62	105	883
80/2000/11 (LTA 2 (11))	.903	.16	1373	2624	144	5.87	59	972
70/3000/14 (LTA 3 (14))	1.363	.10	1211	4918	129	8.93	53	1202
50/1000/14	.371	.09	306	255	26	11.37	10	735
60/1000/14	.402	.13	486	315	43	7.93	18	762
70/1000/14	.436	.18	723	360	68	6.06	28	793
80/1000/14	.472	.23	1025	390	101	4.71	41	830
90/1000/14	.513	.29	1406	390	145	3.86	59	874
100/1000/14	.564	.39	1883	375	203	3.21	83	930
110/1000/14 (LTA 1 (14))	.625	.43	2477	345	279	2.73	114	999
120/1000/14	.706	.49	3220	315	381	2.41	156	1090
50/2000/14	.517	.07	354	1004	31	12.81	12	811
60/2000/14	.632	.10	594	1496	56	9.24	23	879
70/2000/14	.778	.13	937	2024	93	7.39	38	963
80/2000/14 (LTA 2 (14))	.985	.16	1432	2789	152	6.04	62	1079
90/2000/14	1.283	.18	2138	3893	243	5.28	99	1240
100/2000/14	1.734	.20	3162	5457	388	4.69	158	1474
110/2000/14	2.450	.20	4670	8006	628	4.32	256	1827
120/2000/14	3.628	.21	6927	12,188	1032	4.18	421	2375
90/1000/11	.450	.32	1322	330	134	3.70	55	766
100/1000/11	.495	.38	1774	315	187	3.10	76	818

TABLE J-2-3

LTA COST/EFFECTIVENESS MODEL OUTPUTS

LTA (Speed/Range/Crew) = 110/1000/8

Effectiveness and cost		Distance to station (miles) 0	100	200	300	400	500
Flight endurance, patrol (hrs)	t_{FP}	8.9	8.9	8.9	13.7	18.6	22.2
Flight endurance, trail (hrs)	t_{FT}	31.4	26.6	21.0	21.6	23.1	24.3
On station fraction, patrol	f_{SP}	1.00	.80	.59	.51	.43	.32
On station fraction, trail	f_{ST}	1.00	.93	.83	.69	.54	.38
Effective speed, (knots)	v_E	110	86.5	65.0	45.9	32.4	21.0
Average fuel rate patrol (gal./hr.)	$\dot{W}_{AVP}$	218.9	218.8	219.0	142.0	105.0	87.6
Average fuel rate, trail (gal./hr.)	$\dot{W}_{AVT}$	62.1	74.6	93.0	90.2	84.5	80.1
Hourly cost, patrol ($/hr.)	$\$C_P$	717	717	717	685	670	663
Hourly cost, trail ($/hr.)	$\$C_T$	652	657	665	664	662	660
Cost effectiveness measures		**0**	**100**	**200**	**300**	**400**	**500**
Miles on station/cost, (hrs./$1,000)	I_{P1}	153.5	122.2	90.8	67.0	48.3	31.7
Square miles on station/ cost, (sq. mi./$)	I_{P2}	5833	4642	3449	2546	1835	1206
Hours on station/cost, (hrs./$1,000)	I_T	1.53	1.42	1.24	1.04	.82	.57
Miles on station/gallon (mi./gal.)	I_{FP1}	.50	.40	.30	.32	.31	.24
Square miles on station per gallon (sq. mi./gal.)	I_{FP2}	19.1	15.2	11.3	12.3	11.7	9.1
Hours on station/gallon, trail (hrs./1,000 gal.)	I_{FT}	16	13	9	8	6	5

TABLE J-2-4

LTA COST/EFFECTIVENESS MODEL OUTPUTS
LTA (Speed/Range/Crew) = 110/100 /11

Effectiveness and cost		Distance to station (miles) 0	100	200	300	400	500
Flight endurance, patrol (hrs)	t_{FP}	8.9	8.9	8.9	13.8	18.8	22.7
Flight endurance, trail (hrs)	t_{FT}	33.1	29.0	22.7	22.9	24.3	25.5
On station fraction, patrol	f_{SP}	1.00	.80	.59	.52	.44	.33
On station fraction, trail	f_{ST}	1.00	.94	.84	.71	.56	.40
Effective speed, (knots)	v_E	110	87.6	65.3	46.3	32.9	21.9
Average fuel rate patrol (gal./hr.)	$\dot{W}_{AVP}$	261.8	261.8	262	169.4	124.5	103.3
Average fuel rate, trail (gal./hr.)	$\dot{W}_{AVT}$	70.8	83.9	104.1	102.3	96.6	92.0
Hourly cost, patrol ($/hr.)	$\$C_P$	885	885	885	847	829	820
Hourly cost, trail ($/hr.)	$\$C_T$	807	811	820	820	817	815
Cost effectiveness measures		**0**	**100**	**200**	**300**	**400**	**500**
Miles on station/cost, (hrs./$1,000)	I_{P1}	124.4	99.1	73.8	54.6	39.7	26.7
Square miles on station/cost, (sq. mi./$)	I_{P2}	4725	3765	2804	2076	1510	1016
Hours on station/cost, (hrs./$1,000)	I_T	1.24	1.16	1.02	.86	.69	.50
Miles on station/gallon, (mi./gal.)	I_{FP1}	.42	.33	.25	.27	.26	.21
Square miles on station per gallon (sq. mi./gal.)	I_{FP2}	16.1	12.7	9.5	10.4	10.1	8.1
Hours on station/gallon, trail (hrs./1,000 gal.)	I_{FT}	14	12	8	7	4	

TABLE J-2-5

LTA COST/EFFECTIVENESS MODEL OUTPUTS

LTA (Speed/Range/Crew) = 80 /2000/11

Effectiveness and cost		Distance to station (miles) 0	100	200	300	400	500
Flight endurance, patrol (hrs)	t_{FP}	25.1	25.1	25.1	25.1	25.1	31.2
Flight endurance, trail (hrs)	t_{FT}	89.5	119.4	111.5	103.0	93.9	91.5
On station fraction, patrol	f_{SP}	1.00	.90	.80	.70	.60	.56
On station fraction, trail	f_{ST}	1.00	.98	.96	.93	.89	.85
Effective speed, (knots)	v_E	80.0	72.0	64.1	56.1	48.1	40.7
Average fuel rate patrol (gal./hr.)	$\dot{W}_{AVP}$	143.4	143.4	143.4	143.5	143.5	115.3
Average fuel rate, trail (gal./hr.)	$\dot{W}_{AVT}$	40.2	42.7	45.9	30.6	31.6	31.8
Hourly cost, patrol ($/hr.)	$\$C_P$	972	972	972	972	972	960
Hourly cost, trail ($/hr.)	$\$C_T$	930	925	926	927	229	929
Cost effectiveness measures		**0**	**100**	**200**	**300**	**400**	**500**
Miles on station/cost, (hrs./$1,000)	I_{P1}	82.3	74.1	65.9	57.7	49.5	42.4
Square miles on station/cost, (sq. mi./$)	I_{P2}	3128	2817	2505	2193	1880	1611
Hours on station/cost, (hrs./$1,000)	I_T	1.08	1.06	1.03	1.00	.96	.91
Miles on station/gallon, (mi./gal.)	I_{FP1}	.56	.50	.45	.39	.34	.35
Square miles on station per gallon (sq. mi./gal.)	I_{FP2}	21.2	19.1	17.0	14.9	12.7	13.4
Hours on station/gallon, trail (hrs./1,000 gal.)	I_{FT}	25	33	30	27	23	22

TABLE J-2-6

LTA COST/EFFECTIVENESS MODEL OUTPUTS

LTA (Speed/Range/Crew) = 70/3000/14

Effectiveness and cost		Distance to station (miles) 0	100	200	300	400	500
Flight endurance, patrol (hrs)	t_{FP}	43.1	43.1	43.1	43.1	43.1	43.1
Flight endurance, trail (hrs)	t_{FT}	197	188.4	180	171	161	150
On station fraction, patrol	f_{SP}	1.00	.93	.87	.80	.73	.67
On station fraction, trail	f_{ST}	1.00	.98	.97	.95	.93	.90
Effective speed, (knots)	v_E	70.0	65.4	60.7	56.1	51.4	46.8
Average fuel rate patrol (gal./hr.)	$\dot{W}_{AVP}$	128.0	128.1	128.1	128.1	128.1	128.1
Average fuel rate, trail (gal./hr.)	$\dot{W}_{AVT}$	28.0	28.3	28.8	29.3	30.0	30.9
Hourly cost, patrol ($/hr.)	$\$C_P$	1202	1201	1202	1202	1202	1202
Hourly cost, trail ($/hr.)	$\$C_T$	1161	1161	1162	1162	1163	1164
Cost effectiveness measures		**0**	**100**	**200**	**300**	**400**	**500**
Miles on station/cost, (hrs./$1,000)	I_{P1}	58.3	54.4	50.5	46.7	42.8	38.9
Square miles on station/cost, (sq. mi./$)	I_{P2}	2214	2067	1920	1773	1626	1479
Hours on station/cost, (hrs./$1,000)	I_T	.86	.85	.83	.82	.80	.78
Miles on station/gallon, (mi./gal.)	I_{FP1}	.55	.51	.47	.44	.40	.37
Square miles on station per gallon (sq. mi./gal.)	I_{FP2}	20.8	19.4	18.0	16.6	15.2	13.9
Hours on station/gallon, trail (hrs./1,000 gal.)	I_{FT}	36	34	32	30	27	25

TABLE J-2-7

LTA COST/EFFECTIVENESS MODEL OUTPUTS

LTA (Speed/Range/Crew) = 50/1000/14

Effectiveness and cost		Distance to station (miles) 0	100	200	300	400	500
Flight endurance, patrol (hrs)	t_{FP}	19.4	19.4	19.4	30.4	42.4	52.6
Flight endurance, trail (hrs)	t_{FT}	53.3	47.1	40.4	442.7	47.4	52.6
On station fraction, patrol	f_{SP}	1.00	.79	.59	.52	.45	.37
On station fraction, trail	f_{ST}	1.00	.92	.80	.66	.51	.37
Effective speed, (knots)	v_E	50.0	39.7	29.4	21.0	15.4	11.0
Average fuel rate patrol (gal./hr.)	$\dot{W}_{AVP}$	26.0	26.0	26.0	16.6	11.9	9.6
Average fuel rate, trail (gal./hr.)	$\dot{W}_{AVT}$	9.47	10.72	12.5	11.83	10.65	9.60
Hourly cost, patrol ($/hr.)	$\$C_P$	735	735	735	731	730	729
Hourly cost, trail ($/hr.)	$\$C_T$	729	729	730	730	729	729
Cost effectiveness measures		**0**	**100**	**200**	**300**	**400**	**500**
Miles on station/cost, (hrs./$1,000)	I_{P1}	68.0	54.0	40.0	28.8	21.1	15.1
Square miles on station/cost, (sq. mi./$)	I_{P2}	2585	2052	1519	1093	803	573
Hours on station/cost, (hrs./$1,000)	I_T	1.37	1.26	1.10	.90	.70	.50
Miles on station/gallon, (mi./gal.)	I_{FP1}	1.92	1.53	1.13	1.27	1.30	1.15
Square miles on station per gallon (sq. mi./gal.)	I_{FP2}	73.1	58.0	42.9	48.2	49.2	43.5
Hours on station/gallon, trail (hrs./1,000 gal.)	I_{FT}	106	86	64	56	48	38

TABLE J-2-8

LTA COST/EFFECTIVENESS MODEL OUTPUTS

LTA (Speed/Range/Crew) = 60/1000/14

Effectiveness and cost		Distance to station (miles) 0	100	200	300	400	500
Flight endurance, patrol (hrs)	t_{FP}	16.7	16.7	16.7	26.2	36.4	45.0
Flight endurance, trail (hrs)	t_{FT}	48.1	42.1	43.1	44.4	47.3	50.4
On station fraction, patrol	f_{SP}	1.00	.80	.60	.53	.47	.38
On station fraction, trail	f_{ST}	1.00	.92	.85	.73	.59	.45
Effective speed, (knots)	v_E	60.0	48.0	36.1	26.0	19.2	13.8
Average fuel rate patrol (gal./hr.)	$\dot{W}_{AVP}$	43.1	43.1	43.1	27.5	19.8	16.0
Average fuel rate, trail (gal./hr.)	$\dot{W}_{AVT}$	15.0	17.1	16.7	16.2	15.2	14.3
Hourly cost, patrol ($/hr.)	$\$C_P$	762	762	762	756	752	751
Hourly cost, trail ($/hr.)	$\$C_T$	750	751	751	751	750	750

Cost effectiveness measures		0	100	200	300	400	500
Miles on station/cost, (hrs./$1,000)	I_{P1}	78.7	63.1	47.3	34.4	25.5	18.4
Square miles on station/ cost, (sq. mi./$)	I_{P2}	2992	2396	1799	1308	969	698
Hours on station/cost, (hrs./$1,000)	I_T	1.33	1.23	1.13	.97	.79	.60
Miles on station/gallon, (mi./gal.)	I_{FP1}	1.39	1.12	.84	.94	.97	.86
Square miles on station per gallon (sq. mi./gal.)	I_{FP2}	52.9	42.4	31.8	35.9	36.8	32.7
Hours on station/gallon, trail (hrs./1,000 gal.)	I_{FT}	67	54	51	45	39	31

TABLE J-2-9

LTA COST/EFFECTIVENESS MODEL OUTPUTS

LTA (Speed/Range/Crew) = 70/1000/14

Effectiveness and cost		Distance to station (miles) 0	100	200	300	400	500
Flight endurance, patrol (hrs)	t_{FP}	14.3	14.3	14.3	22.3	30.8	37.9
Flight endurance, trail (hrs)	t_{FT}	48.0	42.0	35.5	36.6	39.0	45.5
On station fraction, patrol	f_{SP}	1.00	.80	.60	.53	.46	.37
On station fraction, trail	f_{ST}	1.00	.93	.84	.71	.58	.48
Effective speed, (knots)	v_E	70.0	56.0	42.0	30.1	22.1	15.6
Average fuel rate patrol (gal./hr.)	$\dot{W}_{AVP}$	68.3	68.3	68.3	43.7	31.6	25.7
Average fuel rate, trail (gal./hr.)	$\dot{W}_{AVT}$	20.3	23.2	27.5	26.6	25.0	21.4
Hourly cost, patrol ($/hr.)	$\$C_P$	793	793	793	783	778	776
Hourly cost, trail ($/hr.)	$\$C_T$	773	775	776	776	774	774

Cost effectiveness measures		0	100	200	300	400	500
Miles on station/cost, (hrs./$1,000)	I_{P1}	88.3	70.6	52.9	38.5	28.4	20.2
Square miles on station/ cost, (sq. mi./$)	I_{P2}	3354	2682	2010	1463	1078	767
Hours on station/cost, (hrs./$1,000)	I_T	1.29	1.20	1.08	.91 .74	.62	
Miles on station/gallon, (mi./gal.)	I_{FP1}	1.03	.82	.61	.69	.70	.61
Square miles on station per gallon (sq. mi./gal.)	I_{FP2}	39.0	31.2	23.3	26.2	26.5	23.1
Hours on station/gallon, trail (hrs./1,000 gal.)	I_{FT}	49	40	31	27	23	22

TABLE J-2-10

LTA COST/EFFECTIVENESS MODEL OUTPUTS

LTA (Speed/Range/Crew) = 80/1000/14

Effectiveness and cost		Distance to station (miles) 0	100	200	300	400	500
Flight endurance, patrol (hrs)	t_{FP}	12.5	12.5	12.5	19.6	27.0	33.2
Flight endurance, trail (hrs)	t_{FT}	46.4	40.3	33.8	34.8	36.9	38.8
On station fraction, patrol	f_{SP}	1.00	.80	.60	.53	.46	.37
On station fraction, trail	f_{ST}	1.00	.94	.85	.74	.61	.46
Effective speed, (knots)	v_E	80.0	64.0	48.1	34.5	25.3	17.9
Average fuel rate patrol (gal./hr.)	$\dot{W}_{AVP}$	101.6	101.6	101.7	65.1	47.1	38.4
Average fuel rate, trail (gal./hr.)	$\dot{W}_{AVT}$	27.4	31.6	37.7	36.6	34.5	32.8
Hourly cost, patrol ($/hr.)	$\$C_P$	830	830	830	815	808	805
Hourly cost, trail ($/hr.)	$\$C_T$	800	802	804	804	803	802

Cost effectiveness measures		0	100	200	300	400	500
Miles on station/cost, (hrs./$1,000)	I_{P1}	96.4	77.1	57.9	42.3	31.3	22.2
Square miles on station/cost, (sq. mi./$)	I_{P2}	3661	2931	2199	1609	1188	843
Hours on station/cost, (hrs./$1,000)	I_T	1.25	1.17	1.06	.91	.75	.58
Miles on station/gallon, (mi./gal.)	I_{FP1}	.79	.63	.47	.53	.54	.46
Square miles on station per gallon (sq. mi./gal.)	I_{FP2}	29.9	23.9	18.0	20.2	20.4	17.7
Hours on station/gallon, trail (hrs./1,000 gal.)	I_{FT}	36	30	23	20	18	14

TABLE J-2-11

LTA COST/EFFECTIVENESS MODEL OUTPUTS

LTA (Speed/Range/Crew) = 90/1000/14

Effectiveness and cost		Distance to station (miles)					
		0	100	200	300	400	500
Flight endurance, patrol (hrs)	t_{FP}	11.1	11.1	11.1	17.2	23.7	29.0
Flight endurance, trail (hrs)	t_{FT}	41.7	36.2	30.4	31.2	33.0	34.5
On station fraction, patrol	f_{SP}	1.00	.80	.60	.52	.45	.36
On station fraction, trail	f_{ST}	1.00	.94	.85	.74	.61	.46
Effective speed, (knots)	v_E	90	71.9	53.8	38.5	28.0	19.5
Average fuel rate patrol (gal./hr.)	$\dot{W}_{AVP}$	146.2	146.2	146.3	93.9	68.2	55.8
Average fuel rate, trail (gal./hr.)	$\dot{W}_{AVT}$	38.8	44.6	53.1	51.8	49.1	46.8
Hourly cost, patrol ($/hr.)	$\$C_P$	875	875	875	853	843	838
Hourly cost, trail ($/hr.)	$\$C_T$	831	833	837	836	835	834

Cost effectiveness measures		0	100	200	300	400	500
Miles on station/cost, (hrs./$1,000)	I_{P1}	102.9	82.2	61.5	45.1	33.2	23.2
Square miles on station/ cost, (sq. mi./$)	I_{P2}	3911	3124	2337	1715	1261	883
Hours on station/cost, (hrs./$1,000)	I_T	1.20	1.13	1.02	.88	.73	.56
Miles on station/gallon, (mi./gal.)	I_{FP1}	.62	.49	.37	.41	.41	.35
Square miles on station per gallon (sq. mi./gal.)	I_{FP2}	23.4	18.7	14.0	15.6	15.6	13.3
Hours on station/gallon, trail (hrs./1,000 gal.)	I_{FT}	26	21	16	14	12	10

TABLE J-2-12

LTA COST/EFFECTIVENESS MODEL OUTPUTS

LTA (Speed/Range/Crew) = 100/1000/14

Effectiveness and cost		Distance to station (miles) 0	100	200	300	400	500
Flight endurance, patrol (hrs)	t_{FP}	9.90	9.90	9.89	15.4	21.0	25.6
Flight endurance, trail (hrs)	t_{FT}	37.7	32.3	26.7	27.3	28.8	30.0
On station fraction, patrol	f_{SP}	1.00	.80	.60	.52	.45	.35
On station fraction, trail	f_{ST}	1.00	.94	.85	.73	.60	.44
Effective speed, (knots)	v_E	100	79.8	59.6	42.5	30.6	20.9
Average fuel rate patrol (gal./hr.)	$\dot{W}_{AVP}$	205.3	205.3	205.4	132.3	96.6	79.5
Average fuel rate, trail (gal./hr.)	$\dot{W}_{AVT}$	54.0	62.9	76.1	74.5	70.7	67.7
Hourly cost, patrol ($/hr.)	$\$C_P$	931	931	931	901	887	880
Hourly cost, trail ($/hr.)	$\$C_T$	869	873	878	876	876	875
Cost effectiveness measures		**0**	**100**	**200**	**300**	**400**	**500**
Miles on station/cost, (hrs./$1,000)	I_{P1}	107.4	85.7	64.0	47.1	34.5	23.8
Square miles on station/cost, (sq. mi./$)	I_{P2}	4082	3257	2431	1791	1311	903
Hours on station/cost, (hrs./$1,000)	I_T	1.15	1.08	.97	.83	.68	.51
Miles on station/gallon, (mi./gal.)	I_{FP1}	.49	.39	.29	.32	.32	.26
Square miles on station per gallon (sq. mi./gal.)	I_{FP2}	18.5	14.8	11.0	12.2	12.0	10.0
Hours on station/gallon, trail (hrs./1,000 gal.)	I_{FT}	19	15	11	10	8	7

TABLE J-2-13

LTA COST/EFFECTIVENESS MODEL OUTPUTS

LTA (Speed/Range/Crew) = 110/1000/14

Effectiveness and cost		Distance to station (miles) 0	100	200	300	400	500
Flight endurance, patrol (hrs)	t_{FP}	9.0	9.0	9.0	13.9	19.0	23.0
Flight endurance, trail (hrs)	t_{FT}	34.0	28.8	23.4	23.8	25.1	26.2
On station fraction, patrol	f_{SP}	1.00	.80	.59	.52	.44	.34
On station fraction, trail	f_{ST}	1.00	.94	.84	.72	.58	.42
Effective speed, (knots)	v_E	110	87.7	65.4	46.5	33.3	22.5
Average fuel rate patrol (gal./hr.)	$\dot{W}_{AVP}$	282.7	282.7	282.9	182.6	133.8	110.6
Average fuel rate, trail (gal./hr.)	$\dot{W}_{AVT}$	74.7	88.2	108.5	106.6	101.3	97.1
Hourly cost, patrol ($/hr.)	$\$C_P$	1001	1000	1000	960	940	930
Hourly cost, trail ($/hr.)	$\$C_T$	916	919	928	928	926	925
Cost effectiveness measures		**0**	**100**	**200**	**300**	**400**	**500**
Miles on station/cost, (hrs./$1,000)	I_{P1}	109.9	87.7	65.4	48.5	35.4	24.1
Square miles on station/ cost, (sq. mi./$)	I_{P2}	4178	3322	2485	1843	1346	917
Hours on station/cost, (hrs./$1,000)	I_T	1.09	1.02	.91	.77	.62	.46
Miles on station/gallon, (mi./gal.)	I_{FP1}	.39	.31	.23	.25	.25	.20
Square miles on station per gallon (sq. mi./gal.)	I_{FP2}	14.8	11.8	8.8	9.7	9.5	7.7
Hours on station/gallon, trail (hrs./1,000 gal.)	I_{FT}	13	11	8	7	6	4

TABLE J-2-14

LTA COST/EFFECTIVENESS MODEL OUTPUTS

LTA (Speed/Range/Crew) = 50/2000/14

Effectiveness and cost		Distance to station (miles) 0	100	200	300	400	500
Flight endurance, patrol (hrs)	t_{FP}	39.7	39.7	39.6	39.6	39.6	49.3
Flight endurance, trail (hrs)	t_{FT}	113.3	106.7	99.7	92.5	84.9	85.9
On station fraction, patrol	f_{SP}	1.00	.90	.80	.70	.60	.55
On station fraction, trail	f_{ST}	1.00	.96	.92	.87	.81	.74
Effective speed, (knots)	v_E	50.0	45.0	39.9	34.9	29.8	25.2
Average fuel rate patrol (gal./hr.)	$\dot{W}_{AVP}$	30.8	30.8	30.8	30.8	30.8	24.8
Average fuel rate, trail (gal./hr.)	$\dot{W}_{AVT}$	10.8	11.5	12.3	13.2	14.3	14.2
Hourly cost, patrol ($/hr.)	$\$C_P$	811	811	811	811	811	809
Hourly cost, trail ($/hr.)	$\$C_T$	803	803	804	804	805	804
Cost effectiveness measures		**0**	**100**	**200**	**300**	**400**	**500**
Miles on station/cost, (hrs./$1,000)	I_{P1}	61.7	55.4	49.2	43.0	36.8	31.2
Square miles on station/cost, (sq. mi./$)	I_{P2}	2343	2107	1870	1634	1397	1184
Hours on station/cost, (hrs./$1,000)	I_T	1.25	1.20	1.14	1.08	1.01	.92
Miles on station/gallon, (mi./gal.)	I_{FP1}	1.62	1.46	1.29	1.13	.97	1.01
Square miles on station per gallon (sq. mi./gal.)	I_{FP2}	61.7	55.4	49.2	43.0	36.7	38.7
Hours on station/gallon, trail (hrs./1,000 gal.)	I_{FT}	93	83	75	66	57	52

TABLE J-2-15

LTA COST/EFFECTIVENESS MODEL OUTPUTS
LTA (Speed/Range/Crew) = 60/2000/14

Effectiveness and cost		Distance to station (miles) 0	100	200	300	400	500
Flight endurance, patrol (hrs)	t_{FP}	33.4	33.4	33.3	33.3	33.3	41.5
Flight endurance, trail (hrs)	t_{FT}	124.3	116.9	108.9	100.2	95.2	95.4
On station fraction, patrol	f_{SP}	1.00	.90	.80	.70	.60	.56
On station fraction, trail	f_{ST}	1.00	.97	.94	.90	.86	.81
Effective speed, (knots)	v_E	60.0	54.0	48.0	42.0	36.0	30.5
Average fuel rate patrol (gal./hr.)	$\dot{W}_{AVP}$	55.7	55.7	55.7	55.7	55.7	44.8
Average fuel rate, trail (gal./hr.)	$\dot{W}_{AVT}$	14.9	15.9	17.1	18.5	19.5	19.5
Hourly cost, patrol ($/hr.)	$\$C_P$	879	879	879	879	879	874
Hourly cost, trail ($/hr.)	$\$C_T$	862	863	863	864	864	864

Cost effectiveness measures		0	100	200	300	400	500
Miles on station/cost, (hrs./$1,000)	I_{P1}	68.3	61.4	54.6	47.8	41.0	34.8
Square miles on station/ cost, (sq. mi./$)	I_{P2}	2594	2335	2075	1816	1556	1323
Hours on station/cost, (hrs./$1,000)	I_T	1.16	1.12	1.09	1.04	1.00	.94
Miles on station/gallon, (mi./gal.)	I_{FP1}	1.08	.97	.86	.75	.65	.68
Square miles on station per gallon (sq. mi./gal.)	I_{FP2}	41.0	36.9	32.8	28.6	24.5	25.8
Hours on station/gallon, trail (hrs./1,000 gal.)	I_{FT}	67	61	55	49	44	42

TABLE J-2-16

LTA COST/EFFECTIVENESS MODEL OUTPUTS

LTA (Speed/Range/Crew) = 70/2000/14

Effectiveness and cost		Distance to station (miles) 0	100	200	300	400	500
Flight endurance, patrol (hrs)	t_{FP}	28.8	28.8	28.8	28.8	28.8	35.8
Flight endurance, trail (hrs)	t_{FT}	101.9	95.7	111.8	103.0	95.6	94.7
On station fraction, patrol	f_{SP}	1.00	.90	.80	.70	.60	.56
On station fraction, trail	f_{ST}	1.00	.97	.95	.92	.88	.83
Effective speed, (knots)	v_E	70.0	63.1	56.1	49.2	42.2	35.7
Average fuel rate patrol (gal./hr.)	$\dot{W}_{AVP}$	92.5	92.5	92.6	92.6	92.6	74.4
Average fuel rate, trail (gal./hr.)	$\dot{W}_{AVT}$	26.2	27.8	23.8	25.8	27.9	28.1
Hourly cost, patrol ($/hr.)	$\$C_P$	963	963	963	963	963	955
Hourly cost, trail ($/hr.)	$\$C_T$	936	936	935	936	936	936

Cost effectiveness measures		0	100	200	300	400	500
Miles on station/cost, (hrs./$1,000)	I_{P1}	72.7	65.5	58.3	51.1	43.8	37.4
Square miles on station/ cost, (sq. mi./$)	I_{P2}	2763	2489	2214	1940	1665	1421
Hours on station/cost, (hrs./$1,000)	I_T	1.07	1.04	1.02	.98	.94	.89
Miles on station/gallon, (mi./gal.)	I_{FP1}	.76	.68	.61	.53	.46	.48
Square miles on station per gallon (sq. mi./gal.)	I_{FP2}	28.8	25.9	23.0	20.2	17.3	18.2
Hours on station/gallon, trail (hrs./1,000 gal.)	I_{FT}	38	35	40	36	32	30

TABLE J-2-17

LTA COST/EFFECTIVENESS MODEL OUTPUTS

LTA (Speed/Range/Crew) = 80/2000/14

Effectiveness and cost		Distance to station (miles) 0	100	200	300	400	500
Flight endurance, patrol (hrs)	t_{FP}	25.1	25.1	25.1	25.1	25.1	31.2
Flight endurance, trail (hrs)	t_{FT}	100.7	94.6	87.9	100.3	91.1	89.5
On station fraction, patrol	f_{SP}	1.00	.90	.80	.70	.60	.56
On station fraction, trail	f_{ST}	1.00	.97	.94	.93	.89	.85
Effective speed, (knots)	v_E	80.0	72.0	64.1	56.1	48.1	40.7
Average fuel rate patrol (gal./hr.)	$\dot{W}_{AVP}$	151.3	151.3	151.3	151.4	151.4	121.7
Average fuel rate, trail (gal./hr.)	$\dot{W}_{AVT}$	37.7	40.2	43.2	37.9	41.7	42.4
Hourly cost, patrol ($/hr.)	$\$C_P$	1079	1079	1079	1079	1079	1067
Hourly cost, trail ($/hr.)	$\$C_T$	1032	1033	1035	1032	1034	1034
Cost effectiveness measures		**0**	**100**	**200**	**300**	**400**	**500**
Miles on station/cost, (hrs./$1,000)	I_{P1}	74.2	66.8	59.4	52.0	44.6	38.2
Square miles on station/ cost, (sq. mi./$)	I_{P2}	2818	2538	2257	1976	1695	1450
Hours on station/cost, (hrs./$1,000)	I_T	.97	.94	.91	.90	.86	.82
Miles on station/gallon, (mi./gal.)	I_{FP1}	.53	.48	.42	.37	.32	.33
Square miles on station per gallon (sq. mi./gal.)	I_{FP2}	20.1	18.1	16.1	14.1	12.1	12.7
Hours on station/gallon, trail (hrs./1,000 gal.)	I_{FT}	27	24	22	25	21	20

TABLE J-2-18

LTA COST/EFFECTIVENESS MODEL OUTPUTS

LTA (Speed/Range/Crew) = 90/2000/14

Effectiveness and cost		Distance to station (miles) 0	100	200	300	400	500
Flight endurance, patrol (hrs)	t_{FP}	22.4	22.4	22.4	22.4	22.4	27.9
Flight endurance, trail (hrs)	t_{FT}	97.9	92.0	85.6	78.7	88.3	86.6
On station fraction, patrol	f_{SP}	1.00	.90	.80	.70	.60	.56
On station fraction, trail	f_{ST}	1.00	.97	.95	.92	.90	.86
Effective speed, (knots)	v_E	90	81.1	72.2	63.2	54.3	46.0
Average fuel rate patrol (gal./hr.)	$\dot{W}_{AVP}$	242	242.0	242.1	242.1	242.2	194.6
Average fuel rate, trail (gal./hr.)	$\dot{W}_{AVT}$	58.2	59.0	63.4	69.0	61.4	62.7
Hourly cost, patrol ($/hr.)	$\$C_P$	1240	1240	1240	1240	1240	1220
Hourly cost, trail ($/hr.)	$\$C_T$	1165	1165	1167	1169	1166	1167

Cost effectiveness measures		0	100	200	300	400	500
Miles on station/cost, (hrs./$1,000)	I_{P1}	72.6	65.4	58.2	51.0	43.8	37.7
Square miles on station/ cost, (sq. mi./$)	I_{P2}	2759	2486	2212	1938	1664	1432
Hours on station/cost, (hrs./$1,000)	I_T	.86	.83	.81	.79	.77	.74
Miles on station/gallon, (mi./gal.)	I_{FP1}	.37	.34	.30	.26	.22	.24
Square miles on station per gallon (sq. mi./gal.)	I_{FP2}	14.1	12.7	11.3	9.9	8.5	9.0
Hours on station/gallon, trail (hrs./1,000 gal.)	I_{FT}	17	16	15	13	15	14

TABLE J-2-19

LTA COST/EFFECTIVENESS MODEL OUTPUTS

LTA (Speed/Range/Crew) = 100/2000/14

Effectiveness and cost		Distance to station (miles) 0	100	200	300	400	500
Flight endurance, patrol (hrs)	t_{FP}	20.1	20.1	20.1	20.1	20.1	25.0
Flight endurance, trail (hrs)	t_{FT}	93.3	87.4	81.3	74.7	83.2	81.5
On station fraction, patrol	f_{SP}	1.00	.90	.80	.70	.60	.56
On station fraction, trail	f_{ST}	1.00	.98	.95	.92	.90	.87
Effective speed, (knots)	v_E	100	90.0	80.1	70.1	60.1	50.9
Average fuel rate patrol (gal./hr.)	$\dot{W}_{AVP}$	386.5	386.5	386.6	386.7	386.9	310.9
Average fuel rate, trail (gal./hr.)	$\dot{W}_{AVT}$	83.1	88.8	95.4	103.8	93.2	95.2
Hourly cost, patrol ($/hr.)	$\$C_P$	1473	1473	1473	1473	1474	1443
Hourly cost, trail ($/hr.)	$\$C_T$	1350	1352	1355	1358	1354	1355

Cost effectiveness measures		0	100	200	300	400	500
Miles on station/cost (hr./$1,000)	I_{P1}	67.9	61.1	54.3	47.6	40.8	35.3
Square miles on station/cost, (sq. mi./$)	I_{P2}	2579	2322	2065	1807	1550	1340
Hours on station/cost, (hrs./$1,000)	I_1	.74	.72	.70	.68	.66	.64
Miles on station/gallon, (mi./gal.)	I_{FP1}	.26	.23	.21	.18	.16	.16
Square miles on station per gallon (sq. mi./gal.)	I_{FP2}	9.83	8.85	7.87	6.89	5.90	6.22
Hours on station/gallon, trail (hrs./1,000 gal.)	I_{FT}	12	11	10	9	10	9

TABLE J-2-20

LTA COST/EFFECTIVENESS MODEL OUTPUTS

LTA (Speed/Range/Crew) = 110/2000/14

Effectiveness and cost		Distance to station (miles) 0	100	200	300	400	500
Flight endurance, patrol (hrs)	t_{FP}	18.2	18.2	18.2	18.2	18.2	22.7
Flight endurance, trail (hrs)	t_{FT}	89.0	83.1	77.2	70.8	79.3	77.7
On station fraction, patrol	f_{SP}	1.00	.90	.80	.70	.60	.56
On station fraction, trail	f_{ST}	1.00	.98	.95	.92	.91	.87
Effective speed, (knots)	v_E	110	99.0	88.1	77.1	66.1	56.0
Average fuel rate patrol (gal./hr.)	$\dot{W}_{AVP}$	625.8	625.8	626.0	626.2	626.4	503.0
Average fuel rate, trail (gal./hr.)	$\dot{W}_{AVT}$	128.2	137.3	147.8	161.1	143.8	146.8
Hourly cost, patrol ($/hr.)	$\$C_P$	1826	1826	1826	1826	1826	1776
Hourly cost, trail ($/hr.)	$\$C_T$	1623	1627	1631	1637	1630	1631

Cost effectiveness measures		0	100	200	300	400	500
Miles on station/cost, (hrs./$1,000)	I_{P1}	60.2	54.2	48.2	42.2	36.2	31.5
Square miles on station/cost, (sq. mi./$)	I_{P2}	2289	2061	1832	1604	1375	1197
Hours on station/cost, (hrs./$1,000)	I_T	.62	.60	.58	.56	.56	.53
Miles on station/gallon, (mi./gal.)	I_{FP1}	.18	.16	.14	.12	.11	.11
Square miles on station per gallon (sq. mi./gal.)	I_{FP2}	6.68	6.01	5.35	4.68	4.01	4.23
Hours on station/gallon, trail (hrs./1,000 gal.)	I_{FT}	8	7	6	6	6	6

TABLE J-2-21

LTA COST/EFFECTIVENESS MODEL OUTPUTS

LTA (Speed/Range/Crew) = 90/1000/11

Effectiveness and cost		Distance to station (miles) 0	100	200	300	400	500
Flight endurance, patrol (hrs)	t_{FP}	11.0	11.0	11.0	17.0	23.3	28.4
Flight endurance, trail (hrs)	t_{FT}	40.5	35.1	29.3	30.1	31.8	33.3
On station fraction, patrol	f_{SP}	1.00	.80	.60	.52	.44	.35
On station fraction, trail	f_{ST}	1.00	.94	.85	.73	.59	.44
Effective speed, (knots)	v_E	90.0	71.8	53.6	38.2	27.5	18.7
Average fuel rate patrol (gal./hr.)	$\dot{W}_{AVP}$	135.4	135.4	135.5	87.3	63.7	52.4
Average fuel rate, trail (gal./hr.)	$\dot{W}_{AVT}$	36.7	42.4	50.7	49.4	46.7	44.6
Hourly cost, patrol ($/hr.)	$\$C_P$	767	767	767	747	737	733
Hourly cost, trail ($/hr.)	$\$C_T$	726	728	732	731	730	729

Cost effectiveness measures		0	100	200	300	400	500
Miles on station/cost, (hrs./$1,000)	I_{P1}	117.4	93.7	69.9	51.1	37.3	25.6
Square miles on station/ cost, (sq. mi./$)	I_{P2}	4461	3559	2654	1941	1415	972
Hours on station/cost, (hrs./$1,000)	I_T	1.38	1.29	1.16	1.00	.81	.61
Miles on station/gallon, (mi./gal.)	I_{FP1}	.66	.53	.40	.44	.43	.36
Square miles on station per gallon (sq. mi./gal.)	I_{FP2}	25.3	20.2	15.0	16.6	16.4	13.5
Hours on station/gallon, trail (hrs./1,000 gal.)	I_{FT}	27	22	17	15	13	10

TABLE J-2-22

LTA COST/EFFECTIVENESS MODEL OUTPUTS

LTA (Speed/Range/Crew) = 100/1000/11

Effectiveness and cost		Distance to station (miles) 0	100	200	300	400	500
Flight endurance, patrol (hrs)	t_{FP}	9.9	9.9	9.9	15.4	21.1	25.6
Flight endurance, trail (hrs)	t_{FT}	37.4	32.0	26.4	27.0	28.4	29.7
On station fraction, patrol	f_{SP}	1.00	.80	.60	.52	.45	.35
On station fraction, trail	f_{ST}	1.00	.94	.85	.73	.59	.44
Effective speed, (knots)	v_E	100.0	79.9	59.7	42.6	30.7	20.9
Average fuel rate patrol (gal./hr.)	$\dot{W}_{AVP}$	189.2	189.2	189.4	122.0	89.2	73.5
Average fuel rate, trail (gal./hr.)	$\dot{W}_{AVT}$	50.2	58.7	71.2	69.7	66.1	63.3
Hourly cost, patrol ($/hr.)	$\$C_P$	819	819	819	792	778	772
Hourly cost, trail ($/hr.)	$\$C_T$	762	766	771	770	769	768

Cost effectiveness measures		0	100	200	300	400	500
Miles on station/cost, (hrs./$1,000)	I_{P1}	122.1	97.5	72.9	53.8	39.4	27.1
Square miles on station/ cost, (sq. mi./$)	I_{P2}	4640	3706	2771	2044	1497	1030
Hours on station/cost, (hrs./$1,000)	I_T	1.31	1.22	1.10	.94	.77	.57
Miles on station/gallon, (mi./gal.)	I_{FP1}	.53	.42	.32	.35	.34	.28
Square miles on station per gallon (sq. mi./gal.)	I_{FP2}	20.1	16.0	12.0	13.3	13.1	10.8
Hours on station/gallon, trail (hrs./1,000 gal.)	I_{FT}	20	16	12	10	9	7

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1. INTRODUCTION

This volume presents the engineering and investment cost analysis used in the conceptual airship model.

Airship, in this volume, refers to blimps and dirigibles, which are categories of lighter-than-air vehicles. Other categories of LTA vehicles, such as balloons, buoyant lifting body hybrids, and rotor lift hybrids, are not considered. The nomenclature of some engineering features of blimps and dirigibles is described below.

Chapter 2 presents general characteristics of airships and shows the effect of varying several engineering specifications such as design speed and range, and payload weights. The purpose of the chapter is to show the nature of the engineering and investment cost characteristics of airships and how these characteristics can be expected to change.

The estimation of the airship geometry is analyzed in chapter 3. Dimensions, areas, and lift gas, as well as other volumes that are needed later, are considered.

For this geometry, the estimation of aerodynamic drag and lift is analyzed in chapter 4.

Chapter 5 presents methods for estimating the characteristics of the propulsion plant required to provide a thrust equal to the estimated aerodynamic drag.

Chapter 6 presents an analysis of the weight of each of the remaining components of the airship, such as the weights of structural components. Weights for accommodations enclosures and facilities, and for personnel stores, are estimated as functions of the specified design flight duration. The required volume for these components is estimated at the end of chapter 6.

Chapter 7 presents an analysis of the investment cost for airships. Development, prototype, and basic production cost are considered. Production cost reduction associated with increasing production quantity is included.

Chapter 8 describes a computer program that can perform the calculations required for the conceptual airship model.

Appendix A is a list of symbols, with definitions and units, used in this volume. Appendix B is a listing of the computer program.

AIRSHIP CONSTRUCTION AND NOMENCLATURE

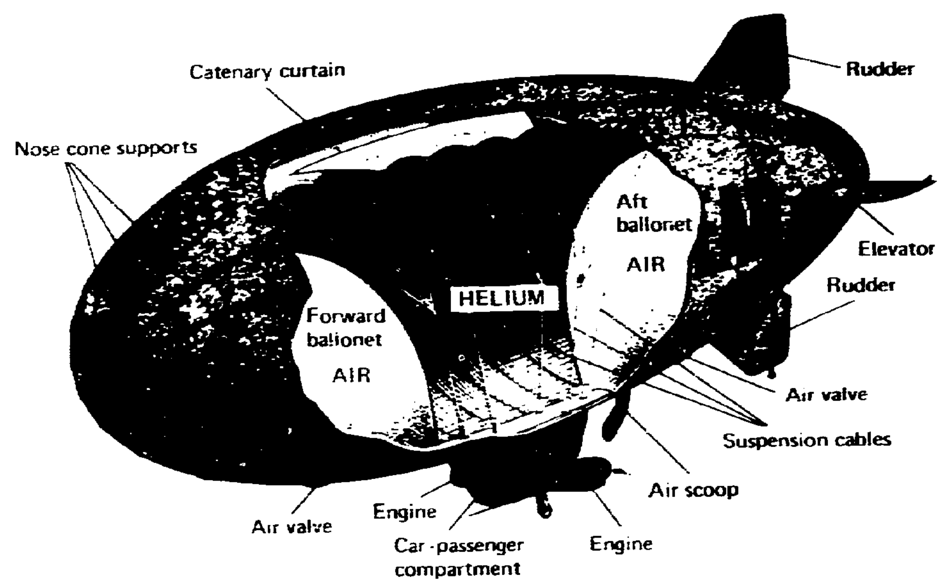
The conventional airship is a powered, streamlined body of revolution vehicle lifted by air displacement; that is, the net lifting force is equal to the difference in weight of displaced air minus the weight of the lifting gas within its envelope or hull. Two distinct types of airships are the blimp, with a nonrigid envelope that has structural strength due to internal pressurization, and the dirigible, which has a rigid structure, thus structural strength does not require internal pressurization. A third structural type, the semirigid, is a blend of the first two types, with a rigid-structure keel only, and will not be considered further here.

Blimps

The construction of a blimp is illustrated in figure 1. It consists of an envelope that encloses the pressurized lifting gas, with stabilizing and control surfaces attached on the tail and a car structure supported below the envelope. Historically, the envelope material consisted of several plies of cotton with various coatings. Recent blimps have used plies of Dacron with neoprene coatings. Dacron has a higher strength-to-weight ratio than cotton. Dacron envelope material has good gas retention and weathering characteristics. An external aluminum pigment coating is usually applied to increase solar radiation reflectivity. In the 1970's, new polymer-film materials became available that could decrease envelope weights for blimps.

Envelope material strength is an important characteristic because the blimp envelope is pressurized. The air scoop and a blower system provide pressurized air to the ballonets. The required pressure differential depends on the bending moment expected in flight. (The relation between pressurization and loads for a pressurized structure can be seen directly for a fabric building that is pressurized. If a snow load of about 1 foot is expected, the internal pressurization must be sufficient to support this vertical load.) The pressure differential for blimps has been about 3 inches of water (0.8 percent of atmospheric pressure). Larger pressure differentials increase the envelope weight.

As blimp altitude is increased, the lifting gas within the envelope expands due to the decreased external pressure. To permit this expansion, air ballonets consisting of thin flexible material are installed within the envelope. They are located forward, aft, and one, or more, amidships for larger blimps. An air distribution system of ducts, dampers, and exhaust valves, with controls, provides the necessary constant differential pressure as altitude is changed. The system also permits changing the total ballonet volume so the lifting gas can expand when altitude increases, and is used to change the relative fullness of the fore and aft ballonets for trimming the airship longitudinally in pitch.



Source: *Goodyear, NASA, Vol. III, 19, p. 6.*

FIG. 1: TYPICAL BLIMP CONSTRUCTION

When the ballonets are completely deflated, and the envelope is 100 percent full of lifting gas, the blimp is at its design maximum altitude. On further ascent, valving (loss) of the relatively expensive lifting gas occurs. If lifting gas is valved, then upon descent the ballonets will be pumped completely full of air before the takeoff altitude has been reached. The blimp can return to its takeoff altitude only by pumping air directly into the lifting gas.

Because the blimp contains its structural strength from pressurization, it is necessary to operate the blower intermittently when moored. The small pressure differential used is less than normal weather variations of barometric pressure, so blower operation must be continuously monitored or controlled to maintain the proper pressure differential.

Helium and hydrogen have been used as the lifting gas. Hydrogen provides significantly greater lift, but helium is considerably safer to use. Normally, the envelope is not filled with the lifting gas. A 95 percent fullness at takeoff permits blimp operation to a maximum altitude of 1,742 feet. For greater operating altitudes, the envelope must contain less than 95 percent lifting gas. Helium diffuses outward through the envelope material and is lost; air diffuses inward and becomes a contaminant. Polymer-film materials of the 1976 era would reduce the diffusion rate.

On blimps, the car structure and attacked propulsion plant are supported by a combination of two suspension systems. The internal suspension cables distribute the concentrated load of the car to a pair of laterally symmetrical catenary curtains inside the top of the envelope. Another catenary system from the car up to reinforced patches on the envelope distributes car pitching and yawing loads to the envelope.

Ground handling lines are attached to reinforced patches on the envelope at the bow and stern. They are used to hold the blimp in one place and to move it.

The car structure provides space for the flight controls and communications in a pilot's compartment, support for outriggers on which engines are mounted, support for internal tanks for engine fuel, and support for landing gear. The car structure may be extended in length for payload and mission requirements, such as cargo, electronic equipment and operating personnel, and living accommodations for personnel on long missions.

The nose cone supports consist of several longitudinal stiffener battens to withstand airflow loads and to distribute the concentrated mooring mast load into the envelope. The cone structure also includes a rotating mooring spendle at its axis.

The tail surfaces are lightweight frame structures covered with doped fabric. They are mounted on reinforced areas on the envelope and braced by cables to other reinforced patches. A cruciform tail configuration is shown in figure 3. An X-form or an inverted-Y configuration can also be used.

Aerodynamic lift is usually used by blimps along with the static lift. When loaded heavy at takeoff the blimp is easier to handle and control; however, a takeoff ground run is needed to develop the aerodynamic lift required. Heaviness at landing facilitates control and handling. In flight, both blimps and dirigibles use aerodynamic lift for maneuvering and controlling the altitude.

Early U.S. blimps had volumes of 35,000 to 200,000 cubic feet. During the 1950's, volumes were increased to more than 1 million cubic feet. Some characteristics of the 1950 blimps are listed in table 1. The U.S. Navy blimps of the same decade were designated by ZPG- numbers. Most of them had envelope volumes close to 1 million cubic feet; however, the last four (ZPG-3W class) had an envelope volume of 1.49 million cubic feet.

The static lift shown in table 1 is the net buoyancy at sea level, obtained by subtracting the weight of the lifting gas itself from the buoyancy of the envelope volume. The static lift of the U.S. Navy blimps was around 60,000 pounds, increasing to 94,000 pounds for the ZPG-3W class. Useful lift at sea level is the lift remaining after the weight of structure, car, propulsion plant, etc., is subtracted from the static lift. Useful lift can be used for personnel, accommodations, fuel, and payload, Despite the large size of these blimps, the weights were small. The aerodynamic lift was also small, about 10 percent of the static lift. It provided an increase of useful lift of about 25 percent.

The installed propulsion power of U.S. Navy blimps was low--around 2,000 horsepower. The maximum speeds were about 75 knots. At a cruise speed of 40 knots these blimps provided high endurance hours that were large compared to conventional aircraft.

Maximum altitude without valving (releasing lifting gas) was around 10,000 feet. To obtain such altitudes, less gas was used at takeoff, and the useful lift was therefore markedly decreased.

In 1976 there are three operational blimps in the United States: the Mayflower III, the America, and the Columbia II, which are advertising blimps of the Goodyear Tire and Rubber Company. Table 2 shows that the dimensions of the Goodyear blimp America are about half those of the earlier Navy blimps and its volume is about one-eighth of earlier blimps. Even with aerodynamic lift, the useful lift of the America at sea level is less than 2 tons. Also, its maximum speed is only 50 knots and its range is 585 miles.

Dirigibles

The structural strength of a dirigible is provided by the framework indicated in figure 2. The framework consists of main rings (or frames), intermediate rings, and

TABLE 1

CHARACTERISTICS OF U.S. CURRENT AND 1950s' BLIMPS

Characteristic	ZPG-1	ZPG-2	ZPG-2W	ZPG-3W	America
Delivery dates	1951	1953-57	1955-57	1959-60	1968
Number produced	1	12	5	4	1
Envelope volume (cu.ft.)	875,000	975,000	975,000	1,490,000	202,200
Length (ft.)	324	343	343	403	(175)
Diameter (ft.)	74	75	75	85	(47)
Static lift (lb.)[a]	52,620	61,910	61,910	94,615	11,900
Useful lift (lb.)[a]	(12,470)	23,907	24,616	38,033	3,650
Aerodynamic lift (lb.)[a]	6,000	6,000	6,000	10,500	430
Propulsion (h.p.)	1,600	1,600	1,600	2,550	420
Max speed (kt.)	74	73	70	82	50
Cruise speed (kt.)	40	40	40		
Cruise altitude (ft.)					
Endurance (hr.)[b]	85	59	56[c]	80	13
Range (n.mi.)	3,400	2,360	2,128		585
Maximum altitude (ft.)	10,800	9,500	9,500	9,600	7,500

Source: Boeing 1975, Vol. I, p. 3-5,6 (reference 6), and Goodyear 1975, Vol. III, pp. 25-26, reference 8).

[a] At sea level pressure altitude.

[b] At cruise speed.

[c] At 38 knots.

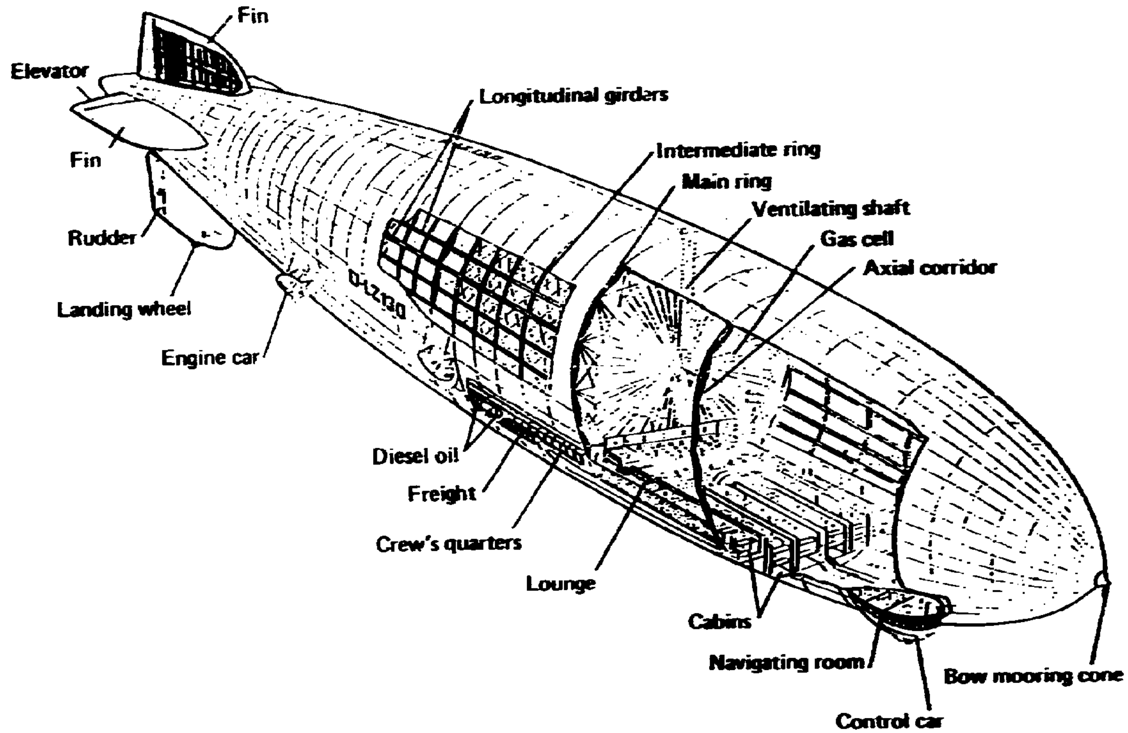


FIG. 2: TYPICAL DIRIGIBLE CONSTRUCTION

longitudinal girders tied together by wires located to take certain loads in tension. The envelope is a nonstructural covering. (In the 1930s it was a doped cotton fabric.)

The volume between main rings has no structural wires; these spaces are occupied by independent gas cells containing the lift gas. The gas cells float upward against a netting installed just inside the envelope. The cells expand or contract as the altitude is changed.

Several cells were used to prevent gas sloshing. (Gas sloshes the same way liquid does with roll and pitch in surface ship water and fuel tanks.) If separate compartment cells were not used in the dirigible, all the lifting gas would have moved to the high end when the dirigible pitched, giving a large pitching moment (lift gas in blimps is held in place by ballonet pressure). The requirement for gas cells also provided a safety factor against catastrophic loss of gas.

Clearance between the netting and the external surface reduced the total cell volume to less than the envelope volume. The cells were partially filled with lifting gas at sea level, expanding as altitude was increased. Large automatic preset poppet valves provided protection against excess pressure differential on the gas cell material when the gas cell was filled.

On a dirigible, the car that protruded from the streamline form of the envelope contained only flight control and operation facilities. The car structure was attached directly to the structural framework. The engine nacelles were separate from the car and were also attached directly to the structural framework. Fuel, payload, accomodations, and ballast were usually located within the envelope, reducing the gas volume relative to envelope volume. Access was provided within the envelope to the various parts of the dirigible, particularly to the engines, by a system of catwalks.

The U.S. Navy used a few dirigibles in the 1920s and 1930s. The U.S. Navy Shenandoah, Los Angeles, and Akron/Macon dirigibles provide relevant data for dirigibles, although the technology is 40 to 50 years old. Characteristics of some dirigibles are shown in table 2. Dirigibles had much larger envelope volumes than blimps. With the blimp envelope materials then available, it was necessary to go to dirigible construction to obtain the increased volumes. The Akron/Macon could carry internally up to five F-9C2 scout airplanes, with a takeoff weight of 2, 770 pounds each.

The propulsion power, maximum speed, cruise speed, and cruise altitude of dirigibles were low compared to airplanes. Endurance hours were large.

TABLE 2

CHARACTERISTICS OF U.S. HISTORICAL DIRIGIBLES

Characteristic	Shenandoah	Los Angeles	Macon	Hindenburg
Delivery date	1923	1924	1931	1936
Number produced	1	1	2	1
Envelope volume (cu.ft.)	2,290,000	2,800,000	7,400,000	7,650.000
Length (ft.)	680	660	785	814
Diameter (ft.)	79	91	133	135
Static lift (lb.)[a]	126,517	153,140	403,465	456,076
Useful lift (lb.)[a]	46,117	63,900	166,972	207,076
Propulsion (h.p.)	1,500	2,000	4,480	4,400
Maximum speed (kt.)	58	65	72	
Cruise speed (kt.)	50	50	50	50
Endurance (hr.)	55	89	159	200
Range (n.mi.)	2,750	4,450	7,950	10,000

Source: Boeing 1975, Vol. I, p. 3-12 (reference 6), and Goodyear 1975, Vol. III, pp. 19,20 (reference 8).

[a] At sea level.

2. CONCEPTUAL COMPARISONS

The conceptual design model of airships includes several classes of characteristics. This chapter introduces the technical and investment cost characteristics. First, typical weight fraction distributions among the components of an airship are considered. Then lift-drag ratio variation, as a measure of propulsion efficiency, is presented. Next, for blimps only, the influence of propulsion type and envelope material type is examined. A description of the sensitivities to several technical specifications follows. Then, the differences between blimps and dirigibles are briefly considered. Finally, a partial comparison of transportation airships with a small and large airplane is presented.

These comparisons show the level and variation of airship characteristics quantitatively and illustrate the kinds of analyses that can be carried out using the conceptual airship model.

WEIGHT DISTRIBUTION

For illustration, the following airship weights are considered: lift gas and air; structure; power plant; fuel; and payload-crew.[1] These weights, for a reference set of blimps with turboprops and 1976 polymer-film envelope, are shown in figure 3. The weights are expressed as a percent of takeoff weight (total weight plus aerodynamic lift) and as a function of sustained speed at design altitude. Figure 3 presents results for three ranges at sustained speed of 50 to 100 knots. Lift gas and air weight for this 1976 blimp comprise 26 percent of total airship weight. Structural weight is about 27 percent of total airship weight for this type of 1976 polymer-film envelope; it decreases as speed and range increase. The power plant weight fraction is 7 to 10 percent. This fraction increases as speed increases.

The sum of lift gas and air weight, structural weight, and power plant weight represents about 60 percent of total airship weight. The remaining 40 percent of airship weight is distributed between fuel and payload-crew (upper part, figure 3). The required fuel weight fraction is substantial, especially for faster speeds and longer ranges. The payload-crew weight fraction decreases rapidly as speed and range increase. At 100 knots and 3,000 miles, the payload-crew weight fraction is less than 2 percent. Thus, a large airship is required even for a small payload. But, at 50 knots and 1,000 miles, the payload-crew weight fraction is 26 percent.

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[1] In terms of the conceptual weight components defined in chapter 6 these groups consist of $W_{63} + W_{64}$; $W_1 + W_3$ + car; W_{62}; and $W_{41} + W_{43} + W_{44} + W_5$, respectively.

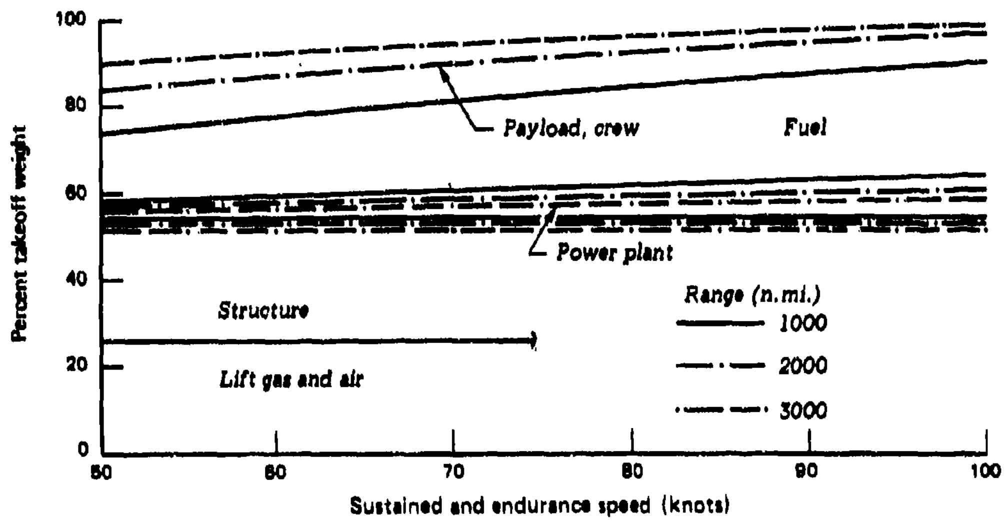

FIG. 3: WEIGHT DISTRIBUTION – 1976 BLIMPS

BUOYANT LIFT-DRAG RATIO

Airplane lift-drag ratio can be designed to remain constant regardless of airplane size and speed. For airships, however, the lift-drag ratio is a function of envelope volume and speed.

An estimate of airship buoyant lift-drag ratio λ_B can be obtained analytically. The sea level buoyant lift L_B is equal to the product of unit lift w_{GL} of the lift gas, the sea level gas volume fraction f_G of the envelope, and the envelope volume ∇_E. The zero lift drag D_0 is equal to half the atmospheric mass density ρ, times the product of the square of flight speed V, hull wetted area A_{WH}, and zero lift drag coefficient C_{D0}. Thus:

$$L_B = wf_G \nabla_E; \quad (1)$$

$$D_0 = 0.5 \rho V^2 A_{WH} C_{D0} \quad (2)$$

Equation (39) in chapter 3 can be used to eliminate the hull wetted area. Further substitutions from equations (43) and (38) of chapter 3 permit writing A_{WH} in terms of the hull length-diameter ratio and ∇_E . Substituting the resulting expression for A_{WH} in equation (2) for D_0 permits writing the buoyant lift-drag ratio L_B/D_0 as:

$$\lambda_B = \frac{L_B}{D_0} = \frac{w_B f_G \, (\nabla_E^{1/3}/V^2)}{(2\pi)^{1/3}(1+0.9/(L/D)^2(L/D)^{1/3}\rho C_{D0}} \quad . \tag{3}$$

For 94 percent purity helium ($w_B = 0.0618$), a sea level gas volume fraction of unity, length-diameter ratio of 5, sea level ($\rho = 0.00238$), zero lift drag coefficient of 0.0038, and converting V to V_K in knots, equation (3) becomes:

$$\lambda_B = 734 \ {}_E^{1/3}/V_K^2 \quad . \tag{4}$$

The buoyant lift-drag ratio increases slowly as envelope volume increases, and decreases sharply as speed increases. Numerical values are shown by the solid lines in figure 4. At 50 knots, λ_B lift-drag ratio is large. At 100 knots, λ_B is below typical airplane lift-drag ratios of around 15. The numerical values shown in the figure are good approximations of more detailed calculations. When flight altitude is increased, f_G must decrease proportional to ρ to permit lift gas expansion so f_G/ρ in equation (9) is constant. For large dirigibles, C_{D0} may be less than 0.0038.

AERODYNAMIC LIFT AND TAKEOFF

In addition to buoyant lift, airships can use aerodynamic lift that is produced by hull angle of attack. The aerodynamic lift L_A is given by an equation of the form of equation (2) for D_0 , with $\nabla_E^{1/3}$ replacing the hull wetted area, and the lift coefficient C_L replacing C_{D0} . The equation for lift drag D_L is of similar form. The lift drag coefficient is approximated as KC_L^2 with K a constant. Then:

$$L_A = 0.5\rho V^2 \nabla_E^{2/3} C_L \quad ; \tag{5}$$

$$D_L = 0.5\rho V^2 \nabla_E^{2/3} K C_L^2 \tag{6}$$

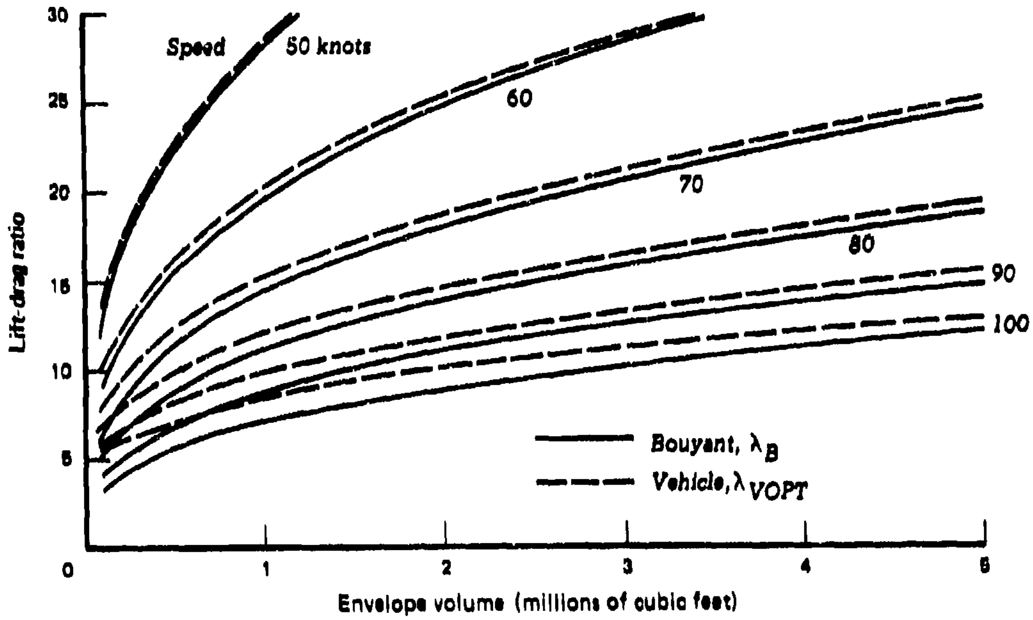

FIG. 4: LIFT-DRAG RATIO VARIATION

With 2 lifts and 2 drags, airships have 4 different lift-drag ratios. They are analyzed in chapter 4 (equations (123) to (143)). The following results and definitions are needed here:

$$\lambda_B = \frac{L_B}{D_0} = \frac{\beta\ \nabla_E^{1/3}}{V^2} \quad ; \tag{7}$$

$$\beta = 734; \quad \omega = L_A/L_B \quad ; \tag{8}$$

$$\lambda_{AA} = L_A/D_L = \gamma/\omega(\nabla_E^{1/3}/V^2) \quad ; \tag{9}$$

$$\gamma = \frac{\rho}{2w_B f_G K} = 0.061 \quad . \tag{10}$$

The buoyant lift is written with a coefficient β defined by the coefficient of $\nabla_E^{1/3}/V^2$ in equation (3). Its value for the illustrative calculations is 734, as in equation (4). The lift ratio ω is the ratio of aerodynamic lift to buoyant lift. The aerodynamic alone lift-drag ratio λ_{AA} is used in the analysis and introduces the coefficient γ. The value of γ for the illustrative calculations with K equal 0.90, is 0.061.

The airship lift-drag ratio analogous to an airplane lift-drag ratio is defined as the vehicle lift-drag ratio λ_V in chapter 4. It is given by:

$$\lambda_V = \frac{L_B+L_A}{D_0+D_L} = \frac{\lambda_B(1+\omega)}{1+(\beta/\gamma)(\nabla_E^{1/3}/V^2)^2\omega^2} \tag{11}$$

This relation is general for buoyant airships and for airships using aerodynamic lift. Inspection of equation (11) shows that it has a maximum as ω increases. The maximum λ_{VMX} and the lift ratio ω_{VOPT} at which it occurs are given by:

$$\lambda_{VMX} = \lambda_B(1 + \omega_{VOPT}/2) \quad ; \tag{12}$$

$$\omega_{VOPT} = (1 + \beta\gamma/\lambda_B^2)^{0.5} \quad . \tag{13}$$

Numerical values of λ_{VMX} are shown by the dashed lines in figure 4. Comparison of the variation of λ_{VMX} and λ_B in the figure shows that aerodynamic lift does not significantly increase the lift-drag ratio. The percentage increase of λ_{VMX} over λ_B is large in the lower left corner (small, fast airships), but the increment is still only as much as 3. These increases do not make the airship lift-drag ratio competitive with airplane lift-drag ratios unless λ_B was already competitive.

In chapter 4, the vehicle optimum angles of attack are shown to be larger than can be achieved with normal landing gear length. Increasing the landing gear length would increase its weight. This can be considered by conceptual model calculations.

Propulsion Plant Weight

Aerodynamic lift does decrease the size and cost of conceptual airships. This results because there is a decrease in weight rather than an increase in lift-drag ratio. This can be illustrated by a crude analytical model. The engine system weight is equal to the product of installed specific weight p pounds per horsepower (including propeller, nacelle, and outrigger) times drag $\mathcal{D}$ and speed V, and divided by 550 (for conversion to horsepower) times the propulsive efficiency η_p. The fuel and system weight is equal to the product of specific fuel consumption σ, $DV/550\eta$, and the flight time which is equal to range R divided by V. The net propulsion plant weight W_{PP} is the sum of engine and fuel weights minus the aerodynamic lift L_A used for carrying fuel:

$$W_{PP} = \frac{pDV}{550\eta} + \frac{\sigma DR}{550\eta} - L_A \tag{14}$$

The drag term, equal to D_0+D_L, can be eliminated by using equation (11). From the definition of ω, the result can be written:

$$\frac{W_{PP}}{L_B} = \frac{pV + \sigma R}{550\eta_p} \left(\frac{1}{\lambda_B} + \frac{\lambda_B \omega^2}{\gamma\beta}\right) - \omega \quad . \tag{15}$$

If ω is 0.1, the propulsion plant weight ratio is decreased if the coefficient of ω^2 is less than 10. The influence on airship size can be illustrated by setting buoyant lift equal to the sum of structural weight (written as a fraction s of L_B) plus W_{PP} and a fixed payload weight W_{PAY}, and then solving for L_B/W_{PAY}:

$$L_B = sL_B + W_{PP} + W_{PAY} \; ; \tag{16}$$

$$\frac{L_B}{W_{PAY}} = \frac{1}{1-s-(W_{PP}/L_B)} \tag{17}$$

For illustration, when units are converted to knots and nautical miles, with p equal 2, σ equal 0.6, η_p equal 0.75, β and γ from equations (8) and (10), and s equal 0.3, the equations become:

$$\frac{W_{PP}}{L_B} = \frac{0.82V_K+0.29R_{NM}}{100} \left(\frac{V_K^2}{734\, \nabla_E^{1/3}} + 16.4\, \frac{\nabla_E^{1/3}\omega^2}{V_E^2}\right) - \omega \; ;$$

$$\frac{L_B}{W_{PAY}} = \frac{1}{0.7+W_{PP}/L_B} \tag{18}$$

The accuracy of these equations is adequate only for illustration. Calculated values L_B/W_{PAY} are shown in figure 5 as a function of lift ratio ω. At 50 knots and 1,000 miles, there is a small reduction of L_B/W_{PAY}. The reduction is insensitive to ω. At 50 knots and 3,000 miles, there is little reduction of L_B/L_{PAY}. The curve turns upward rapidly when ω is greater than 0.15. At 100 knots, a 1,000-mile range, and a moderate volume of 1 million cubic feet, L_B/W_{PAY} decreases markedly as ω increases. This decrease continues to larger values of lift ratio. Aerodynamic lift appears desirable for small, fast airships, that is, for small $\nabla_E^{1/3}/V_K^2$.

Optimum Aerodynamic Lift

A minimum length landing gear must be used to provide ground clearance for the envelope or blimp car, and for blimp propellers. The elevation provided by a minimum length landing gear makes possible a small takeoff angle of attack. Larger takeoff angles of attack require longer landing gear. The conceptual model can calculate the necessary landing gear length and weight.

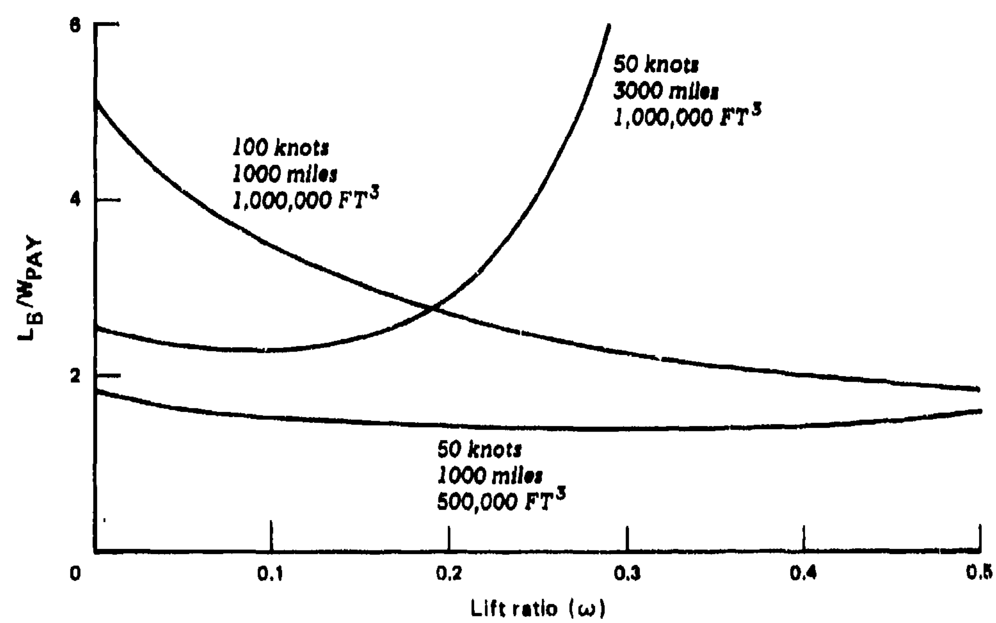

FIG. 5: INFLUENCE OF LIFT RATIO ON SIZE

The influence of takeoff angle of attack is illustrated for the reference set of blimps. They have an X-form tail configuration, retractable landing gear, moderately large propeller diameters, a takeoff angle of attack margin of 3 degrees, and a takeoff speed equal to 60 percent of sustained speed. The ratio of envelope volume to the zero aerodynamic lift envelope volume with no landing gear is shown in figure 6 as a function of the takeoff angle of attack. If landing gear is provided but aerodynamic lift is not used, the envelope volume increases by 5 to 10 percent. Increasing the takeoff angle of attack decreases the envelope volume ratio. At 50 knots the decrease is small, as expected. When range is increased the decrease is even smaller, also as expected.

The transition points at which the landing gear length must be increased are indicated by solid circles in the figure. These points are near the minimums in the envelope volume ratio curves. The minimums occur near a takeoff angle of attack of 7 degrees for the illustrations.

At 100 knots there are much greater decreases of the envelope volume ratio. The decrease of envelope volume at the transition point is as much as 50 percent for the case of a 1,000-mile range. At this point the envelope volume is 430,000 cubic feet, the aerodynamic lift is equal to 36 percent of the static lift, and the overall lift-drag ratio is 7.0.

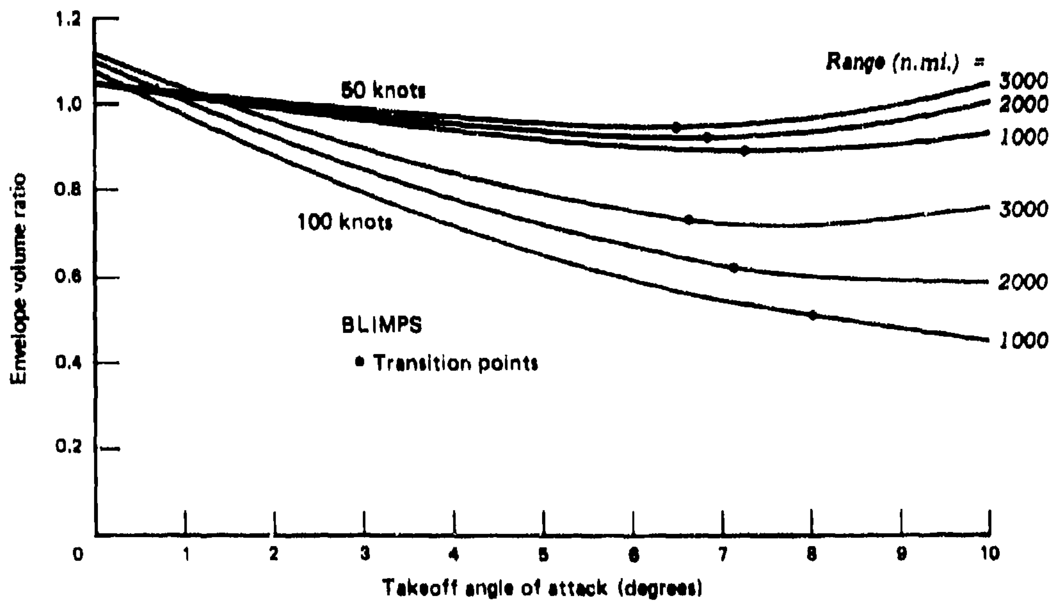

FIG. 6: AERODYNAMIC LIFT EFFECT ON ENVELOPE VOLUME

The ratio of investment cost for these blimps to the investment cost when aerodynamic lift is not used is shown in figure 7. At 50 knots, the cost increases about 10 percent when landing gear is added. It decreases to a minimum close to unity. At a 50-knot speed, use of aerodynamic lift does not reduce the investment cost.

At 100 knots, however, the cost ratio decreases more rapidly. The decrease of investment cost is as much as 39 percent for the case of a 1,000-mile range. The cost decrease is less than the envelope volume decrease because the empty weight fraction of total displacement weight (which is proportional to envelope volume) increases as aerodynamic lift is increased. The aerodynamic lift is used to carry fuel that has zero investment cost, so the empty weight contributing to investment cost becomes a larger fraction of total weight.

The ratio of fuel weight with landing gear to fuel weight without landing gear is shown in figure 8. For a speed of 50 knots, the ratio varies only about 3 percent from unity. However, at 100 knots the fuel weight ratio decreases significantly. At the transition point for the 1,000-mile range case the fuel weight is decreased by 29 percent. Thus, both investment cost and fuel operating cost can be lowered significantly at 100 knots and small ranges.

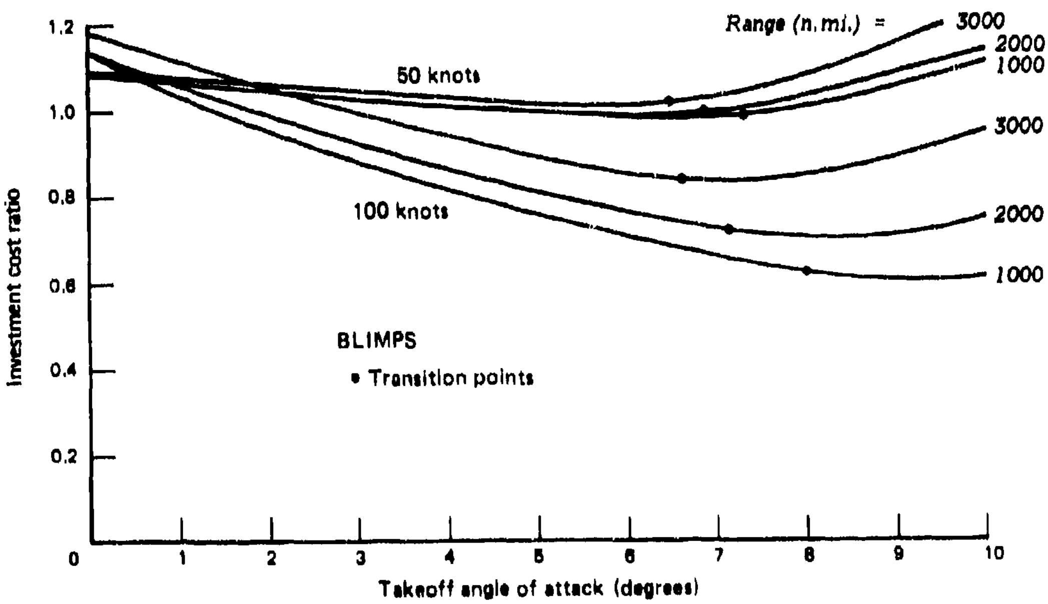

FIG. 7: AERODYNAMIC LIFT EFFECT ON INVESTMENT COST

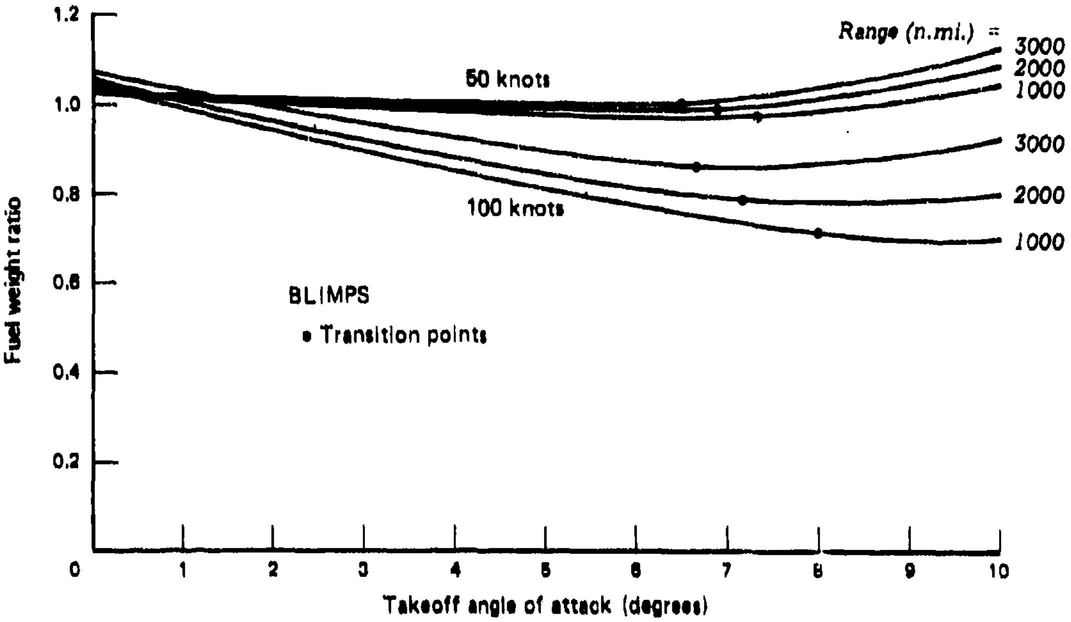

FIG. 8: AERODYNAMIC LIFT EFFECT ON FUEL WEIGHT

All other calculations for blimps presented in this chapter used aerodynamic lift with a takeoff angle of attack at the transition point; thus, the landing gear did not need to be lengthened for takeoff.

Takeoff Distance

When aerodynamic lift is used, the takeoff and landing distances influence both airship operations and the base facilities needed. For conceptual airships these distances may vary significantly. Therefore, an analysis estimating the takeoff ground run x_G is included in chapter 5 on power, engines, and fuel. The ratio x_G/L of ground run to airship length is principally a function of the ratio V_{TO}/V_S of takeoff speed to sustained speed at maximum continuous power. By ignoring the influence of aerodynamic lift, the variation of x_G/L shown in figure 9 is obtained.

The ground run distance ratio increases rapidly. Because airship lengths are relatively large,, even moderate ground run distance ratios can lead to a fairly long ground run requirement. The line in figure 9 represents takeoff angles of attack of 0 to 12 degrees. There is little difference for speed ratios less than about 0.50. For greater speed ratios, the aerodynamic lift influence becomes important; therefore, the line is dashed. The illustration is for a firm-sod field with short grass, using sustained power

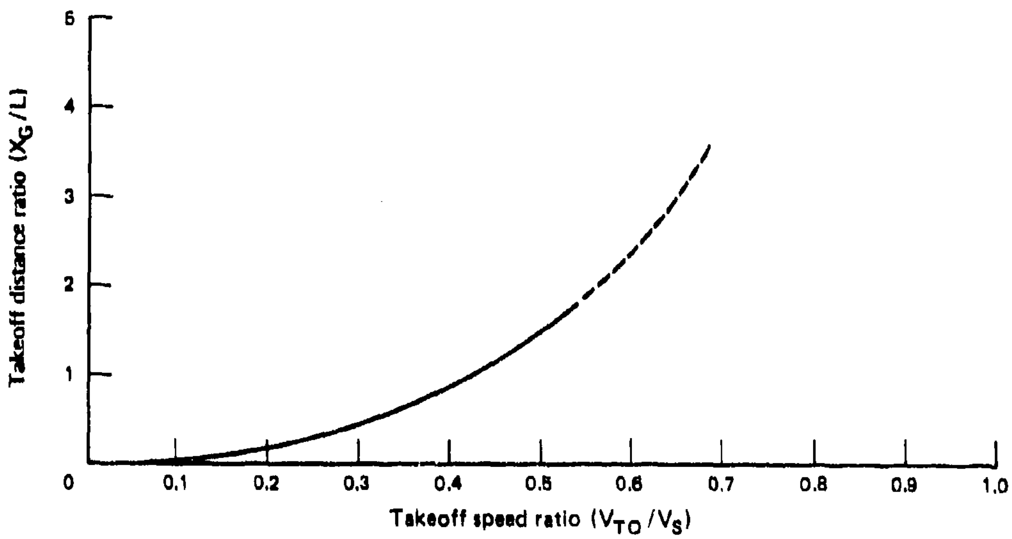

FIG. 9: TAKEOFF DISTANCE VARIATION

equal to 80 percent of takeoff power. Field type changes the ground run distance very little. However, changing the takeoff power ratio to sustained power changes the ground run distance significantly. At moderate speed ratios, the ground run distance is about proportional to the sustained-to-takeoff power ratio.

Takeoff distance to an altitude of 50 feet is considerably greater than the takeoff ground run. It appears to be about 2.5 times the ground run distance.

INFLUENCE OF ENGINE TYPE AND ENVELOPE MATERIAL

This section considers the influence of engine type and envelope material on airship volume and investment cost. The variation of envelope volume and investment cost for the reference set of blimps considered previously is shown in figures 10 and 11. This set has a small payload, turboprop engines, and a 1976 polymer-film envelope material (the triaxial Kevlar film material discussed in chapter 6). This material has not yet been used in airship construction; therefore there is a risk of uncertainty using it in conceptual designs. However, the material has been used in constructing balloons, so it is not a completely untried material.

Figure 10 shows that the envelope volume increases as speed and range increase. At the 1,000-mile range, the volume nearly triples as speed increases from 50 to 100 knots. For a speed of 50 knots, the envelope volume approximately doubles when the range increases from 1,000 to 3,000 miles. At 100 knots, envelope volume more than doubles when the range increases from 1,000 to 2,000 miles.

The conceptual basic construction cost C_{B20} for a production quantity of 20 blimps of this set is shown in figure 11. Previously in this chapter it has been called the investment cost. The basic construction cost includes all contractor costs, but does not include any payload, payload installation, development, engineering or prototype costs. Production runs of more than a few units are usually associated with a reduction in unit costs (the "learning" effect). This influence is included in the construction cost estimates. The costs are given in FY 1976 dollars. The cost analysis on which these conceptual cost estimates are based is presented in chapter 7.

The cost estimation equations are not sufficiently detailed to provide adequate accuracy for some variations. Only overall cost data were obtained; therefore, the cost estimation equations do not differentiate between the cost per pound for turboprop versus reciprocating engines, between polymer-film versus neoprene-Dacron envelope material, nor between highly machined landing gear versus simply assembled car structure. Cost variation comparisons should be judged considering the use of an overall cost per pound estimate.

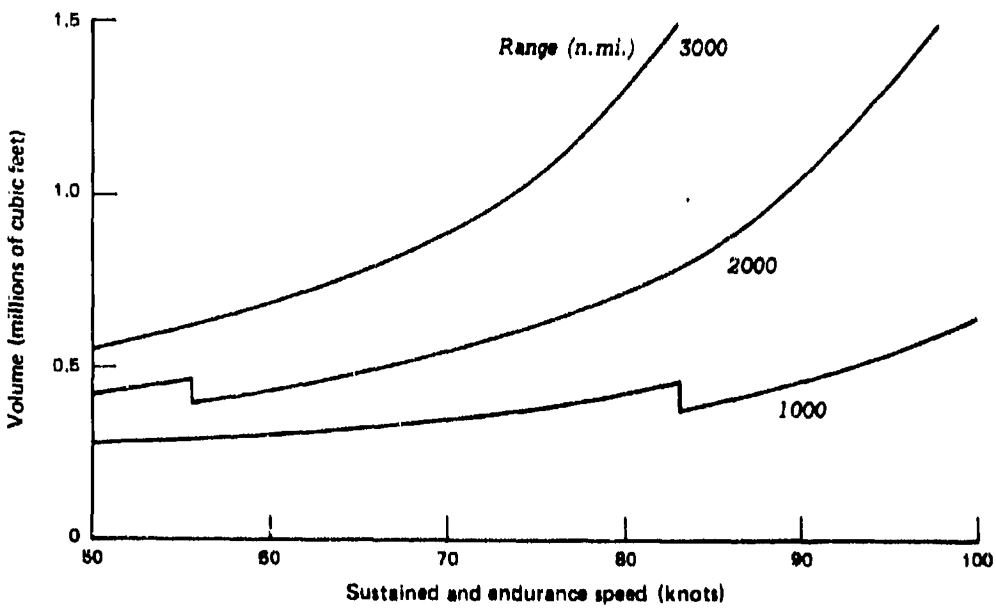

FIG. 10: VOLUMES FOR TURBOPROP/POLYMER BLIMPS

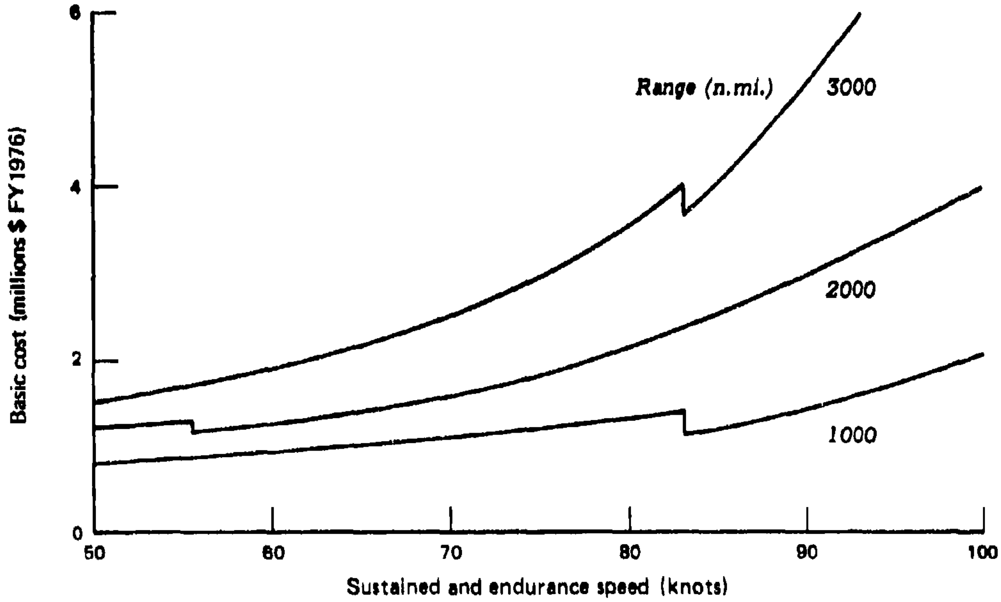

FIG. 11: COST FOR TURBOPROP/POLYMER BLIMPS

The basic cost curves in figure 11 have the same general form as the envelope volume curves in figure 10.

Envelope volume and cost ratios (relative to the turboprop blimps) for a second set of blimps are shown in figures 12 and 13. This set differs from the reference set in that horizontal-opposed reciprocating engines were specified instead of turboprop engines. Generally, blimps with reciprocating engines required smaller volumes than the same case with turboprops. This result occurs because the estimated specific fuel consumption is lower for the reciprocating engines, even though the estimated engine weight per horsepower is larger. The decreases of envelope volume are greatest for low speed and long range cases.

The cost ratios, shown in figure 13, are larger than the envelope volume ratios. This is caused by an increase of the empty weight as a fraction of buoyant weight; the heavier reciprocating engines (in pounds per horsepower) contribute to the empty weight, and the reduced fuel weight decreases the envelope volume and buoyant weight. Thus, the fraction of buoyant weight that leads to investment cost is increased relative to the turboprop set of blimps, giving an increase of the cost ratio relative to the envelope volume ratio. Even though the volume ratio is less than unity for blimps with reciprocating engines and a range of 1,000 miles, the cost ratio is equal to or greater than unity. A significant cost reduction is found only for the blimps with ranges of 2,000 and 3,000 miles and speeds up to 90 knots.

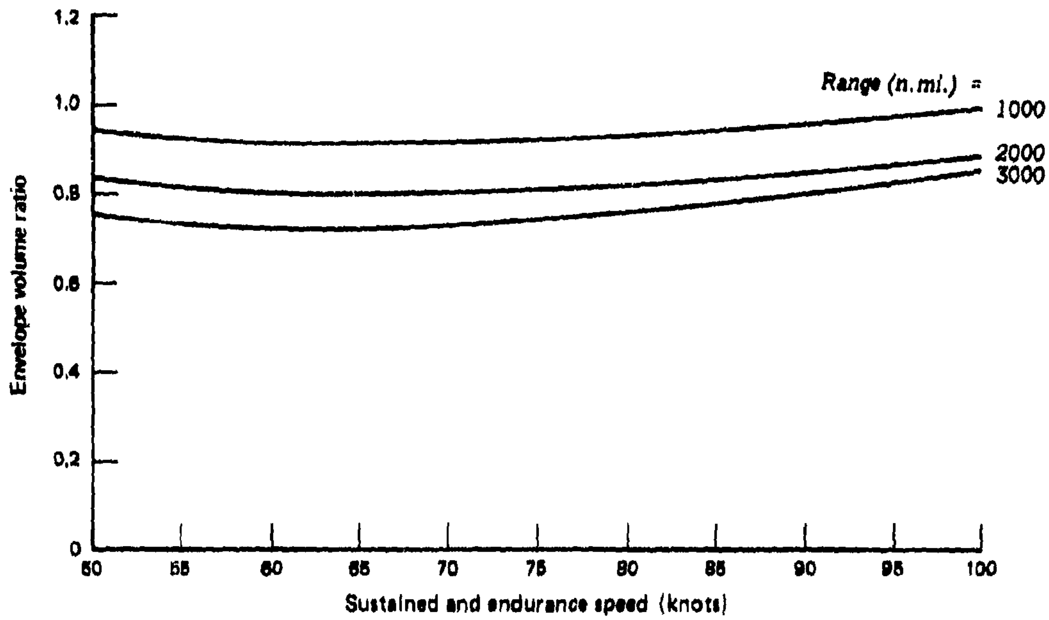

FIG. 12: VOLUME RATIO FOR RECIPROCATING/POLYMER BLIMPS

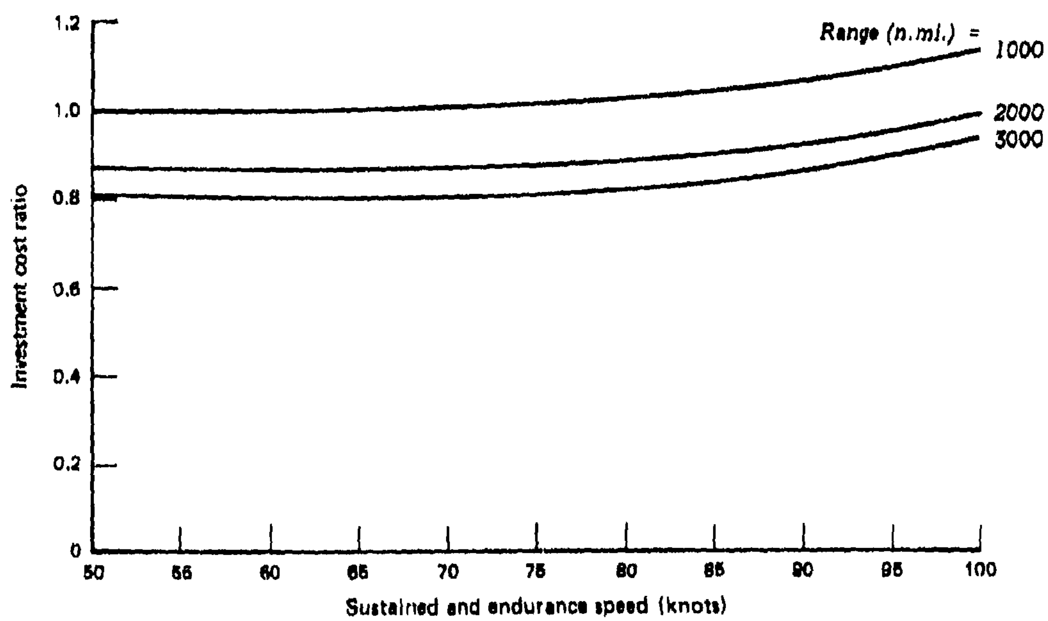

FIG. 13: COST RATIO FOR RECIPROCATING/POLYMER BLIMPS

In chapter 5 it is shown that 1976 reciprocating engines are principally horizontal-opposed configurations up to about 450 horsepower. In contrast, turboprop engines are available in ratings from about 400 to 4,000 horsepower. Turboprop engines are not available for the 50- and 60-knot turboprop blimps of figures 10 and 11; reciprocating engines are not available for the 80-, 90-, and 100-knot blimps. At 70 knots, both types of engines are available. When engine sizes are not available, development costs would be required to provide the desired engine.

The principal alternative to using 1976 polymer-film envelope material is 2-ply neoprene-Dacron which was originally developed in the 1940s. Since then its strength and durability has been improved. Goodyear uses neoprene-Dacron in their advertising blimps. However, neoprene-Dacron material still has a greater weight for given strength then the 1976 polymer-film materials. The ratios of envelope volume and investment cost for blimps using neoprene-Dacron envelope material (relative to the reference set) are shown in figures 14 and 15. This set is 25 to 50 percent larger and costs 50 to 80 percent more than the reference set constructed with polymer-film materials.

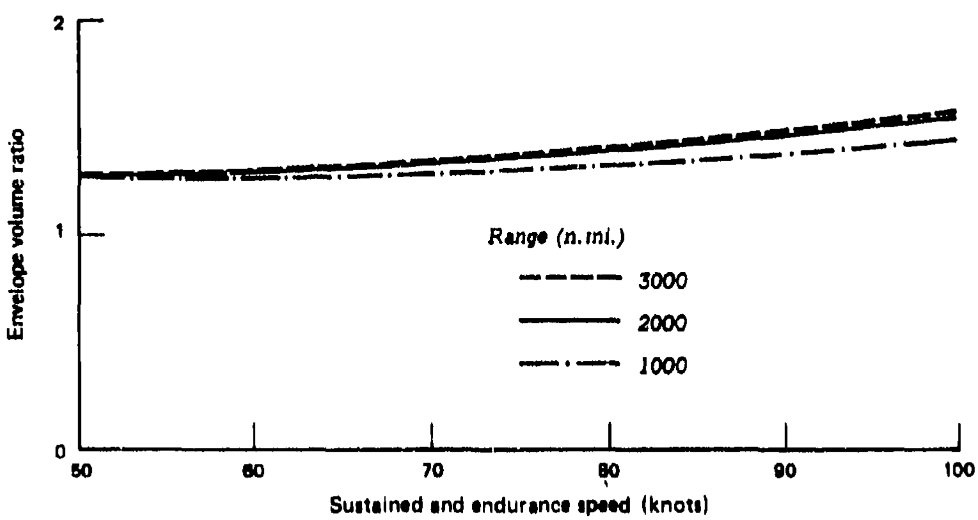

FIG. 14: VOLUME RATIO FOR TURBOPROP/NEOPRENE BLIMPS

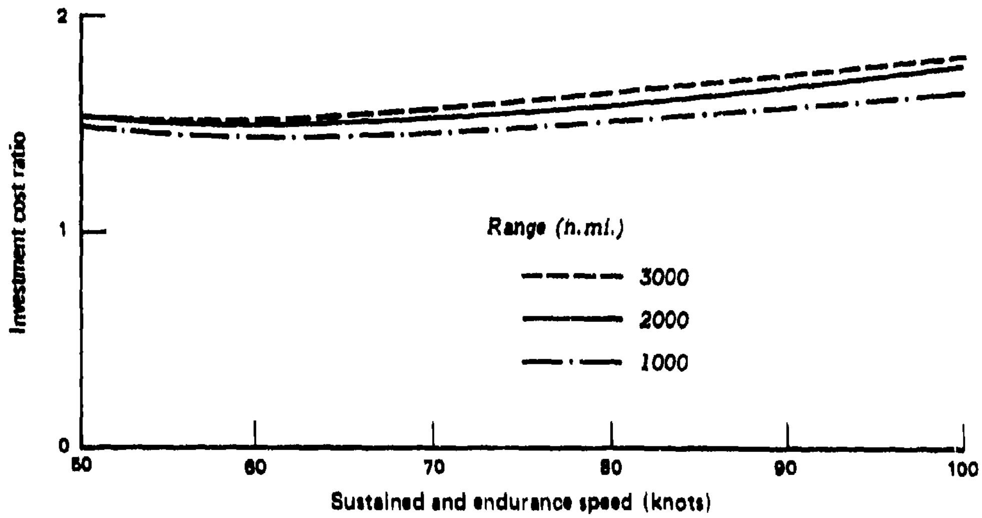

FIG. 15: COST RATIO FOR TURBOPROP/NEOPRENE BLIMPS

INFLUENCE OF OTHER SPECIFICATIONS

This section briefly outlines the influence of other specifications on envelope volume and investment cost. Payload weight, number of passengers, and off-design conditions are considered. Other, less important, specifications include altitude and length-diameter ratio.

The variation of blimps' envelope volume with payload weight is shown in figure 16 for 3 combinations of endurance speed and range. This set uses turboprop engines and 1976 polymer-film envelope material. The envelope volume increases linearly with payload weight; the intercept depends on the speed and range. Increasing the speed from 50 to 100 knots at a 1,000-mile range increases the volume by about 150 percent. At the larger payloads, increasing the range from 1,000 to 2,000 miles at a speed of 100 knots increases the volume by about 50 percent. The basic construction cost for a production quantity of 20 (figure 17) varies in the same way, but the cost increase when the speed is increased from 50 to 100 knots at a 1,000-mile range is only about 50 percent.

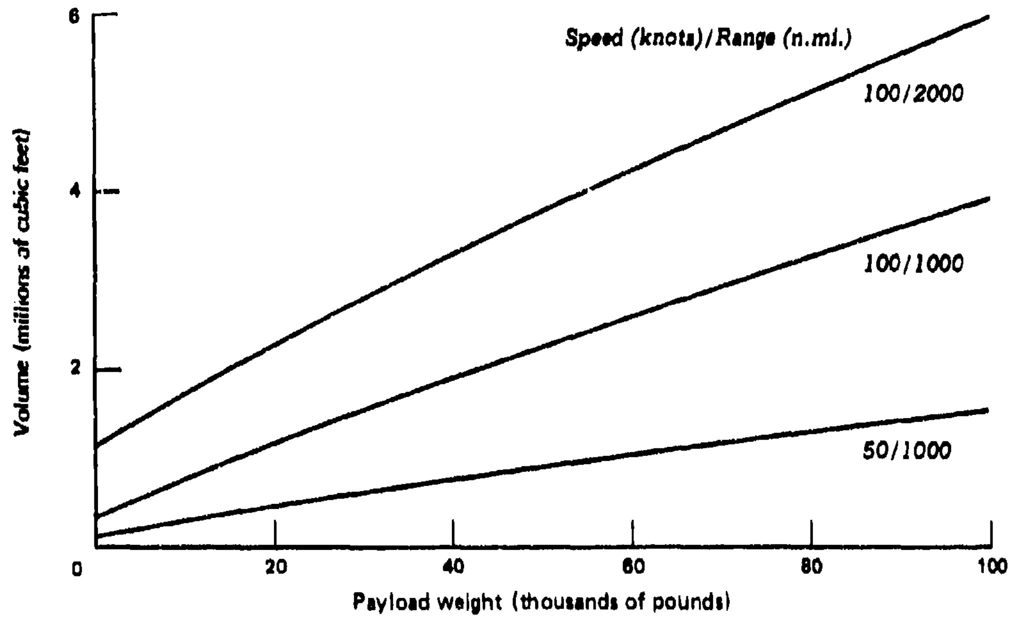

FIG. 16: VOLUME vs. PAYLOAD WEIGHT

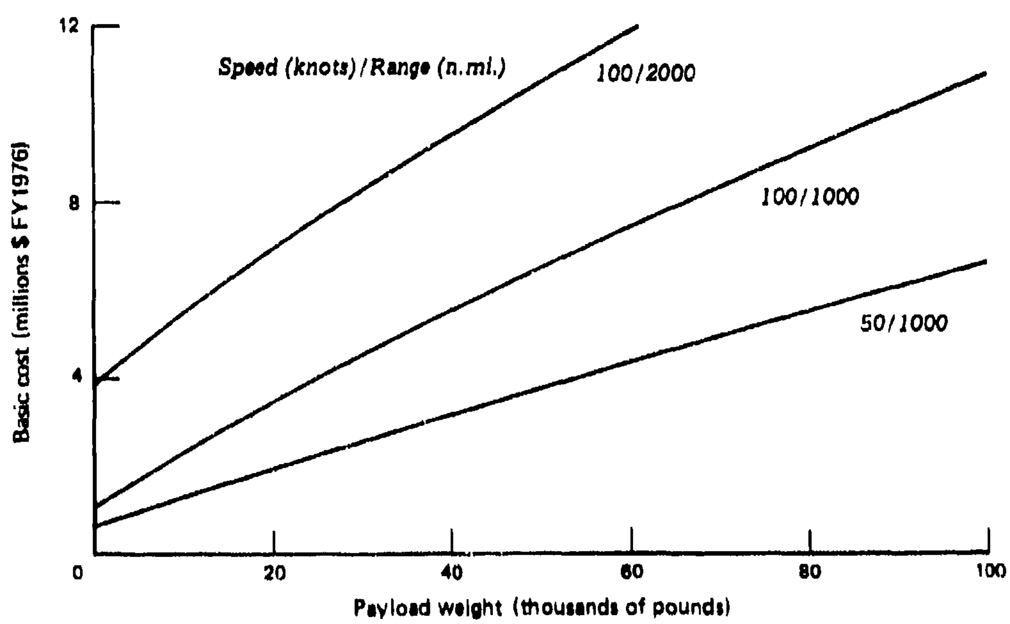

FIG. 17: COST vs. PAYLOAD WEIGHT

The change in the envelope volume that occurs as the number of passengers changes is illustrated in figure 18 for blimps with turboprop engines, 1976 polymer-film envelope material, and a fixed flight crew of eight. The increase of envelope volume is approximately linear. However, little increase is indicated when the speed is increased from 50 to 100 knots at a range of 1,000 miles. This occurs because the model provides accommodations that add to the weight and cost. The longer the flight the greater the increase in weight and cost. For 1,000 miles at 50 knots the flight duration is 20 hours. A flight of this duration requires extensive accommodations. For 1,000 miles at 100 knots the flight is only 10 hours. The weight and cost decrease because fewer accommodations are needed.

The variation of the construction cost as the number of passengers is shown in figure 19. The accommodations influence is even stronger for the basic cost because for the 100-knot, 1,000-mile case, the fuel weight is larger; thus, the empty weight on which costs are based is smaller.

Early airships had sustained speeds of about 80 knots, but they normally operated at lower operating speeds in order to increase operating range and flight duration. The conceptual design model can take into account such specifications. The model also calculates the operating range and flight duration for specified operating speed and altitude.

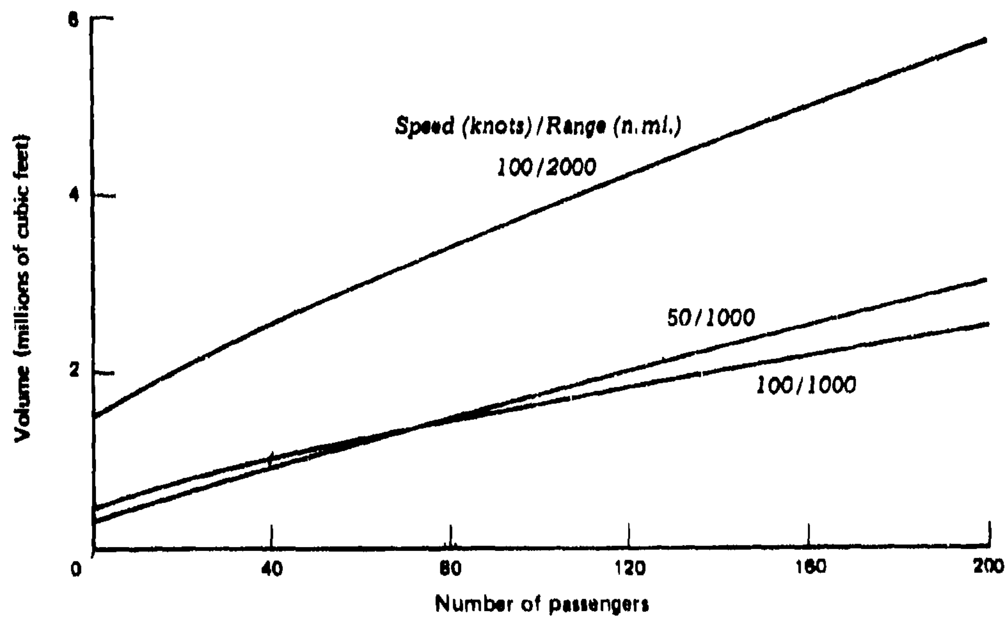

FIG. 18: VOLUME vs. NUMBER OF PASSENGERS

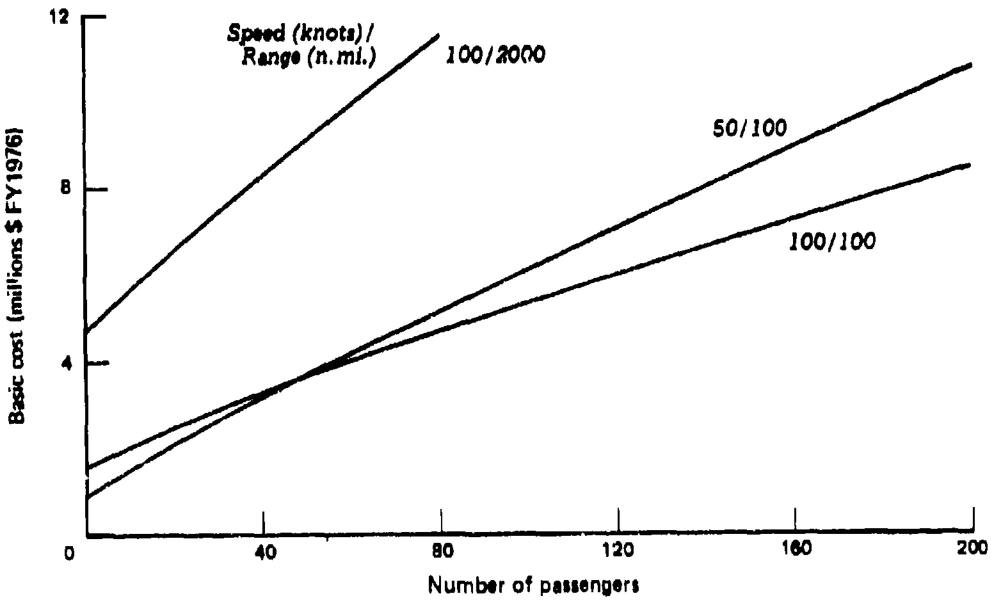

FIG. 19: COST vs. NUMBER OF PASSENGERS

Such results are shown in figures 20 and 21 for two cases at the design cruise altitude of 2,000 feet. For the 50-knot, 1,000-mile blimp a slight increase in range can be achieved if operating speed is reduced to about 35 knots. The peak occurs because the specific fuel consumption increases as the engine power decreases. This balances the reduction of required propulsion power with the decreasing speed.

Figure 20 also shows that the operating range of the 100-knot blimp with an endurance range of 1,000 miles is increased by a factor of about 3 at an operating speed of 40 knots. The illustrations assume that the amount of fuel needed to generate electric power for accommodations and payload is small compared to the amount needed for propulsion. Otherwise, the increases would be somewhat less than shown.

A unique characteristic of airships is their ability to provide very large operating flight durations at low speeds. The variations of flight duration that correspond to the cases in figure 20 are shown in figure 21. For the 50-knot, 1,000-mile blimp a duration of about 36 hours (vice 20) is obtained at operating speeds of about 30 knots. For the 100-knot, 1,000-mile blimp the flight duration is about 90 hours at 30 knots -- nine times its design duration of 10 hours at 100 knots.

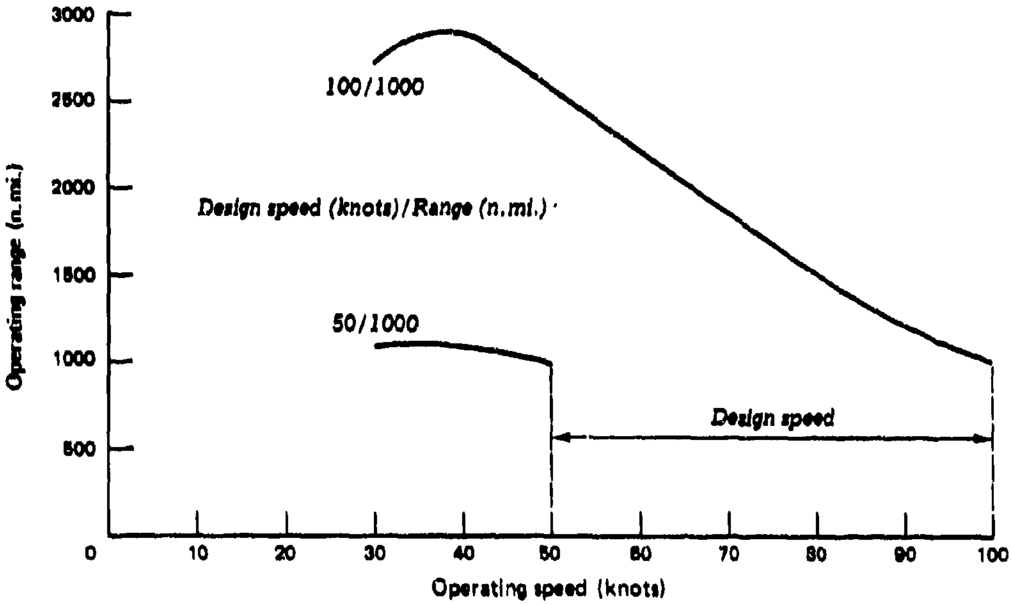

FIG. 20: OPERATING RANGE vs. OPERATING SPEED

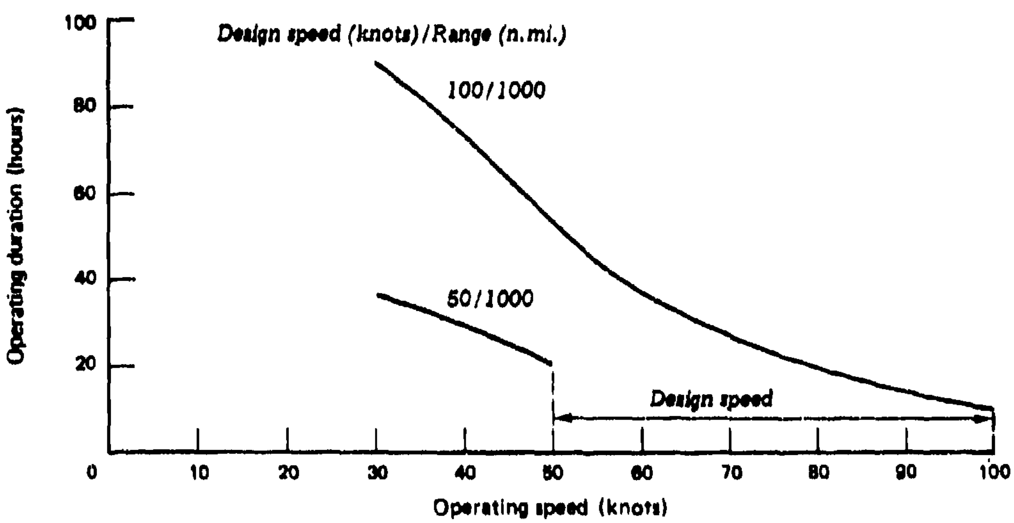

FIG. 21: OPERATING DURATION vs. OPERATING SPEED

These estimated operating flight durations do not include requirements for additional accommodations, facilities, food, and potable water; consideration of these factors would reduce the estimates somewhat.

The variation of the ratio of envelope volume to the volume for a sea level design cruise altitude is shown in figure 22 as a function of design cruise altitude for three speed and range combinations. The ratio of the basic construction cost to the cost for a sea level design for the same cases is shown in figure 23. Blimps with a design cruise altitude of 10,000 feet are approximately 80 percent larger and cost about 50 percent more then similar blimps designed to cruise at sea level.

The influence of envelope length-diameter ratio is illustrated in figure 24 in terms of the ratio of envelope volume to the envelope volume with a length-diameter ratio of 5. The minimum envelope volume ratio occurs in the vicinity of length-diameter ratio equal to 5. The variation is very flat for length-diameter ratios from about 4.5 to 6. When basic cost is compared to basic construction cost the optimum length-diameter ratio is also 5 (figure 25).

BLIMPS, DIRIGIBLES, AND AIRPLANES

At the beginning of this chapter it was illustrated that larger airships have larger lift-drag ratios. However, in the 1930s the maximum strength of the available cotton-rubber envelope material limited blimp envelope volume to about 0.5 million cubic feet. Rigid-structure materials for dirigibles are not subject to a maximum strength limit. The large airships built in the 1930s had to be dirigibles. Development of blimp envelope materials after the 1930s provided an increasing maximum strength and lower weight for given strength. By 1960 blimp envelope volume had evolved to 1.5 million cubic feet. 1976 polymer-film envelope materials provide even greater maximum strength than other materials and still lower weight for a given strength. However, seaming technology for joining sections of these envelope materials limits blimp sizes to about 6 million cubic feet. If larger airships were required it would be necessary to consider dirigibles alone.

Thus, the structural materials used are crucial when comparing blimps and dirigibles. However, an illustration is desirable so buoyant dirigibles are compared with the reference set of blimps. The dirigibles have turboprop engines and potential 1976 rigid-structure materials. Water recovery condensers were not included in the dirigible calculations. Figures 26 and 27 show the comparison of 1976 blimps with dirigibles.

The ratio of dirigible envelope volume to blimp volume for the set of speeds and ranges is shown in figure 26. At a 50-knot speed the envelope volume ratio is close to unity for the cases compared. At 100 knots, there is a considerable difference between the dirigibles and blimps. For a 1,000-mile range the envelope volume of the dirigible is 60 percent greater than that of the blimp. For a 3,000-mile range the volume ratio is close to unit

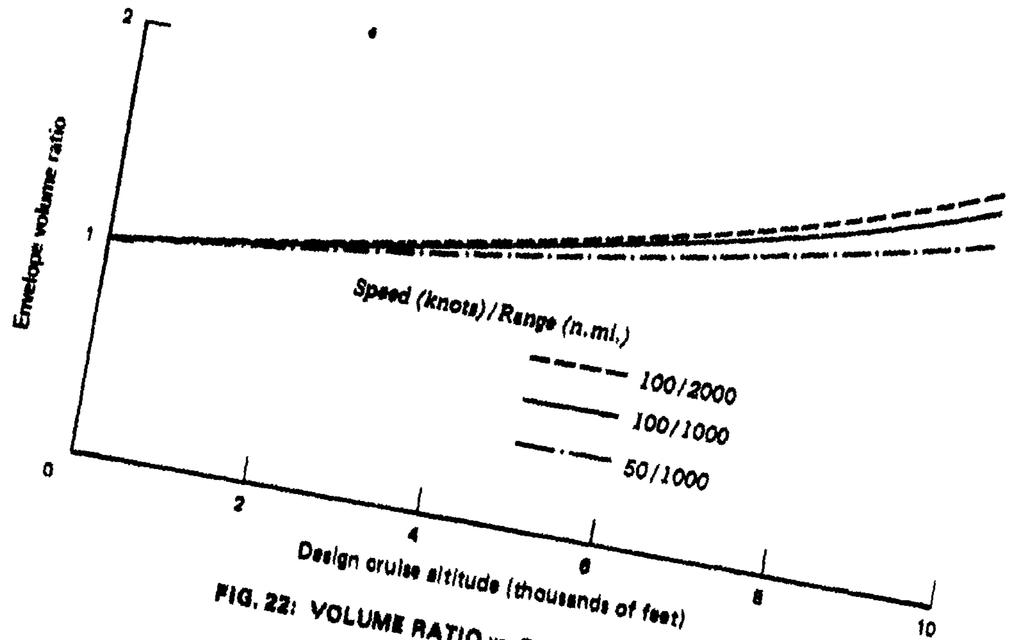

FIG. 22: VOLUME RATIO vs. CRUISE ALTITUDE

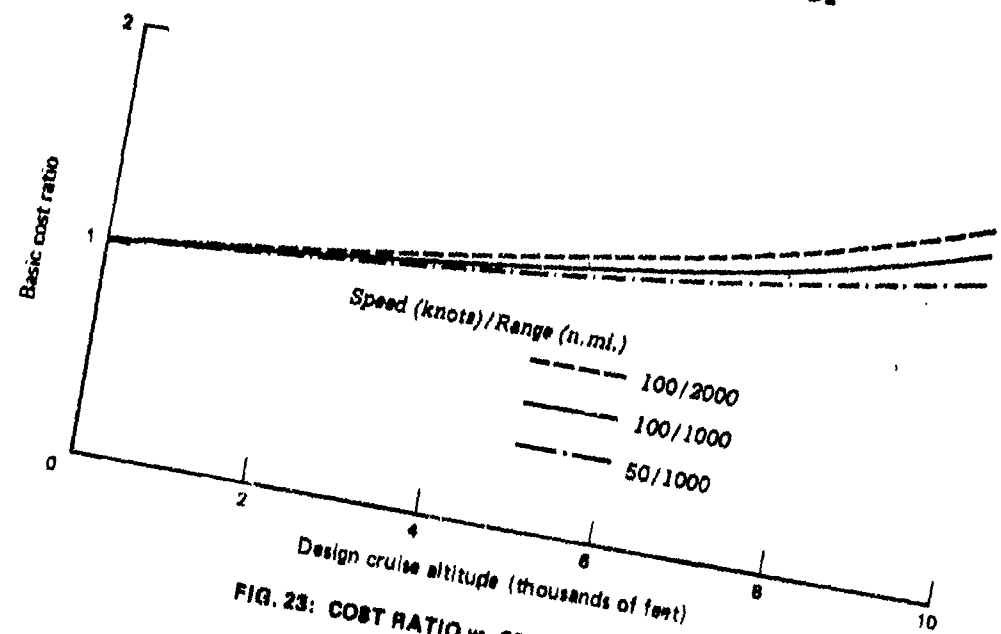

FIG. 23: COST RATIO vs. CRUISE ALTITUDE

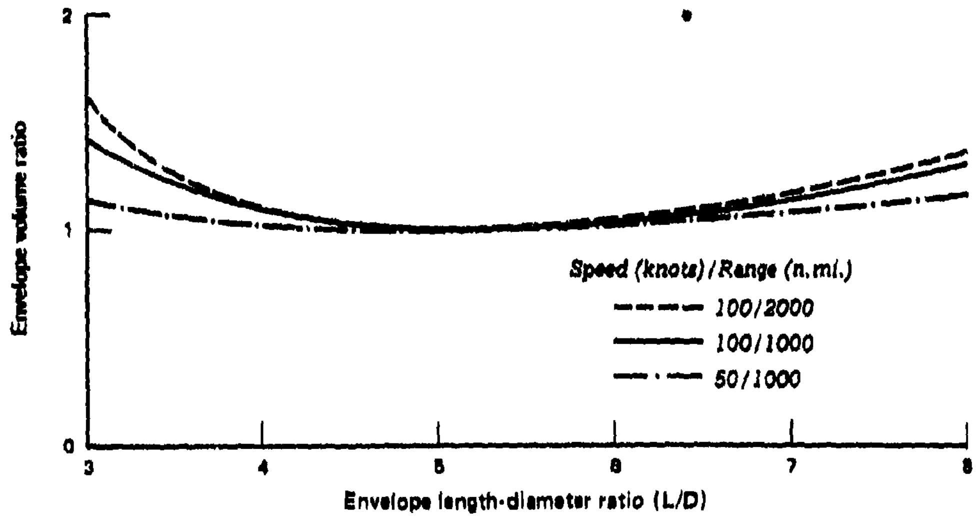

FIG. 24: VOLUME vs. LENGTH-DIAMETER RATIO

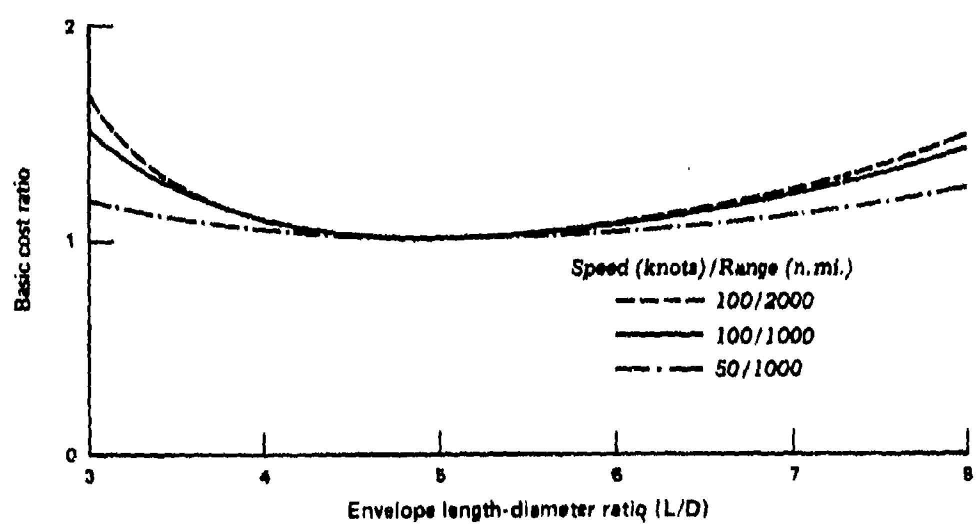

FIG. 25: ENVELOPE LENGTH-DIAMETER RATIO (L/D)

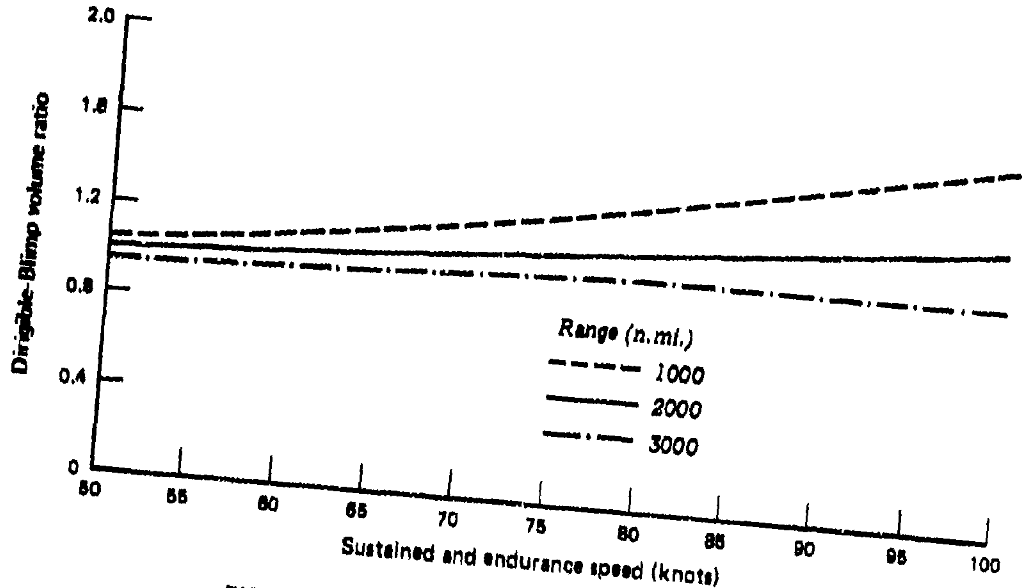

FIG. 26: VOLUME – 1976 BLIMPS AND DIRIGIBLES

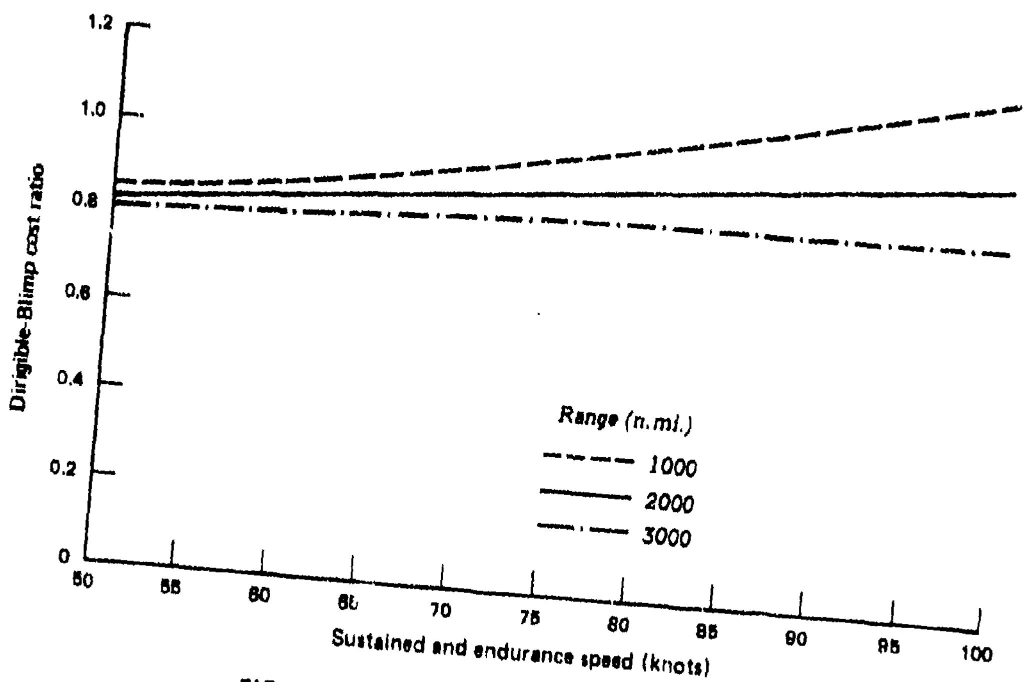

FIG. 27: COST – 1976 BLIMPS AND DIRIGIBLES

for all speeds. The envelope volumes of the blimps and dirigibles in this comparison varied from 260,000 cubic feet to 3,500,000 cubic feet.

When both dirigibles and blimps travel at 50 knots the ratio of dirigible basic cost to blimp basic cost (figure 27) is almost 85 percent. The ratio stays near 85 percent when the range is 3,000 miles and the speed is increased to 100 knots. At smaller ranges the cost ratio increases as the speed increases.

Blimps and dirigibles using 1976 materials could be competitive on the basis of envelope volume and basic construction cost. Thus, selecting between them could be based on other criteria. Evaluating other criteria is beyond the scope of this investigation.

The characteristics of airships are relevant only when compared with the characteristics of alternative vehicles. In the 1930s, German airships provided transatlantic transportation direct from Germany to the United States and South America. As many as 16 round trips, in spring and summer, were made. At that time airplanes could not provide the necessary range for these routes. The Hindenburg airship traveled the United States route at about 60 knots. This was two to three times the speed of the only alternative transportation vehicles, i.e., surface ships.

The range and speed capability of airplanes evolved rapidly after the 1930s. Since then, transportation costs have decreased (in constant dollars) and demand has increased rapidly. In 1976 extensive national and international airplane airline systems exist.

On a transportation basis, airship vehicles should be compared with passenger airplanes. A comparison of investment cost is presented based on the data for 1976 airplanes and conceptual airship calculations. Several companies produce business airplanes. They are purchased for their ability to deliver people and goods much more quickly than automobiles at 55 miles per hour; fuel consumption is also considered. A turboprop "business airplane" approximating the Beech Aircraft Corporation's Super KingAir was used for the first comparison. Its charcteristics, on the basis of Jane's Aircraft, 1974-5, are shown in table 3.

For comparison, a blimp airship was selected. Its characteristics are also shown in table 3, and variations are described below. The blimp speed is 100 knots and its cruise altitude is 4,000 feet. It has the same range, crew, and passenger capability as the business airplane. (The business airplane passengers vary from 6 for luxury accommodations to 13 for commuter accommodations.)

TABLE 3

AIRPLANE AND AIRSHIP COMPARISON

	Business aircraft		Airline aircraft	
	Airplane	Blimp	Airplane	Dirigible
Speed (kt.)	270	100	520	100
Range (n.mi.)	1,000	1,000	5,000	5,000
Altitude (ft.)	16,000	4,000	30,000	4,000
Crew	2	2	3	3
Passengers	6-13	10	374	374
Takeoff weight (lb.)	12,500	32,300	710,000	1,870,000
Volume (cu.ft.)	-	317,000	-	24,400,000
Length (ft.)	44	249	231	1,061
Wing span (ft.)[a]	54	50	196	212
Power (h.p.)	1,700	1,960	180,000[b]	22.660
Fuel weight (lb.)	3,628	10,200	315,691	514,000
Empty weight (lb.)	7,315	12,000	354,000	625,000
Gound run (ft.)	1,855		-	0
Takeoff (50')(ft.)	2,580		9,450	-
Cost (thous. of 1976 $)	1,000[c]	770[d]	30,000[e]	41,000[d]

[a]Hull diameter for airships.

[b]Rated thrust is 180,000 pounds.

[c]Equipped, around $1 million (Business Week, June 28, 1976, p.114).

[d]Basic construction cost, production quantity of 200.

[e]Business Week, October 11, 1976 .

The blimp takeoff weight is more than twice the airplane takeoff weight. It is about six times longer than the airplane. The blimp's diameter is about equal to the wing span of the airplane. The blimp requires more engine power than the airplane. Thus, the greater power over a longer flight time for identical ranges causes the blimp to require about three times as much fuel. The ground run distance and takeoff distance (over 50 feet obstacles) are much shorter for the blimp than for the airplane.

A cost estimate for the business airplane with equipment is shown in table 3. The estimated basic construction cost for the blimp (without equipment) for a production quantity of 200 is 23 percent less than the airplane cost.

The business blimps had turboprop engines, 1976 polymer-film envelope materials, X-form tail configuration, and aerodynamic lift with takeoff speed equal to 60 percent of endurance speed. Sustained speed was equal to endurance speed. No provision was made for ballasting procedures for operations over land, where business blimps would be used. The variation of fuel weight with speed is shown in figure 28. At speeds above 60 knots, the blimp uses more fuel than the business airplane. Figure 29 shows how the basic cost changes according to production quantity. Cost decreases rapidly with production to a quantity of 100, and decreases slowly thereafter. In order to compare blimps with airplanes a 100-knot speed was selected.

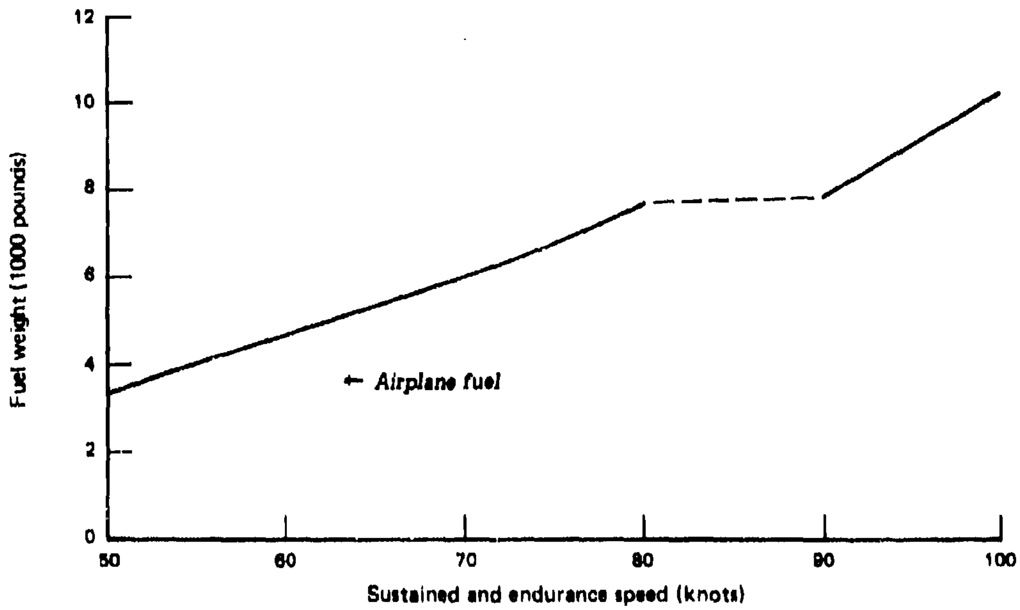

FIG. 28: BUSINESS BLIMP FUEL WEIGHT

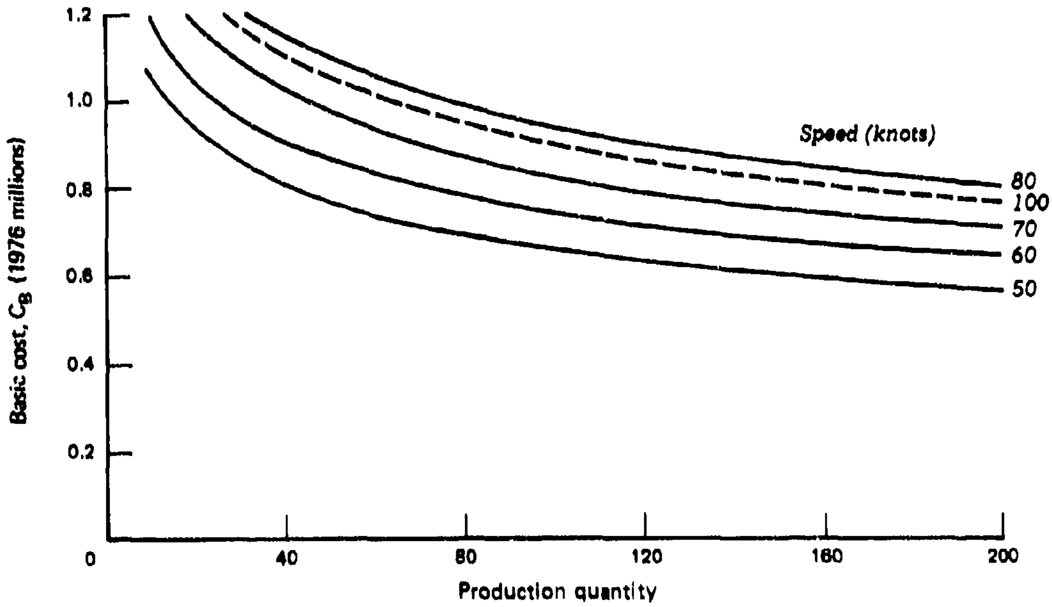

FIG. 29: BUSINESS BLIMP BASIC COST

A large "airline airplane" approximating the Boeing 747 was used for the second comparison. Its characteristics are outlined in table 3. A conceptual airline dirigible was selected for comparison, and its characteristics are shown in table 3. The comparison is similar to that for the business blimp: dirigible diameter is greater than the airplane dimensions; dirigible fuel is 50 percent greater than that of the airplane; and dirigible empty weight is 73 percent greater than that of the airplane.

The variation of fuel weight for the airline dirigible is shown in figure 30. The dirigible fuel at 50 knots is one-third that of the airplane but exceeds the airplane fuel for speeds greater than about 80 knots. The variation of the dirigible basic cost is shown in figure 31.

Operating costs and airfield costs must also be considered in a complete comparison of airplane and airship passenger transportation. This is not in the scope of this investigation.

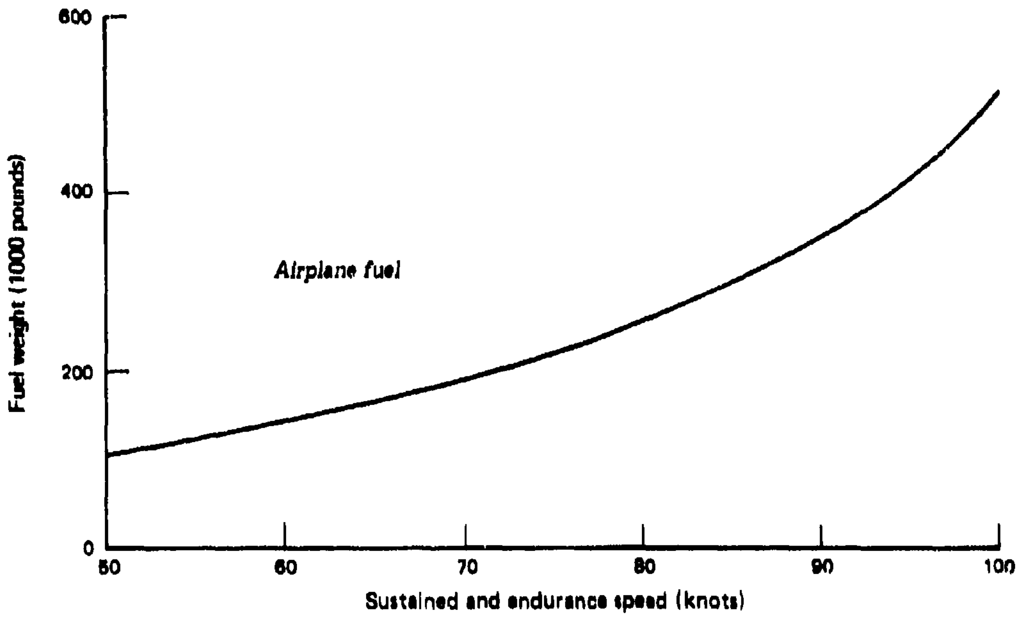

FIG. 30: AIRLINE DIRIGIBLE FUEL WEIGHT

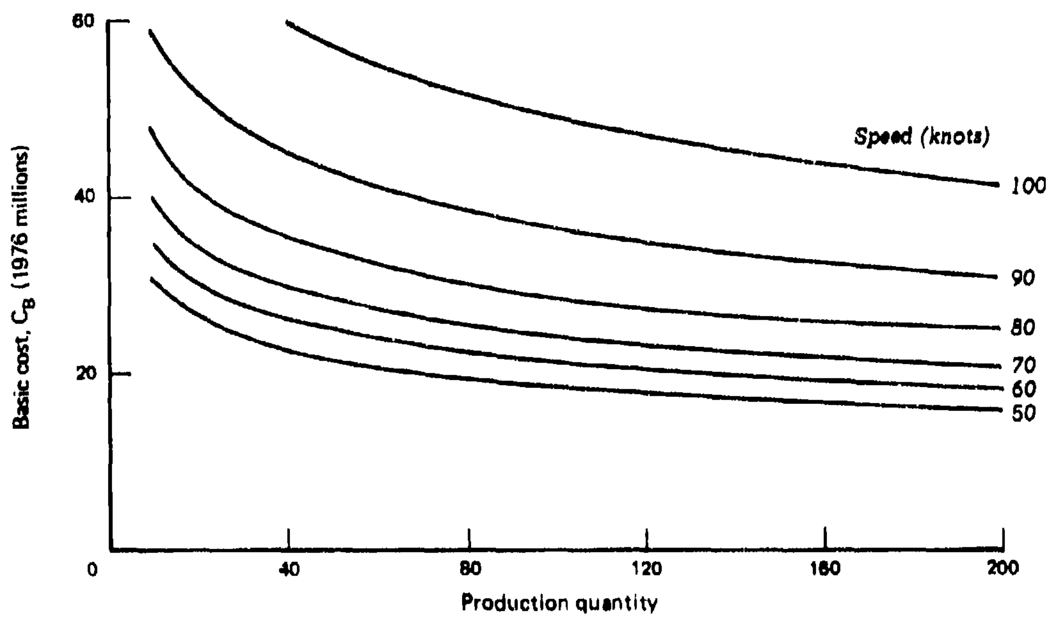

FIG. 31: AIRLINE DIRIGIBLE BASIC COST

3. AIRSHIP LIFT GASES AND GEOMETRY

This chapter first examines the properties of the standard atmosphere and of lift gases. Airship gas volume and weights are estimated. Then estimating geometrical dimensions of the airship hull, tail, and car is considered. Estimates of the wetted areas of the hull and tail are also presented.

THE STANDARD ATMOSPHERE AND LIFT GASES

The characteristics of the International Standard Atmosphere (reference 16) as functions of altitude are defined by piecewise continuous equations in different altitude regimes. Although airships can be designed for greater altitudes, concern in this volume is with lower altitudes; therefore only the equations for altitudes of -5 kilometers (-16,404 feet) to 11 kilometers (36,089 feet) are considered.

The pressure p, absolute temperature T, mass density ρ, density ratio σ_z at altitude z, and viscosity μ are given in terms of their base (subscript B) values at sea level by:

$$\begin{aligned} T/T_B &= 1 - 6.876 \times 10^{-6} z \\ p/p_B &= (T/T_B)^{5.256} \\ \sigma_z &= \rho/\rho_B = (T/T_B)^{4.256} \\ \mu &= 5.169 \times 10^{-7} (T/T_B)^{3/2} / (T/T_B + .3831) \end{aligned} \tag{19}$$

For the altitude regime considered, the acceleration of gravity is essentially constant so the weight desity ratio w/w_B is equal to the mass density ratio ρ/ρ_B.

The altitude z is in feet. The base (sea level) values are:

$$\begin{aligned} T_B &= 518.69^{\circ}R \\ p_B &= 2116.2 \text{ pounds per square foot} \\ \rho_B &= 0.0023769 \text{ slugs per cubic foot} \\ w_B &= 0.076475 \text{ pounds per cubic foot.} \end{aligned} \tag{20}$$

These equations permit calculation of the standard atmosphere characteristics at altitudes up to 36,089 feet. Values of the density ratio σ_z are listed in table 4.

Several low density gases could be used as the lifting gas for airships. However, only two lifting gases, helium and hydrogen, are considered. Other potential lifting gases have densities approximately four times the standard density of helium, so they are relatively inefficient and are not considered.

TABLE 4

STANDARD ATMOSPHERE DENSITY RATIOS

Altitude (feet)	Density ratio (σ_z)	Altitude (feet)	Density ratio (σ_z)
0	1.000	11,000	.715
1,000	.971	12,000	.693
2,000	.943	13,000	.671
3,000	.915	14,000	.650
4,000	.888	15,000	.629
5,000	.862	16,000	.609
6,000	.836	17,000	.589
7,000	.811	18,000	.570
8,000	.786	19,000	.551
9,000	.762	20,000	.533
10,000	.738		

Some characteristics of helium and hydrogen at standard sea level are shown in table 5 for standard sea level conditions. The specific lift (per cubic foot) is equal to the density of air minus the density of the lifting gas. The table shows that hydrogen provides the largest specific lift, leading to a smaller airship or a greater lift for a given airship. In addition, the cost of hydrogen per pound of lift is lower than for both purity levels of helium.

However, hydrogen is flammable at 4 to 74 percent volume mixtures with air. Therefore, it is undesirable to use hydrogen as a lifting gas.

Helium provides a specific lift, close to that obtained when hydrogen is used: 93 percent as much when both helium and hydrogen are 100 percent pure. The cost of helium is considerably greater (Federal Government supplies might cost less for Federal agencies), but the cost of gas is still a relatively small part of the total airship cost. Helium is not flammable and it is this safety characteristic that is the basis for selecting helium as the principal lifting gas to be considered.

In airship operations, the lifting gas diffuses outward through the envelope, and atmospheric air diffuses inward. Therefore, the lifting gas is not pure, but consists of a mixture of the lifting gas and atmospheric air. The purity of the lifting gas varies during operations as diffusion proceeds, as impure gas is withdrawn for purification, and as pure lifting gas is added.

To account for lifting gas impurity, a conventional 94 percent purity standard is often used. The characteristics of 94 percent pure helium are included in table 5. The decreased specific lift leads to a larger airship. For calculations, the standard sea level weight density w_{G0} of helium of fractional purity P_G is:

$$w_{G0} = 0.01057P_G + 0.07647(1 - P_G) \quad . \tag{21}$$

TABLE 5

STANDARD CHARACTERISTICS OF SOME LIFTING GASES

Gas	Density[a] (lb./cu.ft.)	Specific lift (lb./1000 cu.ft.)	Cost[b] ($/1000 cu.ft.)	Lift cost ($/lb.)
Hydrogen	0.00532	71.03	4.69	0.066
Helium, 100%	0.01057	65.78	54.73	0.83
Helium, 94%	0.01452	61.83	51.44	0.83
Standard air	0.07647	-	-	-

[a]At sea level in the International Standard Atmosphere.
[b]From Boeing, Vol. I., p. 5-39 (reference 6). In 1976 dollars.

Several gas-related weights and volumes are needed. Sea level conditions are used as the reference. The total weight W_T of the airship is equal to the product of sea level air weight-density times the envelope volume ∇_E :

$$W_T = .07647 \nabla_E \quad . \tag{22}$$

The maximum gas volume ∇_{GMX} can be expressed as a fraction f_G of the envelope volume:

$$\nabla_{GMX} = f_G \nabla_E \quad . \tag{23}$$

The static lift W_{ST} , also called the gross lift, is the lift at sea level when the maximum gas volume is filled with gas:

$$W_{ST} = (.07647 - w_{G0}) f_G \nabla_E \quad . \tag{24}$$

The static lift is only a reference weight because operations usually require some altitude, and the full gas altitude should be greater than the operational altitude to avoid loss of gas due to valving.

At sea level, the useful load W_{USO} is equal to the excess of static lift over the empty weight W_E :

$$W_{US0} = W_{ST} - W_E \quad . \tag{25}$$

Estimation of empty weight is considered later.

For operations with a gas altitude z , both the air weight density and the gas weight density in equation (24) are decreased by the atmospheric density ratio σ_z at altitude z . Thus the useful load W_{USz} for a gas altitude z is:

$$W_{USz} = \sigma_z W_{ST} - W_E$$

$$W_{USz} = W_{US0} - (1 - \sigma_z) W_{ST} \quad . \tag{26}$$

Division by W_{USO} gives the ratio of useful load for altitude operations to that at sea level:

$$W_{USz} / W_{US0} = 1 - (W_{ST} / W_{US0}) (1 - \sigma_z) \quad . \tag{27}$$

The altitude z in these equations should be greater than the specified operating altitude z_{OP} to avoid loss of gas by valving. The model includes a specification for for gas-altitutude margin z_{MRG} . Calculations for altitude are made for z equal to the sum of operating altitude and margin altitude:

$$z = z_{OP} + z_{MRG} \quad . \tag{28}$$

For operations at an altitude z , the gas weight $w_{G0} f_G \nabla_E$ associated with the static lift must be decreased at the sea level reference condition by a factor σ_z . The air weight inside the envelope increases. The air occupies the volume not occupied by the gas. The gas volume fraction is $\sigma_z f_G$, so the air volume fraction at sea level is $(1 - \sigma_z f_G)$. Thus, the gas and air weights at sea level that contribute to the total weight are given by:

$$W_{G0} = \sigma_z w_{G0} f_G \nabla_E$$

$$W_{A0} = 0.07647\,(1 - \sigma_z f_G)\,\nabla_E \quad . \tag{29}$$

A design limit maximum altitude related to the installed ballonet volume exists for blimps. The blimp design-masimum altitude z_{BDMX} is a design specification whose historical value has varied from 7,300 feet to 13,000 feet for U.S. blimps. To operate at the z_{BDMX} gas altitude, the ballonet must be completely filled with air at takeoff, and the blimp ballonet volume ∇_{BB} must be large enough to accommodate the expansion of the gas that occurs as altitude is increased. A gas volume ∇_{G0} at sea level increases to $\nabla_{G0}/\sigma_{zBDMX}$, which must be equal to $f_G \nabla_E$ at the design-maximum altitude. Hence, the required blimp ballonet volume is:

$$(\nabla_E - \nabla_{BB})/\sigma_{zBDMX} = f_G \nabla_E \tag{30}$$

$$\nabla_{BB}/\nabla_E = f_G\,(1 - f_G \sigma_{zBDMX}) \quad .$$

Solving for f_G gives:

$$f_G = \frac{\nabla_{BB}/\nabla_E}{\sigma_{zBDMX}} \quad . \tag{31}$$

The calculated value of the ratio on the right side of this equation is shown for blimps in table 6. The calculated ratios indicate that for blimps f_G is essentially unity. However, it is desired to consider possible use of car volume ∇_{CEN} within the envelope so the relation for the gas volume factor for blimps becomes:

$$f_G = 1.00 - \nabla_{CEN}/\nabla_E \quad . \tag{32}$$

Data for envelope and maximum gas volume for dirigibles are shown in table 7. The ratio of maximum gas volume ∇_{GMS} to envelope volume is close to 0.93, which is considerably less than the unity value for blimps. Some of the nongas volume of dirigibles is clearance ∇_{CL} for clearance between the netting that contains and constrains the gas cells and the external covering and wiring. Useful volume ∇_{USE} within the envelope is required for useful load (fuel, payload, passengers, and accommodations) and access, crew accommodations, and equipment. In symbols, the gas volume factor f_G for dirigibles is:

$$f_G = 1 - \nabla_{CL}/\nabla_E - \nabla_{USE}/\nabla_E \quad . \qquad (33)$$

The clearance volume is significant due to the large hull wetted area A_{WH} . For an average radial clearance r_{CL} assumed constant over all the wetted surface, the clearance volume is:

$$\nabla_{CL} = r_{CL} A_{WH} \quad . \qquad (34)$$

TABLE 6

BALLONET AND GAS VOLUME OF BLIMPS

Blimp	Envelope volume (1000 cu.ft.)	Ballonet volume (1000 cu.ft.)	Design max altitude (feet)	$\frac{\nabla_{BB}/\nabla_E}{1-\sigma_{zBDMX}}$
Goodyear Columbia II	147.3	38.6	10,000	.999
Goodyear America	202.7	41.95	7,500	.994
U.S. Navy K-135	456	119	10,000	1.001
U.S. Navy ZPG-2	975	247	9,500	.996
U.S. Navy ZPG-3W	1,490	383	9,600	.993

Source: Goodyear 1975, Vol. III, pp. 25, 26, reference 8.

Equations are shown later in this chapter for A_{WH} and ∇_E in terms of envelope length-diameter ratio L/D and prismatic coefficient C_p. Substituting equations (39), (43), and (38) into equation (34) gives:

$$\frac{\nabla_{CL}}{\nabla_E} = \frac{4r_{CL}}{D} \frac{1+0.9/(L/D)^2}{C_p^{2/3}} \quad . \tag{35}$$

TABLE 7

GAS VOLUME OF DIRIGIBLES

Dirigible	Envelope volume (1000 cu.ft.)	Max gas volume (1000 cu.ft.)	$\frac{\nabla_{GMX}}{\nabla_E}$	∇_{CL}/∇_E r_{CL} = .006D
U.S. Navy Shenandoah	2,290	2,148	.938	.031
U.S. Navy Los Angeles	2,800	2,600	.929	.032
U.S. Navy Macon	7,400	6,850	.926	.032

Source: Goodyear 1975, Vol. III, p. 19, reference 8.

For $L/D = 6$ and $C_p = 0.65$, the second factor is equal to 1.37, so the percentage clearance volume is about 5.5 times the percentage radial clearance relative to maximum diameter. Data for radial clearance and useful envelope volume were not found. It was assumed that that radial clearance is:

$$r_{CL} = 0.006D \quad . \tag{36}$$

Values for ∇_{CL}/∇_E calculated from equation (35) using $r_{CL} = 0.006D$ are shown in table 7.

AIRSHIP HULL AND FIN GEOMETRY

Airship geometry refers to the geometrical dimensions: envelope length, maximum diameter and wetted area; fin configuration, area, and exposed span; and car dimensions. Envelope geometry data for some U.S. blimps and dirigibles are shown in table 8. The envelope length L and diameter D can be combined in the dimensionless length-diameter ratio L/D for specifying conceptual airships. The envelope length-diameter ratio L/D for blimps was about 4; the values were from 3.74 to 4.74. For the dirigibles, L/D varied from 5.91 to 8.64. The general shape of the envelope can be expressed by its prismatic coefficient C_P, which is defined as the ratio of the envelope volume ∇_E to the volume $(\pi/4)D^2L$ of the circumscribing right cylinder:

$$C_P = \nabla_E/(\pi/4)D^2L \quad . \tag{37}$$

Calculated values of C_P, using the envelope volume shown in the table are included in table 8. They vary from 0.639 to 0.692 and tend to be somewhat larger for the dirigibles than for the blimps. When the prismatic coefficient is specified, the equation defining C_P can be rewritten to solve for D and L :

$$D = \left(\frac{4}{\pi C_P}\right)^{1/3} \left(\frac{\nabla_E}{L/D}\right)^{1/3}$$

$$L = \left(\frac{4}{\pi C_P}\right)^{1/3} \left((L/D)^2 \nabla_E \right)^{1/3} \tag{38}$$

It is convenient to express the hull wetted area A_{WH} in terms of a coefficient. Three different coefficients, used historically, are defined by:

$$C_S = A_{WH}/\pi DL$$

$$C_S^* = A_{WH}/(\nabla_E^2 (L/D))^{1/3} \tag{39}$$

$$C_S^\nabla = A_{WH}/\sqrt{\nabla_E L}$$

The first coefficient, C_S, is used throughout the remainder of this volume.

For geometrically similar bodies of revolution the local radius r, as a function of longitudinal distance x from the bow, is defined in terms of the maximum radius R by:

$$r = Rf(\xi) \quad ,$$

where $$0 \le (\xi = x/L) \le 1 \quad , \tag{40}$$

and $$0 \le f(\xi) \le 1 \quad .$$

TABLE 8

AIRSHIP ENVELOPE GEOMETRY DATA

Airship	Envelope length (feet)	Envelope diameter (feet)	L/D ratio	Envelope volume (1000 cu.ft.)	C_P ratio
Goodyear Mayflower III	157	42.0	3.74	147	.676
Goodyear America	190	46.0	4.14	203	.643
U.S. Navy K-135	253	60.0	4.22	436	.637
U.S. Navy ZPG-2	343	75.0	4.57	975	.643
U.S. Navy ZPG-3W	403	85.0	4.74	1,490	.652
U.S. Navy Shenandoah	680	78.7	8.64	2,290	.692
U.S. Navy Los Angeles	660	90.7	7.28	2,800	.657
U.S. Navy Macon	785	132.9	5.91	7,400	.680

Source: Goodyear 1975, Vol. III, pp. 19, 25, 26 (reference 8).
Boeing, Vol. I, pp. 3-6 (reference 6).

In terms of $f(\xi)$ the envelope volume ∇_E and the prismatic coefficient C_p defined in equation (37) become:

$$\nabla_E = \int_0^L \pi r^2 dx = \pi R^2 L \int_0^1 f^2(\xi)\, d\xi$$

$$C_p = \int_0^1 f^2(\xi)\, d\xi \qquad (41)$$

Similarly, the wetted area and coefficient become:

$$A_{WH} = \int_0^L \sqrt{1 + \frac{dr}{dx}^2}\; 2\pi r dx$$

$$A_{WH} = 2\pi RL \int_0^1 \sqrt{1 + \frac{(df/d\xi)}{2(L/D)}^2}\; f(\xi)\, d\xi \qquad (42)$$

$$C_S = \int_0^1 \sqrt{1 + \frac{(df/d\xi)}{2(L/D)}^2}\; f(\xi)\, d\xi$$

Thus, C_S is a function of L/D (in the radical) and also a function of C_P, which depends on $f(\xi)$.

However, it appears impossible to obtain a mathematical general expression for these relations. It appears that C_S is approximately proportional to $C_P^{2/3}$. This approximation was applied to data for airship forms of the 1920s, shown in table 9. The data are for test models from 1919 to 1922 used in the U. S. Navy wind tunnel. The wetted area ratios $C_S/C_P^{2/3}$ are shown in figure 32 as a function of envelope length-diameter ratios. They tend to decrease when L/D increases.

Additional data for full-scale airships were obtained and are shown in figure 32. The following equation was selected for estimating C_S :

$$C_S = C_P^{2/3}\,(1 + 0.9/(L/D)^2) \quad . \qquad (43)$$

TABLE 9

AIRSHIP MODEL ENVELOPE WETTED AREA DATA

Airship	L (feet)	D (feet)	A_{WH} (sq.ft.)	C_S	C_p	L/D
Navy B	3.527	.6967	5.800	.751	.6176	5.06
Navy C	2.949	.6417	4.750	.799	.6562	4.62
Navy F	3.125	.6417	5.007	.795	.6621	4.87
E.P.	3.092	.6417	4.597	.737	.5891	4.82
Parseval I	3.942	.6417	5.465	.688	.5679	6.14
Parseval II	3.208	.6417	4.528	.700	.5677	4.99
Parseval III	3.208	.6417	4.750	.734	.6095	4.99
AA	1.992	.5833	2.760	.756	.6003	3.41
C-class						
.25D[a]	3.109	.6417	5.073	.809	.6749	4.85
.5 D	3.270	.6417	5.398	.819	.6909	5.10
1 D	3.590	.6417	6.043	.835	.7184	5 57
2 D	4.232	.6417	7.337	.860	.7611	6.60
3 D	4.872	.6417	8.627	.878	.7925	7.59
4 D	5.515	.6417	9.922	.892	.8167	8.59
5 D	6.158	.6417	11.218	.904	.8358	9.60
Shenandoah	5.645	.6560	9.270	.797	.7000	8.60

Source: Burgess, table 10, page 72, reference 7.

[a]Length of constant-diameter center section.

The purpose of the airship tail is to provide adequate static and dynamic longitudinal stability. Although stability is not considered explicitly in this model, if the hull moment coefficient and fin lift coefficient were proportional to pitch angle, and if tail length were proportional to envelope length, then the required total tail area would be proportional to $(C_p \Delta_E^2 / (L/D)^2)^{1/3}$

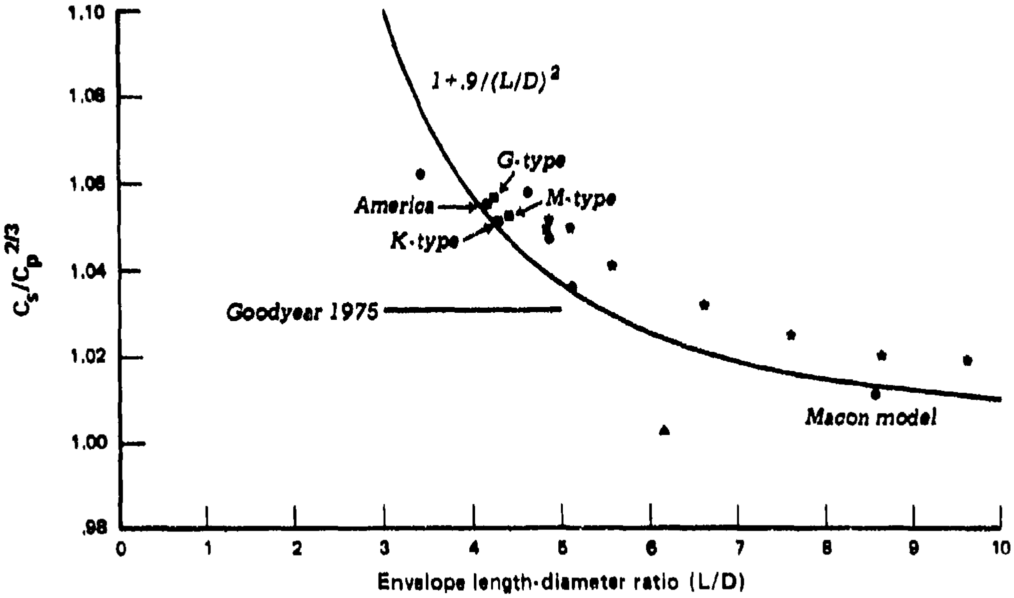

FIG. 32: VARIATION OF ENVELOPE AREA COEFFICIENT

Data, obtained from several sources, including scaled measurements of small-scale sketches, are shown in table 10. Fin area and fin span are the average exposed fin area for each fin and the maximum exposed span for each fin. Most of the fins extend to the maximum hull diameter.

The approximation for fin area A_F stated above was tested by calculating the parameter $(L/D)^{2/3} A_F / C_P^{1/3} \nabla_E^{2/3}$.

For the fin maximum exposed span b_F , the ratio $(L/D)^{1/3} b_F/D$ was tested. The variation of both parameters is shown in figure 33 as a function of L/D . Each parameter is approximately constant with moderate scatter. On the basis of the results in figure 33, the following equations are selected for estimating A_F and b_{FMX}:

$$A_F = 0.30 C_P^{1/3} \nabla_E^{2/3} / (L/D)^{2/3} \quad \text{, cruciform, X-form}$$

$$A_F = 0.40 C_P^{1/2} \nabla_E^{2/3} / (L/D)^{2/3} \quad \text{, inverted-Y} \qquad (44)$$

$$b_F = 0.60 D/(L/D)^{1/3}$$

For an inverted-Y tail configuration the coefficient for A_F is increased to keep a fixed total tail area.

TABLE 10

AIRSHIP TAIL FIN GEOMETRY DATA

	Fin area[a] (sq.ft.)	Fin span[b] (ft.)	Number of fins	Fin configuration
Goodyear Mayflower III	250	15	4	Cruciform
Goodyear America	300	17	4	Cruciform
U.S. Navy K-135	452	17	4	Cruciform
U.S. Navy ZPG-2	898	29	4	X-form
U.S. Navy ZPG-3W	1,300	31	4	X-form
U.S. Navy Shenandoah	950	23[c]	4	Cruciform
U.S. Navy Los Angeles	1,350	27[c]	4	Cruciform
U.S. Navy Macon	3,672	42	4	Cruciform

[a]Exposed fin area. Average area, if fins not identical.

[b]Maximum exposed fin span, each fin, or horizontal fins if larger.

[c]Fins did not extend to envelope maximum diameter.

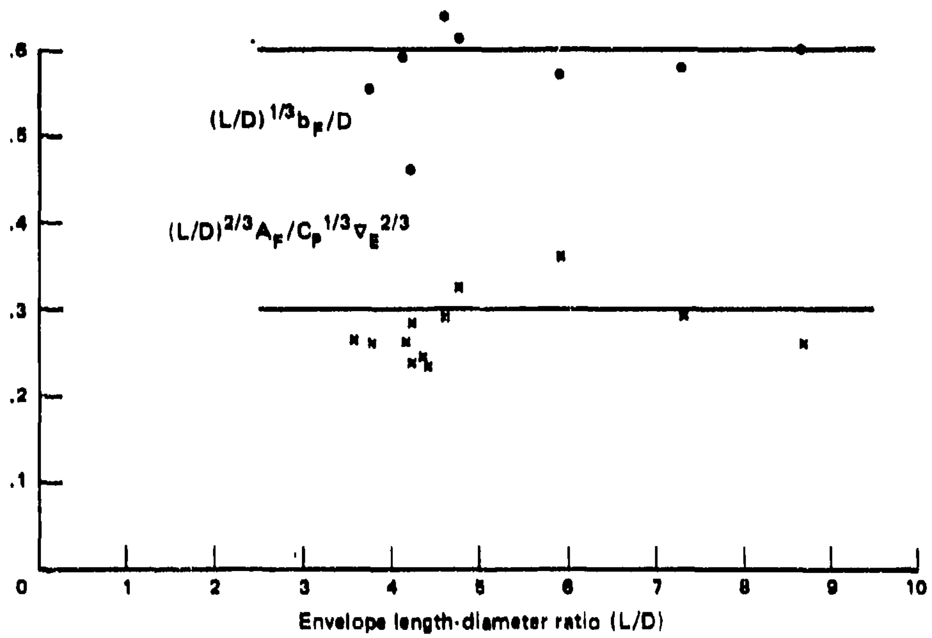

FIG. 33: VARIATION OF FIN PARAMETERS

Additional detailed fin data were obtained for 3 blimps. They are shown in table 11. The relative fixed and movable control surface areas are illustrated. Also, the horizontal fins area is from 21 to 31 percent greater than the vertical fins area. The parameters $(L/D)^{2/3}A_F/C_P^{1/3}\ \nabla_E^{1/2}$ for these data are included in figure 33.

Only one data point was obtained for the fin thickness-chord ratio $(t/c)_F$. Burgess, figure 1 (reference 7), shows a construction-detail drawing of the U.S. Navy Los Angeles dirigible. The drawing shows a fin cross section from which $(t/c)_F$ can be estimated as about 0.12. A value of 0.10 was selected for dirigibles. Numerical data for $(t/c)_F$ for blimps were not found. From photographs and discussions with former pilots, it appears that the thickness-chord ratio is small. Such small values are technically feasible because blimp fins are braced laterally, with wire cable. A $(t/c)_F$ value of 0.02 was selected. Thus:

$$(t/c)_F = 0.02,\ \text{blimps}$$
$$(t/c)_F = 0.10,\ \text{dirigibles} \qquad (45)$$

TABLE 11

DATA FOR AIRSHIP TAIL AREAS[a]

Airship	Horizontal Fixed (sq.ft.)	Horizontal Movable (sq.ft.)	Vertical Fixed (sq.ft.)	Vertical Movable (sq.ft.)	Total tail area (sq.ft.)	Envelope volume (1000 cu.ft.)
U.S. Navy G-type	524	194	435	112	1,265	196.7
U.S. Navy K-type	732	260	616	199	1,807	425.0
U.S. Navy M-type	946	334	638	338	2,256	647.5

Source: Goodyear Reports, "Descriptive Specifications," references 11-13.

[a]Prismatic coefficients are 0.650, 0.649, and 0.652 respectively. Length-diameter ratios are 4.23, 4.31, and 4.40, respectively.

Other fin geometry characteristics needed can be calculated from the above equations. The tail area A_T is equal to 4 times the fin area for cruciform or X-form configurations:

$$A_T = 1.20 C_p^{1/3} \nabla_E^{2/3} / (L/D)^{2/3} \quad . \qquad (46)$$

If an inverted-Y configuration is used, A_T is assumed unchanged. For all 3 configurations, the tail wetted area A_{TW} is twice A_T :

$$A_{TW} = 2A_T \quad . \qquad (47)$$

The average fin chord c_{FAV} is assumed to be given by A_F/b_F with b_F estimated as above:

$$c_F = A_F/b_F \quad . \qquad (48)$$

The fin effective aspect ratio R_{BC} is needed to estimate the aerodynamic lift. The general aerodynamic definition of aspect ratio is $(\text{span})^2/(\text{area})$. For airship fins it is assumed that the airship body provides a 100 percent effective end-plate. Then span is twice b_F and area is twice A_F, so that:

$$R_{BC} = (2b_F)^2/(2A_F) = 2b_F^2/A_F \quad . \tag{49}$$

AIRSHIP CAR GEOMETRY

Blimp car geometry must provide volume for its specified contents. It must also provide for the geometry of engine nacelles and landing gear. For dirigibles, the car provides only an operational control center.

The car of a blimp must provide a required car volume ∇_{RC}. Estimation of ∇_{RC} is considered in chapter 6 on weight and volume. Some U.S. Navy blimps (Jane's Aircraft, 1953-54) extended the car upward into the envelope, thus reducing the gas volume. The upper level of the car was used for living quarters, with operational and mechanical equipment on the lower level. Gas system valves and ducts were usually above the car.

Table 12 lists car geometry data for blimps and dirigibles. The car length ratios L_C/L for blimps vary considerably, presumably as needed to provide the required volume for each case. It appears desirable to limit L_C/L to about 0.20 or less for blimps for structural loading conditions. For blimps, the car width ratio w_C/D appears to be about 0.15 or less. The cars are relatively long and narrow, with L_C/w_C ratios from 5.25 to 10.35.

To develop a conceptual model for blimp car dimensions, the following symbols are needed:

∇_{RC} = required car volume, cubic feet

h_{DK} = car deck height, feet (8 feet)

h_{OVR} = overhead height for equipment, feet (50)

h_{OVRMX} = maximum overhead, feet (5 feet)

L_2 = length second deck, feet

In terms of these symbols, the available car volume, which must be equal to ∇_{RC}, is:

TABLE 12

DATA FOR AIRSHIP CAR GEOMETRY

Airship	Car dimensions: Length (feet)	Width[a] (feet)	Height[b] (feet)	$\frac{L_C}{L}$	$\frac{W_C}{D}$	$\frac{L_C}{W_C}$
Goodyear Mayflower III	23	7	8	0.146	0.167	3.29
		4			0.095	5.75
Goodyear America	23	7	8	0.121	0.152	3.29
		4			0.087	5.75
U.S. Navy K-135	42	8	14	0.193	0.148	5.25
U.S. Navy ZPG-2	73		13	0.213		
U.S. Navy ZPG-3W	83	8	9	0.206	0.094	10.35
U.S. Navy Shenandoah	47[c]	9[c]	10[c]	0.069	0.114	5.22
U.S. Navy Los Angeles	62	11	11	0.094	0.121	5.64
U.S. Navy Macon	50		14	0.064		

Source: Sketches in Boeing, Vol. I, pp. 3-7, 15, 16, reference 6, and *Jane's All the World's Aircraft*, various issues.

[a] Excludes width of engines, propellers, and outriggers.

[b] Frontal height external to envelope contour.

[c] Separate car, suspended below envelope.

$$L_c w_c (h_{DK} + h_{OVR}) + L_2 w_c h_{DK} = \nabla_{RC} \quad . \tag{51}$$

It is assumed that if there is a second deck the overhead height is located inside the envelope contour, so the car frontal area A_{CRF} is:

$$A_{CRF} = w_c (h_{DK} + h_{OVR}) \ , \quad \text{if } L_2 = 0$$

$$A_{CRF} = w_c h_{DK} \ , \qquad \text{if } L_2 \neq 0 \ . \tag{52}$$

When a second deck is required the car envelope volume ∇_{CEN}, which is not available for gas, is:

$$\nabla_{CEN} = L_c w_c h_{OVR} + L_2 w_c h_{DK} \quad . \tag{53}$$

Equation (51) provides the basis for a step-by-step calculation of L_c, w_c, h_{OVR}, and L_2 so that equations (52) and (53) can be evaluated. It was assumed that for very small blimps a minimum car size would exist. If more volume is required, first the car length would be increased, up to .2L. Then car width would be increased, up to .15D. This would be followed by increasing overhead height, up to h_{OVRMX}, and, finally, a second deck would be added. The calculation steps are:

(54)

(1) $L_c = 12, \ w_c = 4, \ h_{OVR} = 0, \ L_2 = 0$

(2) $L_c = \nabla_{RC}/w_c h_{DK}$; If $L_c \leq .2L$, Go to (6).

(3) $L_c = .2L, \ w_c = \nabla_{RC}/L_c h_{DK}$; If $w_c \leq .15D$, Go to (6).

(4) $w_c = .15D, \ h_{VR} = \nabla_{RC}/L_c w_c - h_{DK}$;

If $h_{OVR} \leq h_{OVRMX}$, Go to (6).

(5) $h_{OVR} = h_{OVRMX}, \ L_2 = (\nabla_{RC} - L_c w_c (h_{DK} + h_{OVR}))/w_c h_{DK}$

(6) Calculate A_{CRF} and ∇_{CEN} .

Dirigibles had rather large control cars according to the data shown in table 12. The mechanical ship control equipment of the 1930s was quite bulky, and a car crew of several persons per watch was used. The car was located forward, along the keel. Forward visibility for operating control required a frontal height, including fairing, of 10 to 12 feet. The width was relatively small. It is assumed that 1976 dirigibles of all sizes would use electrical-electronic control equipment of relatively small volume, and smaller crew complements. For conceptual estimates of dirigible car geometry, the required car volume ∇_{RC} should include provision for flight crew personnel and flight control equipment. With a constraint $L_C \leq 5w_C$ for dirigibles, the calculation steps are:

$$
\begin{aligned}
&(1) \quad L_C = 12, \; w_C = 4 \\
&(2) \quad L_C = \nabla_{RC}/w_C h_{DK} \; ; \text{ If } L_C \leq 5w_C \text{ , Go to (4)} \quad . \\
&(3) \quad L_C = \sqrt{5\,\nabla_{RC}/h_{DK}} \; , \; w_C = 0.2L_C \\
&(4) \quad A_{CRF} = w_C(h_{DK} + 3) \; , \; \nabla_{CEN} = 0 \quad .
\end{aligned}
\qquad (55)
$$

Setting ∇_{CEN} equal to zero ignores any use of envelope volume by the car.

NACELLES

All blimps are assumed to have 2 engines in nacelles mounted symmetrically on each side of the car. The rigid structure of a dirigible permits using a specified larger number of engines and nacelles.

Engine nacelle geometry can be estimated by using the engine frontal area to calculate a nacelle diameter. The nacelle is assumed to be a body of revolution. The cross section in nacelles on historical airships was not always circular, but the approximation appears reasonable, and 1976 airship nacelles would probably be bodies of revolution. In chapter 5 on power, engines, and fuel, the nacelle frontal area A_{FNC} is estimated. Setting A_{FNC} equal to the area of a circle gives the nacelle diamter D_{NC} as:

$$D_{NC} = \sqrt{(4/\pi)\,A_{FNC}} \quad . \qquad (56)$$

The nacelle length L_{NC} must be estimated. This can be done by using a nacelle length-diameter ratio $(L/D)_{NC}$. The value of $(L/D)_{NC}$ must be at least large enough to provide enclosure for the engine type used. Small values are adequate for radial reciprocating engines, but turboprop engines require larger values. In chapter 5, values for the engine length-diameter ratio $(L/D)_{ENG}$ are selected for several types of engine. Using a standard value of 3 for $(L/D)_{NC}$:

$$
\begin{aligned}
(L/D)_{NC} &= 3 \ , \\
(L/D)_{NC} &\geq (L/D)_{ENG} \ , \\
L_{NC} &= (L/D)_{NC} D_{NC} \ .
\end{aligned}
\tag{57}
$$

These equations are to be applied in the order shown.

There is a potential tradeoff between nacelle drag and nacelle weight. In chapter 4 on drag and lift, it is shown that the external aerodynamic drag coefficient for a body of revolution is a flat minimum for length-diameter ratios of 2.5 to 3.5. In chapter 6 on weight and volume, the nacelle weight is estimated as proportional to nacelle surface area. With constant D_{NC} to provide the frontal area, the surface area is proportional to $(L/D)_{NC}$, so larger length-diameter ratios increase the weight. These tradeoffs can be investigated by use of the conceptual model.

Constraints on nacelle geometry include in-flight access for early dirigibles. The engines for these dirigibles were relatively small. A minimum diameter of 6 feet is assumed to be required for personnel work space. The length-diameter ratios of these nacelles were much less than the standard value of 3. This can be represented by retaining the nacelle length given by equation (57), which gives more drag but less nacelle weight than if length were increased. It was assumed that 1976 airships would not provide in-flight accesses to the nacelles. Then:

$$D_{NC} = 6, \text{ historical dirigibles} \quad . \tag{58}$$

This constraint is to be applied after D_{NC} has been calculated according to equation (56).

The later blimps had retractable tricycle landing gear, with the main gear mounted on the engine nacelles aft of the nose of the nacelle (the gear was attached just aft of the radial reciprocating engine). Retraction of gear into turboprop engine nacelles might require an increased nacelle diameter, but this is not included in the conceptual model. However, if conceptual landing gear length is increased it becomes necessary either to use fixed gear or to increase the length of the engine nacelle to enclose the retracted gear (partial enclosure is not considered in the conceptual model). For this purpose, a nacelle length equal to at least 1.3 times the nacelle gear length L_{GRN} is selected. The nacelle diameter is not changed, which increases the drag but limits the increase of nacelle weight. Thus:

$$L_{NC} \geq 1.3L_{GRN}\text{, blimp, retractable gear.} \qquad (59)$$

This constraint is to be applied after L_{NC} has been calculated according to equation (57).

OUTRIGGERS

The outrigger structures that supported engine nacelles of earlier airships had a variety of structural geometries. Most of them included an open ladder for access between the envelope and the nacelle. Engines were started by hand cranking until the 1940s, and local personnel operated the engines according to telephoned commands. Some airship engine nacelles had integral water-recovery condensers. After World War II, blimp engines had electric starters and cockpit control, but access for in-flight maintenance was still provided.

The form of the outrigger structure influences its aerodynamic drag contribution and its weight. Historic airships used combinations of struts and bracing cables. Later blimps used tubular struts enclosed in streamlining airfoil shapes. The ZPG-3W blimp used a thick cantilever airfoil pylon, sloping downward from the envelope edge of the car. The pylon was thick enough to provide enclosed access to the nacelle. Three types of outrigger structures are considered in the model: open-frame tubular, covered tubular, and cantilever pylon.

Front-view sketches of 2 outriggers are shown in figure 34 (also see figure 35 for blimps). The length L_{OUT} of the outrigger structure is determined by the propeller diameter D_P, the propeller clearance C_{PRP} from the car or envelope, and the clearance C_{ABV} above the propeller disk to the top of the car of a blimp. Propeller diameter is investigated later in chapter 6 on power, engines, and fuel. On the basis of scaling small drawings of earlier airships, the following clearances are selected:

$$C_{PRP} = 2, \text{ for blimps}$$

$$C_{PRP} = 4, \text{ for dirigibles} \qquad (60)$$

$$C_{ABV} = 2, \text{ blimps only}$$

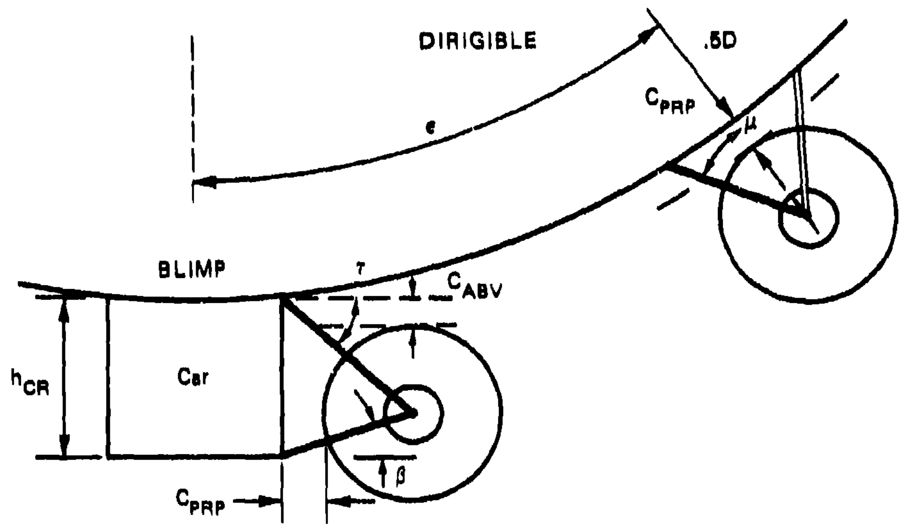

FIG. 34: SKETCH OF OUTRIGGER GEOMETRY

For the blimp, the outrigger length can be calculated by subtracting half the nacelle diameter from the distance between the center of the propeller disk and the support points:

$$L_{OUT1} = \sqrt{(C_{PRP} + 0.5D_P)^2 + (C_{ABV} + 0.5D_P)^2} - 0.5D_{NC} \quad , \qquad (61)$$

$$L_{OUT2} = \sqrt{(C_{PRP} + 0.5D_P)^2 + (h_{CR} - C_{ABV} - 0.5D_P)^2} - 0.5D_{NC} \quad ,$$

The subscripts 1 and 2 refer to the upper and lower outrigger structure, respectively. Both are needed for tubular outriggers. Only one is needed for a cantilever pylon outrigger.

For dirigibles, a symmetrical outrigger form is shown in figure 34. The angle λ is measured from the center line to each leg. The distance along the center line from the center of the propeller disk to the envelope is $0.5D_P + C_{PRP}$. Thus, the outrigger length is:

$$L_{OUT} = (0.5D_P + C_{PRP}) / \cos\mu - 0.5D_{NC} \quad . \qquad (62)$$

For the outrigger to intersect the envelope it is necessary that μ be not too great: λ_{MX}, where

$$\mu \leq \tan^{-1} (D/(D + D_P + 2C_{PRP})) \quad . \tag{63}$$

It is assumed that the engine angle ϵ must be large enough so that the bottom of the propeller distance is no lower than the bottom of the envelope.

$$(0.5D + 0.5D_P + C_{PRP}) \cos \epsilon + 0.5D_P \leq 0.5D \quad , \tag{64}$$

$$\epsilon \leq \cos^{-1} ((D + D_P) / (D + D_P + 2C_{PRP})) \quad .$$

The top angle τ and bottom angle β shown for the blimp in figure 34 define the geometry of the blimp outrigger (along with the 2 lengths). They are given by:

$$\tau = \tan^{-1}\left(\frac{C_{ABV} + 0.5D_P}{C_{PRP} + 0.5D_P}\right) \quad ;$$

$$\beta = \tan^{-1}\left(\frac{h_{CR} - C_{ABV} - 0.5D_P}{C_{PRP} + 0.5D_P}\right) \quad . \tag{65}$$

When propeller diameter increases sufficiently, the angle β becomes negative.

The frontal area A_{OUTF} of the outriggers for the blimp is also needed. For this purpose it is assumed that all tubular outriggers are constructed of chrome molybdenum steel tubes with tube diameter D_{TB} equal to 0.15 feet (1.80 inch). Wall thickness and number can be varied to provide the necessary structural strength (see chapter 5 on power, engines, and fuel). It is further assumed that open-frame tubular outriggers for blimps consist of 1 set of tubes for the upper structure, with the necessary number in the set arranged longitudinally in-line and at sufficient angle to the perpendicular to the blimp car to provide adequate structural strength for longitudinal loads. This frontal area for 2 nacelles is $2D_{TB}L_{OUT1}$. For the lower structure it is assumed that at least 2 tubes are used longitudinally, with diagonals to withstand compression, and at least 2 tubes are used in the vertical plane to provide a truss that can withstand compression loads. The lower structure then has a frontal area of $2(2D_{TB})L_{OUT2}$. The sum gives:

$$A_{OUTF} = (2L_{OUT1} + 4L_{OUT2})D_{TB}, \text{ open-frame tubular.}$$

$$D_{TB} = 0.15 \quad . \qquad (66)$$

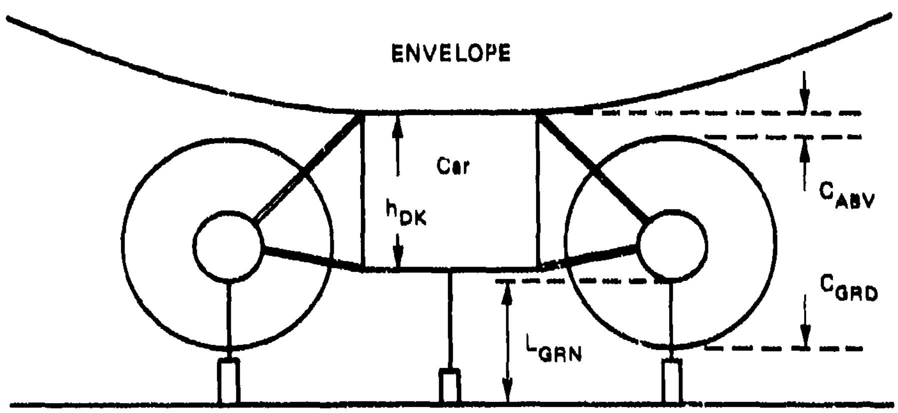

FIG. 35: SKETCH OF BLIMP LANDING GEAR

For covered tubular outriggers for blimps it is assumed that the upper structure is used to provide ram air to pressurize the ballonets. Both the upper and lower structures then have a frontal thickness of 3 times D_{TB} , or 0.45 feet. This frontal area is to be enclosed in streamlined airfoil shapes. Streamlined airfoils can have a nearly constant thickness over about the middle third of their chord. It is assumed that the longitudinal separation of the tubes is not greater than this fraction of the chord. It is shown in chapter 4 on drag and lift that an outrigger thickness-chord ratio $(t/c)_{OUT}$ of 0.25 produces minimum drag. The frontal area and chord for covered tubular outriggers for blimps are then:

$$A_{OUTF} = 6D_{TB}(L_{OUT1} + L_{OUT2})$$

$$c_{OUT} = 3D_{TB}/(t/c)_{OUT}$$

$$D_{TB} = 0.15 \qquad (67)$$

$$(t/c)_{OUT} = 0.25$$

For cantilever pylon outriggers for blimps, the ratio frontal thickness t_{POUT} to outrigger length L_{OUT} is important in determining its weight. A value of 0.2 is selected for (t_{POUT}/L_{OUT}). Then the frontal area and chord can be estimated as:

$$t_{POUT} = (t_{POUT}/L_{OUT})L_{OUT\,1}$$

$$AOUTF = 2t_{POUT}L_{OUT\,1}$$

$$c_{OUT} = t_{POUT}/(t/c)_{OUT} \qquad (68)$$

$$(t_{POUT}/L_{OUT}) = 0.2$$

$$(t/c)_{OUT} = 0.25 \quad .$$

For dirigibles, only open-frame tubular outriggers are considered. For the top and bottom members, each with two tubes placed longitudinally, the frontal area for a number of engines N_{ENG} is:

$$A_{OUTF} = 4N_{ENG}D_{TB}L_{OUT}$$

$$D_{TB} = 0.15 \quad . \qquad (69)$$

LANDING GEAR

Blimps first had landing gear in the 1930s. The first type used was a bicycle gear placed on the bottom of the car and on the lower tail fin of a cruciform tail configuration, Some of the car landing gears were retractable. The last U.S. Navy blimps had retractable tricycle landing gear. Tricycle gear, in contrast to bicycle gear, provides lateral stabilization during mooring, ground movements, takeoff, and landing.

A sketch of blimp landing gear geometry is shown in figure 35. A propeller ground clearance C_{GRD} of 2 to 4 feet was used on historical blimps. It is assumed that an equal clearance is required for the blimp. An average value is selected as the standard ground clearance:

$$C_{GRD} = 3 \quad . \tag{70}$$

From the sketch, the nacelle landing gear length L_{GRN} can be written using symbols. The associated car landing gear length L_{GRC} can also be written in symbols.

$$L_{GRN} = C_{GRD} + 0.5(D_P - D_{NC}) \quad ,$$

$$L_{GRC} = C_{ABV} + D_P + C_{GRD} - h_{DK} \quad . \tag{71}$$

Equations (71) will often be valid. However, inspection shows that if D_P is sufficiently small it is possible for L_{GRC} to be small or negative. Therefore, after calculating equations (71) it is necessary to ensure that L_{GRC} is equal to at least C_{GRD}. If it must be increased, a different equation for the landing gear lengths must be used:

$$L_{GRC} = C_{GRD} \quad , \tag{72}$$

$$L_{GRN} = h_{DK} + C_{GRD} - (C_{ABV} + 0.5(D_P + D_N)) \quad .$$

With any landing gear length, the maximum takeoff angle of attack (and, hence, aerodynamic lift) is limited by the geometry of the gear, envelope, and lower fins. If larger takeoff angles of attack are desired, the landing gear length must be increased. A conceptual model of the relations can be developed on the basis of approximate geometry sketched in figure 36. The lower part of the sketch shows a side view of the takeoff geometry, with a cruciform tail configuration extending to the maximum diameter of the envelope. The tangent of the maximum pitch angle θ_{MX} is equal to the distance between the bottom of the nacelle landing wheel and the fin, divided by the longitudinal distance from the wheel to the aft corner of the lower fin.

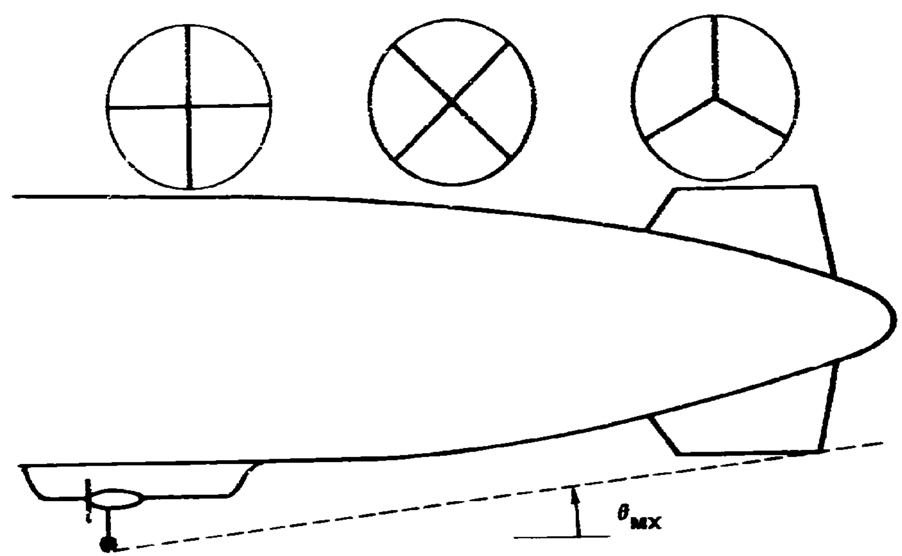

FIG. 36: SKETCH OF TAKEOFF GEOMETRY

However, from the sketches of fins in the upper part of the figure the vertical distance must be increased by 0.5D(1 - cosine), where the cosine is of an angle depending on the tail configuration. In terms of a fin factor F_{FIN} equal to the (1 - cosine) term:

$$
\begin{aligned}
F_{FIN} &= 0 && \text{for cruciform tails} \quad , \\
F_{FIN} &= 0.293 && \text{for X-form tails} \quad , \\
F_{FIN} &= 0.500 && \text{for inverted-Y tails} \quad .
\end{aligned} \tag{73}
$$

The longitudinal distance from the nacelle landing gear to the corner of the lower fins is close to 0.48 times envelope length (from scaling of sketches). In terms of a gear distance factor F_{GR} , giving the fraction of envelope length L :

$$F_{GR} = 0.48 \tag{74}$$

Then, using L_{GRC} and h_{DK} to obtain envelope height above the ground:

$$\theta_{MX} = \tan^{-1}(L_{GRC} + h_{DK} + 0.5F_{FIN}D)/F_{GR}L) \quad . \tag{75}$$

When θ is given, and is greater than θ_{MX} , this equation can be written as an expression for the required value for L_{GRC} , as shown below.

The takeoff angle of attack α_{TO} should be less than θ_{MX} by at least an angle margin α_{MRG} to avoid impact of the lower fins on the ground. A standard value of 3 degrees margin is selected on the basis of the aerodynamic lift data for the ZPG-3W blimp. The maximum takeoff angle of attack α_{TOMX} is θ_{MX} minus α_{MRG} :

$$
\begin{aligned}
\alpha_{MRG} &= 3 \text{ degrees} \\
\alpha_{TOMX} &= \text{Max}(\theta_{MX} - \alpha_{MRG} \, , \, 0) \quad .
\end{aligned} \tag{76}
$$

If α_{TOMX} is negative, it is set equal to zero, decreasing the margin.

The logic steps for these calculations can now be shown. It is defined that if the specified takeoff angle of attack α_{TOS} is zero, an approximate optimum takeoff angle of attack equal to α_{TOMX} is to be used. Otherwise, α_{TO} is to be equal to α_{TOS} . The steps are as follows:

(1) $L_{GRC} = C_{ABV} + D_P + C_{GRD} - h_{DK}$

$L_{GRN} = C_{GRD} + 0.5(D_P - D_N)$

(2) If $L_{GRC} \geq C_{GRD}$, Go to (3).

$L_{GRC} = C_{GRD}$

$L_{GRN} = h_{DK} + C_{GRD} - (C_{ABV} + 0.5(D_P + D_N))$

(3) $\theta_{MX} = \tan^{-1}((L_{GRC} + h_{CR} + 0.5F_{FIN}D) / F_{GR}L)$

$\alpha_{TOMX} = \mathrm{Max}(\theta_{MX} - \alpha_{MRG}, 0)$

(4) If $\alpha_{TOS} = 0$, Go to (7). (77)

(5) If $\alpha_{TOS} \leq \alpha_{TOMX}$, Go to (6).

$L_{GRC} = F_{GR}L \tan(\alpha_{TOS} + \alpha_{MRG}) - 0.5F_{FIN}D - h_{DK}$

$L_{GRN} = h_{DK} + L_{GRC} - (C_{ABV} + 0.5(D_P + D_N))$

(6) $\alpha_{TO} = \alpha_{TOS}$, Go to (8).

(7) $\alpha_{TO} = \alpha_{TOMX}$

(8) Calculation completed.

Bicycle landing gear for blimps or dirigibles can be approximated as follows. It is assumed that blimp propellers require a ground clearance C_{GRD} , that dirigible propeller disks are no lower than the bottom of the envelope, and that a dirigible envelope clearance equal to C_{GRD} is required.

$$L_{GRC} = \mathrm{Max}\,(C_{ABV} + D_P + C_{GRD} - h_{DK}\ ,\ C_{GRD})\ ,\ \text{blimps}$$

$$L_{GRC} = C_{GRD}\ ,\ \text{dirigibles}$$

$$\theta_{MX} = \tan^{-1}\left((L_{GRC} + 0.5F_{FIN}D)\,/F_{GR}L \right) \qquad (78)$$

$$\alpha_{TOMX} = \mathrm{Max}\,(\theta_{MX} - \alpha_{MRG}\ ,\ 0)\ .$$

The logic steps proceed as for the tricycle landing gear:

(1) If $\alpha_{TOS} = 0$, Go to (4).

(2) If $\alpha_{TOS} \leq \alpha_{TOMX}$, Go to (3).

$$L_{GRC} = F_{GR}L \tan(\alpha_{TOS} + \alpha_{MRG}) - 0.5F_{FIN}D \qquad (79)$$

(3) $\alpha_{TO} = \alpha_{TOS}$, Go to (5).

(4) $\alpha_{TO} = \alpha_{TOMX}$

(5) Calculation completed.

The frontal area A_{GRF} of fixed (nonretractable) landing gear is the sum of contributions for each unit of the gear. The frontal width of each unit is assumed to be proportional to its length for limiting the bending moment and structural weight due to lateral loads. From scaled sketches, a width of 0.05 times length is selected. Then the frontal areas are:

$$A_{GRF} = 0.05\,(L_{GRC}^2 + 2L_{GRN}^2)\ ,\ \text{tricycle gear}\ ;$$

$$A_{GRF} = 0.05L_{GRC}^2\ ,\ \text{bicycle gear}\ . \qquad (80)$$

4. AERODYNAMIC DRAG AND LIFT

This chapter considers the aerodynamic forces on an airship. The estimation of zero-lift drag is considered first. This is followed by an analysis of aerodynamic lift, the lift drag that results from the lift, and the aerodynamic pitching moment. Deflection of elevators to hold the airship at a desired angle of attack, which requires a zero pitching moment at that angle of attack, leads to a so-called "trim drag." This effect is included implicitly rather than separately. Finally, the aerodynamic-gust structural moment that occurs when the airship encounters an atmospheric wind gust is considered for later use in estimating structural weights.

The drag, lift, and pitching moment are estimated in terms of conventional coefficients. The hull (envelope) wetted area A_{WH} is used as the reference area for most of these coefficients.

ZERO-LIFT DRAG

The zero-lift drag of an airship consists of friction, profile, and separation drag contributions by the hull (envelope), tail, car, propulsion nacelles, outriggers, and landing gear. Estimates for these contributions are presented in this section.

The drag coefficient C_D for a drag $\mathcal{D}$ is defined in terms of air mass density ρ, flight speed V, and a reference area A_R as:

$$C_D = \mathcal{D}/0.5\rho V^2 A_R \quad . \tag{81}$$

The reference area used for each drag contribution is defined below. The overall zero-lift drag coefficient C_{D0} is referred to hull wetted area A_{WH}, so each contribution is multiplied by A_R/A_{WH} to convert to the A_{WH} reference area.

The friction drag is important itself. The profile and separation drag appear to be closely proportional to the friction drag of the hull, tail, and nacelles. Therefore, friction drag in general is considered first. The Reynolds number R_N is defined in terms of the air mass density ρ, flight speed V, component length L_C, and air viscosity μ, as:

$$R_N = \rho V L_C/\mu \quad . \tag{82}$$

The friction drag coefficient C_{DF} for a component is defined in terms of the drag $\mathcal{D}$, and wetted area A_W by:

$$C_{DF} = \mathcal{D}/((1/2)\ \rho V^2 A_W) \quad . \tag{83}$$

It is important to use consistent units such that R_N and C_{DF} have no dimensions.

The friction drag coefficient is principally a function of Reynolds number, but the nature (laminar or turbulent) of the boundary layer and the nature (smooth or rough) of the surface of the component are also important parameters. For large Reynolds numbers (greater than about 1 million) the boundary layer is expected to be turbulent (reference 2). Airships satisfy this constraint except at extremely low speeds or large altitudes. An accepted equation for the turbulent boundary layer friction drag coefficient on smooth flat plates is the Karman equation, also called the Schoenherr equation (Schlichting, page 439, reference 20):

$$1/\sqrt{C_{DF}} = 4.13 \log (C_{DF} R_N) \quad . \tag{84}$$

Iteration is required to solve for C_{DF} . A simple power law is used here to start the iteration process.

$$C_{DF} = 0.028/R_N^{.14} \quad . \tag{85}$$

The variations of C_{DF} for smooth surfaces, according to the above two equations, is shown in figure 37.

The wetted surfaces of airships are not aerodynamically smooth solid surfaces. Theoretical calculations from Schlichting, page 448 (reference 20), for sand roughness of height k_S in a flat plate turbulent boundary were used as data. Some points were read from the figure of calculated results, and were reduced by 4 percent to match their zero roughness curve to equation (84) here. These are shown as solid circles in figure 37.

The approach used by Colebrook (reference in Handbook for Mechanical Engineers, 1967, page 3-59 (reference 4) for roughness in pipe flow was used to obtain a generalization of equation (84) including roughness. After fitting the asymtotic C_{DF} as a function of L_c/k_S in the form of equation (84), interpolation terms were added, giving:

$$\frac{1}{\sqrt{C_{DF}}} = -4.13 \log \frac{1}{C_{DF} R_N} + \frac{0.86/(L_c/k_S)^{0.86}}{1+80\,(\sqrt{C_{DF}}\,(L_c/k_S)/C_{DF} R_N)^{1.5}} \quad . \qquad (86)$$

Lines calculated from this equation are shown in figure 37.

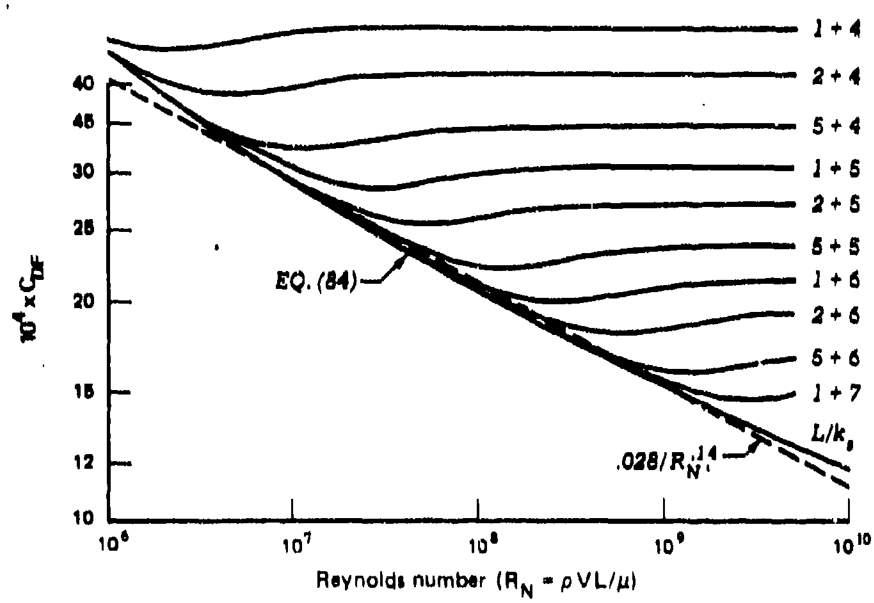

FIG. 37: FRICTION DRAG COEFFICIENT VARIATION

A standard method for selecting effective sand-grain height corresponding to the experimental uniform covering condition does not exist. The roughness height is treated as a parameter in this model. An appropriate value for airship surfaces appears to be 0.005 inch. The resulting roughness friction increment is 0.0004 to 0.0005 for the envelope and 0.0007 to 0.0008 for the fins.

Hull (Envelope)

A standard method for estimating the zero-lift drag coefficient C_{DH} based on hull wetted area, for a body of revolution in terms of its friction drag coefficient C_{DFH}, from Hoerner (pp. 6-17, reference 15), is:

$$C_{DH} = C_{DFH}(1 + 1.5/(L/D)^{1.5} + 7/(L/D)^{3}) \quad . \tag{87}$$

Several of the bodies on which this empirical relation is based were bare airship hulls. The component length for the hull Reynolds number is the envelope length L.

Tail Drag Coefficient

For airfoil-type sections, Hoerner (p. 6-6, reference 15) gives a similar equation in terms of the thickness-chord ratio $(t/c)_F$ of the fins. For wetted tail area A_{WT}, the fin drag coefficient C_{DF} is:

$$C_{DT} = C_{DFT}(1 + 2\,(t/c)_F + 60\,(t/c)_F^4)\,(A_{TW}/A_{WH}) \quad . \tag{88}$$

Here, the reference area for C_{DF} is the hull wetted area A_{WH}. The friction drag coefficient is to be calculated on the basis of the average tail fin chord c_F.

A cable drag contribution must be included for blimps. The bases of the fins of blimps are attached to the envelope material. The fins are braced by diagonal lateral cables attached to the envelope. The diameter of these cables is about 1/8 inch. Their Reynolds number (based on diameter) is subcritical and their drag coefficient based on frontal area is close to unity (Hoerner, pp. 3-9, 4-5, 13-20, reference 15). Several small-diameter cables must be used to distribute the lateral load on the fin to the envelope. The load on the cables is proportional to the side force on the fin from gust loading. The cross-sectional area and number of cables are also proportional to the side force. The frontal area A_{CBLF} of the cables is proportional to their diameter and to fin exposed span b_F. Substituting estimates for the parameters in this simple approximation indicates that:

$$A_{CBLF} \simeq 6\text{x}10^{-4} b_F \sqrt{u_{GD} V A_T} \quad , \tag{89}$$

where u_{GD} is the design gust velocity. For blimps, a cable drag coefficient C_{DCBL} is then:

$$C_{DCBL} = 1(A_{CBLF}/A_{WH}) \text{ , blimps } . \tag{90}$$

The tail structure of dirigibles is usually integral with the hull structure near the stern, often with an integral carry-through structure from one fin to the opposite one. Cable support was not used historically, so C_{DCBL} is zero for such dirigibles. However, an aerodynamic interference drag is associated with the intersection of a fin and a body. Hoerner's data (pp. 8-10, 13-16 of reference 15) indicate that the interference drag coefficient C_{DTIN} based on thickness t squared is approximately equal to t/c for each fin. Writing $t^2(t/c)$ as $(t/c)^3c^2$ gives:

$$C_{DTIN} = 4(t/c)_F^3 c_F^2/A_{WH} \text{ , cruciform, X-form } .$$

$$C_{DTIN} = 3(t/c)_F^3 c_F^2/A_{WH} \text{ , inverted-Y } . \tag{91}$$

The interference drag is small for the small $(t/c)_F$ values for blimps. However, for dirigibles it is of the same magnitude as the cable drag for blimps.

Car Drag Coefficient

Hoerner also presents data for the drag coefficient C_{DX} of several canopy and turret shapes. This drag coefficient is based on cross-section area of the canopy (Hoerner, pp. 8-4, 13-2, 15-30, reference 15). These canopies approximate the shape and size of blimp cars relative to the main body. The incremental drag coefficients C_{DX} vary from 0.05 to 0.15 for various shapes. Airship cars are fairly blunt and are unlikely to attain the lower values. In terms of the car frontal area A_{CRF} the car drag coefficient C_{DCR} is estimated as:

$$C_{DCR} = C_{DX}(A_{CRF}/A_{WH}) \text{ , } C_{DX} = 0.10 \quad . \tag{92}$$

Wind tunnel tests of the Akron dirigible (NACA Report 432, page 598, reference 16) showed a "less than 3 percent of bare hull" drag for the car. This percentage appears to correspond to C_{DX} between 0.10 and 0.15.

Propulsion Nacelle Drag Coefficient

Propulsion nacelles can be approximated as bodies of revolution. The drag of propulsion nacelles consists of ah external drag and internal drag contribution, the latter associated with cooling air for an engine nacelle. The resultant nacelle frontal area A_{FNC} (from chapter 3) is used as a drag coefficient reference area.

The external drag coefficient based on frontal area for bodies of revolution can be approximated from equation (87) for the hull by multiplying the L/D function by 3(L/D). The nacelle external drag coefficient C_{DNCE} for each nacelle is:

$$C_{DNCE} = C_{DFN} [3(L/D)_N + 4.5/(L/D)_N^{1/2} + 21/(L/D)_N^2] (A_{NCF}/A_{WH}) \quad . \tag{94}$$

The component length for the nacelle Reynolds number is the nacelle length L_{NC}. The ratio C_{DNCE}/C_{DFN}, ignoring the A_{NCE}/A_{WH} factor, is shown in figure 38 as a function of $(L/D)_N$. The figure includes a dashed line indicating the influence of decreasing C_{DFN} with increasing L, on the assumption that C_{DFN} is proportional to $L^{-0.14}$. The minimum drag coefficient occurs for L/D about 2.5 to 3.0. For L/D between 2.0 and 4.0 the curves are quite flat.

The internal drag coefficient C_{DNCI} for propulsion nacelles requiring cooling air can also be based on nacelle frontal area. C_{DNCI} varies with engine power, flight speed, and engine installation (Hoerner, pp. 9-5 to 9, 13-7, reference 15). However, a moderately low constant value of 0.05 is selected:

$$C_{DNCI} = 0.05(A_{NCF}/A_{WH}) \quad . \tag{95}$$

Outrigger Drag Coefficient

Outriggers are used to support engine nacelles at some distance from the car of a blimp or the envelope of a dirigible, at a distance to provide clearance between the propeller disk and the airship structure. Chapter 3 discusses outriggers of open-frame tubular, covered tubular, and cantilever pylon types. Outrigger frontal area A_{OUTF} is also estimated in chapter 3. For the open-frame tubular type the drag coefficient based on frontal area is selected as unity. This takes into account possible low Reynolds numbers, interference drag at tube connections, and the increased airspeed and rotation of the propeller slipstream. Then the outrigger drag coefficient C_{DOUT} contribution is:

$$C_{DOUT} = 1.0\,(A_{OUTF}/A_{WH}) \text{ , open-frame tubular} \qquad (96)$$

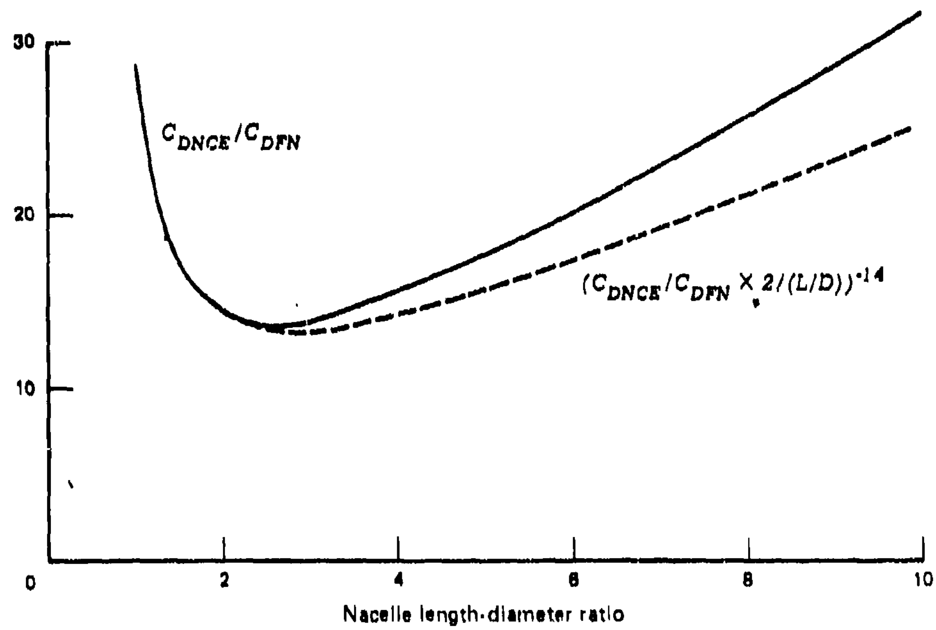

FIG. 38: INFLUENCE OF NACELLE L/D

For covered tubular and cantilever pylon types the drag coefficient based on frontal area can be obtained by multiplying the $(t/c)_F$ function in equation (88) for the fin drag coefficient by $1/(t/c)_F$:

$$C_{DOUT} = C_{DFOUT}\left[1/(t/c)_{OUT} + 2 + 60\,(t/c)^3_{OUT}\right](A_{OUTF}/A_{WH}) \quad . \qquad (97)$$

The component length for the outrigger Reynolds number is the outstanding chord c_{OUT} . The ratio C_{DOUT}/C_{DFOUT} , ignoring the A_{OUTF}/A_{WH} factor, is shown in figure 39 as a function of $(t/c)_{OUT}$. The figure includes a dashed line indicating the influence of decreasing C_{DFOUT} with increasing chord, on the assumption that C_{DFOUT} is proportional to $c^{-0.14}$. The minimum drag coefficient occurs near a $(t/c)_{OUT}$ of 0.25, but the curves are quite flat for $(t/c)_{OUT}$ between 0.2 and 0.35. A standard value of 0.25 for $(t/c)_{OUT}$ is selected in chapter 3 on the basis of this drag coefficient minimum.

Each end of the members of covered tubular or cantilever pylon outriggers produces an interference drag. It can be estimated by the relation for fins that was used above for equation (91). Covered tubular outriggers have eight ends. Cantilever pylon outriggers have four ends. Thus, the outrigger interference drag coefficient is:

$$C_{DOUTI} = 8\,(t/c)^3_{OUT}\,c^2_{OUT}/A_{WH}\ , \text{ covered tubular} \ ;$$
$$C_{DOUTI} = 4\,(t/c)^2_{OUT}\,c^2_{OUT}/A_{WH}\ , \text{ cantilever pylon} \ . \qquad (98)$$

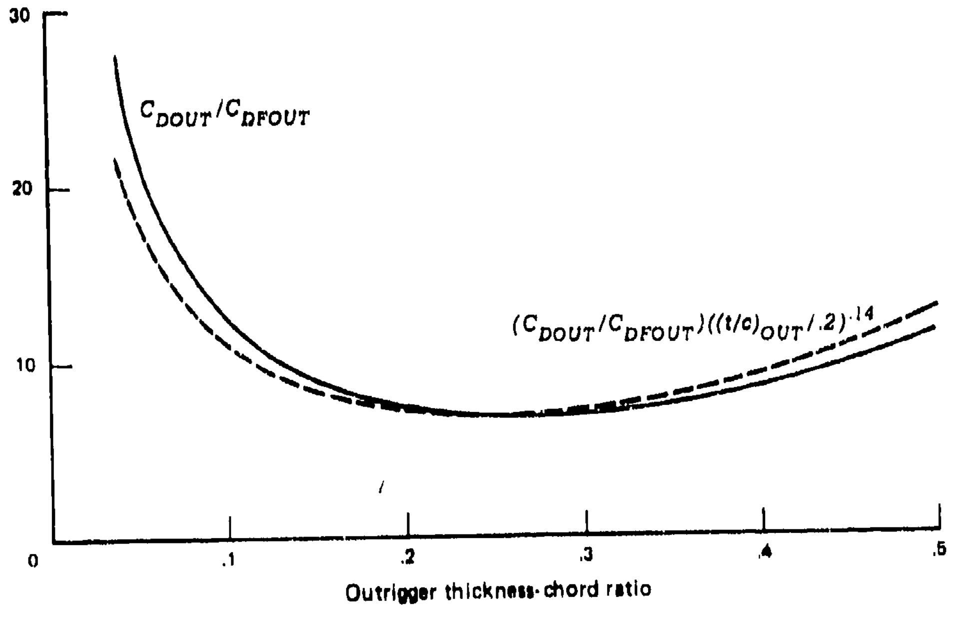

FIG. 39: INFLUENCE OF OUTRIGGER, t/c

Landing Gear Drag Coefficient

Landing gear drag is considered in this model only when fixed (nonretractable) landing gear are specified. The landing gear frontal area A_{GRF} is estimated in chapter 3. A drag coefficient on frontal area of unity is selected. This increase beyond a value (0.75) for elongated cylinders is intended to account for protuberances (including tires) and the increased airspeed and rotation of the propeller slipstream. The landing gear drag coefficient C_{DGR} then becomes:

$$C_{DGR} = 1.0 \, (A_{GRF}/A_{WH}) \, , \quad \text{fixed landing gear.} \qquad (98)$$

Other Airship Drag Estimation Data

The information in table 13 on airship drag contributions is given by Goodyear, Vol. IV, p. E-4 (reference 8). For dirigibles, the percent of drag contribution attributed to these components is about half that for blimps.

TABLE 13

DRAG CONTRIBUTION (PERCENT OF HULL DRAG)

Component	Blimps	Dirigibles
Fins	33.	16.7
Car	11.5	(a)
Engine, outrigger	14.	10.
Miscellaneous	5.	5.
	63.5	31.7

(a) 20 square feet flat plate drag area.

The data in table 13 were used for checking the detailed estimates for early airships.

AERODYNAMIC LIFT

Aerodynamic lift is produced when the hull of an airship is inclined at an angle of attack α to the direction of motion. An associated drag is also produced. Control surface drag or trim drag also results.

Body (hull) aerodynamic lift is rather small for bodies of revolution. Approximately half the aerodynamic lift of an airship is associated with the tail (fin) surfaces. In addition, both the body lift and the tail lift are quadratic in angle of attack. Conceptual estimation of airship dynamic lift and induced drag must include these characteristics.

The analysis here is based on wind tunnel data for a large model of the U.S. Navy dirigible Akron. The data are tabulated in NACA Report 432 (reference 18). Wind tunnel data for several small-model airships from NACA Report 394 (reference 17) were also used. The largest dynamic pressure data were used. In terms of the lift $\mathcal{L}$ and the lift drag D_L, the lift coefficient C_L, and lift-induced drag coefficient C_{DL} are defined with $\nabla_E^{2/3}$ as the reference area as:

$$C_L = \mathcal{L}/0.5\rho V^2 \nabla_E^{2/3} \quad ;$$

$$C_{DL} = D_L/0.5\, \rho V^2 \nabla_E^{2/3} \quad . \tag{99}$$

The variation of the lift coefficient with zero elevator deflection is shown in figure 40 as a function of angle of attack α in degrees for the Akron body alone (C_{LB}) and for the body plus tail configurations 1 and 2 (C_{L0BT1} and C_{L0BT2}). Control car and engine installations were not included. The variation is not linear. The tails more than double the lift coefficient, but there is little difference between the tail 1 and tail 2 cases. The associated C_{L0}/α^o ratios are shown in figure 41. The points indicate a linear variation. Hence, with constants a and b, $C_{L0} = a\,\alpha^o + b\,\alpha^{o2}$ applies. The constants for the 3 cases can be read from the figure and converted to radian α form to obtain:

$$C_{LB} = 0.1604\alpha + 1.0505\alpha^2 \quad ;$$

$$C_{L0BT1} = 0.5730\alpha + 1.6742\alpha^2 \quad ; \tag{100}$$

$$C_{L0BT2} = 0.6073\alpha + 1.6085\alpha^2 \quad .$$

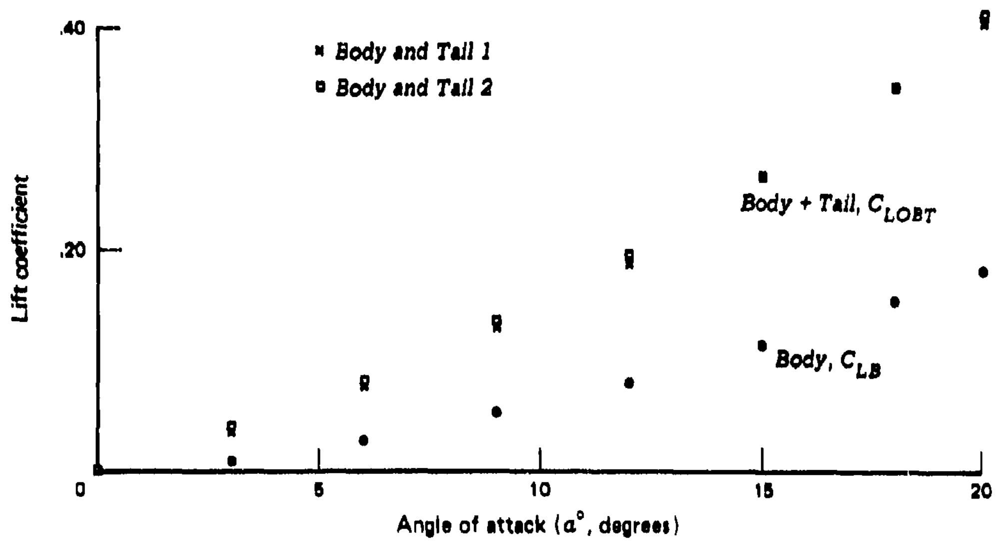

FIG. 40: AKRON ZERO-ELEVATOR LIFT COEFFICIENT

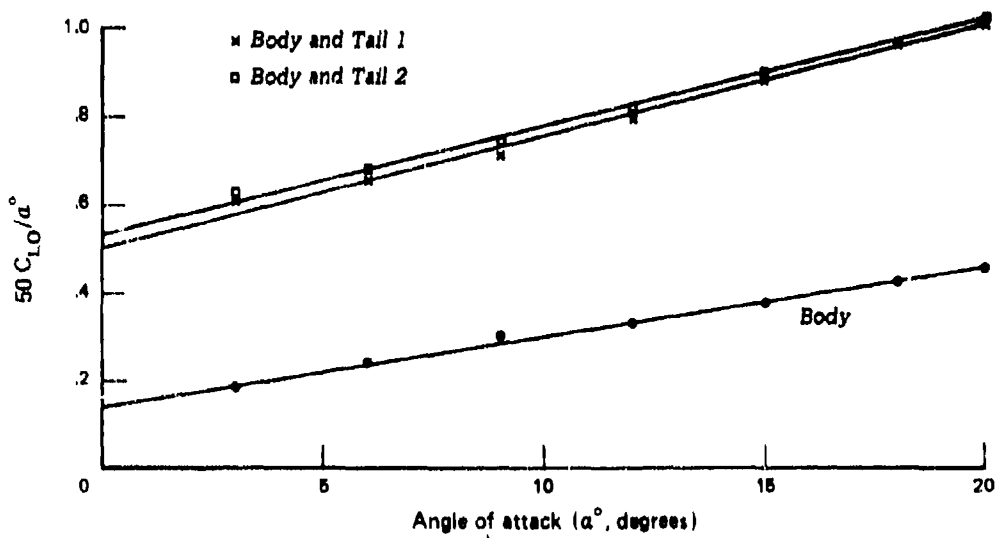

FIG. 41: AKRON $C_{LO}/\alpha°$, RATIOS

It is now assumed that the "tail" lift coefficients C_{LOT1} and C_{LOT2}, including interaction with the body flow, can be approximated by subtracting C_{LOB} from the respective body tail equations giving:

$$C_{LOT1} = 0.4125\alpha + 0.6237\alpha^2 \quad ;$$
$$C_{LOT2} = 0.4469\alpha + 0.5581\alpha^2 \quad . \qquad (101)$$

It is desired to be able to estimate the coefficients in equations (100) and (101) as functions of hull and tail geometry and areas.

The geometry data for the Akron wind tunnel model is shown in table 14. The Akron model hull L/D ratio was 5.92 and its prismatic coefficient C_p was 0.678. For reasonable airship hull shapes and C_p values, hull lift probably would not change much. Data for bare hull lift coefficient of small models (about 2 to 4 feet) with several L/D ratios for those cases where the lift at zero angle of attack was relatively close to zero are from graphs in NACA Report 394. These data are shown in figure 42. The line in the figure is for the Akron model according to equation (100). The dispersion of the points appears to be experimental scatter. There is no trend of variation from the Akron line with change of L/D.

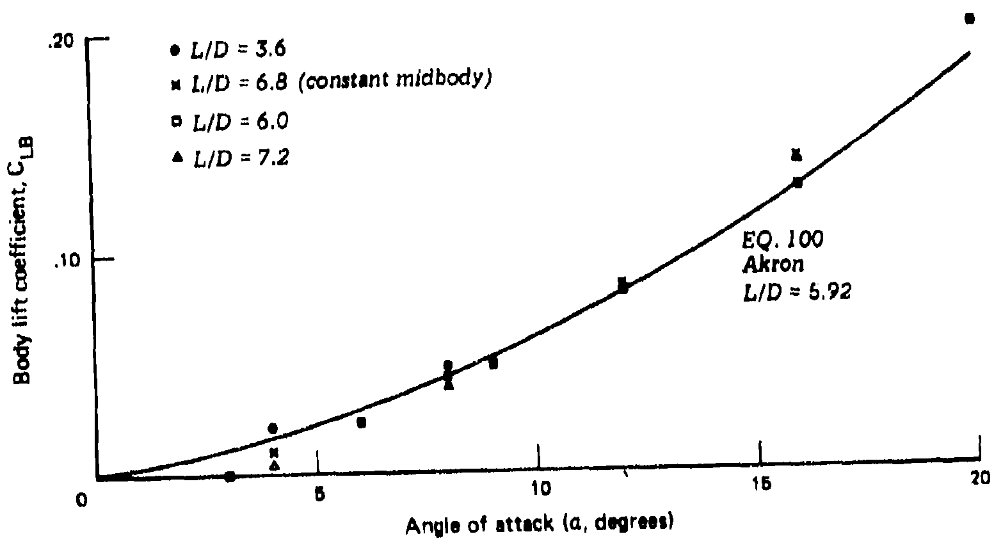

FIG. 42: SMALL-MODEL BODY LIFT COEFFICIENT

TABLE 14

GEOMETRY DATA FOR 1/40-SCALE AKRON MODEL

Hull			Tail 1	Tail 2
Length (ft.)	19.62	A_{HT} (sq.ft.)	5.074	4.590
Diameter (ft.)	3.32	b_F (ft.)	.972	1.041
Volume (cu.ft.)	115.	$4b_F^2/A_{HT}$	.745	.953
L/D	5.92	$2\pi b_F^2/A_{HT}$	1.170	1.497
C_P	.678	A_{EL}/A_{HT}	.198	.203
Center of buoyancy/L	464	ElevAxis/L	.909	.906

On this basis, equation (100) is selected for estimating the body lift coefficient C_{LB} for any L/D and C_P.

Before investigating the influence of tail geometry in detail, it is desirable to use the small-model data to consider possible overall effects on the zero elevator body tail lift coefficient. These models had tail fins and control cars (of 2 sizes) on the hull. The data, read from graphs, are shown here in figure 43, which includes the line for the Akron model with tail 1, according to equation (100). It is apparent that there is a strong influence associated with the variation of hull length-diameter ratio L/D. From the C_{LB} comparison in figure 40, the influence is not due to body L/D directly. It may be due to tail characteristics, but the size and shape of the tails are not included in NACA Report 394.

It is convenient to use substitute symbols for the coefficients in equation (101):

$$C_{LOT} = a_{LT}\alpha + b_{LT}\alpha^2 \quad . \tag{102}$$

These new coefficients are to be estimated in terms of geometric characteristics of the airship.

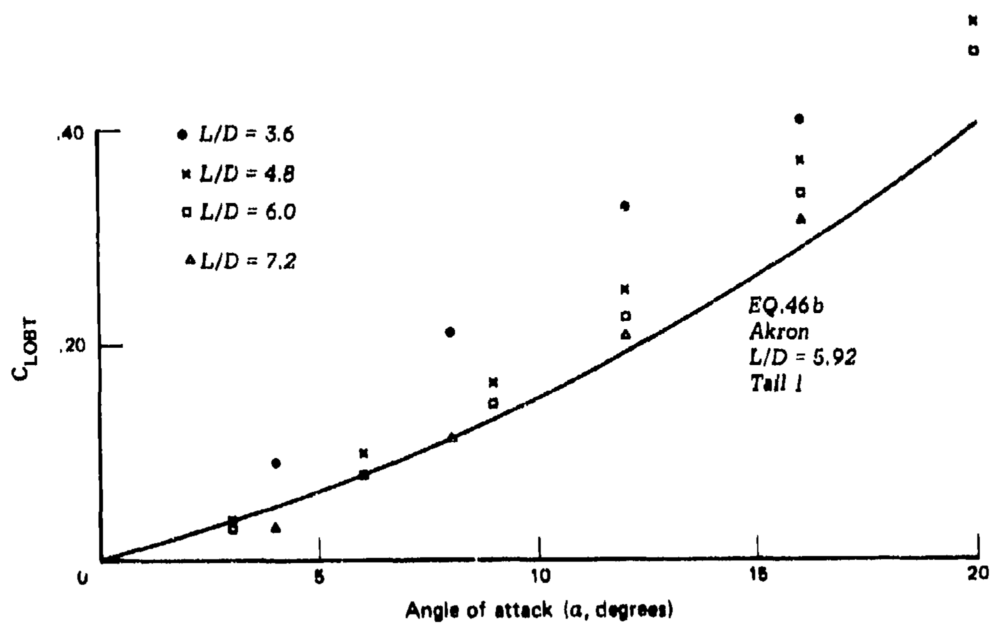

FIG. 43: SMALL-MODEL ZERO-ELEVATOR LIFT COEFFICIENT

NACA Report 432 gives full specifications, including dimensional sketches, of the fins used as tail 1 and tail 2 on the Akron model. (Only the horizontal fins are considered here.) The horizontal tail area A_{HT} and platform were both changed. The areas are listed in table 14. Zero elevator tail lift coefficients C^*_{L0T} are based on horizontal tail area instead of $\nabla_E^{2/3}$. These can be obtained from equations (101). They are:

$$C^*_{L0T1} = 1.923\alpha + 2.907\alpha^2 \quad ;$$

$$C^*_{L0T2} = 2.302\alpha + 2.875\alpha^2 \quad . \tag{103}$$

Theoretically, for isolated small aspect ratio AR wings, the first coefficient would be $0.5\pi AR$. Table 14 shows the maximum exposed horizontal fin span b_F and $4b_F^2/A_{HT}$ as the aspect ratio. The calculated $0.5\pi AR$ values are also shown in table 14. The coefficients of α in equations (103) are 1.64 and 1.54 times as large. A constant factor of 1.6 is selected and included as a wing-body interaction term. Then:

$$a_{LT} = 1.6\,(0.5\,\pi AR)\,A_{HT}/\nabla_E^{2/3} \quad . \tag{104}$$

The interaction factor of 1.6 was assumed to apply also to the coefficient of the α^2 term. This reduces the remaining constants to 1.817 and 1.797. The theory for aspect ratio approaching zero indicates that a lift coefficient term would be $2\alpha^2$. Hoerner (page 7-18, reference 15) found from experimental data that the coefficient of α^2 approaches zero at zero AR. He also found that for round-edged wings the coefficient increases to about 2 near AR of unity, and then decreases. Some of Hoerner's points are shown in figure 44 with an approximation line. Using the equation for the line:

$$b_{LT} = 1.6\,(4\sqrt{AR}\,\exp(0.82\,AR))\,A_{HT}/\nabla_E^{2/3} \quad . \tag{105}$$

Using equations (102), (104), and (105), the calculated tail lift coefficients for the Akron models are:

$$C_{L0T1} = 0.402\alpha + 0.644\alpha^2 \text{, calculated Akron, tail 1} \quad ;$$

$$C_{L0T2} = 0.465\alpha + 0.555\alpha^2 \text{, calculated Akron, tail 2} \quad . \tag{106}$$

Comparing the calculated coefficients for the Akron with the data values of equation (101) shows differences of -3 to 4 percent.

Data for the influence of elevator deflection δ_E (positive downward) are tabulated for the large-model Akron in NACA Report 432. Figures 45 and 46 show the ratio of the incremental elevator lift coefficient C_{LE} to δ_E^o as a function of angle of attack. There is considerable scatter, and positive and negative middle values of δ_E^o appear to be asymmetrical. The slopes are about the same. The intercepts are different in the same direction that the a_{LT} values vary (equation (101)). About 0.37 of a_{LT} is needed to match the intercepts in the figures. The lines in the figures are given in radians by:

$$C_{LE} = 0.37 a_{LT} \delta_E (1 + \alpha) \quad . \tag{107}$$

The lift coefficient estimation equations can now be summarized:

$$\begin{aligned}
C_L &= C_{LB} + C_{LOT} + C_{LE} \\
C_{LB} &= 0.160\alpha + 1.05\alpha^2 \\
C_{LOT} &= a_{LT}\alpha + b_{LT}\alpha^2 \\
a_{LT} &= 0.8\pi \mathit{AR}\ A_{HT}/\nabla_E^{2/3} \\
b_{LT} &= 6.4 \sqrt{\mathit{AR}}\ \exp(-.82\ \mathit{AR})\ A_{HT}/\nabla_E^{2/3} \\
C_{LE} &= 0.37 a_{LT} \delta_E (1 + \alpha)
\end{aligned} \tag{108}$$

AERODYNAMIC LIFT DRAG

Now the lift drag coefficient C_{DL} must be investigated. Data for the large-model Akron from NACA Report 432 were used. Because C_L is quadratic in α , the ratio C_{DL0}/α^{o2} was considered for the zero elevator case. Figure 47 shows the ratios as functions of α in degrees for the body alone and the two tail cases. The data points show significant scatter; the high point for tail 2 at 3 degrees was ignored.

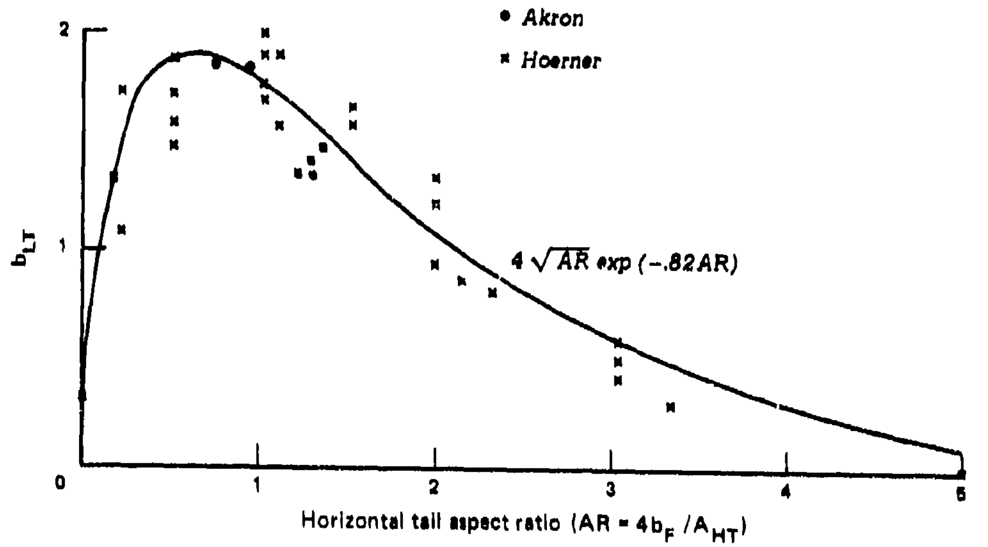

FIG. 44: VARIATION OF b_{LT}

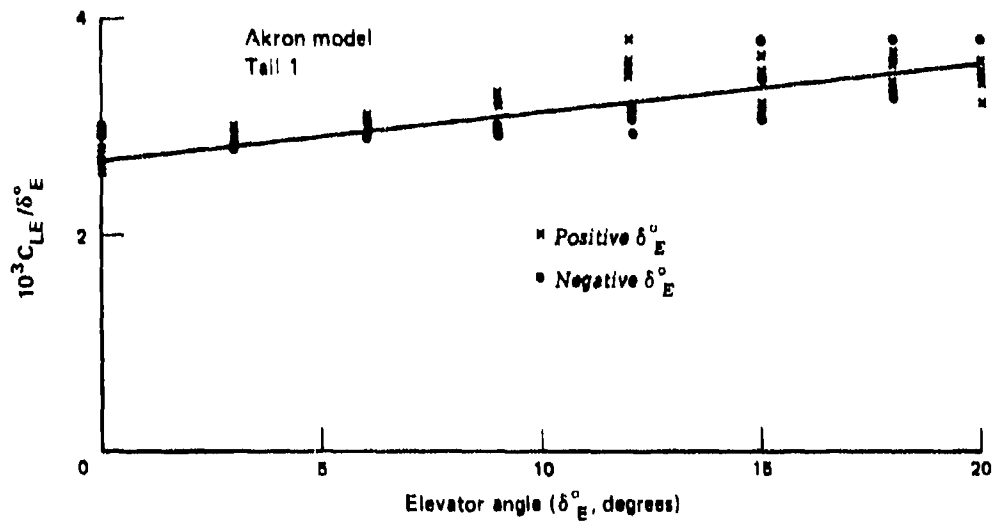

FIG. 45: VARIATION OF ELEVATOR LIFT COEFFICIENT

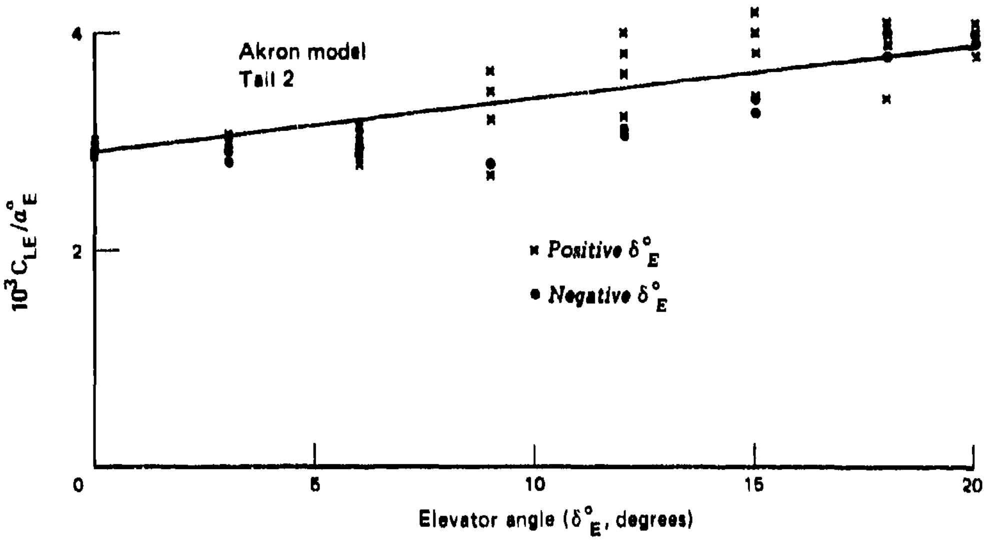

FIG. 46: VARIATION OF ELEVATOR LIFT COEFFICIENT

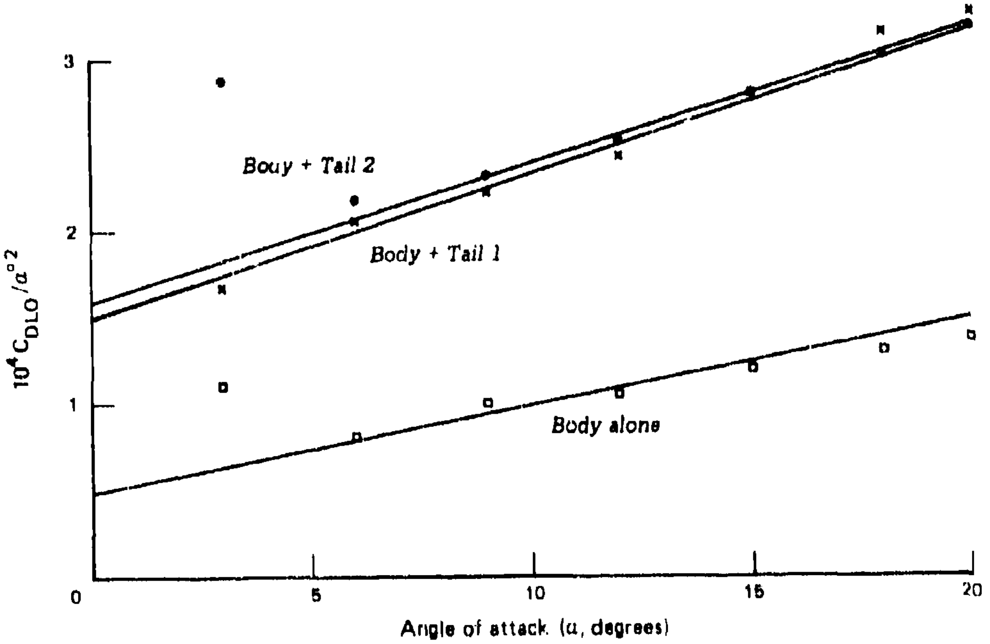

FIG. 47: AKRON MODEL $C_{DLO}/\alpha^{\circ 2}$ RATIO

Aerodynamic theory indicates that the linear lift term should lead to a quadratic drag term with, for isolated wings, half the coefficient. It also indicates that the quadratic lift term should lead to a cubic drag term with the same coefficient for isolated wings. Using the body alone lift coefficient data of equations (100) with coefficient ratios of unity and converting to the scales in figure 47 gives an intercept of 0.49 and slope of 0.056. A reasonable approximation for the coefficient can be obtained using this intercept, but the slope must be reduced by 10 percent. The line shown in the figure for the body alone is given in radians by:

$$C_{DLB} = 0.160\alpha^2 + 0.9\,(1.05)\alpha^3. \tag{109}$$

For the body tail cases, use of coefficient ratios of unity for the data tail contributions of equations (101), plus equation (109) for the body, gives intercept of 1.75 and 1.85 and slopes of 0.083 and 0.080. Reasonable approximations can be obtained with these slopes, but the tail contribution to the intercept was reduced for the lines shown in figure 47. Thus:

$$\begin{aligned} C_{DLOT1} &= 0.8\,(0.412)\,\alpha^2 + 0.624\alpha^3 \quad , \\ C_{DLOT2} &= 0.8\,(0.447)\,\alpha^2 + 0.558\alpha^3. \end{aligned} \tag{110}$$

The coefficient ratio for the first term may be greater than the theoretical 0.5 for isolated wings due to its location in the upward flow (upwash) around the aft section of the body.

The elevator incremental lift drag coefficient C_{DLE} can be obtained for the Akron model from the NACA Report 432 tabulations. If all the elevator incremental lift associated with C_{LE} were produced on the elevator surface, without interaction lift, then C_{DLE} would be expected to be close to $C_{LE}(\delta_E + \alpha)$ because $\delta_E + \alpha$ is the inclination of the elevator. With C_{LE} proportional to $\delta_E(1 + \alpha)$ in equation (107), several product terms appear. However, only the simple proportionality to C_{LE} was considered. Figures 48 and 49 show the ratio $C_{DLE}/\delta_E^o(1 + \alpha)$ as a function of α in degrees for constant δ_E^o. The trends with α and δ_E are clear but not completely smooth. There appears to be a gap around δ_E equal zero. However, reasonable approximation is provided by the assumed equation form, with different constants for δ_E and α.

$$C_{DLE} = C_{LE}\,(0.5\,\delta_E + 1.3\alpha) \quad . \tag{111}$$

Lines are shown in figures 48 and 49 according to this equation, for δ^o_E equal -20, -10, 0, 10, and 20 degrees.

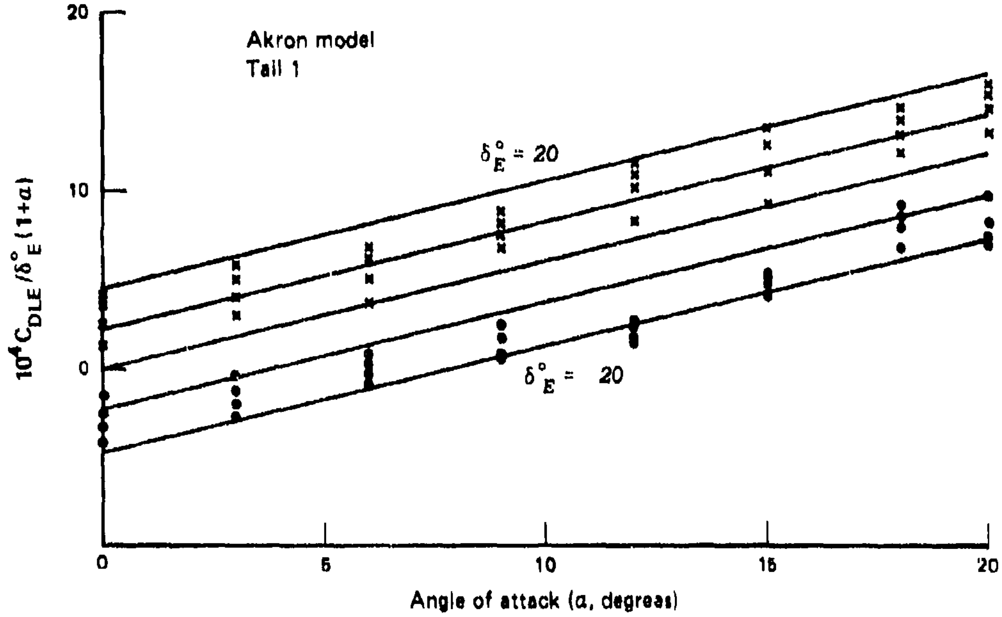

FIG. 48: ELEVATOR LIFT DRAG COEFFICIENT

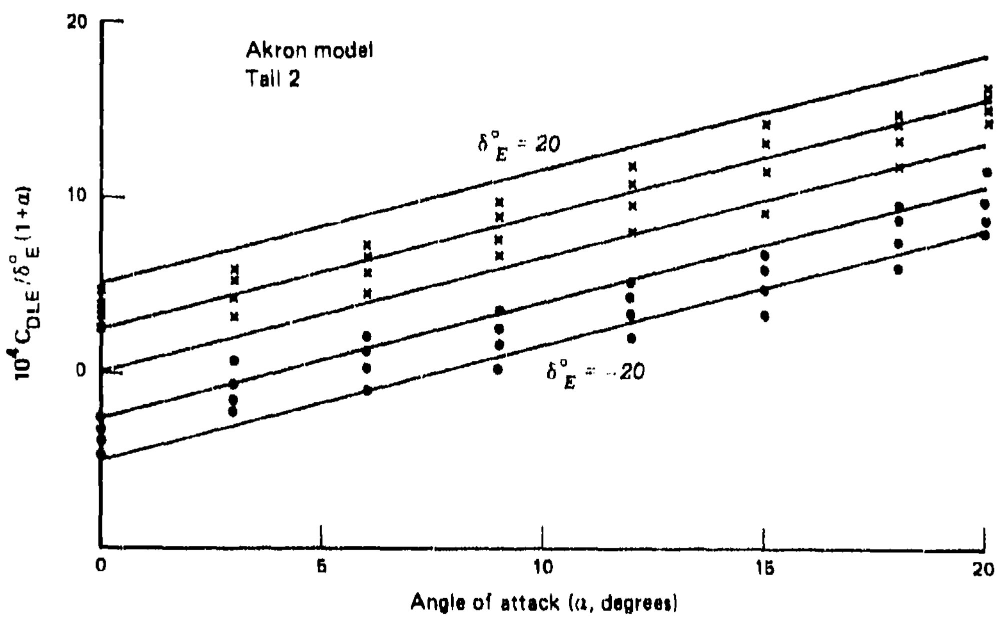

FIG. 49: ELEVATOR LIFT DRAG COEFFICIENT

The estimation equations for the lift drag coefficient can now be summarized:

$$C_{DL} = C_{DLB} + C_{DLOT} + C_{DLE}$$

$$C_{DLB} = 0.160\alpha + 0.945\alpha^2 \qquad (112)$$

$$C_{DLOT} = 0.8a_{LT}\alpha^2 + b_{LT}\alpha^3$$

$$C_{DLE} = C_{LE}\,(0.8\,\delta_E + 1.6\alpha)$$

AERODYNAMIC PITCHING MOMENT

The elevator angle to be used in the aerodynamic lift and lift drag coefficient equations is determined by pitching moment conditions. The moment coefficient C_M analogous to the lift and drag coefficients (equations (99)) is defined in terms of the pitching moment M positive bow up, about the center of buoyancy by:

$$C_M = M/0.5\,\pi V^2 \nabla_E \quad . \qquad (113)$$

Figure 50 shows the variation of the body moment coefficient C_{MB} for the Akron model body alone as a function of angle of attack. The line in the figure is given by:

$$C_{MB} = 1.55\alpha - 1.40\alpha^2 \quad . \qquad (114)$$

The small-model graphical data of NACA Report 394 (reference 17) was used to investigate the influence of length-diameter L/D ratio on the coefficients in equation (114). After converting to C_{MB} as defined here, comparison indicated no influence of L/D.

When tail surfaces are added to the body, the lift of the horizontal tail produces a negative pitching moment due to its moment arm fL , where f is a fraction of hull length L. However, it was found previously that the lift interaction factors were necessary to correlate with the experimental data. Some of the interaction lift may be produced on the body at moment arms other than that of the elevator. Therefore, factors ϕ_1 , ϕ_2 , and ϕ_E are included in writing the following forms for the moment coefficient:

$$C_M = C_{MB} - fLA_{HT}\,(C^*_{LT} + C^*_{LE}/\nabla_E$$

$$C_M = C_{MB} - f(L/\nabla_E^{1/3})\,(\phi_1 a_{1t}\alpha + \phi_2 b_{LT}\alpha^2 + 0.37\phi_E a_{LT}\delta_E(1+\alpha) \qquad (115)$$

$$C_M = (1.55 - \phi_1 f(L/\nabla_E^{1/3})\,a_{LT})\alpha$$

$$- (1.40 + \phi_2 f(L/\nabla_E^{1/3})\,b_{LT})\alpha^2$$

$$- \phi_E f(L/\nabla_E^{1/3})\,0.37 a_{LT}\delta_E(1 - \alpha) \quad .$$

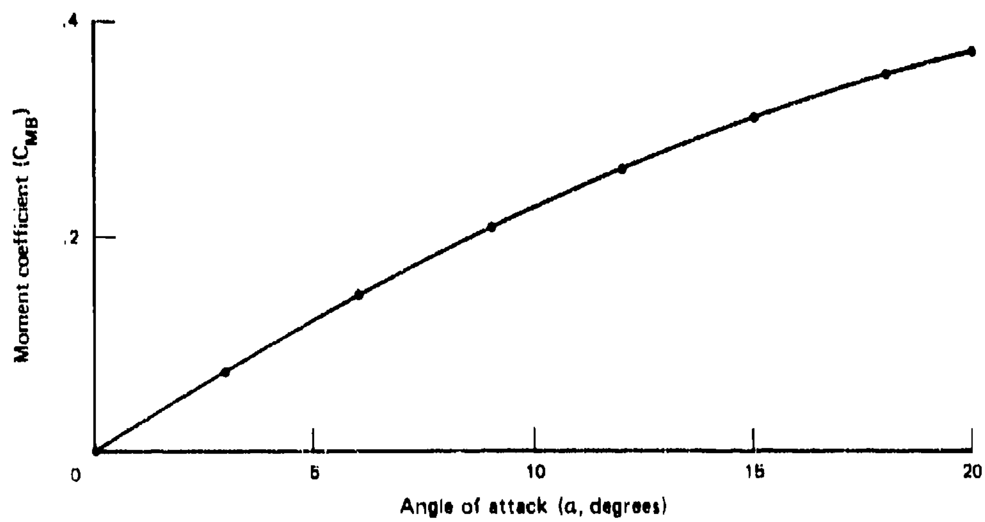

FIG. 50: AKRON BODY MOMENT COEFFICIENT

For the Akron model, table 14 shows the center of buoyancy at 0.464L and the elevator axis at 0.909L and 0.906L. Taking the difference as f, 0.445 and 0.442 are obtained, so $fL/\nabla_E^{1/3}$ was 1.795 and 1.783. Using the data values for a_{LT} and b_{LT} from equation (101) reduces equation (115) for the models to:

$$C_M = (1.55 - 0.704\phi_1)\alpha - (1.40 + 1.12\phi_2)\alpha^2$$

$$- 0.274\phi_E \delta_E (1 + \alpha) \quad \text{, tail 1} \qquad (116)$$

$$C_M = (1.53 - 0.797\phi_1)\alpha - (1.40 + 0.995\phi_2)\alpha^2$$

$$- 0.295\phi_E \delta_E (1 + \alpha) \quad \text{, tail 2} \quad .$$

The third term in these equations was correlated first. The ratio $(C_M(\delta_E = 0) - C_M)/\delta_E$ is shown in figures 51 and 52. There is considerable scatter, as was the case for the elevator lift coefficient (figures 45 and 46). For positive elevator deflections there is an upward trend with increasing α . The lines shown in the figures are the third terms in equations (116), with ϕ_E equal unity It is selected that ϕ_E be unity throughout this volume.

To correlate the first 2 terms the calculated estimate for the elevator was used. The variation of

$$(C_M + 0.274\,\delta_E\,(1 + \alpha))\,/\alpha^o \quad \text{, tail 1} \quad ;$$

$$(C_M + 0.295\,\delta_E\,(1 + \alpha))\,/\alpha^o \quad \text{, tail 2} \qquad (117)$$

is shown in figures 53 and 54. There is considerable scatter at low angles of attack, especially for tail 2. The slopes indicated by equation (116) with ϕ_2 equal unity are 2.52 and 2.395 in radians, or 0.768 and 0.730 in the units of the figures. Both slopes are reasonable for the data, so ϕ_2 is selected to be equal to unity. However, the estimated intercepts according to equation (116) with ϕ_2 equal unity are too low to fit the data. The approximation to the moment coefficient is quite sensitive to ϕ_1 . The lower aspect ratio tail 1 extends farther forward from the elevator hinge line, and a smaller ϕ_1 is needed. As a rough approximation:

$$\phi_1 = 0.82\,\sqrt{AR} \,. \qquad (118)$$

The lines shown in figures 53 and 54 are calculated using this equation for ϕ_1 .

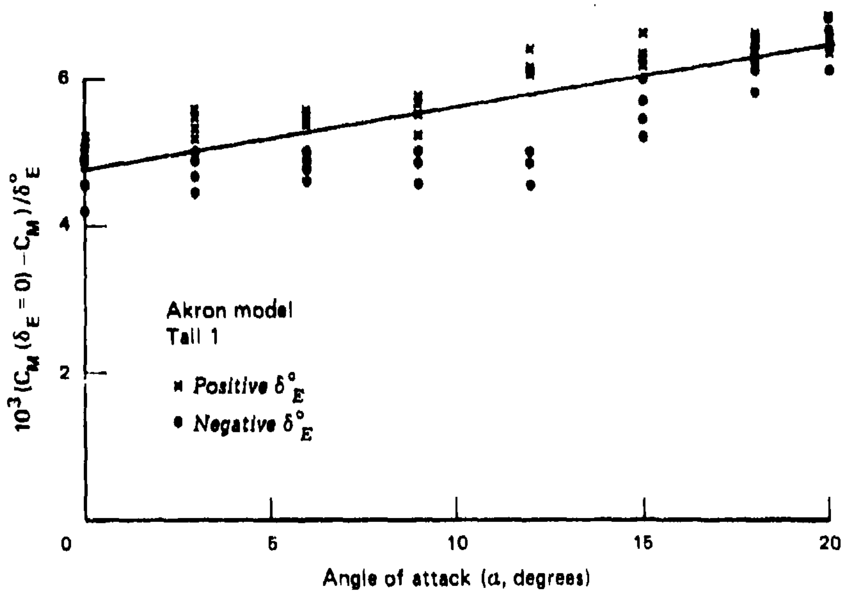

FIG. 51: ELEVATOR MOMENT

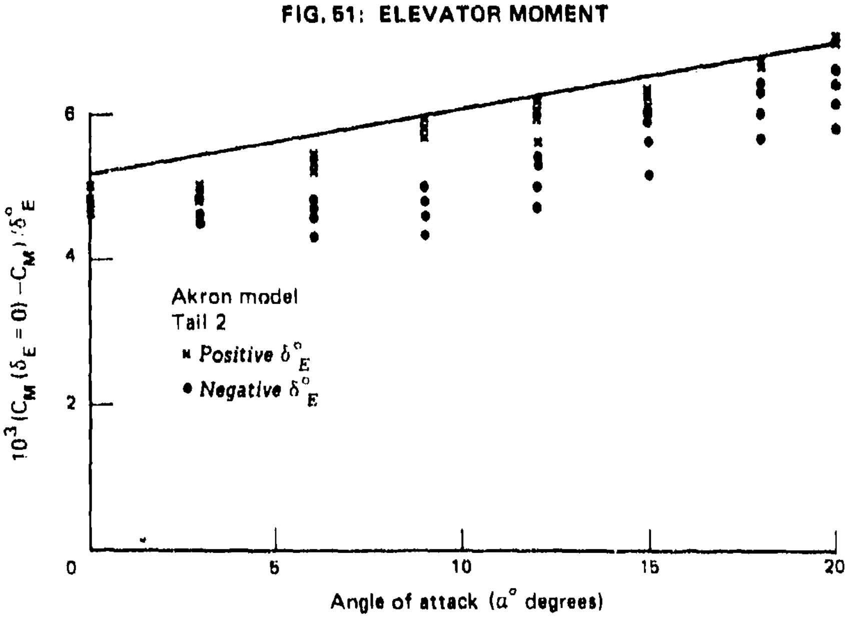

FIG. 52: ELEVATOR MOMENT INCREMENT

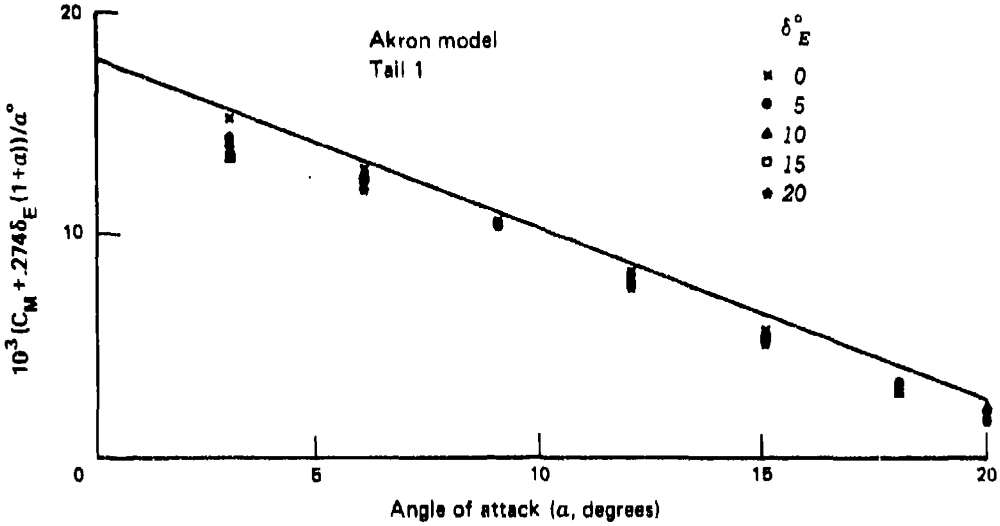

FIG. 53: ZERO-ELEVATOR MOMENT COEFFICIENT

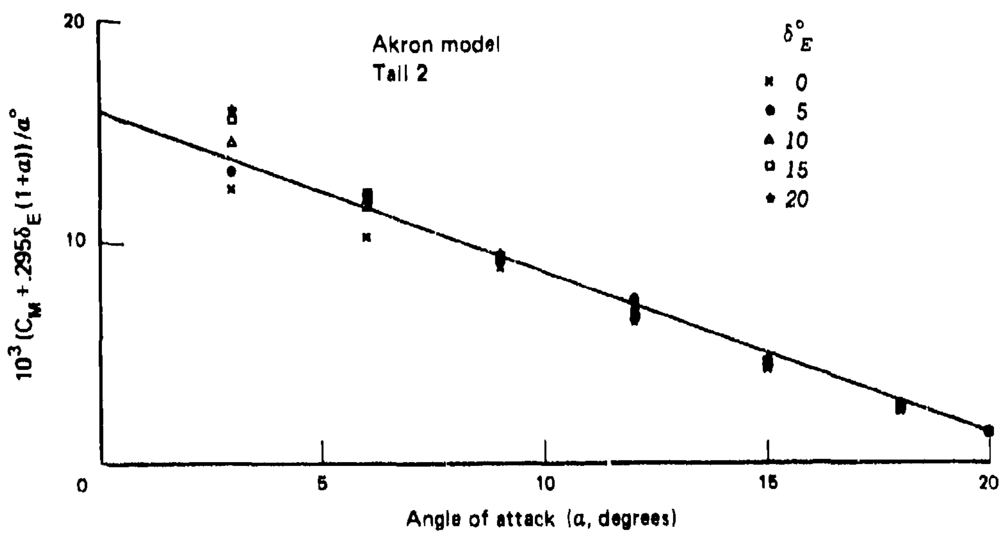

FIG. 54: ZERO-ELEVATOR MOMENT COEFFICIENT

Now the equations for the moment coefficient for the Akron model become:

$$C_M = 1.03\alpha - 2.52\alpha^2 - 0.274\,\delta_E(1+\alpha)\ , \text{ tail 1 };$$
$$C_M = 0.912\alpha - 2.39\alpha^2 - 0.295\,\delta_E(1+\alpha)\ , \text{ tail 2 }. \tag{119}$$

These equations are shown as lines in figure 55. For tail 1, the lines are high compared to the data points on the right half of the figure. For tail 2, the lines are low on the left half of the figure.

The condition for determining the elevator deflection to be used for estimating the drag is that the airship must be trimmed; that is, it must be in static moment equilibrium with C_M equal zero. The trimmed elevator deflection δ_{ET} for the Akron models is obtained by setting C_M equal to zero in equations (119):

$$\delta_{ET} = (3.76\alpha - 9.20\alpha^2) / (1+\alpha)\ , \text{ tail 1}$$
$$\delta_{ET} = (3.09\alpha - 8.10\alpha^2) / (1+\alpha)\ , \text{ tail 2 }. \tag{120}$$

The lines given by these equations in degree units are shown in figure 56. The points in figure 56 are for the Akron model data, obtained graphically from smoothed C_M curves.

The general equations for the moment coefficient and trimmed elevator angle as selected above are:

$$\begin{aligned} C_M = {} & (1.55 - 0.82\sqrt{AR}\ f(L/\nabla_E^{1/3})\ a_{LT})\alpha \\ & - (1.40 + f(L/\nabla_E^{1/3})\ b_{LT})\ \alpha^2 \\ & - f(L/\nabla_E^{1/3})\ 0.37a_{LT}\delta_E(1+\alpha) \end{aligned} \tag{121}$$

$$\delta_{ET} = \frac{(1.55 - 0.82\sqrt{AR}\ f(L/\nabla_E^{1/3})\ \alpha - (1.40 + f(L/\nabla_E^{1/3})\ b_{LT})\alpha^2}{f(L/\nabla_E^{1/3})\ 0.37a_{LT}(1+\alpha)}$$

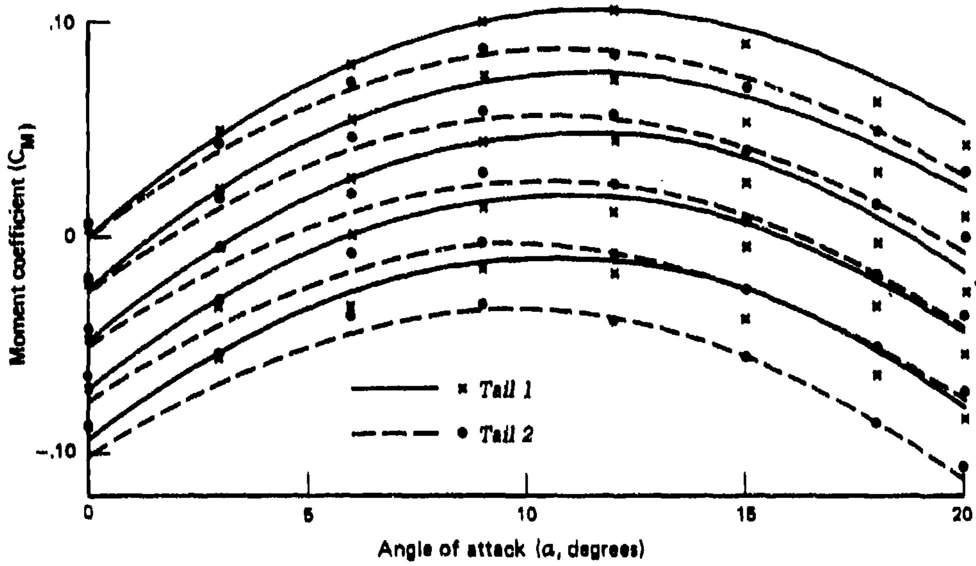

FIG. 55: AKRON MODEL MOMENT COEFFICIENT

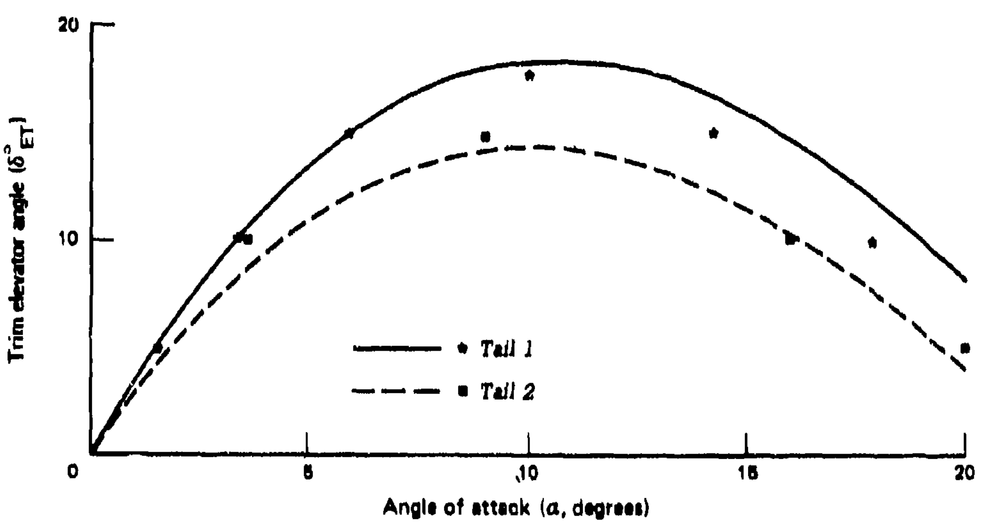

FIG. 56: AKRON MODEL TRIM ELEVATOR ANGLE

AIRSHIP LIFT-DRAG RATIOS

A simplified analysis of airship aerodynamic lift and its use in combination with buoyant lift is presented in this section. In particular, lift-drag ratios are investigated. The lift coefficient data for the Akron model are shown in figure 57 for zero elevator and for trimmed elevator. With zero elevator deflection the lift coefficient line is curved as shown previously. However, for trimmed elevator deflection the lift coefficient is proportional to angle of attack and greater at each angle of attack. The proportionality can be used in analytical illustrative calculations. The slope of the line in the figure is 0.021 per degree. The increase of lift coefficient shows that a given lift will be obtained at a smaller angle of attack than indicated by the zero elevator data.

The variation of the drag coefficient data for the Akron model with angle of attack for zero elevator and for trimmed elevator is shown in figure 58. Both are sharply curved upward. At a given angle of attack the drag coefficient for the trimmed case is larger than that for zero elevator.

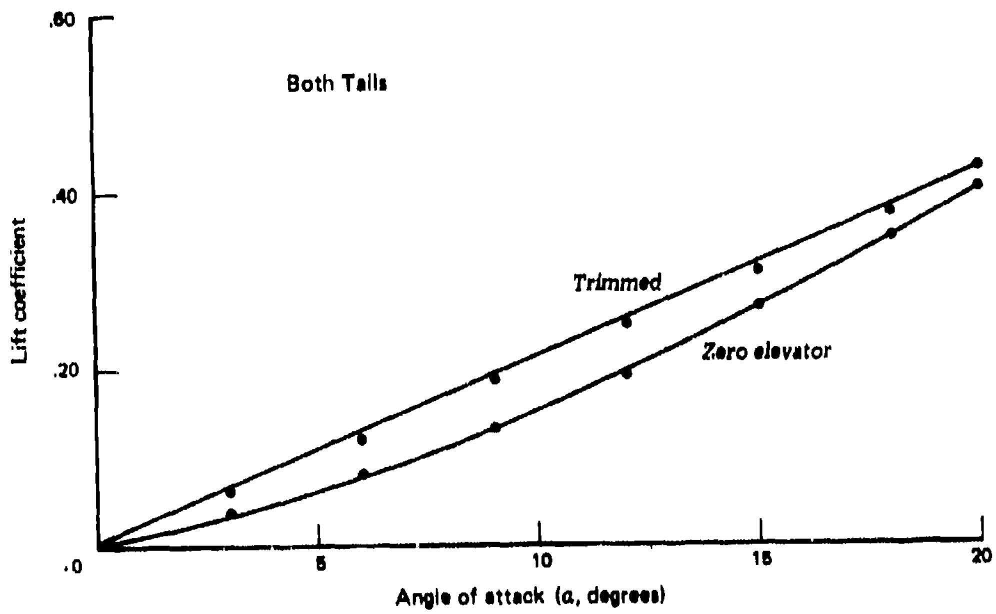

FIG. 57: AKRON MODEL LIFT COEFFICIENT

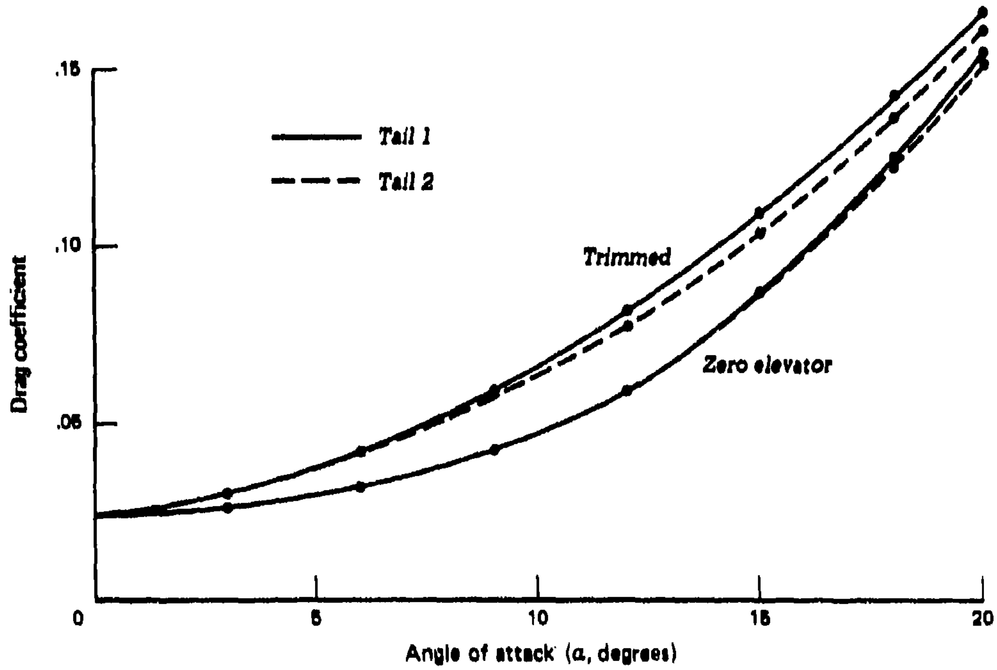

FIG. 58: AKRON MODEL DRAG COEFFICIENT

For airplane wings, the lift drag coefficient C_{DL} is proportional to the square of the lift coefficient C_L. The Akron model data for the lift drag coefficient is shown in figure 59 as a function of C_L^2. The data points for both tail configurations, and for zero elevator and trimmed, all form a narrow band. The line for a proportional approximation is shown in the figure. The trend of the data points is actually curved and can be better fitted by the power law shown in the figure. However, for lift coefficients not greater than about 0.2 ($C_L^2 = 0.04$), the simple proportional approximation can be useful. The equations for trimmed lift coefficient and lift drag coefficient from figures 56 and 58 are:

$$C_L = 0.021\alpha \text{ , trimmed, } \alpha \text{ in degree ;}$$

$$C_{DL} = KC_L^2 \text{ , } K = 0.9 \text{ , approximation ;} \qquad (122)$$

$$C_{DL} = 0.63C_L^{1.75} \text{ .}$$

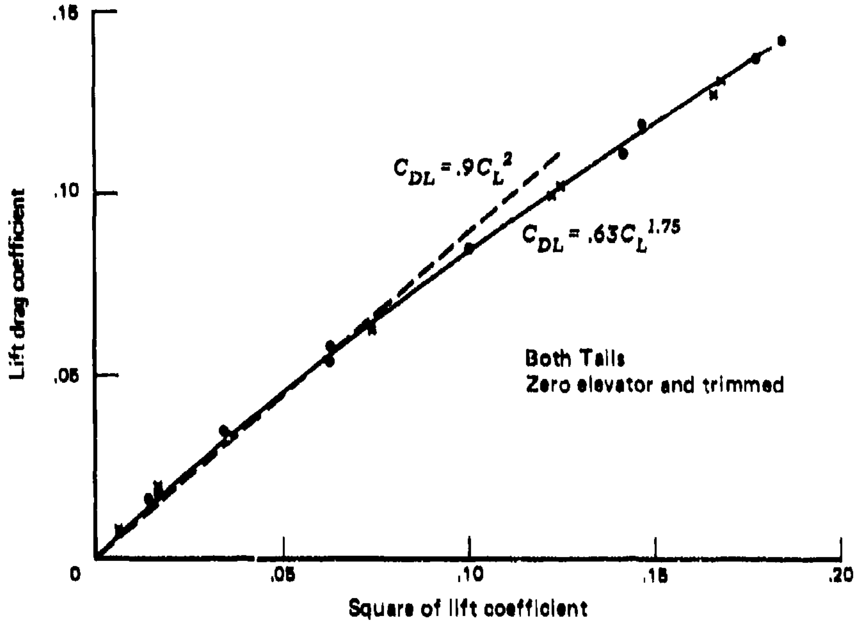

FIG. 59: AKRON MODEL LIFT DRAG VARIATION

Airships have buoyant lift L_B , aerodynamic lift L_A , zero lift drag D_0 , and lift drag D_L . Several lift-drag ratios can be formed. The buoyant lift-drag ratio λ_B , defined as equal L_B/D_0 , can be written simply. Buoyant lift is taken as the sea level buoyancy. It is equal to the product of the gas unit lift w_B , the gas volume fraction f_G at sea level, and the envelope volume ∇_E :

$$L_B = w_B f_G \nabla_E \quad . \tag{123}$$

The zero lift drag is given by:

$$D_0 = 0.5\rho V^2 A_{WH} C_{D0} \quad . \tag{124}$$

In chapter 3 the hull wetted area A_{WH} was defined in terms of the surface coefficient C_S . Substitutions from equations (39), (43), and (38) from chapter 3 give:

$$D_0 = (2\pi)^{1/3}(1 + 0.9/(L/D)^2)\,(L/D)^{1/3}\rho C_{D0} V^2 \nabla_E^{2/3} \quad . \tag{125}$$

Thus the buoyant lift-drag ratio is:

$$\lambda_B = \frac{L_B}{D_0} = \frac{w_B f_G}{(2\pi)^{1/3}\,(1+0.9/\,(L/D^2)\,(L/D)^{1/3}\rho C_{D0}} \quad \frac{\nabla_E^{1/3}}{V^2} \quad . \qquad (126)$$

For 94 percent purity helium ($w_B = 0.0618$) , a gas volume fraction of 0.96, length-diameter ratio L/D of 5, sea level ($\rho = 0.00238$) and a drag coefficient of 0.0038, and conversion of V to V_K in knots the buoyant lift-drag ratio is given by:

$$\lambda_B = 706\,(\nabla_E^{1/3}/V_K^2 \quad . \qquad (127)$$

The buoyant lift-drag ratio is principally a function of envelope volume and speed. For flight at altitude f_{G0} must decrease proportional to ρ to permit lift gas expansion. Therefore, f_G/ρ is constant.

The variation of λ_B according to equation (127) is shown in figure 60. Buoyant lift-drag ratio increases slowly with increasing envelope volume. It decreases rapidly when speed is increased. Buoyant lift-drag ratios exceeding the lift-drag ratio of airplanes (around 15) can be obtained only by using relatively low speeds or extremely large airships.

The dashed lines in figure 60 show the maximum vehicle lift-drag ratio λ_{VMX} . It is derived below as the maximum value of $(L_B + L_A) / (D_0 + D_L)$ obtainable by varying L_A . Figure 60 shows that use of aerodynamic lift produces relatively small increases of lift-drag ratio. The percentage increases are large in the lower left corner of the figure, that is, for small fast airships. However, as discussed below (figure 65) the necessary optimum angles of attack in the lower left corner cannot be obtained (except by increasing landing gear weight) due to takeoff angle of attack limitations. Therefore, airship lift-drag ratios remain close to the buoyant lift-drag ratio λ_B.

Another possible lift-drag ratio is the aerodynamic alone ratio λ_{AA} defined as equal L_A/D_L . It is irrelevant physically, but an equation for it is useful for substitution in the subsequent analysis. The aerodynamic lift is given by:

$$L_A = 0.5\,\rho V^2 \nabla_E^{2/3} C_L \quad . \qquad (128)$$

Using the approximation of equation (122) for the lift drag coefficient, with K representing the constant, the lift drag is:

$$D_L = 0.5\,\rho V^2 \nabla_E^{2/3} K C_L^2 \quad . \tag{129}$$

Then:

$$\lambda_{AA} = \frac{L_A}{D_L} = \frac{1}{KC_L} \quad . \tag{130}$$

Akron model data for λ_{AA} are shown in figure 61 as a function of angle of attack. The trimmed elevator values are considerably lower than those for zero elevator. The $1/0.9C_L$ approximation is shown in the figure. It is a poor approximation for angles of attack around 5 degrees.

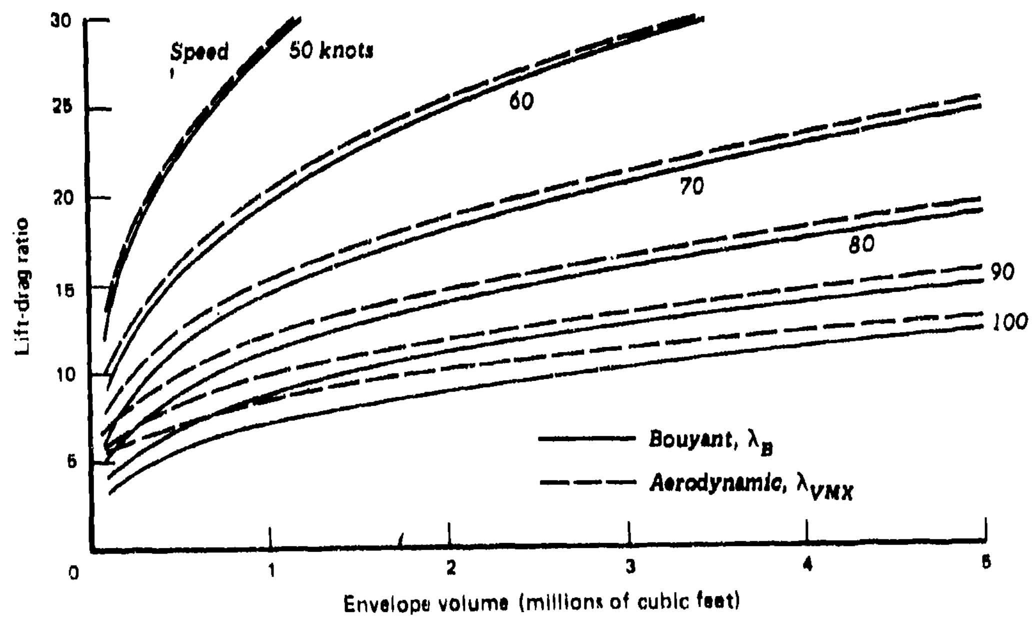

FIG. 60: LIFT-DRAG RATIO VARIATION

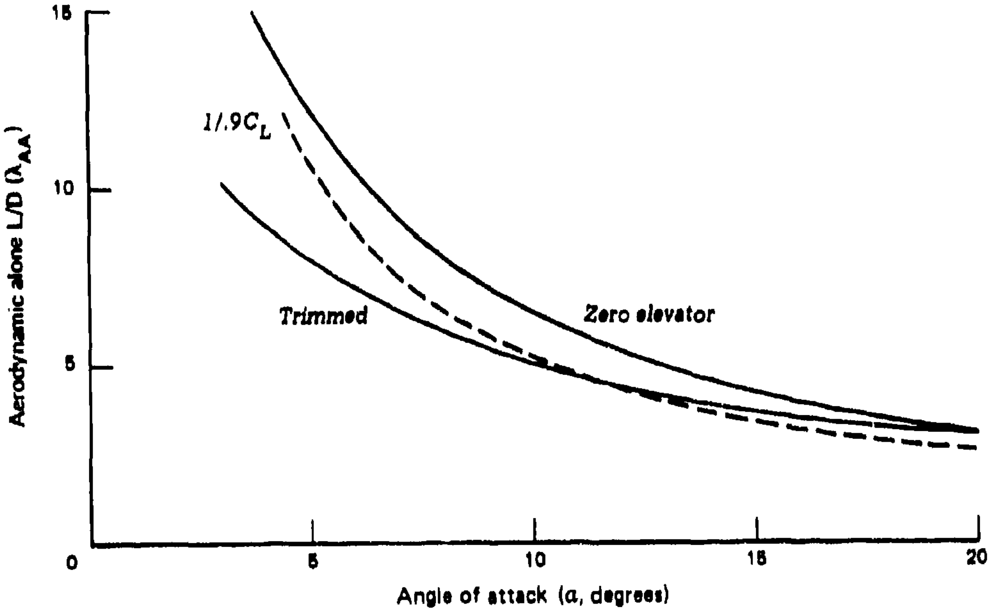

FIG. 61: AKRON MODEL AERODYNAMIC ALONE L/D

Equation (130) is not useful for the following analysis. To eliminate C_L, the ratio ω of aerodynamic to buoyant lift can be used as a parameter. From equations (123) and (128), followed by solving for C_L:

$$\omega = \frac{L_A}{L_B} = \frac{0.5\,\rho V^2 \nabla_E^{2/3} C_L}{w_B f_G \nabla_E} \; ; \qquad (131)$$

$$C_L = \frac{2 w_B f_G\, \omega}{\rho} \; \frac{\nabla_E^{1/3}}{V^2} \; .$$

Substituting C_L in equation (130) gives:

$$\lambda_{AA} = \frac{\rho}{2 w_B f_G\, K} \; \frac{1}{\omega \nabla_E^{1/3} / V^2} \; . \qquad (132)$$

For sea level ($\rho = 0.00238$) , 94 percent purity helium ($w_B = 0.0618$) , a gas volume fraction of 0.96, lift-drag constant K of 0.9, and conversion of V to V_K in knots, equation (132) becomes:

$$\lambda_{AA} = 0.0635/(\omega \nabla_E^{1/3}/V_K^2) \quad . \tag{133}$$

The influence of envelope volume and speed on λ_{AA} are reciprocal to their influence on the buoyant lift-drag ratio (equation (127)). Increasing the aerodynamic lift ratio ω reduces λ_{AA} rapidly, as already seen in figure 61. The parameter $\omega \Delta_E^{1/3}/V^2$ is actually independent of envelope volume and speed. Using the definition of ω, and equations (123) and (128) :

$$\omega \frac{\Delta_E^{1/3}}{V^2} = \frac{\rho}{2 w_B f_{G0}} \quad C_L \quad . \tag{134}$$

It was noted that figure 57 shows that the Akron model C_L for trimmed elevator is proportional to angle of attack, so $\omega \nabla_E^{1/3}/V^2$ is also proportional to angle of attack for the Akron model.

Aerodynamic And Vehicle Lift-Drag Ratios

Two more lift-drag ratios can be defined. The analysis uses λ_B and λ_{AA}. For convenience they are written in the form:

$$\lambda_B = \beta (\nabla_E^{1/3}/V_K^2) \quad , \beta = 706 \qquad ;$$
$$\lambda_{AA} = \gamma / (\omega \nabla_E^{1/3}/V_K^2) \quad , \gamma = 0.0635 \tag{135}$$

The constants β and γ can be obtained in general by comparison with equations (126) and (132).

The aerodynamic lift-drag ratio λ_A is defined as:

$$\lambda_A = \frac{L_A}{D_0 + D_L} \tag{136}$$

The buoyant lift is ignored but all 3 aerodynamic forces are considered. Eliminating D_0 and D_L by using the definitions of λ_B and λ_{AA} gives:

$$\lambda_A = \frac{L_A}{L_A/\lambda_B + L_A/\lambda_{AA}} \quad . \tag{137}$$

Using the definition of ω and clearing fractions leads to:

$$\lambda_A = \frac{\omega \lambda_B}{1 + \omega \lambda_B/\lambda_{AA}} \quad . \tag{138}$$

Substituting λ_B and λ_{AA} from equation (135) gives the final form:

$$\lambda_A = \frac{\beta\,(\omega \nabla_E^{1/3}/V_K^2)}{1 + (\beta/\lambda)\,(\omega \nabla_E^{1/3}/V_K^2)^2} \quad . \tag{139}$$

Thus λ_A is a function of $\omega \nabla_E^{1/3}/V^2$. Inspection of the equation shows that λ_A has a maximum. The maximum λ_{MAX} and the lift ratio ω_{OPT} at which it occurs are:

$$\lambda_{AMX} = \sqrt{\beta \gamma}/2 = 3.35 \quad , \tag{140}$$

$$\omega_{AOPT} = \frac{\sqrt{\gamma/\beta}}{\nabla_E^{1/3}/V_K^2} = \frac{0.0095}{\nabla_E^{1/3}/V_K^2} \quad .$$

Akron model data for the aerodynamic lift-drag ratio λ_A are shown in figure 62 as a function of angle of attack. The trimmed elevator cases for tail 1 and tail 2 are slightly different. The zero elevator cases are identical for both tails. The maximums are close to the analytical estimate of 3.35 in equation (140). The maximums occur around 10 degrees angle of attack. Equation (139) can be written in terms of angle of attack by substituting $\omega \nabla_E^{1/3}/V^2$ from equation (134), converting from V to V_K in knots, and using $C_L = 0.021\alpha$ in degrees. Calculated points are shown in figure 62. They represent the data satisfactorily for illustrating the variation of λ_A .

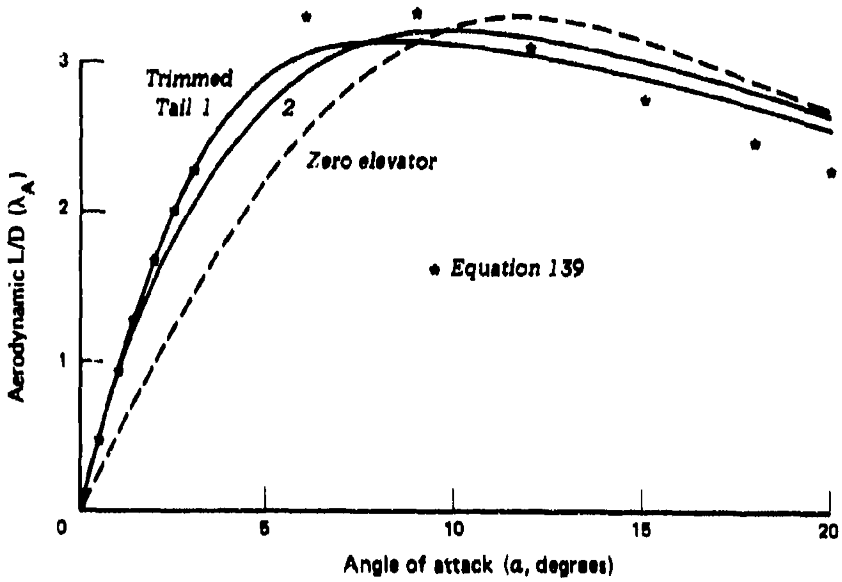

FIG. 62: AKRON MODEL AERODYNAMIC L/D

The aerodynamic lift-drag ratio λ_A shows the inherently low aerodynamic propulsion efficiency of airships. The buoyant lift propulsive efficiency can be much greater, as shown by the discussion of λ_B above. The variation of λ_A is also important for operators of an existing airship. With a fixed propulsion plant, a fixed thrust can be obtained. Hence, a fixed drag can be balanced by the thrust. Then maximum aerodynamic lift can be obtained by operating near the angle of attack for maximum λ_A, that is, near a 10-degree angle of attack. The historical U.S. Navy dirigibles operated this way to cross the hot desert regions of the U.S. Southwest. The hot atmosphere reduced the buoyant lift. Aerodynamic lift at angles of attack near 10 degrees was substituted for the lost buoyant lift.

The final lift-drag ratio is the vehicle lift-drag ratio λ_V. For airships this must include the buoyant lift, so it is defined as:

$$\lambda_V = \frac{L_B + L_A}{D_0 + D_L} \quad . \tag{141}$$

Substituting $L_B = L_A/\omega$ reduces this relation to a factor times λ_A as defined in equation (136). Using equation (139) for λ_A and using λ_B in the numerator, from equation (135), gives:

$$\lambda_V = \frac{\lambda_B(1+\omega)}{1+(\beta/\gamma)\,(\omega\nabla_E^{1/3}/V_K^2)^2} \quad . \qquad (142)$$

By using equation (135) for λ_B and writing $(\omega\nabla_E^{1/3}/V_K^2)$ in terms of angle of attack, λ_V can be calculated for the full-scale Akron (envelope volume of 7,400,000 cubic feet). Figure 63 shows the rapid increase of vehicle lift-drag ratio when speed is decreased at zero angle of attack. It also shows the rapid decrease of vehicle lift-drag ratio when angle of attack is increased. The lines are shown dashed for lift-drag ratios less than about 20 because the Akron installed maximum propulsion power did not permit flight in this region.

Inspection of equation (142) shows that a maximum exists as a function of ω. The maximum appears in figure 63 for the full-scale Akron. It is barely greater than λ_B for the Akron and occurs at a very small angle of attack. By differentiation, the maximum λ_{VMX}, and the lift ratio ω_{OPT} at which it occurs, are found to be given by:

$$\lambda_{VMX} = \lambda_B(1+\omega_{OPT}/2) \quad ,$$

$$\omega_{VOPT} = \sqrt{1+\beta\gamma/\lambda_B^2} \quad . \qquad (143)$$

The variation of calculated values of λ_{VMX} have been shown above in figure 60 for comparison with λ_B.

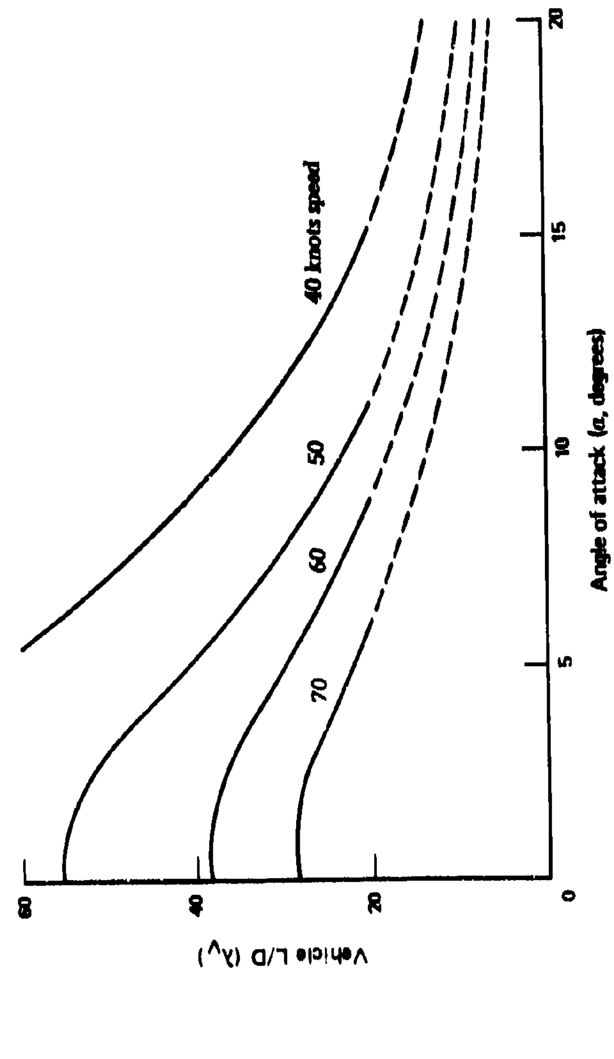

FIG. 63: FULL SCALE AKRON VEHICLE L/D

The variation of ω_{VOPT} for maximum λ_V is shown in figure 64. The optimum lift ratio decreases rapidly as envelope volume increases. It increases rapidly when speed i. increased. Values up to 1.3 are associated with the smallest, fastest airships included in the λ_{VMX} curves of figure 60.

The optimum angle of attack required to obtain the optimum lift ratio can be calculated for the Akron trimmed lift coefficient variation of figure 57 and equation (134). The results for angles of attack up to 6 degrees are shown in figure 65. Angles of attack up to 14 degrees are associated with the λ_{VMX} curves of figure 60.

Flight angle of attack α is constrained by the available takeoff angle of attack α_{TO}. At constant aerodynamic lift, αV^2 is constant. If takeoff speed is 50 percent of flight speed, α will be $\alpha_{TO}/4$. Unless the landing gear are specially lengthened, the takeoff angle of attack is 4 to 8 degrees for blimps. It is smaller for dirigibles. Thus, the available flight angle of attack is constrained to about 1 to 3 degrees.

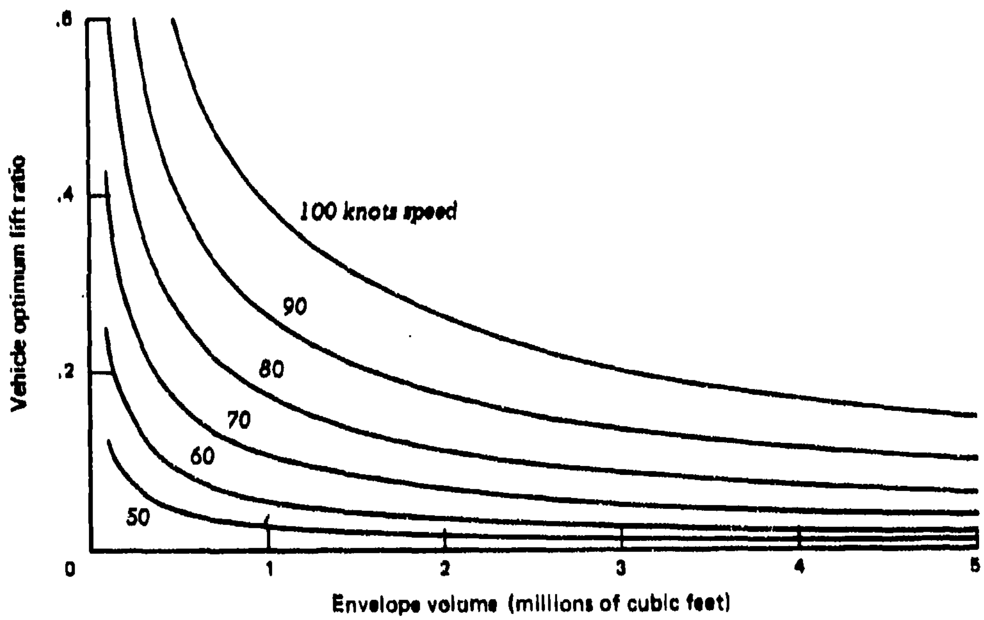

FIG. 64: VARIATION OF VEHICLE OPTIMUM LIFT RATIO

With this constraint, the optimum angles of attack shown in figure 65 cannot be obtained at speeds of 80 knots and greater, nor at small envelope volumes. This results in vehicle lift-drag ratios that are near the buoyant lift-drag ratio.

If landing gear length is increased to provide a larger takeoff angle of attack, its increased weight and drag must be considered. The problem becomes one of balancing aerodynamic gains and weight increase, not just an aerodynamic optimization problem.

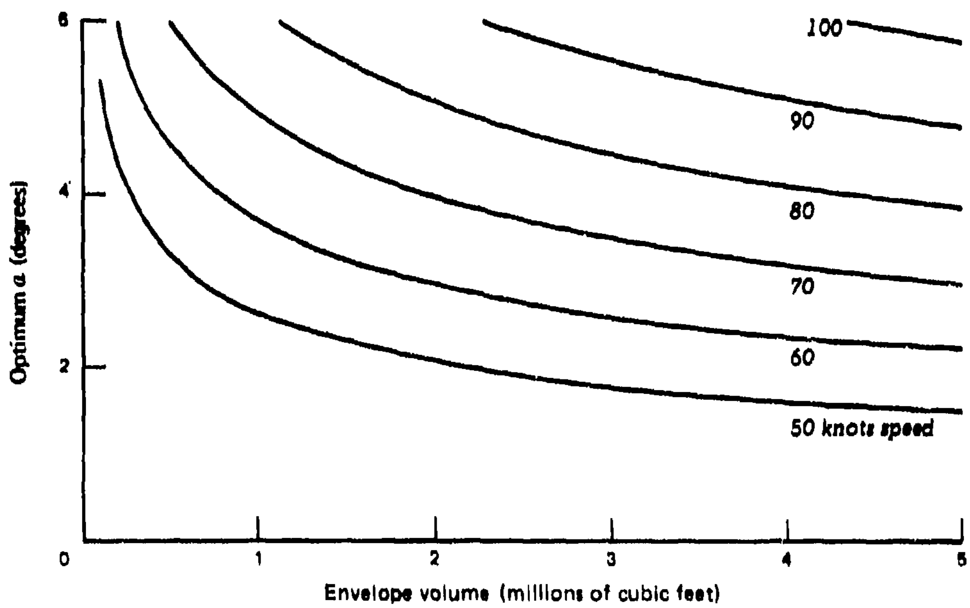

FIG. 65: VEHICLE OPTIMUM ANGLE OF ATTACK

AERODYNAMIC GUST STRUCTURAL MOMENT

The most critical, or governing, structural loads for several structural components of airships are generally agreed to be the moments produced by a longitudinal entry into an atmospheric gust. Estimates for the gust moment are needed for the structural weight analysis. The gust moment varies along the length of the airship. It is zero at each end and attains a maximum value about 60 percent of the length from the bow. The distribution of loads, shear, and bending moment due to gust and other loading conditions must be considered in predesign structural analysis. But for the concept analysis only the maximum gust moment can be used as a measure of the level of the bending moment distribution.

The gust moment is generated by aerodynamic lift forces produced when the airship enters a region of different vertical atmospheric wind speed. The gust is characterized by the gust speed u_G, which is the maximum change of vertical wind speed, and the gust length over which the change of wind speed occurs. Design rules in 1976 usually specify u_G equal to 35 feet per second. Gust moment research suggests that the largest gust moment is produced by a gust length of half the airship length. A full analysis of the gust moment should consider the distribution of aerodynamic forces along the body, changing with time and with appropriate time lag development of force in the rapidly changing local air velocities. The analysis should also include the influence of body upward translation and pitch rotation on the aerodynamic forces, and the resultant inertia forces on the structural moment and body motion. Perhaps the influence of elastic deformation should be included. The needed aerodynamic flow knowledge is limited, thus making such a full analysis difficult to perform, even in detail design.

The maximum gust moment coefficient C_{MMG} is defined in terms of the maximum gust moment M_{GMX}, atmospheric density and maximum airship speed V_{MX} as:

$$C_{MMG} = M_{GMX}/(0.5\,\rho V_{MX}^2 \nabla_E^{2/3} L) \quad . \tag{144}$$

The $\nabla_E^{2/3}$ term is a reference area for the gust aerodynamic lift. The body length L is the reference length for the moment arm of the lift distribution.

The gust speed ratio u_G/V_{MX} is a measure of the sudden change of angle of attack due to encountering the gust. Its use for historical airships $(u_G/V_{MX} \simeq 0.3)$ is less appropriate than for airplanes $(u_G/V_{MX} < 0.1)$. For gust response, the appropriate lift coefficient may be the body alone one. Its linear term (equation (100)) gives a gust increment lift coefficient of approximately $0.16(u_G/V_{MX})$. Assuming that the initial gust lift acts near the bow, the moment arm to the cross section of maximum bending moment is approximately $0.5L$. Thus,

$$M_{GMX} \simeq 0.5\,\rho V_{MX}^2 \Delta_E^{2/3}(0.18(u_G/V_{MX}))0.5L \ ;$$

$$C_{MMG} \simeq 0.09 u_G/V_{MX} \quad . \tag{145}$$

These expressions provide only a rationalization for the form of the variation of the maximum gust moment.

However, MIT data (reference 1) indicate that the maximum gust moment is approximately proportional to u_G/V_{MX} up to values of about 0.30, and nearly constant for larger values. In addition, water tunnel gust simulations with the Akron, cited by Goodyear (1975, Vol. III, p. 105, reference 8) gave a maximum moment at $u_G/V_{MX} = 2/7$ of:

$$M_{GMX} = 0.332(u_G/V_{MX})0.5\,\rho V_{MX}^2 \Delta_E \quad . \tag{146}$$

To obtain the associated coefficient, equation (38) for L , and table 8 for C_p and L/D (see the Macon row values) give:

$$C_{MMG} = 0.332(\pi C_p/4(L/D)^2)^{1/3}(u_G/V_{MX}) \quad ;$$
$$C_{MMG} = 0.082(u_G/V_{MX}) \quad . \tag{147}$$

The constant here is somewhat less than the rough estimate of equation (145). However, the experimental data for only one L/D provides no information on whether the $(L/D)^{2/3}$ term in the first of equations (147) should be retained.

Goodyear (1975, Vol. III, p. 107, reference 8) did gust moment calculations using slender body aerodynamic theory for L/D values of 3, 4, 5, and 5.91. The resultant ratios of the constant 0.332 in equation (146) for M_{GMX} can be accurately fitted by $0.102(L/D)^{2/3}$. Then:

$$M_{GMX} = 0.102(L/D)^{2/3}(u_G/V_{MX})0.5\,\rho V_{MX}^2 \Delta_E \quad ;$$
$$C_{MMG} = 0.094 C_P^{1/3}(u_G/V_{MX}) = 0.082(u_G/V_{MX}) \quad . \tag{148}$$

From equation (148) it is still uncertain whether C_P variation can be dropped. It is dropped for this analysis.

An equation used for design of several blimps that experienced no gust load problems is given by Goodyear (1975, Vol. III, p. 104, and Vol. IV, p. E-6, reference 8)

$$M_{GMX} = 0.018(0.5)\,\rho V_D^2 \Delta_E^{2/3} L \quad \text{, blimp design.} \tag{149}$$

The "design" speed V_D is given in the reference in terms of cruise speed V_{CR} and design wind speed V_W as $1.08(V_{CR} + V_W)$. Ignoring this point for a moment, the associated moment coefficient is:

$$C_{MMG} = 0.018 \tag{150}$$

In comparison to $0.082(u_G/V_{MX})$ for dirigibles, this blimp equation permits a gust speed of about 26 feet per second for 70-knot blimps, or 25 percent low relative to 35 feet per second.

Returning to V_D, a value of 60 knots may have been used in equation (149), that is, V_{CR} about 40, V_W about 15 knots. If the dirigible moment equation were to be used at V^* less than V_{MX} but with the coefficient C^*_{MMG} still defined in terms of V_{MX}, then:

$$C^*_{MMG} = [0.082(V^*/V_{MX})^2]\,(u_G/V_{MX}) \quad . \tag{151}$$

The apparent coefficient $0.082(V^*/V_{MX})^2$ is then low. For the apparent 25 percent low relation of the preceding paragraph, V^*/V_{MX} of 0.87 would suffice, and this is close to the ratio of 60 to 70 knots.

Thus, there may be no difference in the moment coefficient equations. The possible difference in the use of moment equation does lead to different design gust moments, because M_{GMX} is proportional to the V used. Consistent use of V_{MX} is selected here, with a 15 percent reduction of moment blimps, assuming that flexibility of the pressurized structure may reduce the loads and their effect. In summary:

$$\begin{aligned} M_{GMX} &= 0.070(u_G/V_{MX})\,0.5\,\rho V_{MX}^2 \Delta_E^{2/3} L \text{ , blimps } ; \\ M_{GMX} &= 0.082(u_G/V_{MX})\,0.5\,\rho V_{MX}^2 \Delta_E^{2/3} L \text{ , dirigibles } . \end{aligned} \tag{152}$$

Earlier dirigibles were not designed to meet this gust moment criterion. Goodyear (Vol. III, p. 110, reference 8) indicates the following fractions were used:

Akron/Macon	0.85
Los Angeles	0.53
Shenandoah	0.38
Hindenburg	0.77
Graf Zeppelin	0.59

These ratios are needed to correlate model calculation results with data for these dirigibles.

5. POWER, ENGINES, AND FUEL

This chapter considers conceptual estimates of the propulsion power and the power plant required for the airship. The required power depends on the drag estimated in the preceding chapter, the flight airspeed, and the efficiency of the propellers. Therefore, the relations between power and propellers are investigated first. Also examined are the diameter and weight of the propeller.

Takeoff ground run distance depends on the variation of propeller thrust as the airship speed is increased during takeoff and is estimated following the investigation of propeller characteristics.

The power plant characteristics depend on the power required at maximum speed, the type of engine used, and the engine installation requirements such as cooling, nacelles, and outriggers. Diesel engines, reciprocating engines, and turboprop engines are considered. For each engine type, the engine weight, frontal area, length-diameter ratio, power rating ratios, and specific fuel consumption are investigated. Weights for engine installation are estimated.

Finally, fuel and fuel system weight are considered.

POWER AND PROPELLERS

This model includes only propellers because propellers provide the most efficient propulsion at relatively low airspeeds compared with other types of propulsors. Figure 66 shows a Boeing (Vol. I, p. 5-21, reference 6) comparison of turbofan engines with various bypass (BP) ratios. The "Maximum Practical Propeller" line appears to refer to large diameter propellers. It provides much greater propulsive efficiencies in the appropriate speed regime of 50 to 100 knots. Shrouded propellers with a smaller diameter could provide efficiencies similar to those of large diameter free propellers, but the shroud and supporting structure weight and drag reduce the possible advantages.

A propulsor produces a thrust T . To provide a specified speed V , the airship drag D must be balanced by the propulsor thrust. To calculate the required propulsion characteristics the thrust is set equal to D as estimated by the methods presented in chapter 4.

Propulsive efficiency η_p relates the thrust T and flight speed V of a propulsor to the engine power P_E^*:

$$P_E^* = TV/\eta_p \quad , \qquad (153)$$

The symbol P_E^* is used in this volume for the engine power in foot-pounds per second. This is consistent with thrust in pounds and speed in feet per second. The symbol P_E is used for engine power in horsepower. Units conversion is given by:

$$P_E^* = 550 P_E \quad . \tag{154}$$

Propulsive efficiency is defined in terms of an effective thrust equal to the actual thrust the propeller produces minus the increase of drag of bodies (airplane fuselage, nacelles, wing, airship outrigger) in the slipstream of the propeller. In this model an estimated increase of the drag of bodies in the slipstream has been included in the drag estimates.

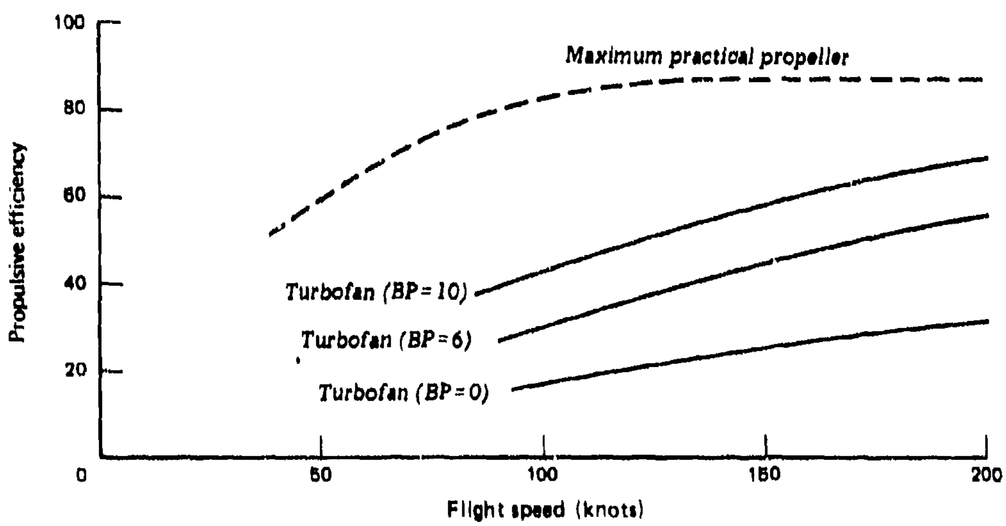

FIG. 66: TYPICAL PROPULSIVE EFFICIENCY VARIATION

The isolated propeller efficiency η ignores any interactions between the propeller and the vehicle. The analysis below is concerned with the isolated-propeller efficiency. For many propeller and nacelle geometry combinations η_P and η will be essentially identical. However, it appears desirable to estimate the influence of the ratio of nacelle diameter D_{NC} to propeller diameter D_P . Approximate data for the efficiency ratio

η_P/η as a function of D_{NC}/D_P were obtained from Weick (pp. 143-152, reference 26). The data are shown in figure 67. The line shown in the figure is given by:

$$\eta_P = \eta(1 - 0.12(D_{NC}/D_P)^3) \quad . \tag{155}$$

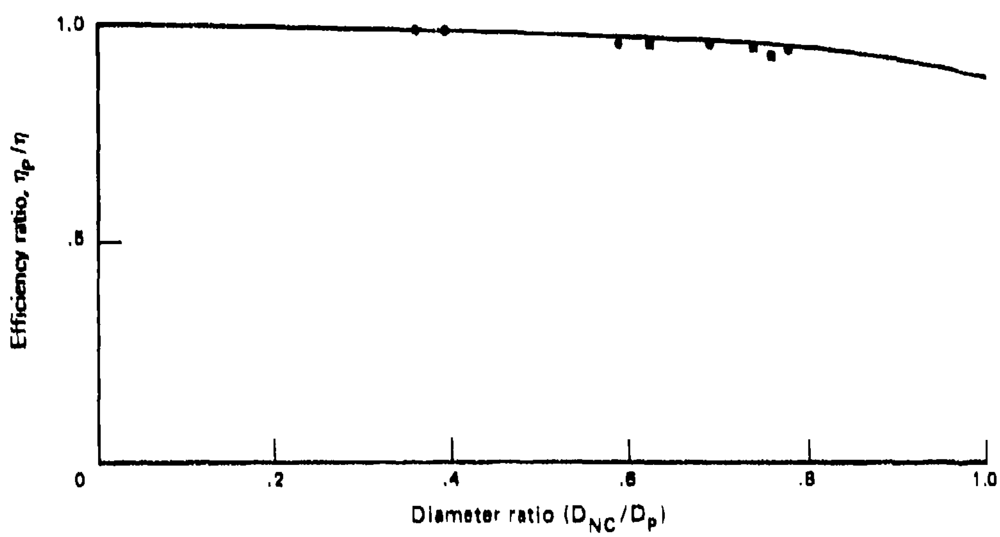

FIG. 67: ESTIMATED EFFICIENCY RATIO

Isolated-Propeller Characteristics

Figure 68 illustrates that isolated propellers can have high efficiencies if the design conditions are appropriate. The upper (envelope) efficiences are 90 percent over the center portion of the figure.

The abscissa in figure 68 is the speed power coefficient C_{SP}, defined in terms of flight speed, atmospheric mass density ρ, and propeller rotational rate n by:

$$C_{SP} = V(\rho/P_E^* n^2)^{0.2} \tag{156}$$

The speed power coefficient does not involve the propeller diameter so using it is convenient when propeller diameter is not yet known. The different lines in figure 68 are for different values of the reference blade angle β at 0.75 of the maximum radius of each blade. For the illustration case the number of blades B is 4, the activity factor α_p is 100, and the average lift coefficient C_{LA} is 0.5. These propeller parameters are defined below.

Figure 68 shows that different blade angles β are required at different values of C_{SP} to obtain the envelope efficiency. A controllable pitch propeller can mechanically set any blade angle. However, the torque (and power) required to rotate the propeller depends on blade angle. The power increases as the blade angle increases. Figure 68 does not provide a determination of propeller efficiency until blade angle is selected within power absorption constraints.

The speed-power coefficient is proportional to flight speed V, which is smaller for airships than for conventional airplane speeds. The speed power coefficient is also inversely proportional to $(P_E^* n^2)^{0.2}$. The influence of low airship speeds in reducing C_{SP} can be compensated by using smaller powers and propeller rotational rates. But, small powers require small flight speed, and this further reduces C_{SP}. For power approximately proportional to V^3, the ratio $V/P_E^{*0.2}$ is proportional to $V^{0.4}$, and C_{SP} increases with increasing flight speed.

When the constraints discussed below are considered, the result is that airships operate near speed-power coefficients of unity. For unity C_{SP} the envelope propeller efficiency is less than the envelope maximum of 90 percent. In addition, attaining the envelope efficiency in the region requires low blade angles of 10 to 20 degrees.

The blade angle curve that must be used to find the propeller efficiency is determined by the propeller advance ratio. The advance ratio J is defined in terms of propeller diameter D_p by:

$$J = V/nD_p \quad . \qquad (157)$$

The variation of J with speed power coefficient and blade angle is illustrated in figure 69. The advance ratio increases with increasing speed power coefficient. Increasing the blade angle increases the advance ratio.

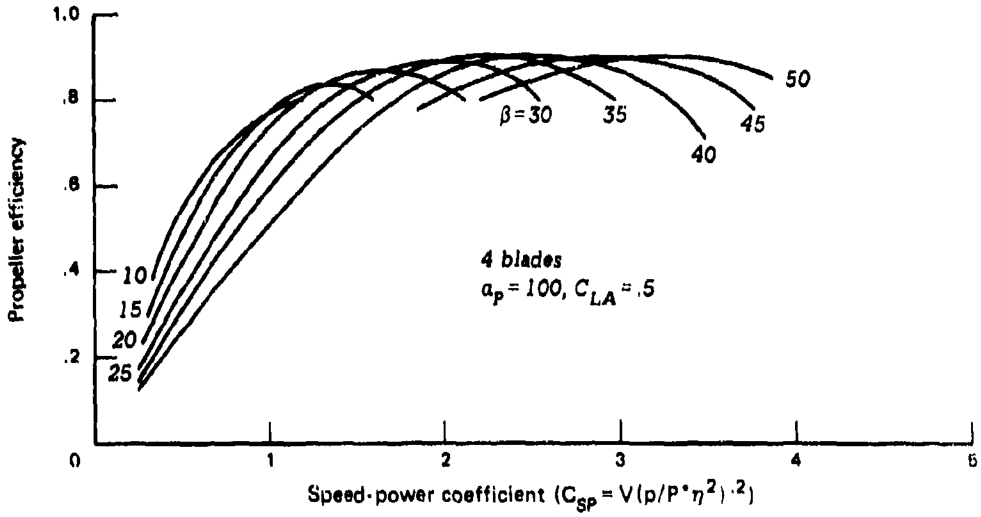

FIG. 68: ILLUSTRATIVE PROPELLER EFFICIENCY

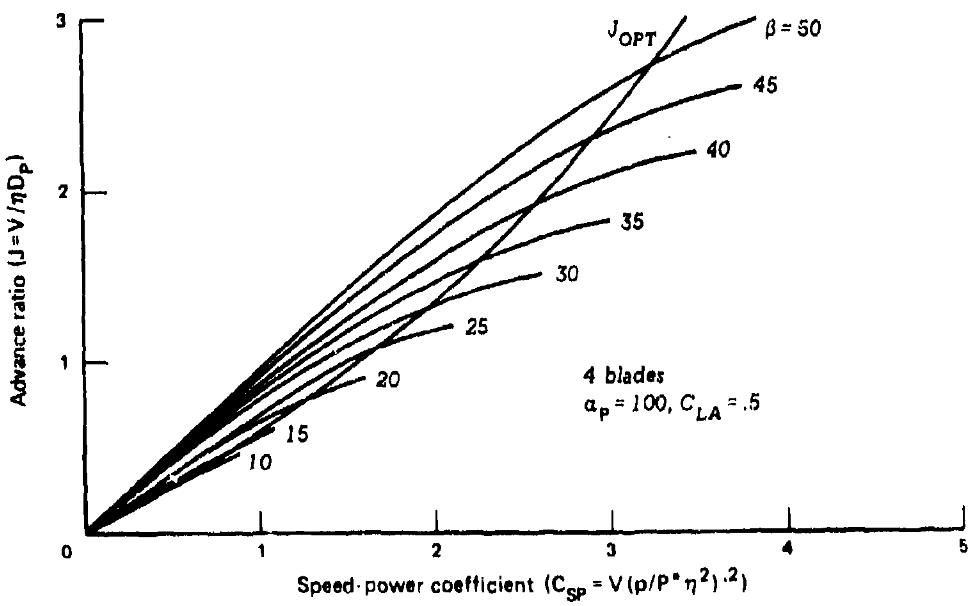

FIG. 69: ILLUSTRATIVE PROPELLER ADVANCE RATIO

For speed power coefficients around unity and blade angles of about 15 degrees, a low speed advance ratio of about 0.5 is required.

Equation (157) can be solved for D_p to obtain:

$$D_p = V/Jn \quad . \tag{158}$$

For a rotation rate of 15 revolutions per second (900 revolutions per minute), flight speed of 100 knots, and J equal to 0.50, a propeller diameter of 22.5 feet is required. This is twice the diameter of typical airplane propellers.

Equation (158) shows the constraint mentioned above. If rotation rate n is decreased by use of reduction gears to increase the speed power coefficient, the propeller diameter must be increased. The increased propeller efficiency requires more reduction gear weight, more propeller weight, more outrigger weight, and more landing gear weight (for blimps). However, the increased propeller efficiency reduces the weight of the engine, nacelle, outrigger, landing gear, and fuel.

Thus, the optimum combination of n and D_p cannot be determined from propeller analysis alone. The entire vehicle system must be considered; that is, the conceptual airship model must be used.

The quantitative variation of the propeller characteristics can be illustrated by calculations using figures 68 and 69 and assuming sea level operation with engine power proportional to V^3 . The envelope propeller efficiency η_E is shown in figure 70 as a function rotation rate, for engine power of 200 and 2,000 horsepower at 80 knots and flight speeds of 60, 80, and 100 knots. There is a small increase of efficiency when flight speed increases at a fixed power. There is a larger decrease of efficiency when power is increased. When the rotation rate increases envelope propeller efficiency decreases slowly.

The variation of the optimum propeller diameter required to obtain the envelope propeller efficiency for the illustrative cases is shown in figure 71. The diameters for 2,000 horsepower are about 70 percent larger than those for 200 horsepower. When the flight speed increases from 60 to 100 knots the optimum propeller diameter increases about 30 percent at fixed engine power.

Rotation rate has a strong effect on the optimum propeller diameter. When the rotation rate increases from 5 to 20 revolutions per second the propeller diameter decreases by 50 percent. This reduction is accompanied by significant weight decreases.

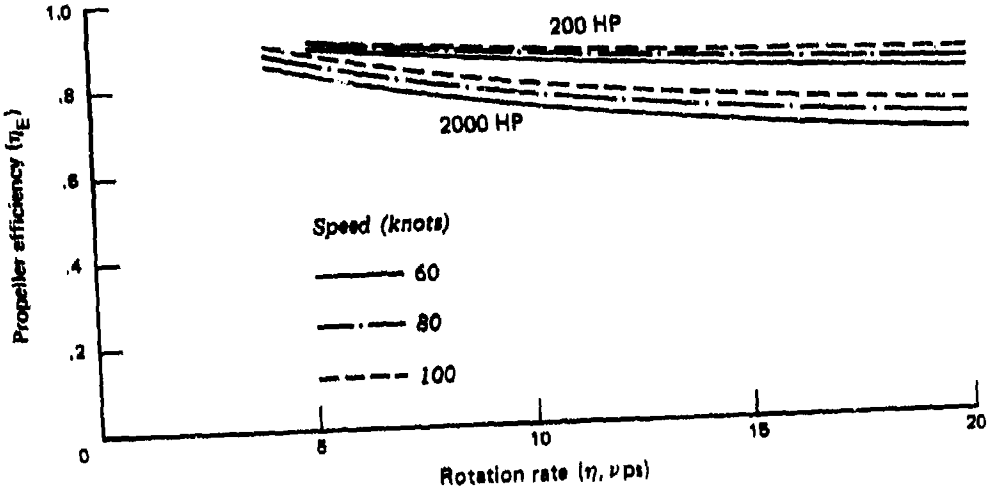

FIG. 70: ILLUSTRATION OF η_E VARIATION

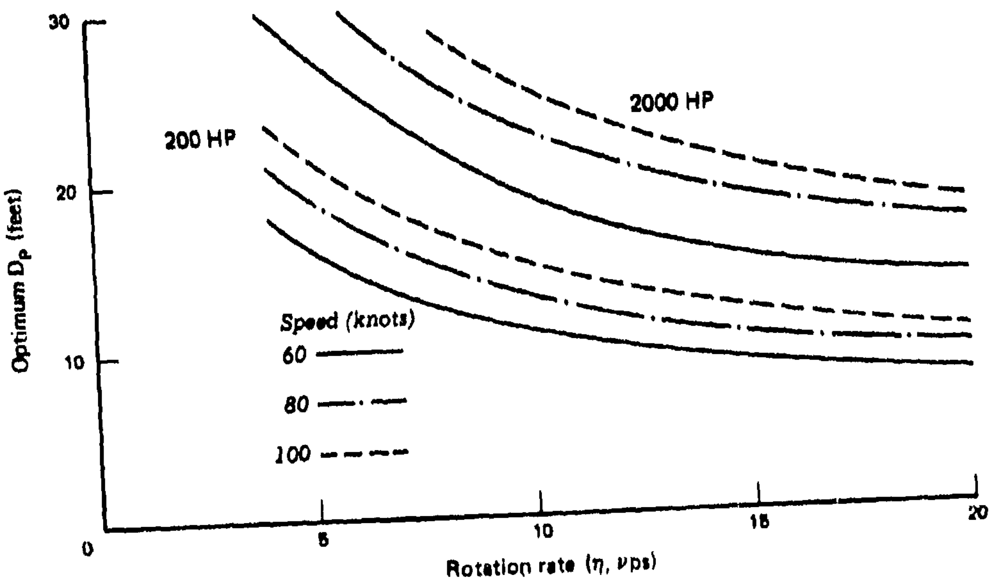

FIG. 71: ILLUSTRATION OF OPTIMUM D_p VARIATION

The propeller diameter decreases when rotational rate increases, but the rotational tip speed V_{TPR} of the propeller increases. Tip speed is given by:

$$V_{TPR} = \pi n D_P \quad . \tag{159}$$

Tip speed should be limited to a Mach number of about 0.90 or less to avoid propeller drag increases. This constraint is needed only for larger propeller rotational rates. If larger tip speeds are used, the propeller efficiency decreases. For a conceptual model it is desirable to avoid this decrease of efficiency. Approximate data for the ratio of efficiency η_M at high rotational tip Mach numbers M_{TPR} to the low Mach number efficiency η were obtained from Weick (pp 126-129, reference 26). The data are shown in figure 72. The ratio is larger for smaller propeller blade thickness-chord ratios. This causes some of the apparent scatter of the data points. To avoid decrease of efficiency it is desirable to keep tip Mach numbers less than about 0.85. At low altitudes this corresponds to tip speeds less that about 950 feet per second:

$$V_{TPR} \leq 950 \quad . \tag{160}$$

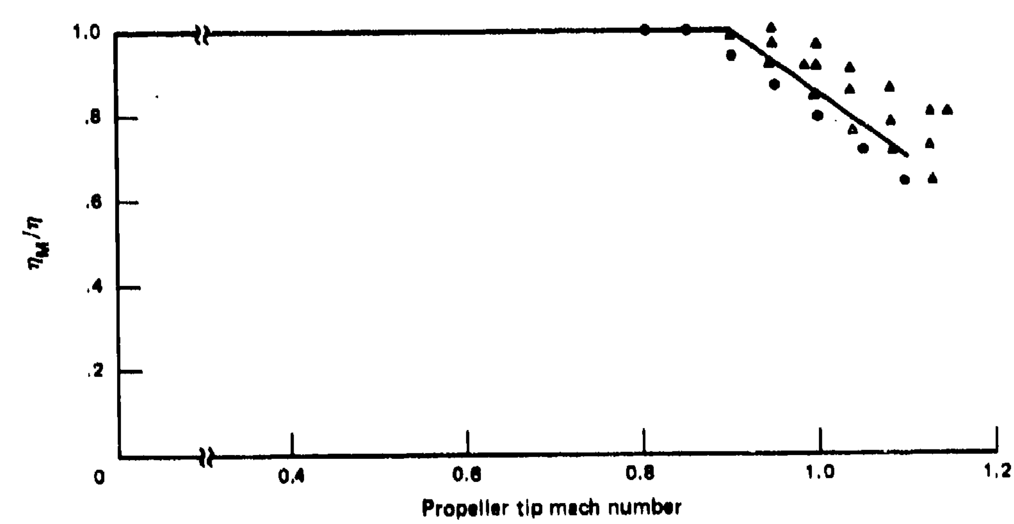

FIG. 72: INFLUENCE OF TIP MACH NUMBER

Propeller Efficiency Estimation

The approach selected for estimating the propeller efficiency η assumes that flight speed V and propeller rotational rate n are known. A standard value of 15 revolutions per second for n gives a reasonable approximation to an overall airship vehicle optimum for many concepts.

If the engine power P_E is conceptual, that is, to be determined, an efficiency is assumed, P_E^* is calculated from $P_E^* = TV/\eta$, and the procedure for specified P_E is followed. Iteration on η is used to obtain the correct P_E.

When engine power is specified it is possible to calculate C_{SP} immediately.

If propeller diameter D_P is free, the optimum diameter D_{POPT} for obtaining the envelope propeller efficiency is used. This requires use of the function $J_{OPT}(C_{SP})$, from which D_{OPT} can be calculated as $D_{OPT} = V/nJ_{OPT}$. In addition, it must be possible to calculate η. Either $\beta_{OPT}(C_{SP})$ and $\eta(C_{SP}, \beta)$ or $\eta_E(C_{SP})$ must be available for this calculation.

Use of the optimum propeller diameter provides a reasonable approximation to an overall airship vehicle optimum. But it is desirable to be able to specify propeller diameter, at least for sensitivity analysis.

If the propeller diameter is specified, then $J = V/nD$ and C_{SP} are both known. It is necessary to have $J(C_{SP}, \beta)$ available in a form that can be solved for β. Then $\eta(C_{SP}, \beta)$ is needed to calculate η.

Thus, it is desired to obtain approximations for the functions $J_{OPT}(C_{SP})$, possibly $\beta_{OPT}(C_{SP})$, $J(C_{SP}, \beta)$, $\eta(C_{SP}, \beta)$, and possibly $\eta_E(C_{SP})$.

Data for isolated free air propellers from a report by Hamilton Standard (reference 14) were used to develop the required conceptual propeller characteristics function. The report provides data from detailed theory calculations for the 40 propellers listed in table 15. The activity factor α_p is defined as a weighted average of the distribution of blade width b with nondimensional radius ζ:

$$\alpha_p = \frac{100,000}{16} \int_{0.15}^{1} \frac{b(\zeta)}{D_p} \zeta^3 d\zeta \qquad (161)$$

The average lift coefficient C_{LA} is defined similarly as a weighted average of the distribution of the design lift coefficient C_{Ld} with nondimensional radius:

$$C_{LA} = 4 \int_{0.15}^{1} C_{LD}(\zeta) \zeta^3 d\zeta \qquad (162)$$

These parameters are measures of the thrust loading of the propeller (thrust per unit propeller disk area).

Half of the propellers have 3 blades. The other half have 4 blades. This analysis was concentrated on the 4-blade propellers.

The propeller characteristics are presented in the reference, as contour plots of η and β in rectangular J, C_P coordinates. (The speed power coefficient can be written in terms of the power coefficient C_P as $C_{SP} = J/C_P^{0.2}$.) Reading data from the contour plots and processing the numbers for the present purpose requires considerable time. Therefore, only part of the propeller data was analyzed.

However, the envelope maximum efficiency η_{EMX} was easily obtained for all cases. The variation of $(1 - \eta_{EMX})$ with C_{LA} is shown in figure 73. The data points show a minimum when C_{LA} is 0.2 to 0.3, depending on α_P. The lines in the figure are given by:

$$1 - \eta_{EMX} = \frac{0.0070}{C_{LA}} + 0.0035 B^{1/3} \alpha_P^{2/3} C_{LA}^{1/2} \qquad (163)$$

The function on the right side of equation (163) is used to define an effective speed power coefficient C_{SP}^* as:

$$C_{SP}^* = V \left(\frac{\rho \, (1. + 0.5 B^{1/3} \alpha_P^{2/3} C_{LA}^{3/2})}{12.7 \; C_{LA} P^* n^2} \right)^{0.2} \qquad (164)$$

TABLE 15

HAMILTON STANDARD PROPELLER DATA CASES[a]

Activity factor α_P	Average lift coefficient C_{LA}	3-blade case number	4-blade case number
80	0.15	19	40
80	.3	20	41
80	.5	21	42
80	.7	22	43
100	.15	23	44
100	.3	24	45*
100	.5	25	46*
100	.7	26	47*
140	.15	27	48
140	.3	28	49
140	.5	28*	50*
140	.7	30	51
180	.15	31	52
180	.3	32	53*
180	.5	33	54*
180	.7	34	55*
220	.15	35	56
220	.3	36	57
220	.5	37	58
220	.7	38	39

Source: Hamilton Standard (reference 14).

[a]The case numbers are the numbers of the figures giving the characteristics.

*Cases used in all of the analysis.

Use of C^*_{SP} for correlation for the different propellers minimizes the variation of characteristics. A correlation for J_{OPT}/C^*_{SP} is shown in figure 74. The ratio is a linear function of C^*_{SP}. The line in the figure is given by:

$$J_{OPT} = 0.45C^*_{SP} + 0.12C^{*2}_{SP} \quad (165)$$

The variation of the associated optimum blade angle β_{OPT} for achieving the envelope propeller efficiency is shown in figure 75. The line in the figure is given by:

$$\beta_{OPT} = 15.5C^*_{SP} \quad . \quad (166)$$

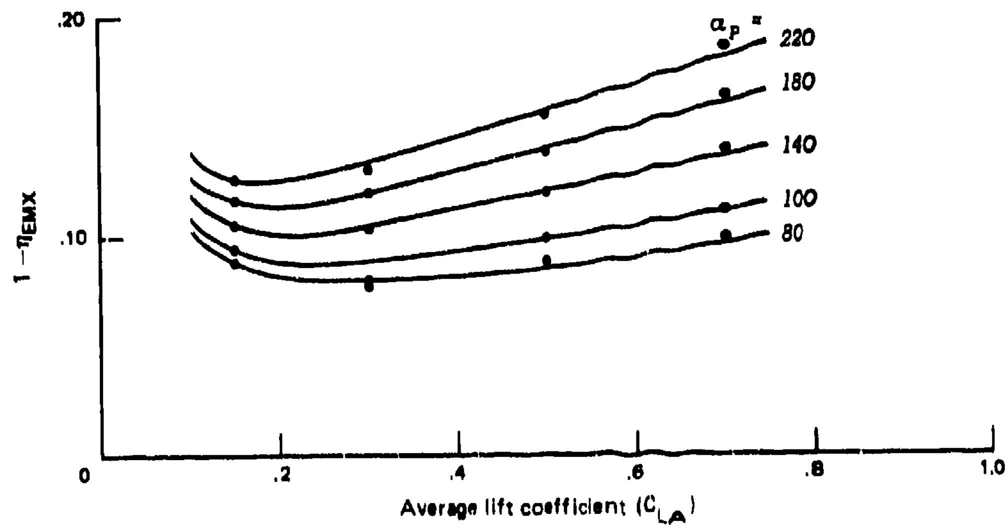

FIG. 73: VARIATION OF ENVELOPE MAXIMUM EFFICIENCY

The variation of J/C^*_{SP} with C^*_{SP} is shown in figure 76 for 8 of the propellers. The scatter bands are about $\pm$ 4 percent wide for each blade angle. The estimation lines shown in the figure are given by:

$$J/C^*_{SP} = (0.45 + 0.011\beta) - (0.060 - 0.0009\beta)\, C^{*\,2}_{SP} \quad . \quad (167)$$

The variation of η / C^*_{SP} is shown in figure 77. The lines are given by:

$$\eta_{EMC} C^*_{SP} / \eta = (0.40 + 0.017\beta^{1.2})\,(1 + (11.46C^*_{SP}/\beta)^3) \quad . \quad (168)$$

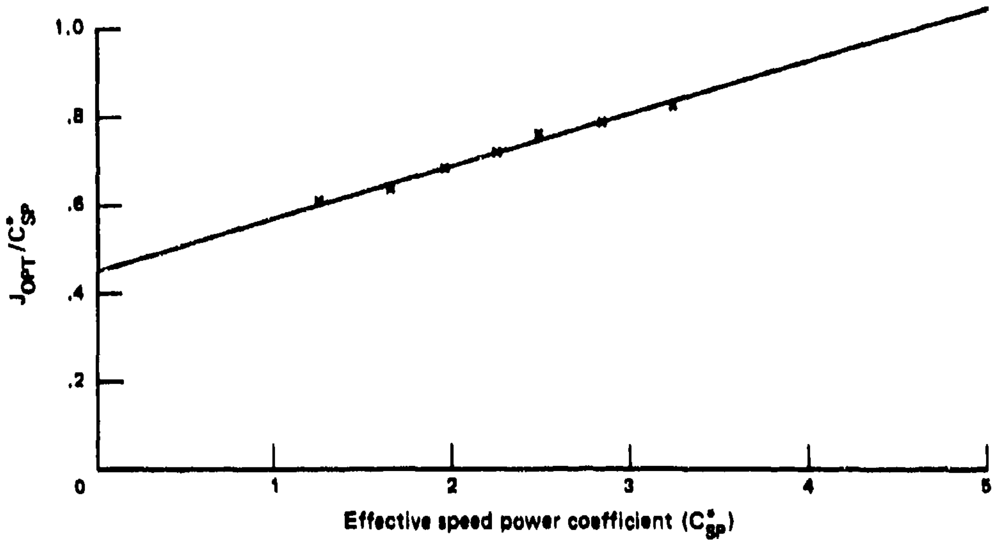

FIG. 74: VARIATION OF J_{OPT}/C^*_{SP}

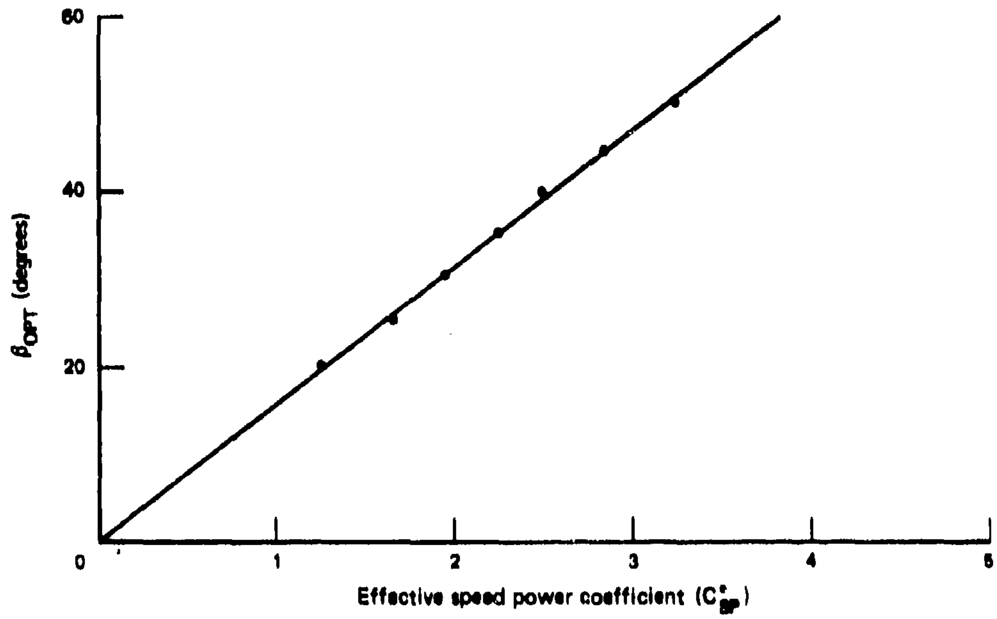

FIG. 75: VARIATION OF OPTIMUM BLADE ANGLE

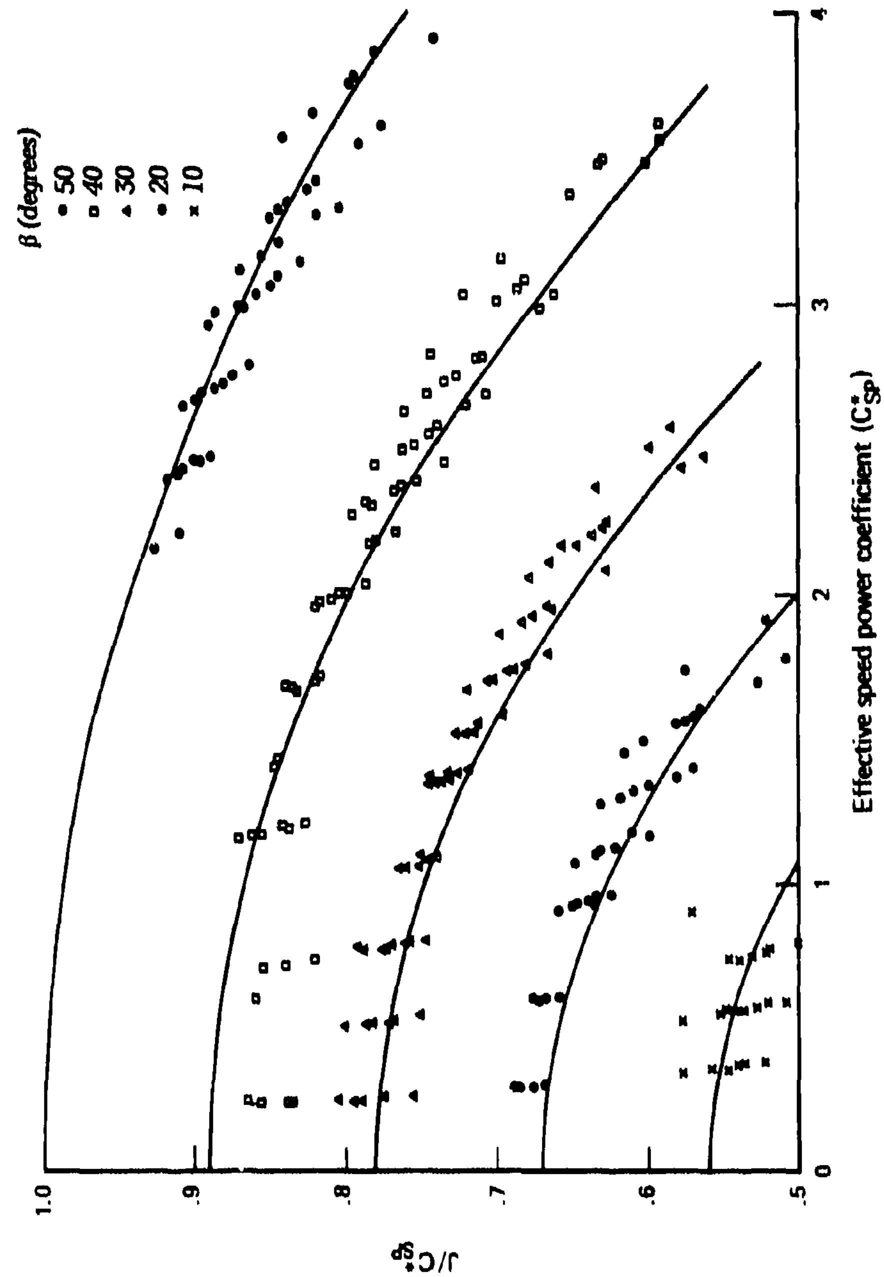

FIG. 76: VARIATION OF J/C*sp

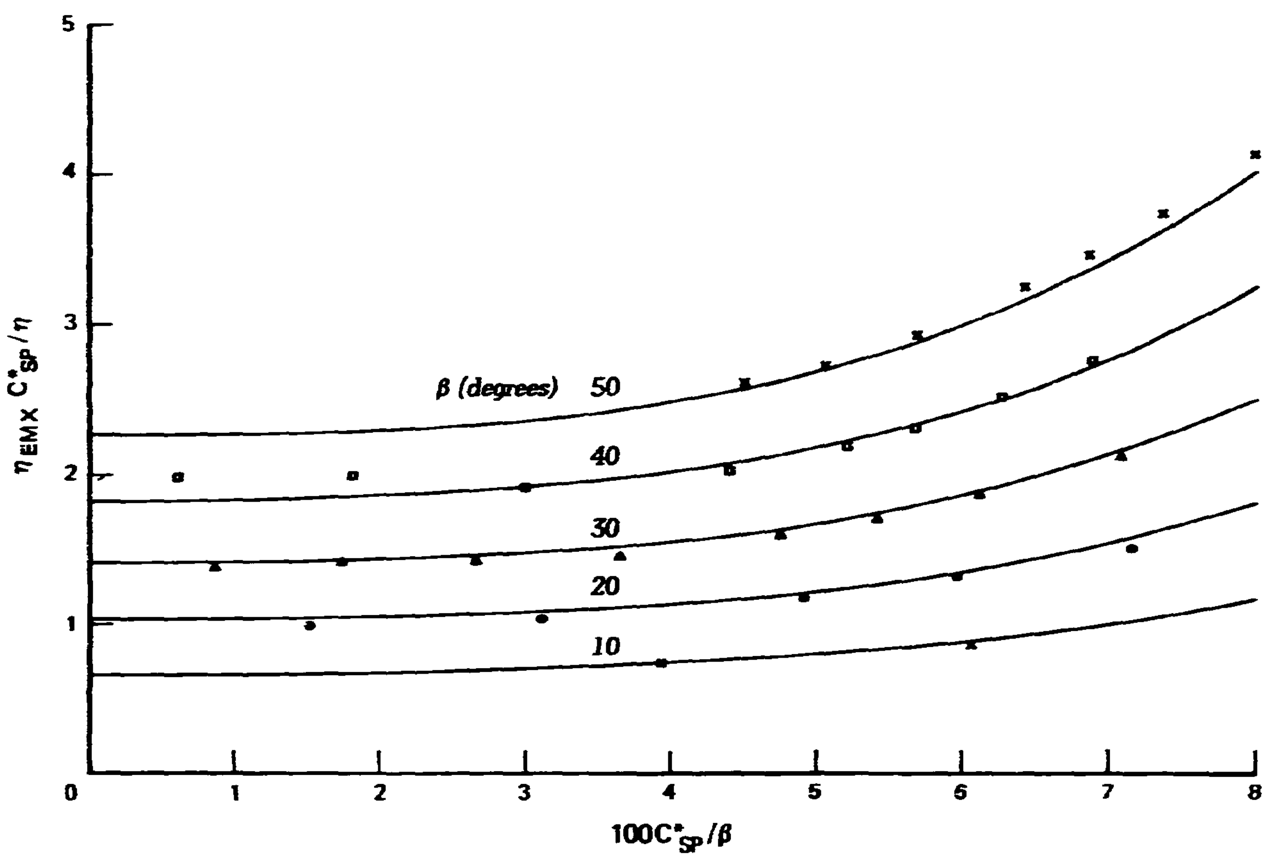

FIG. 77: CORRELATION OF $\eta_{EMX}\ C^*_{SP}/\eta$

Propeller And Reduction Gear Weight

Independent data for estimating propeller and reduction gear weight were not obtained. Goodyear (1975, Vol. IV, p. F-12, reference 8) gives the following equations for propeller weight W_{PROP} and reduction gear weight W_{REG}, based on data provided by Hamilton Standard:

$$W_{PROP} = 0.0684 D_P^2 \alpha_P^{0.75} (V_{TP}/1047)^{0.5} (P_{TO}/D_P^2)^{0.12} \quad ; \tag{169}$$

$$W_{REG} = 4.07 (P_{TO}/n)^{0.84}$$

TAKEOFF DISTANCES

This section considers takeoff distance estimation. The basic takeoff distance is the takeoff ground run distance. It is analyzed below. Takeoff distance to an altitude of 50 feet to clear obstacles can be used as a measure of required field size. Estimation of the latter requires consideration of the initial climbing flight after leaving the runway.

Only one reference to the relation between takeoff distance x_{50} to 50 feet and takeoff ground run x_G was found in the literature (Goodyear, 1968, p. 259, reference 10). The data were for the ZPG-3W blimp. In a head wind of 4.5 knots, measured values were 587 feet ground run and 1,468 feet to an altitude of 50 feet. Airship heaviness was 10,456 pounds. The envelope length of the ZPG-3W was 403 feet (table 8). The data imply a sod runway with a friction coefficient of 0.04, but data on takeoff speed and takeoff angle of attack were not obtained.

The ground run distance ratio x_G/L was 1.46 and the takeoff distance ratio x_{50}/x_G was 2.50. The latter should depend on the excess thrust available at lift-off and, therefore, on the ratio of takeoff speed to sustained speed. However, if the takeoff speed ratio is around 0.50, that is, not too close to unity, then the x_{50}/x_G ratio may not change significantly. For the ZPG-3W:

$$x_{50} = 2.5 x_G \quad . \tag{170}$$

The takeoff distance to an altitude of 50 feet was not considered further.

The takeoff ground run is the distance required to accelerate the airship from zero ground speed to an airspeed at which the aerodynamic lift is equal to the heaviness. The mass to be accelerated is that of the airship total weight W_T plus the heaviness H. The force is equal to the propeller thrust T, minus the drag $\mathcal{D}$ and a ground friction force. The ground friction force is assumed equal to a rolling friction coefficient times the force on the wheels, which is H minus the lift $\mathcal{L}$. In terms of ground distance x, the acceleration is d^2x/dt^2, but in terms of ground speed V_G it is dV_G/dt. Because dt is equal to dx/V_G , the acceleration can also be written as $V_G dV_G/dx$. Then the variables in the differential equation can be separated. The integration limits are zero to x_G and zero to the takeoff ground speed. The equations with the acceleration g of gravity to convert weight to mass, are:

$$\frac{W_T + H}{g} V_G \frac{dV_G}{dx} = T - \mathcal{D} - \mu(H - \mathcal{L}) \quad ; \tag{171}$$

$$x_G = \int^{x_G} dx = \frac{W_T + H}{g} \int_0^{V_{GTO}} \frac{V_G dV_G}{T - \mathcal{D} - \mu(H - \mathcal{L})} \quad .$$

Thrust, drag, and lift are functions of airspeed V , so it is desirable to express the integration in terms of airspeed. Ground speed is equal to airspeed minus wind speed V_W , and dV_G is equal to dV . The integration limits become V_W to takeoff airspeed V_{TO} :

$$x_G = \frac{W_T + H}{g} \int_{V_W}^{V_{TO}} \frac{(V - V_W)\, dV}{T - \mathcal{D} - \mu(H - \mathcal{L})} \quad . \tag{172}$$

The thrust is a decreasing function of airspeed V . For the ZPG-3W blimp, Goodyear (1968, p. 261, reference 10) gives an equation for the takeoff thrust T_{TO} :

$$T_{TO} = 17,300 - 125.6V + 0.414V^2 \quad . \tag{173}$$

The ratio of T_{TO} to the takeoff thrust T_{TO0} at zero airspeed is shown in figure 78 according to this equation, but as a function of airspeed in knots. This variation of thrust depends on the details of the propellers selected for the airship. However, the variation shown in the figure is generalized here only in regard to the ratio P_{TO}/P_{MC} of takeoff to maximum continuous power and the ratio T_S/T_{S0} of the thrust at sustained power and speed to the thrust at sustained power and zero speed. It is assumed that when power is changed, between the sustained (continuous) and takeoff ratings, the thrust changes in the same proportion. Then:

$$T = \frac{T_S}{R_{TS0} R_P} \left(1 - \frac{V}{V_S} + R_{TS0} \left(\frac{V}{V_S} \right)^2 \right); \qquad (174)$$

$$R_P = P_{MC}/P_{TO} = T_{S0}/T_{O0} \qquad ;$$

$$R_{TS0} = T_S/T_{S0} = 0.45$$

The factor $T_S/R_{TS0}R_P$ is simply T_{TO0} . The sustained speed of the ZPG-3W blimp was 82 knots. From figure 78 at 82 knots the thrust ratio was 0.45, which is shown in equation (174) as the standard value for R_{TS0} .

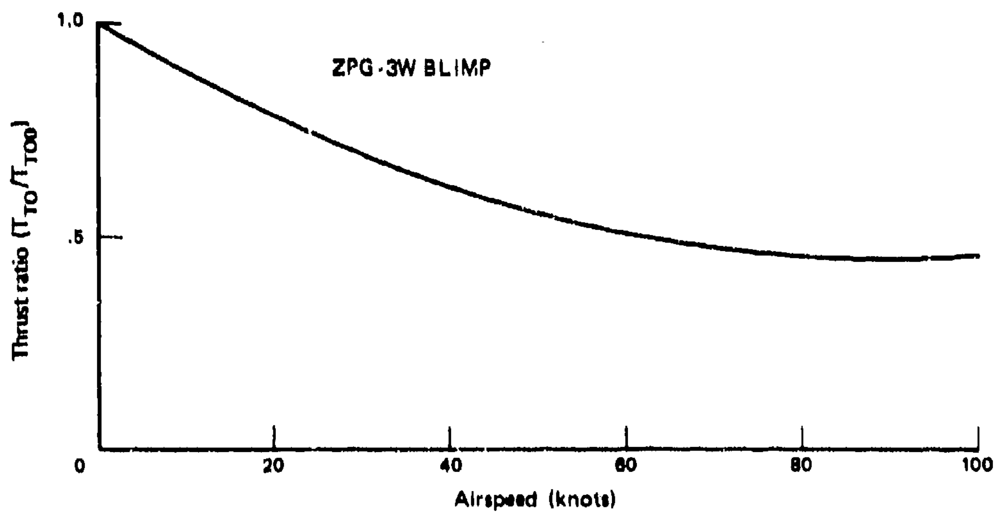

FIG. 78: VARIATION OF THRUST WITH AIRSPEED

The drag $\mathcal{D}$ at airspeed V includes lift drag associated with producing lift. It is assumed that a constant lift coefficient C_{LTO} is maintained during the ground run, even though at low speeds there may not be sufficient elevator moment to keep the airship nose up. The lift drag coefficient is approximated as $K^*C_{LTO}^2$. After takeoff the lift coefficient is inversely proportional to V^2 when the lift is constant. At the sustained flight speed the drag is equal to the sustained thrust. The standard drag equation gives:

$$\mathcal{D} = 0.5\rho V^2 A_{WH}(C_{D0} + K^*C^2_{LTO}) \quad ;$$

$$T_S = 0.5\rho V^2 A_{WH}(D_{D0} + K^*C^2_{LTO}(V_{TO}/V_S)^4) \quad ; \tag{175}$$

$$\mathscr{D} = \phi T_S (V/V_S)^2 \quad ;$$

$$\phi = (C_{D0} + KC^2_{LTO}) \,/\, (C_{D0} + K^*C^2_{LTO}(V_{TO}/V_S)^4)$$

During the ground run, the lift $\mathcal{L}$ is proportional to V^2 and is equal to the heaviness H at takeoff airspeed. Thus:

$$\mathcal{L} = H(V/V_{TO})^2 \tag{176}$$

Inspection of equations (173), (174), and (175) for T, $\mathscr{D}$, and $\mathcal{L}$ shows that there are constant, linear, and quadratic terms. In addition, it is convenient to replace V with $z = V/V_S$ everywhere, and to define V_{TO}/V_S as ν and V_W/V_S as ω. Then equation (172) for x_G becomes:

$$x_G = \frac{W_T + H}{g} \; \frac{V_S^2}{T_{TO0}} \int_{\omega}^{\nu} \frac{(z-\omega)dz}{a - z + cz^2} \quad ;$$

$$z = V/V_S \;, \quad \nu = V_{TO}/V_S \;, \quad \omega = V_W/V \quad ; \tag{177}$$

$$a = 1 - \nu H/T_{TO0}$$

$$c = R_{TS0}\,(1 - R_P\,(\phi - \mu H/T_{TO0}\nu^2)\,)$$

Integration gives 2 logarithmic terms. The second one can be transformed after substituting the limits by multiplying the numerator and denominator by $(1 - \Psi)(1 + \Psi)$ and rationalizing. The final result is:

$$x_G = \frac{W_T + H}{2gc} \; \frac{V_S^2}{T_{TO0}} \left(\ln\left(\frac{a - \nu + c\nu^2}{a - \omega + c\omega^2}\right) \right. \tag{178}$$

$$\left. + \frac{1 - 2c\omega}{\Psi} \; \ln\left(\frac{2a - (1-\Psi)\nu}{2a - (1-\Psi)\omega} \; \frac{2a - (1-\Psi)\omega}{2a - (1+\Psi)\nu}\right) \right) \quad ;$$

$$\Psi = \sqrt{1 - 4ac}$$

The first logarithmic term in equation (178) is numerically negative. The second logarithmic term is positive. The difference between the two is small. Thus, accurate calculations must be performed to avoid gross inaccuracies that occur when approximations are used.

Understanding the variation and magnitude of the takeoff ground run according to equation (178) requires calculations. But the number of calculations can be reduced by using a parametric form of the equation. For this purpose it is convenient to use the takeoff angle of attack α_{TO} and takeoff speed ratio ν as parameters. Equation (178) can then be written in the form:

$$x_G = \frac{W_T + H}{2gc} \frac{V_S^2}{T_{TO0}} f(a, c, \nu, \omega) \quad . \qquad (179)$$

Three steps are required to obtain the parametric form.

First, a and c are functions of μ, R_{TS0}, R_P, and H/T_{TO0}. The heaviness ratio can be expressed in terms of the lift curve slope $C_{L\alpha}$ and α_{TO} as follows:

$$\begin{aligned} A_{WH} &= \chi \nabla_E^{2/3}, \ \chi = 6.54 \quad ; \\ C_{LTO} &= C_{L\alpha}\alpha_{TO}, \ C_{L\alpha} = 0.021 \quad ; \qquad (180) \\ C_{DS} &= C_{D0} + KC_{L\alpha}\alpha_{TO}\nu^4 \quad ; \\ \frac{H}{T_{TO0}} &= R_{TS0}R_P \frac{C_{L\alpha}}{\chi} \frac{\alpha_{TO}}{C_{DS}} \nu^2 \quad . \end{aligned}$$

The parameter χ can be expressed in terms of envelope length-diameter ratio L/D (equations (39) and (38) of chapter 3 on lift gases and geometry). The value shown is for L/D equal 5. For the calculations, a lift curve slope of 0.021 is used (equation (122) of chapter 4 on aerodynamic drag and lift). Its proper value is uncertain because it is not known whether trimmed pitching moment conditions apply during the ground run and whether there are significant aerodynamic "ground" effects. The sustained speed drag coefficient C_{DS} is defined for convenience and can be used in expressing ϕ (equation (175)). Then T_{TO0} is expressed in terms of R_{TS0}, R_P, and T_S (equation (174)). Using H from its defining equation ($H = 0.5\rho V_{TO}^2 \nabla_E^{2/3} C_{L\alpha}\alpha_{TO}$) and T_S from equation (175) the final equation (180) is obtained.

The second step involves transforming the coefficient in equation (179) and dividing it by envelope length L:

$$L = \lambda \nabla_E^{1/3} \, , \quad \lambda = 3.66 \qquad ;$$

$$W_T = \rho g \nabla_E \qquad ; \tag{181}$$

$$\frac{x_G}{L} = \frac{R_{TS0} R_P}{\chi \lambda C_{DS} C} \left(1 + \frac{H}{W_T} \right) f(a, c, \nu, \omega) \quad ,$$

The parameter λ can be expressed as a function of prismatic coefficient and L/D (equation (38) of chapter 3). The value given for the calculations is for a C_P of 0.65 and L/D of 5. The total weight W_T can be expressed as the total buoyancy $\rho g \nabla_E$. Using T_{TO0} in terms of T_{TS0}, R_P, and T_S, the result shown for x_G/L is obtained. Except for H/W_T in the factor, x_G/L is independent of the sustained speed and envelope volume of the airship.

However, H/W_T can be expressed in terms of the defining equation for H and the total buoyancy:

$$\frac{H}{W_T} = \frac{C_{L\alpha} \alpha_{TO} \nu^2}{2 (\nabla_E^{1/3} / V_S^2)} \tag{182}$$

The aerodynamic lift parameter $\nabla_E^{1/3} / V_S^2$ (see the section on lift-drag ratio in chapter 4) influences the value of H/W_T.

The only data obtained for checking this analysis of takeoff ground run distance are those for the ZPG-3W blimp that are cited at the beginning of this section. Data, from various sources, for a calculation for the ZPG-3W are shown in table 16. The takeoff speed was estimated on the basis of discussions with a former ZPG-3W pilot. The zero-lift drag coefficient was estimated from flatplate drag area given by Goodyear (1968, p. 262, reference 10). The agreement between the data value of 587 feet and the calculated 683 feet is satisfactory.

This calculated value is 16 percent greater than the data for the ground run distance. The calculated value would be exact if the takeoff speed had been 38 knots instead of the assumed 40 knots. The correspondence would also be exact if the actual wind speed during the ground run had been 7 knots instead of the 4.5 knots given in the data. It appears that very careful experimental measurements are necessary to validate ground run distance theory. Conversely, considerable variation of x_G in operational conditions can be expected.

TABLE 16

ZPG-3W GROUND RUN CALCULATIONS

Characteristics	Value	Calculated Value
Volume (cu.ft.)	1,490,000	C_{LTO} = 0.148
Total weight (lb.)	113,945	$C_{L\alpha}$ = 0.021
Heaviness (lb.)	10,456	α_{TO} = 6.9 degrees
Sustained speed (kt.)	82.	ν = 0.49
Takeoff speed (kt.)	40.	ω = 0.055
Wind speed (kt.)	4.5	
Takeoff power (h.p.)	3,050	
Sustained power (h.p.)	2,550	R_P = 0.84
T_{O0} (lb.)	17,300	
Sustained thrust (lb.)	6,540	R_{TOS} = 0.45
C_{D0}	0.0041	
$A_{WH}/\nabla_E^{2/3}$	6.45	ϕ = 1.68
K*=0.90/6.45	0.140	
		μ = 0.04
		a = 0.976
		c = -0.145
		ψ = 1.25
x_G (ft.), data	587	x_G = 683

The sensitivity of takeoff ground run to 3 parameters was calculated. The ratio $(x_G/L) / (1 + H/W_T)$ was used. For takeoff speed ratios up to 0.70 the influence of α_{TO} is negligible.

The influence of the rolling friction coefficient μ is also negligible. Typical values are: hard surface, 0.02; hard turf, 0.04; average sod field, 0.05; and long grass, 0.10 (Wood, p. 185, reference 32). For any of these values, the changes of takeoff ground run distance are less than 3 percent.

Airship ground run is governed by the acceleration of the mass of the airship. The influence of the ratio R_p of cruise power to takeoff engine power is shown in figure 79. The ground run increases as R_p increases. Thus extra takeoff power (lower R_p) provides a shorter ground run.

The influence of zero-lift drag coefficient C_{D0} is shown in figure 80. The ground run distance is approximately inversely proportional to C_{D0}. This result is due to the requirement for more sustained power when C_{D0} increases; the additional power provides a more rapid takeoff acceleration.

A final comparison is shown in figure 81. The influence of the wind speed ratio ω is significant for correlation with experimental data and for operations in usual winds.

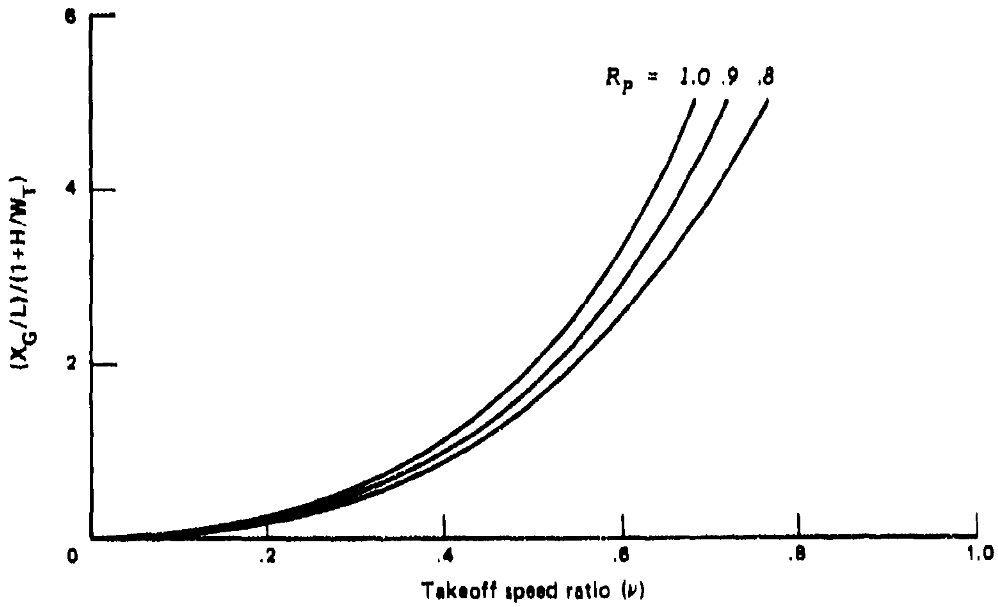

FIG. 79: INFLUENCE OF CRUISE POWER RATIO

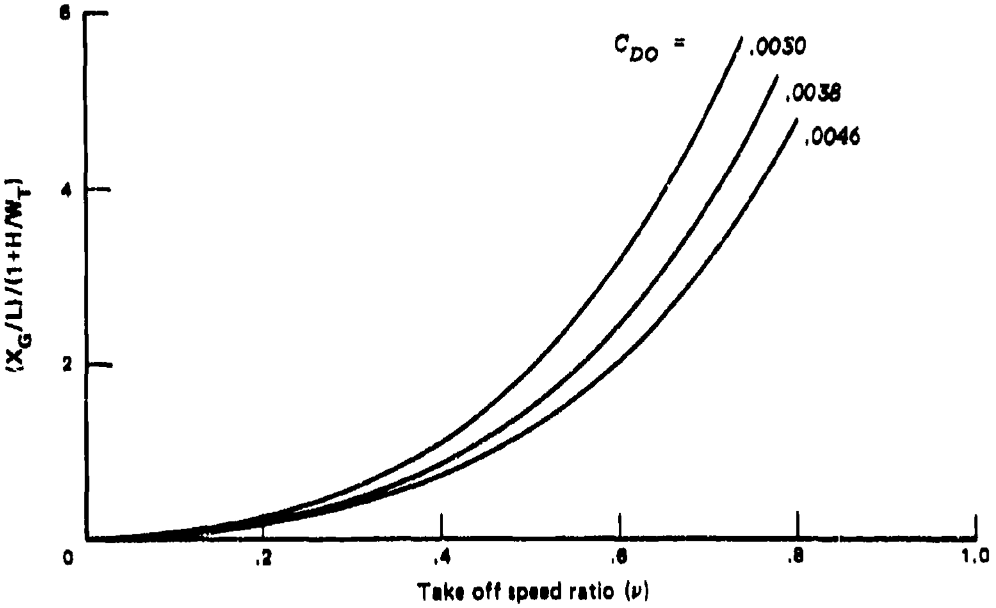

FIG. 80: INFLUENCE OF ZERO LIFT DRAG COEFFICIENT

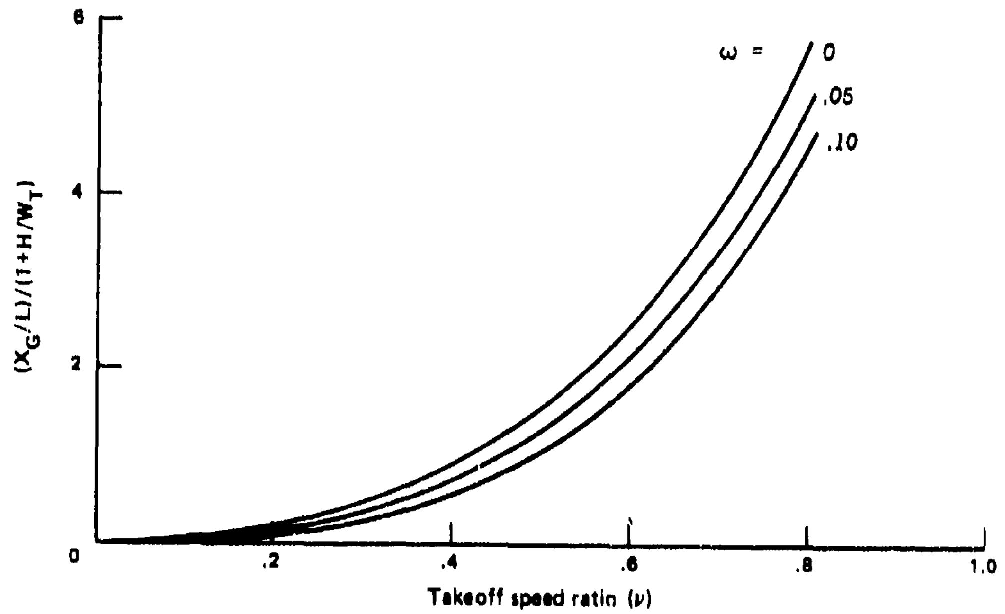

FIG. 81: INFLUENCE OF WIND SPEED RATIO

ENGINE CHARACTERISTICS

Several types of engines could be used for airship propulsion. Diesel engines use high compression for ignition and obtain greater fuel economy and reliability than other reciprocating engines. Reciprocating (Otto thermodynamic cycle) engines use electrical ignition systems. They are lighter but provide poorer fuel economy than diesel engines.

The third type of engine is the turboprop (Brayton cycle). The turboprop has moderate fuel economy and is lighter than the other engine types. In addition, the frontal area of the turboprop engine is very slow. This reduces installation drag of the enclosing nacelles necessary for airship applications.

Each of these engine types is considered below. The principal characteristics are the engine dry weight as delivered by the manufacturer, the projected frontal area that determines the frontal area of an enclosing nacelle, the relation between various power ratings, and a reference fuel economy expressed as specific fuel consumption in pounds of fuel per output horsepower-hour. Next, additional installation weights for cooling, lubrication system, controls, accessories, nacelles, and outriggers to support the nacelles are considered. Finally, fuel weight estimation, including the influence of part-throttle operation, is discussed for all the engine types grouped together. The engine characteristic estimates are based on data for past and available 1976-era engines.

Engine ratings (in horsepower) are given in several forms and can be confusing. A uniform definition of ratings is used here. Ratings are given for sea level altitude. Takeoff power rating is a 1-minute time-limited rating. Maximum continuous power rating (also "normal" power for reciprocating engines). Maximum continuous power may be less than takeoff power. Cruise power rating is usually less than the maximum continuous rating. It is a manufacturer's recommendation for desirable maintenance levels and lifetime.

Diesel Engine Characteristics

Diesel engines can have rotational speeds from 100 to 3,000 r.p.m. Their specific weight per horsepower is almost inversely proportional to rotational speed; therefore, aircraft diesel engines have higher rotational speeds.

Aircraft diesel engine development peaked in the 1930s. Diesel-powered aircraft were used in quantity only in Germany, and only before 1945. There were radial air-cooled, radial liquid-cooled, in-line, in-line Vee, and horizontally opposed configurations. Some had geared propeller drive, and several were supercharged to 7,000- to 20,000-foot altitudes.

Data from Wilkinson 1940, pp. 91-115 (reference 30) are shown in table 17. The maximum continuous power P_{MC} is used as the reference power rating in this volume. Wilkinson's "cruise (max.)... (continuous)" power rating was taken as "maximum continuous" for use here. The weight W_E of the engine is the dry weight. Liquid-cooled engines require about 0.25 (water) to 0.30 pounds per horsepower (ethylene glycol) of coolant liquid in addition to W_E . Some engines have integral reduction gearing to provide desirable propeller rotation rates. Greater reduction is required for larger powers,

TABLE 17

1940 DIESEL ENGINE DATA

Engine	Class[a]	M.C.[b] rating	Weight (lb.)	Gear ratio	Blower[c] (ft.)	L[d] (in.)	w (in.)	h (in.)	σ_R[e] (lb/hphr)
BMW Lanova 114	4R9E	520	1058	1.00	6900	51.1	54.3	--	.37
Bristol Phoenix	4R9A	550	1090	.65	7000	43.0	53.0	--	.39
Clerget 14 F-01	4R14W	700	1477	1.00	8900	61.8	50.0	--	.40
Clerget 16H	4V16W	1600	3750	1.00	16400	112.6	31.5	49.2	.37
Coatalen 12 VRS	4V12W	550	1212	.67	9800	67.7	30.7	38.6	.34
Deschamps V3050	2V12E	950	2400	1.00	10000	99.0	26.5	49.6	.41
Guiberson A1020	4R9A	310	653	1.00	0	38.6	47.1	--	.37
Jalbert-Loire 16H	4H16W	500	1235	.65	0	48.8	24.4	49.6	.39
Junkers 205-E	2I12W	560	1257	.63	0	80.0	23.6	52.2	.35
Junkers 207	2I12W	800	1430		26000	86.0	23.6	52.2	.35
Mercedes LOF-6	4V16W	1100	4320		0				
Mercedes DB 602	4V16W	(900)	4410	.50	0	111.0	37.1	51.8	.36
Salmson SH 18	2R18W	550	1250	1.00	0	56.6	48.8	--	.39
ZOD 260-B	2R9A	260	707	1.00	0	34.6	47.6	--	.40

Source: Wilkinson 1936 (reference 31), 1940 (reference 30), and 1945 (reference 28).

[a] 2/4 cycle; horizontal, in-line, radial, Vee; number cylinders; air-cooled, ethylene glycol, water-cooled.

[b] Maximum continuous power rating (horsepower).

[c] Fuel power altitude, by geared blower or turbosupercharger.

[d] Length, width, and height. Radial diameter under width.

[e] Reference specific fuel consumption at cruise power.

and for the relatively low airship speeds even greater reduction could be desirable. Blower altitude shows the altitude to which an integral geared blower on turbosupercharger maintains a constant power. The length, width, and height data indicate the geometric size of the engine and is used here to estimate the required nacelle frontal area for airship installations. The reference specific fuel consumption σ_R is a manufacturer's specification for cruise power rating and expected aircraft cruise altitude. It does not include lubricating oil consumption, which was from 0.007 to 0.033 pounds per horsepower hour for the engines in the table and averaged about 0.016 pounds per horsepower hour. Also, σ_R does not include possible increases due to engine installation geometry and engine deterioration between overhauls. Variation of the specific fuel consumption from the reference value is considered later.

Diesel engine specific weight W_E/P_{MC} is shown in figure 82. The 1940 data are widely scattered. However, study of the configuration class shows no reduction of the scatter. Therefore, the one line shown in the figure was selected to approximate the variation. The line is given by:

$$\frac{W_E}{P_{MC}} = \frac{4.0 + .020P_{MC}}{1 + .010P_{MC}} \text{ , diesels } . \qquad (183)$$

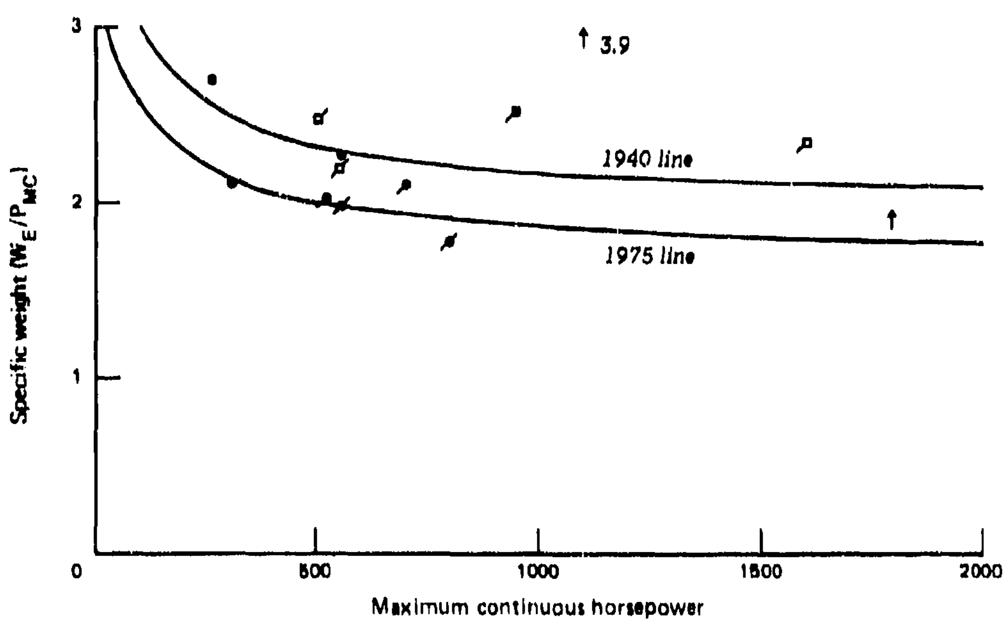

FIG. 82: 1940 DIESEL ENGINE W_E/P_{MC}

Data for 1976 diesels were not obtained. An assumed value at 85 percent of the 1940 estimate is shown in the figure. It is given by:

$$\frac{W_E}{P_{MC}} = \frac{3.4 + 0.17P_{MC}}{1 + 0.010P_{MC}} \quad \text{, 1976 diesel} \quad . \qquad (184)$$

The engine data for width and height were used to estimate nacelle frontal area A_{FNC}. The bare engine frontal area is increased by a factor $4/\pi$ or 1.27 to account for the thickness of nacelle structure. Then the nacelle frontal area for in-line engines is $4wh/\pi$ and for radial engines w^2. The data points in figure 83 separate into 2 trends, 1 for radial engines and another for the in-line (including horizontal and Vee) configurations. The lines shown in the figure are given by:

$$A_{FNC} = 0.17P_{MC}/(1 + 0.008P_{MC}) \text{, 1945 radial diesel} \quad ; \qquad (185)$$

$$A_{FNC} = 0.05P_{MC}/(1 + 0.003P_{MC}) \text{, 1945 in-line diesel} \quad .$$

It is assumed that these estimates are valid for 1976 diesels also.

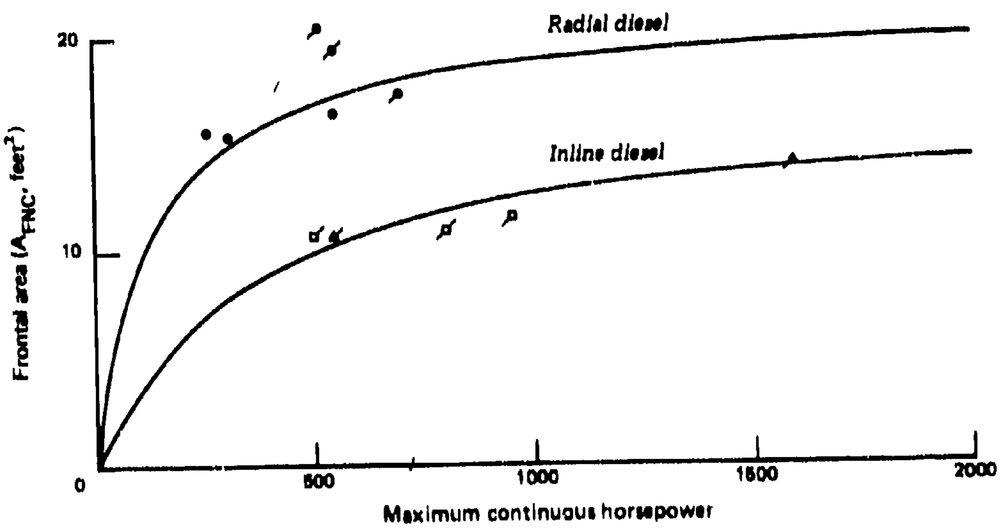

FIG. 83: 1940 DIESEL ENGINE FRONTAL AREA

An engine length-diameter ratio $(L/D)_{ENG}$ is defined for the model as $L/\sqrt{wh}$ for in-line engines and as L/w for the radial engines. This length-diameter ratio is used as a minimum constraint on the nacelle length-diameter ratio. The ratios obtained from the data in table 17 vary from 1.40 to 2.86 for in-line engines and from 0.73 to 1.24 for the radial engines. The following estimations are selected:

$$(L/D)_{ENG} = 3 \; , \quad \text{in-line diesels} \; ; \tag{186}$$

$$(L/D)_{ENG} = 1.5, \quad \text{radial diesels} \; .$$

Power rating ratios for 1940-era diesel engines are shown in figure 84. The takeoff power P_{TO} ratio to P_{MC} varies considerably. A reasonable estimation ratio would be:

$$P_{TO}/P_{MC} = 1.20 \quad , \text{1940 diesel engines} \; . \tag{187}$$

Only 2 values for cruise power P_{CR} were obtained. They give:

$$P_{CR}/P_{MC} = 0.75 \quad , \text{1940 diesel engines} \; . \tag{188}$$

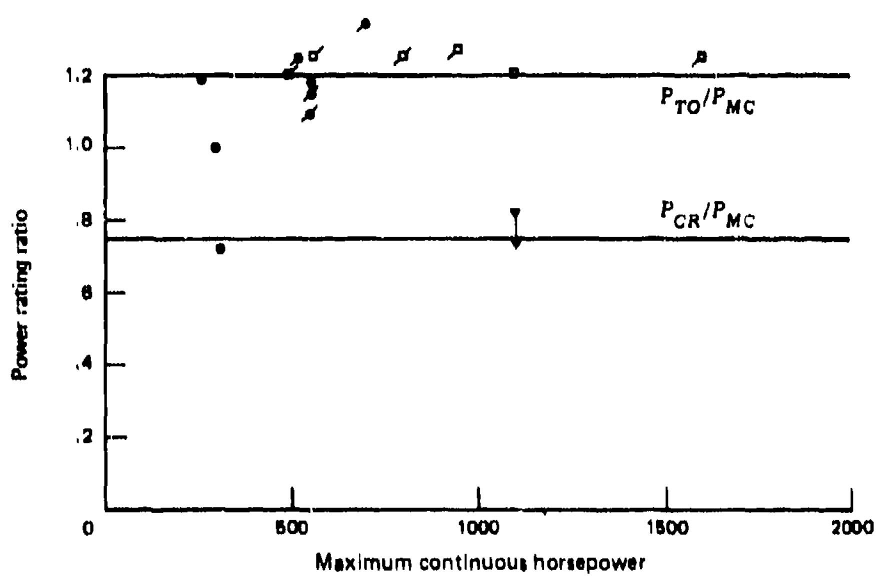

FIG. 84: 1940 DIESEL ENGINE POWER RATIOS

The reference specific fuel consumption data for the 1940 diesel engines are shown in figure 85. The scatter does not provide a basis for selecting a variation with P_{MC} . A constant value is selected:

$$\sigma_R = 0.37 \text{ , 1940 diesel engines .} \tag{189}$$

For diesel engines, lubricating oil consumption must be considered. The reference specific oil consumption σ_{RO} was selected as:

$$\sigma_{RO} = 0.015 \text{ , 1940 diesel engines .} \tag{190}$$

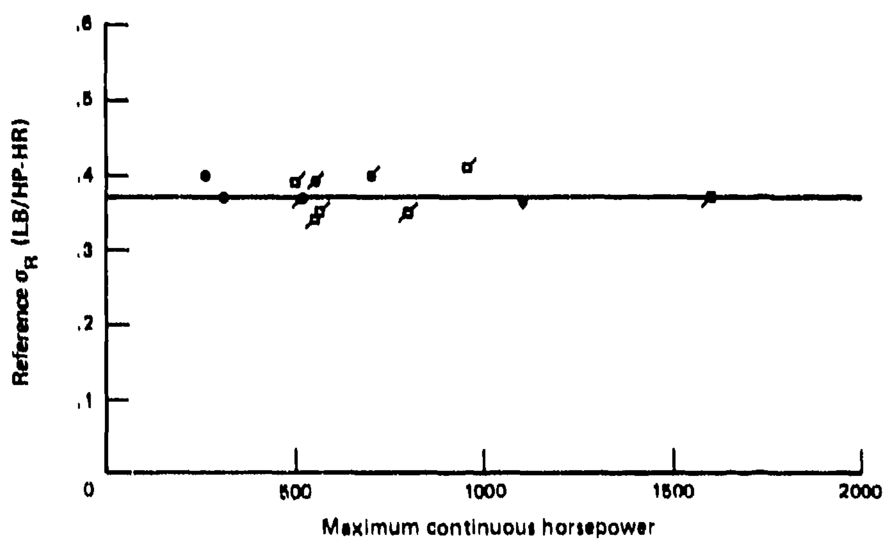

FIG. 85: 1940 DIESEL ENGINE SFC

Reciprocating Engine Characteristics

Air-cooled and liquid-cooled aircraft reciprocating engines attained mature development by the end of World War II in sizes up to 2,000 horsepower. Some improvement in characteristics has occurred since then in moderate power horizontally opposed air-cooled engines for light aircraft. Availability in 1976 is essentially restricted to these light aircraft engines.

Data for a few historical airship engines are shown in table 18. Similar data for other engines are shown graphically only, in the figures below. It appears that none of the engines in table 18 was still in production in 1976.

TABLE 18

SELECTED RECIPROCATING ENGINE DATA

Engine	Ref. year	M.C.[a] rating	Weight (lb.)	Gear ratio	Blower[b] (ft.)	L^c (in.)	w (in.)	h (in.)	$\sigma_R{}^d$ (lb/hphr)	Blimp
Continental[e] R-670-6	1945	240	450	1.00	No	34.2	42.2	—	.49	G-type
Pratt & Whitney R-1340-AN2	1945	550	938	.67	Yes	47.8	51.8	—	.48	K-type
Wright R-1820-82	1954	1275	1404	.56	3000	50.1	55.7	—	.47	ZPG-3W[f]
Continental GO-300-A	1965	175	312	.75	No	39.1	31.5	27.6		Columbia III
Continental IO-360-D	1970	210	294	1.00	No	35.3	31.4	23.7	.44	America
Wright R-3350-38	1970	2920	3675	.38	Yes	89.5	56.6	—	.38	None

Source: Wilkinson 1945 and 1970 (references 28 and 29).

[a] Maximum continuous power ratings (horsepower).

[b] Integral geared supercharger blower and/or turbosupercharger.

[c] Length, width and height. Diameter given under width.

[d] Reference specific fuel consumption at cruise rating.

[e] Data for W670-M

[f] -88 was used on ZPG-3W blimps, with 0.35 gear ratio and apparently an increased weight.

The maximum continuous sea level horsepower P_{MC} rating is used as the reference rating. The weight W_E is the engine alone dry weight. Liquid-cooled engines require about 0.30 pounds per horsepower of ethylene glycol coolant in addition to W_E. Some engines have integral reduction gearing to provide desirable propeller rates. Greater reduction is provided for larger power ratings. When airship speeds are considerably below those of light airplanes, even further reduction could be desirable. Many airplane reciprocating engines have integral supercharged geared blowers or turbosuperchargers to provide seal level power up to the altitudes listed. The length, width, and height data in table 18 indicate the size of engine and are used here to estimate the required nacelle size for airship installations.

The reference specific fuel consumption c_R is a manufacturer's specification for cruise power rating and expected aircraft cruise altitude. It does not include lubricating oil consumption, which was about 0.02 pounds per horsepower hour. It does not consider possible increases from the engine installation geometry and engine deterioration between overhauls. Variation of the specific fuel consumption from the reference value due to power setting changes is considered below.

There were many airplane reciprocating engines in 1945. Data from Wilkinson 1945 (reference 28) for several 1945-era reciprocating engines were used. The specific weight W_E/P_{MC} is shown in figure 86. It decreases rapidly as P_{MC} increases from small values, but approaches an asymptote of about 1.25 pounds per horsepower. The dashed "1945 line" is given by:

$$\frac{W_E}{P_{MC}} = \frac{3.5 + 0.015P_{MC}}{1 + 0.012P_{MC}} \quad \text{, 1945 reciprocating .} \qquad (191)$$

The "1976 line" curve is discussed below. If the specific weight were referred to the take-off power rating, it would generally be smaller.

The nacelle frontal area is calculated as 4wh/π for in-line engines and w^2 for radial engines. The data points in figure 87 separate into 3 trends for horizontally opposed (HO), radial, and liquid-cooled Vee cylinder configurations. The lines shown in the figure are defined by:

$$A_{FNC} = 0.31P_{MC}/(1 + 0.040P_{MC}) \quad \text{, 1945 HO ;}$$

$$A_{FNC} = 0.171P_{MC}/(1 + 0.008P_{MC}) \quad \text{, 1945 radial ;} \qquad (192)$$

$$A_{FNC} = 0.0096P_{MC} \quad \text{, 1945 liquid-cooled Vee .}$$

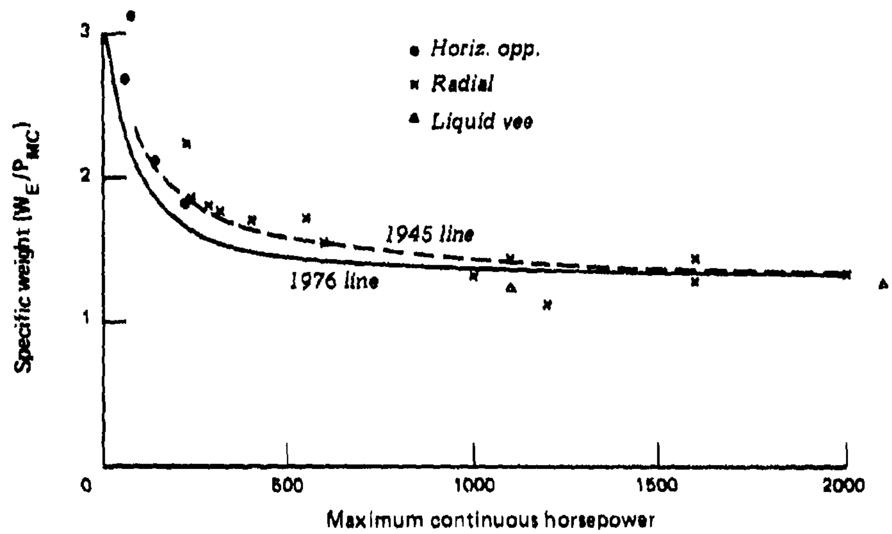

FIG. 66: 1945 RECIPROCATING ENGINE W_E/P_{MC}

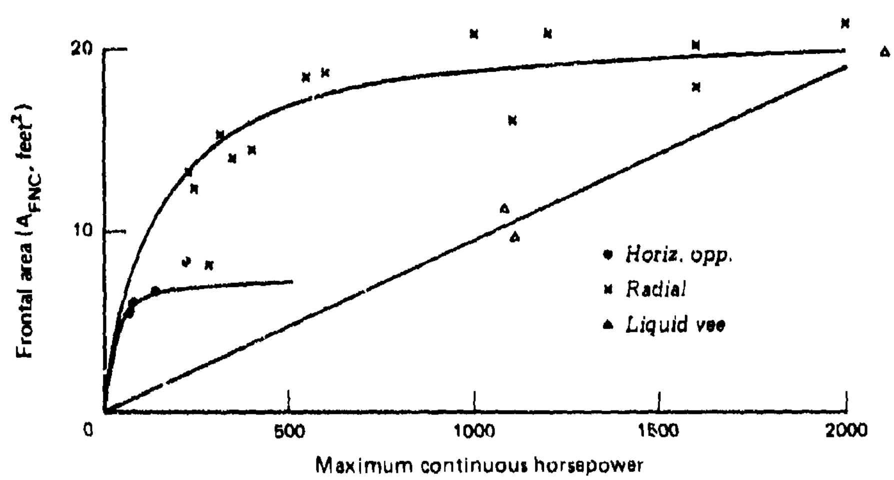

FIG. 67: 1945 RECIPROCATING ENGINE FRONTAL AREA

The engine length-diameter ratios are selected as:

$$(L/D)_{ENG} = 2 \quad \text{, HO reciprocating ;}$$

$$(L/D)_{ENG} = 1.5 \quad \text{, radial reciprocating ;} \tag{193}$$

$$(L/D)_{ENG} = 3 \quad \text{, liquid-cooled Vee}$$

Power rating ratios for the 1945 reciprocating engines are shown in figure 88. The takeoff power P_{TO} ratio to P_{MC} varies considerably. The larger ratios are for the liquid-cooled Vee engines and one brand of radial engine. A reasonable estimation ratio would be 1.10:

$$P_{TO}/P_{MC} = 1.10 \quad \text{, 1945 reciprocating} \tag{194}$$

A reasonable estimation ratio for cruise power P_{CR} to P_{MC} is selected as 0.75:

$$P_{CR}/P_{MC} = 0.75 \quad . \tag{195}$$

The lower data points in figure 88 are for one brand of radial engine.

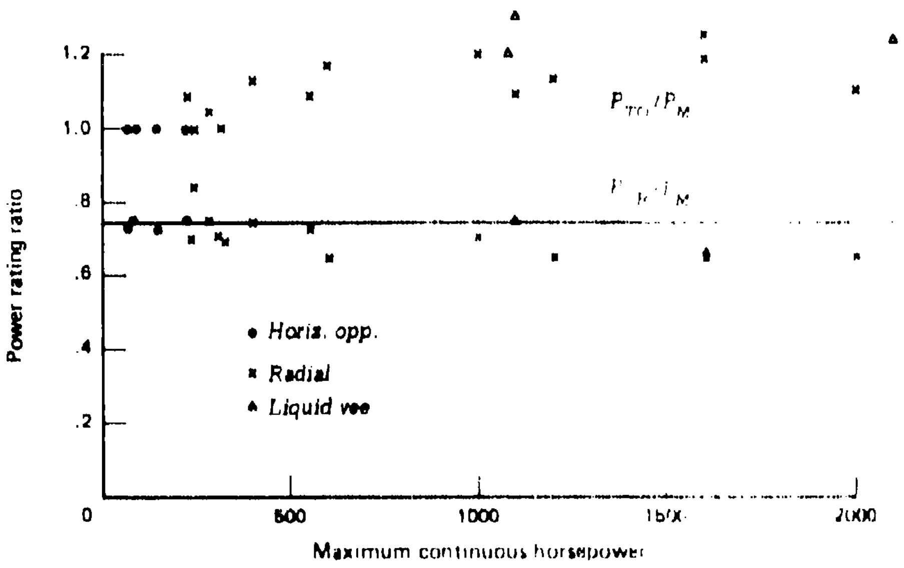

FIG. 88: 1945 RECIPROCATING ENGINE POWER RATIOS

The reference specific fuel consumption shown in figure 89 for this data decreases as maximum continuous power increases, to an apparent asymptote. The line in the figure is given by:

$$\sigma_R = \frac{0.6 + 0.0046 P_{MC}}{1 + 0.0100 P_{MC}} \text{ , 1945 reciprocating .} \qquad (196)$$

For lubricating oil consumption:

$$\sigma_{RO} = 0.02 \text{ , 1945 reciprocating .} \qquad (197)$$

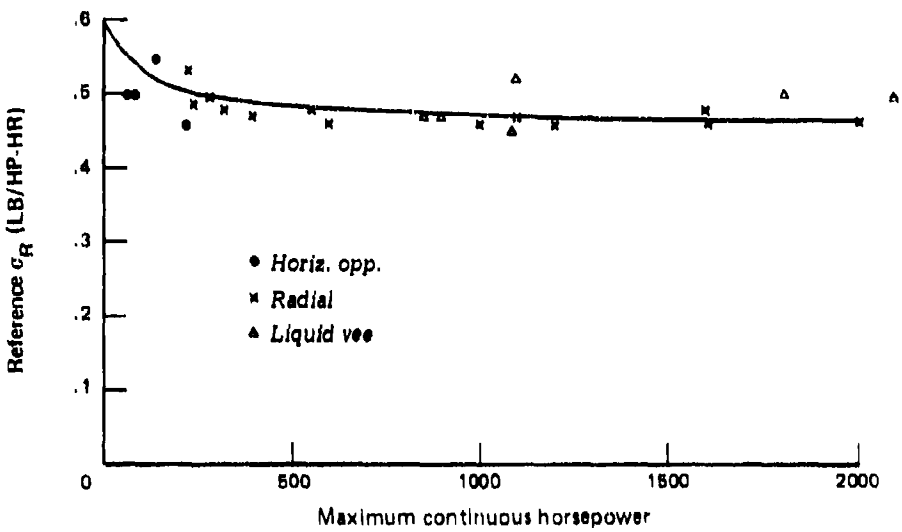

FIG. 89: 1945 RECIPROCATING ENGINE SFC

For 1976 reciprocating engines, data for these 5 characteristics are shown in figures 90 to 93. Few cylinder configurations, other than horizontally opposed ones, are available, and only HO configurations are shown. Maximum continuous power ratings are 450 and less. However, the data in table 18 for the Wright R-3350 were considered in selecting the equations for 1976 reciprocating engines. The data are principally from Wilkinson 1970 (reference 27), with checks from Jane's Aircraft and Aviation Week (reference 3). One symbol is used in the figures for direct drive unsupercharged engines, with a different symbol for geared, supercharged, and both, engines. Except for specific fuel consumption, there appear to be no trends associated with those differences. The line in figure 90 for specific weight is given by:

$$\frac{W_E}{P_{MC}} = \frac{3.5 + 0.020P_{MC}}{1 + 0.016P_{MC}} \quad , \quad 1976\ \text{HO} \quad . \tag{198}$$

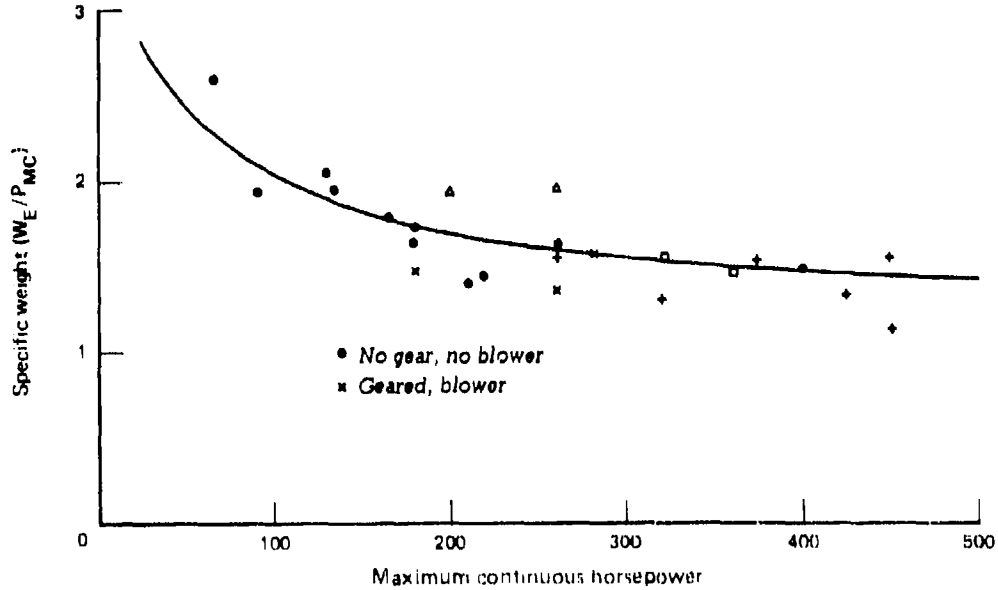

FIG. 90: 1976 RECIPROCATING ENGINE W_E/P_{MC}

The solid line shown in figure 86 is given by this equation; it indicates specific weight for engines with about 500 horsepower decreased about 10 percent in 30 years.

The line in figure 91 for the nacelle frontal area is given by equation (192) for 1945 horizontally opposed engines. The engine length-diameter ratio is taken as unchanged.

$$A_{FNC} = 0.31P_{MC}/(1 + 0.040P_{MC}) \quad , \quad 1976\ \text{HO} \quad ; \tag{199}$$

$$(L/D)_{ENG} = 2 \quad , \quad 1976\ \text{HO}$$

The data points in figure 91 were considered in selecting the 1945 equation, and the 1945 data points are included here in figure 91. Within the considerable scatter there was no change from 1945 to 1976.

The takeoff power ratio in figure 92 is usually unity:

$$P_{TO}/P_{MC} = 1.0 \quad , \quad 1976\ \text{reciprocating} \quad . \tag{200}$$

The cruise power ratio is almost always 0.75:

$$P_{CR}/P_{MC} = 0.75 \quad , \quad 1976 \text{ reciprocating} \quad . \qquad (201)$$

The reference specific fuel consumption in figure 93 appears to trend somewhat lower than in 1945, at least for direct drive nonsupercharged engines. The line in the figure is defined by:

$$\sigma_R = \frac{.6 + .0038P_{MC}}{1 + .0100P_{MC}} \quad , \quad 1976 \text{ reciprocating} \quad . \qquad (202)$$

If operation at altitudes above 10,000 feet is required, a σ_R constant at about 0.50 would provide a better estimate. The lubricating oil consumption appears to have decreased:

$$\sigma_{RO} = 0.015 \quad , \quad 1976 \text{ reciprocating} \quad . \qquad (203)$$

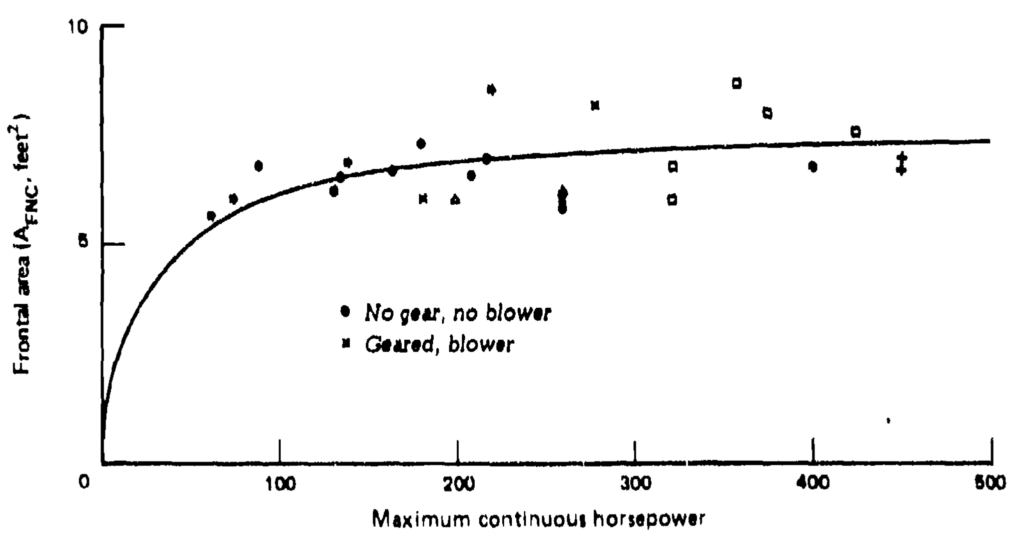

FIG. 91: 1975 RECIPROCATING ENGINE FRONTAL AREA

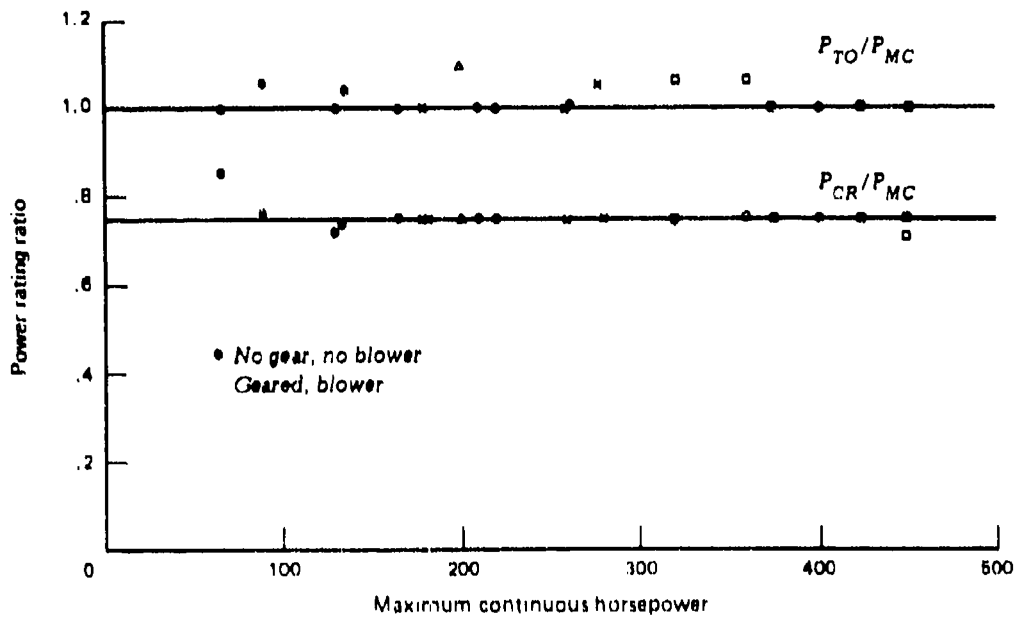

FIG. 92: 1976 RECIPROCATING ENGINE POWER RATIOS

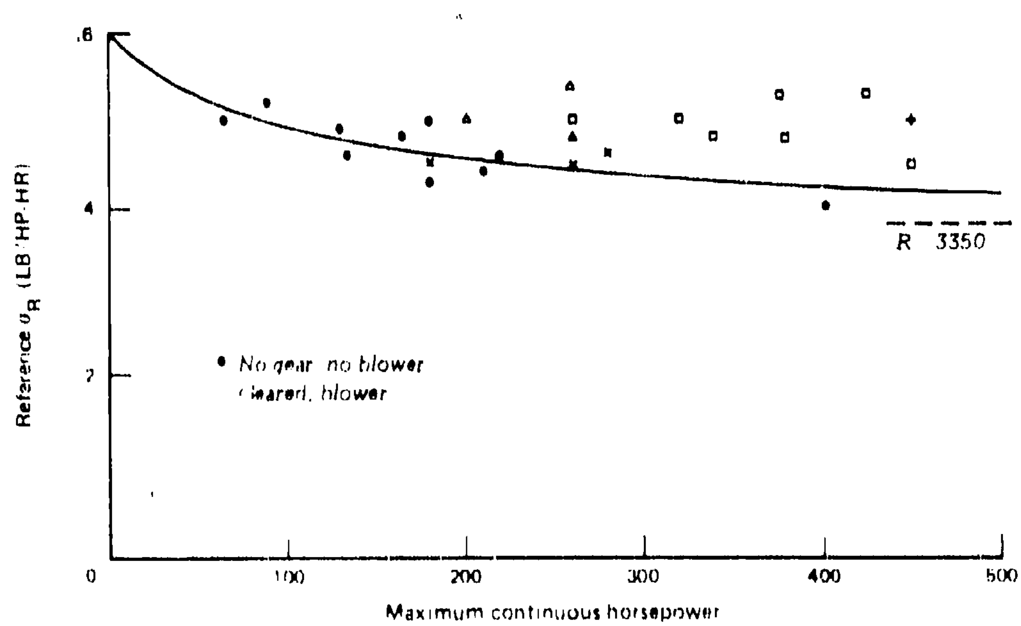

FIG. 93: 1976 RECIPROCATING ENGINE SFC

Turboprop Engine Characteristics

Turboprop engines consist of a compressor, combustion section, and gas turbines driven by expanding combustion gases. One turbine drives the compressor; another drives an output shaft at very large rotational rates. Turboprop engines include integral reduction gearing, giving reductions of about 15 to 1, that drive the propeller shaft. The gearing increases the specific weight and specific fuel consumption.

Several turboprop engines in many models are available in 1976. For correlation herein, takeoff power was taken to be synonymous with "maximum power at sea level," and "Military power." Maximum continuous power was considered to be synonymous with "normal power," and cruise power was identified with "maximum cruise." Data are sometimes given for 90 percent cruise and 75 percent cruise.

The exhaust combustion gases from the turbines of a turboprop engine are usually directed aft in order to provide a moderate jet thrust. Thus, in addition to the direct shaft power produced, an additional "power" is produced by the jet thrust. The combined result is expressed as equivalent horsepower. Explicit consideration of the jet thrust is ignored in this model. Only the shaft power and shaft power ratings are considered. Several values of the ratio of equivalent power P_{EQ} to shaft power P_{SH} for 1976 turboprops are shown in figure 94 for various operating conditions, to illustrate quantitatively the possible significance of using shaft power ratings rather than equivalent power ratings.

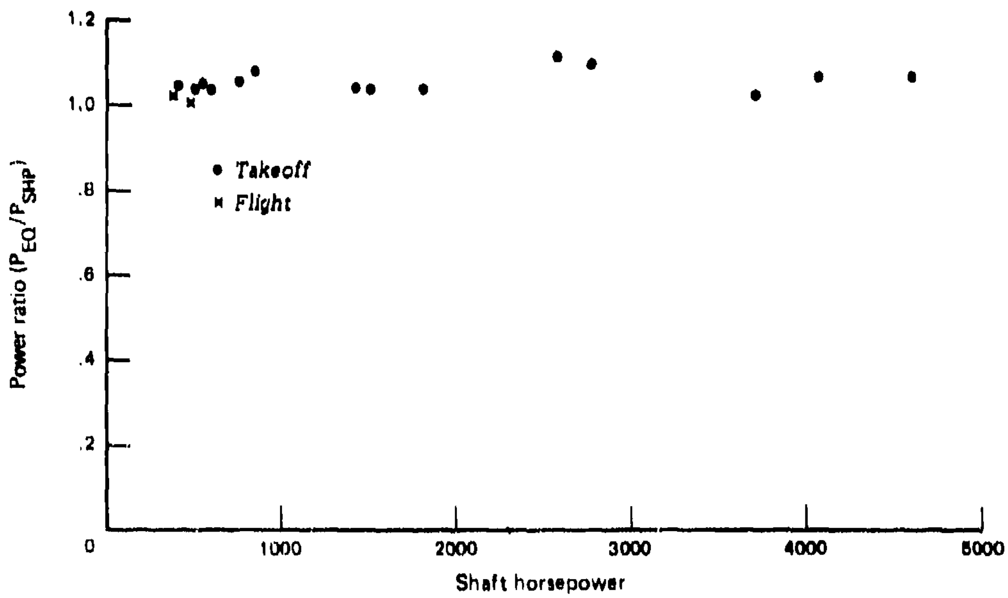

FIG. 94: TURBOPROP P_{EQ}/P_{SHP} RATIO

Most 1976 turboprops produce decreasing power as altitude is increased. An example is shown in figure 95. The decrease is very small at low altitudes. The variation depends on the details of the engine design. If turboprops for airships were de-rated slightly to increase reliability with longer flight times, the decrease of power with altitude might be smaller. Decrease of turboprop power with increasing altitude is not included in this model.

Data for the following correlations for turboprop engines were obtained from Aviation Week, 1976 (reference 3) and Jane's Aircraft, 1973 and 1975. The limited data are shown in table 19. Data in parentheses were obtained by approximation or from references not cited. Complete data for the maximum continuous power rating were not obtained. To supplement it, data for the takeoff power rating and cruise power rating were included in the table. The reference specific fuel consumption σ_R is based on equivalent horsepower and should be somewhat greater for shaft power as used here. The σ_R data in parentheses is 1.03 times data, from the references, for specific fuel consumption at takeoff power.

The specific weight W_E/P_{MC} for turboprop engines is shown in figure 96. Points are also included for W_E/P_{TO} for the engines in table 19 for which P_{MC} was not obtained. These latter points would move up and to the left if P_{MC} were available. The line in the figure, selected to approximate the specific weight, is given by:

$$\frac{W_E}{P_{MC}} = \frac{0.8 + 0.002P_{MC}}{1 + 0.005P_{MC}} \quad , \text{ 1976 turboprops} \quad . \qquad (204)$$

Only the point for the LTC4R-1 engine is inconsistent with the estimation equation.

The frontal area was calculated as $4wh/\pi$. Its variation as a function $\sqrt{P_{MC}}$ is shown in figure 97. The line shown in the figure is selected for estimation. The engine length-diameter ratio $(L/D)_{ENG}$ varies from 1.94 to 4.50. It depends on the geometrical arrangement of reduction gearing and the gas turbine. For the conceptual model a value of 3 is selected.

$$A_{FNC} = 0.15\sqrt{P_{MC}} \quad , \text{ 1976 turboprop engines} \quad ;$$

$$(L/D)_{ENG} = 3 \quad , \text{ 1976 turboprop engines} \quad . \qquad (205)$$

Power rating ratios for 1976 turboprop engines are shown in figure 98. The P_{To}/P_{MC} ratio varies considerably. An average estimate is:

$$P_{TO}/P_{MC} = 1.10 \quad , \text{ 1976 turboprop engines} \quad . \qquad (206)$$

However, the detailed data indicate that first engines of a series have the larger P_{TO}/P_{MC} ratios, then further development increases P_{MC} toward P_{TO} so that the ratio approaches unity.

TABLE 19

1975 TURBOPROP ENGINE DATA

Engine	TO[a] rating	M.C.[a] rating	Cruise[a] rating	Weight (lb.)	L^b (in.)	w (in.)	h (in.)	σ_R^c (lb/hphr)
Allison								
T56-A-7	(3785)			1833	146.0	27.0	39.0	.541
T56-A-15	4591	4061		1825	146.0	27.0	39.0	.517
T63-A-720	420	385		195	45.0	19.0	22.5	(.675)
Arco Lycoming								
T53-L701A	1400			688	58.4	23.0	--	(.584)
T5321A	1800	(1500)		657	65.2	23.0	--	(.584)
LTC4R-1	3690			930	62.2	24.2	--	(.515)
LTP 101	587		501	290	44.0	22.0	(22.0)	.564
Garrett Airesearch								
T76-G10/12	715	650	577	341	44.0	19.0	27.0	(.618)
TPE-331-300	840	840	770	355	46.0	21.0	26.0	(.608)
General Electric								
T64-P4D	3400			1188	110.0	20.1	46.0	(.494)
T64-GE-10	2970			1167	110.0	20.1	46.0	(.515)
CT64-820-4	3133	(2910)		1145	110.0	20.1	46.0	(.494)

Source: Aviation Week, (reference 3) and Jane's Aircraft, 1973 and 1975.

[a] Takeoff power, maximum continuous, and cruise power, shaft power only (horsepower).

[b] Length, width, and height. Diameter given under width.

[c] Reference specific fuel at maximum continuous power.

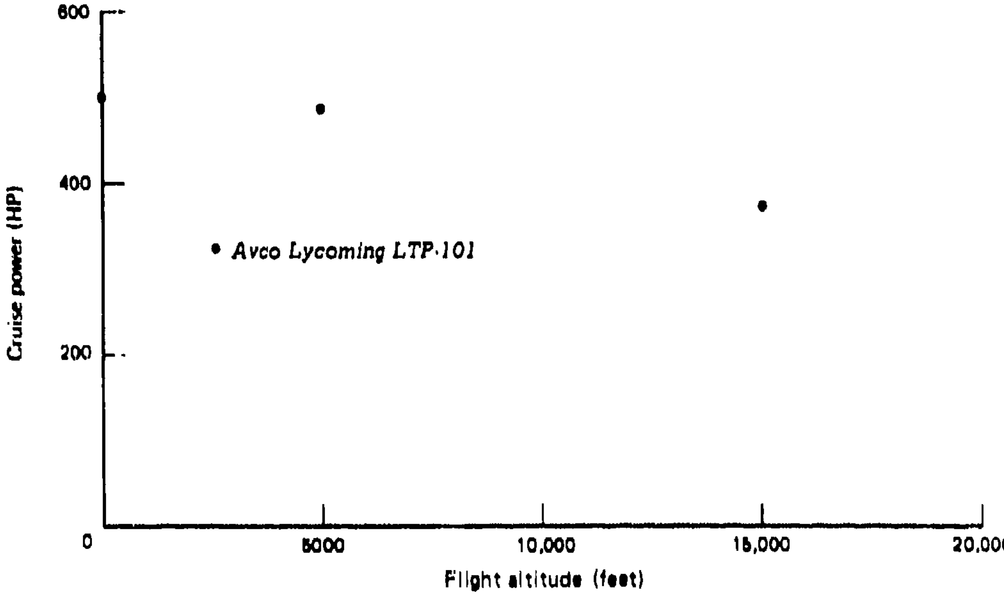

FIG. 95: TURBOPROP POWER vs. ALTITUDE

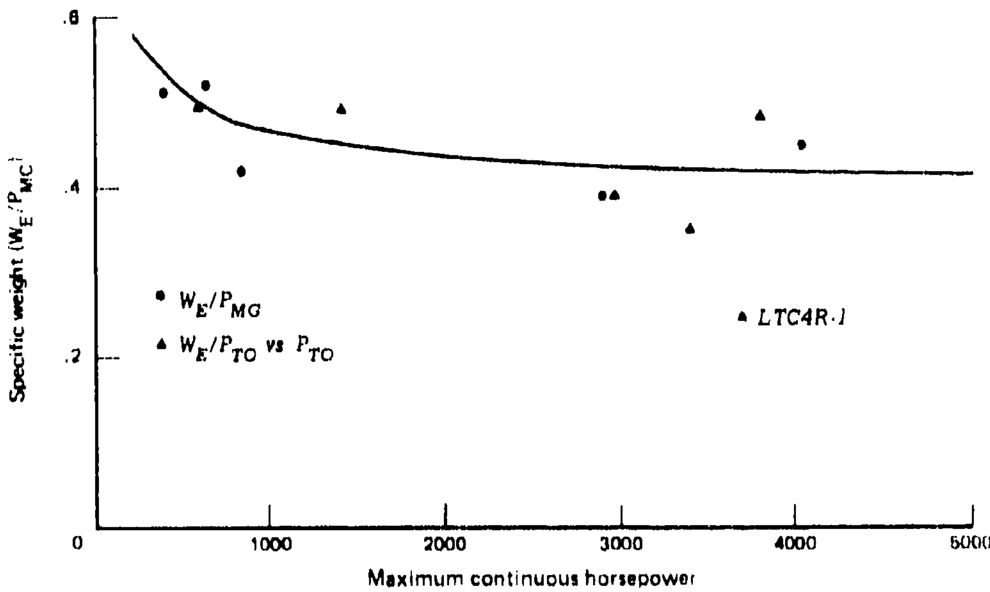

FIG. 96: 1976 TURBOPROP SPECIFIC WEIGHT

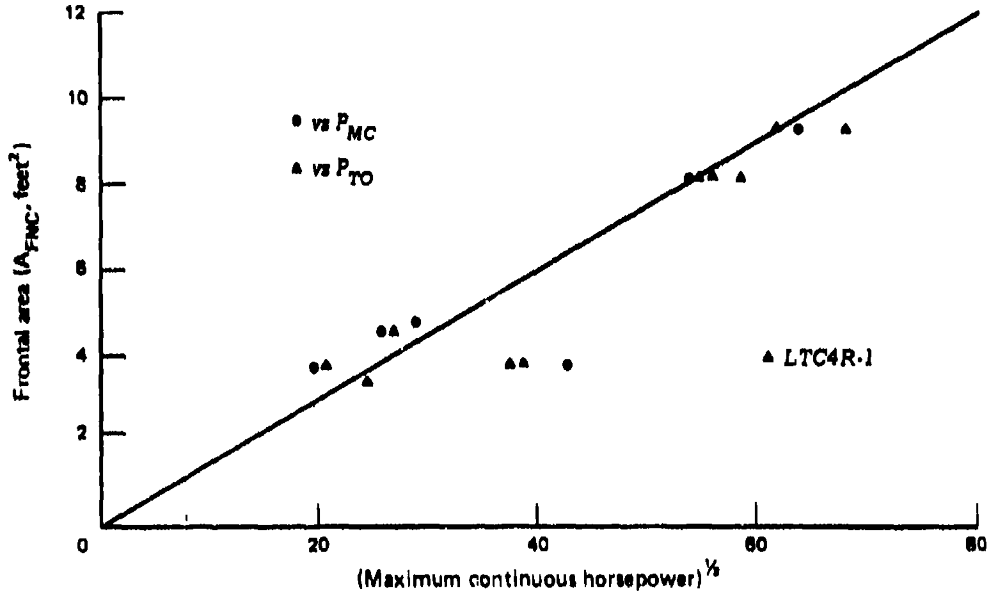

FIG. 97: 1976 TURBOPROP FRONTAL AREA

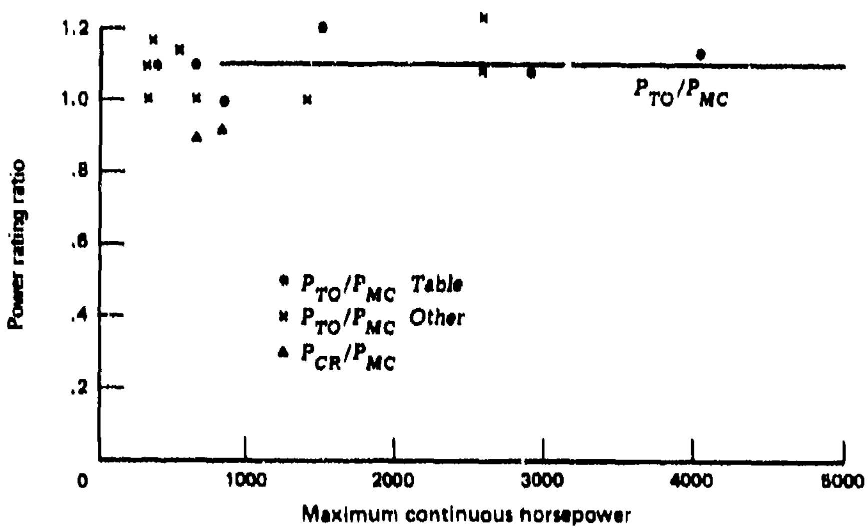

FIG. 98: 1976 TURBOPROP TAKEOFF POWER RATIO

Only 2 points for P_{CR}/P_{MC} are shown in figure 98. They can be approximated as:

$$P_{CR}/P_{MC} = 0.90 \text{ , 1976 turboprop engines .} \qquad (207)$$

The data in table 19 for the reference specific fuel consumption σ_R at maximum continuous power are shown in figure 99. The points versus P_{TO} would move to the left if P_{MC} were available for these engines. The line in the figure, selected for estimation, is given by:

$$\sigma_R = \frac{0.75 + 0.0010P_{MC}}{1 + 0.002P_{MC}} \text{ , 1976 turboprop engines .} \qquad (208)$$

Lubricating oil consumption for turboprop engines is negligible.

$$\sigma_R = 0 \text{ , 1976 turboprop engines .} \qquad (209)$$

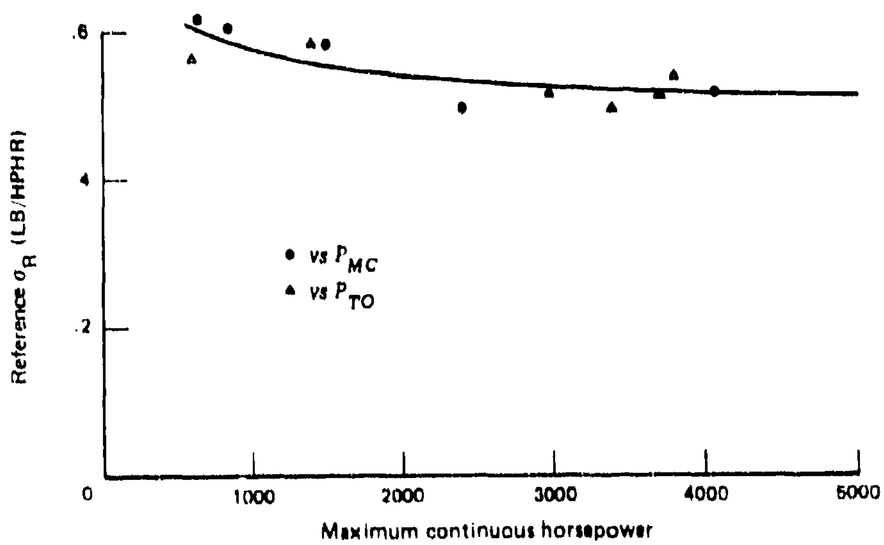

FIG. 99: 1976 TURBOPROP SPECIFIC FUEL CONSUMPTION

ENGINE INSTALLATION WEIGHT

Engine dry weight W_E is only a component of the propulsion power plant weight. The engine requires a control system, a cooling and air induction system, and a lubrication system. Nacelles to enclose the engines and outriggers to support the nacelles are required. Fuel weight is estimated later in this chapter..

Engine control system weight W_{NCON} was obtained only for the reciprocating engines of the ZPG-3W blimp. The data for the ZPG-3W are presented in table 20. Combining the weights of the controls and starting item, and the accessories and miscellaneous gear item, gives a specific weight of 0.15 pounds per horsepower. This value was selected for all engines except turboprops. For turboprops a 50 percent reduction was assumed. Thus:

$$W_{NCON} = 0.15P_{MC} \text{ , except turboprops } ;$$
$$W_{NCON} = 0.07P_{MC} \text{ , turboprops } . \qquad (210)$$

It was noted in the preceding section that a coolant liquid weight of 0.25 to 0.30 pound per horsepower must be included for liquid-cooled engines. Data on radiator weights were not obtained. Cooling and air induction system weight for the reciprocating engines of the ZPG-3W is shown in table 20. It is 0.19 pounds per horsepower. Data for turboprops were not obtained; the ZPG-3W specific weight is selected for turboprops. Then the air induction and cooling system weight W_{CUL} is:

$$W_{CUL} = 0.25P_{MC} \text{ , water (1940 diesels) } ;$$
$$W_{CUL} = 0.30P_{MC} \text{ , ethylene glycol } ; \qquad (211)$$
$$W_{CUL} = 0.19P_{MC} \text{ , air-cooled reciprocating } ;$$
$$W_{CUL} = 0.19P_{MC} \text{ , turboprops } .$$

The lubrication system weight should be related to the reference specific oil consumption σ_{RO} estimated in the preceding section. For a range R in nautical miles at a speed V_K in knots the flight time is R/V_K. The lubricating oil weight W_{LUB} is then:

$$W_{LUB} = \sigma_{RO} \frac{R}{V_K} P_{MC} \quad . \qquad (212)$$

Allowances for reserve oil and the lubrication system should be included. However, use of σ_{RO} for 1976 reciprocating engines (equation 203), a flight duration of 12 hours, and

TABLE 20

BLIMP PROPULSION PLANT WEIGHT DATA

(in pounds)

Item	ZPG-3W
Maximum continuous power (h.p.)	2x1275
2. Power plant group[a]	10,903
2.1 Main power plant	9,376
Engines	3,527
Air, cooling	491
Lubrication	484
Controls, starting	181
Accessory, gear	207
Nacelles	1,446
Outriggers	880
Fuel system	2,160
2.2 Altern power plant	0
2.3 Propulsors	1,527
Propellers	1,527
2.4 Electric plant	0

Source: Goodyear 1975, Vol. III, p. 33 (reference 8).

[a] Conceptual weight groups and components defined for this model later in table 23.

the ZPG-3W engine power of 2,550 horsepower gives 459 pounds. This is sufficiently close to the 484 pounds shown in table 20 for the ZPG-3W. The ZPG-3W carried additional lubricating oil in cans on long endurance missions.

The only detailed propulsion plant weight data obtained are for the ZPG-3W blimp It is shown in table 20. The numbered weight group and components are defined for use in this model. A complete list of the conceptual groups and components is shown in table 23 in chepter 6.

Table 20 gives weights for the nacelles and outriggers. The nacelle weight of 1,446 pounds leads to 0.57 pound per horsepower. However, the nacelle weight should be related to nacelle geometry size rather than engine power itself. A rough estimate of ZPG-3W nacelle geometry by scaling isometric view in the Flight Handbook (reference 19) gives a diameter D_{NC} of about 6 feet and length L_{NC} of 20 feet. Approximating the surface as $\pi D_{NC} L_{NC}$ gives 377 square feet each, leading to a surface unit weight of 1.92 pounds per square foot. A unit weight of 2.0 is selected for the model. Then for a number N_{ENG} of engines the weight W_{NAC} of the nacelles is:

$$W_{NAC} = 2\pi D_{NC} L_{NC} N_{ENG} \qquad (213)$$

This is used for all engine types. The influence of engine type occurs through the required frontal area that determines the nacelle diameter D_N .

Outrigger truss geometry for blimp-type airships is sketched in figure 34 of chapter 3 on lift gases and geometry. For a vertical downward load W_{LOD} the forces F_U on the upper element and F_L on the lower element are:

$$F_U = W_{LOD} \frac{\cos \beta}{\sin(\tau + \beta)}$$

$$F_L = -W_{LOD} \frac{\cos \tau}{\sin(\tau + \beta)} \; . \qquad (214)$$

The angle τ is close to 45 degrees. The lower angle β can be positive as sketched in figure 34, but for large propeller diameters it becomes negative. The variation of trigonometric function factors in equations (214) is shown in figure 100. For conceptual airships the variation of these factors should be considered.

The weight W_U of the upper element, which is loaded in tension, for a safety factor ϕ , length L_U , and material density w , and yield stress σ , is:

$$W_U = \frac{\phi\, w}{\sigma} W_{LOD} L_U \frac{\cos \tau}{\sin(\tau + \beta)} \qquad (215)$$

For a safety factor of 10, a steel density of 490 pounds per cubic foot, and a stress of 75,000 pounds per square inch, the initial factor is 0.00045. The lower element is loaded in compression. To provide column stability with compression loading, a truss of multiple members with diagonal bracing is needed. To account for the multiple members (or, equivalently, for the lower usable stress) a factor of 5 is assumed. Then:

$$W_L = \frac{5\phi w}{\sigma} W_{LOD} L_L \frac{\cos \tau}{\sin(\tau + \beta)} \quad . \qquad (216)$$

Using the same factor of safety and steel, the outrigger weight W_{OUT} becomes:

$$W_{OUT} = (0.00045 L_U + 0.0023 L_L)\, W_{OUT} \frac{\cos\tau + \cos\beta}{\sin(\tau + \beta)} \quad . \qquad (217)$$

For a covered truss, using a streamlined aluminum cover, a weight increase of 100 percent is assumed.

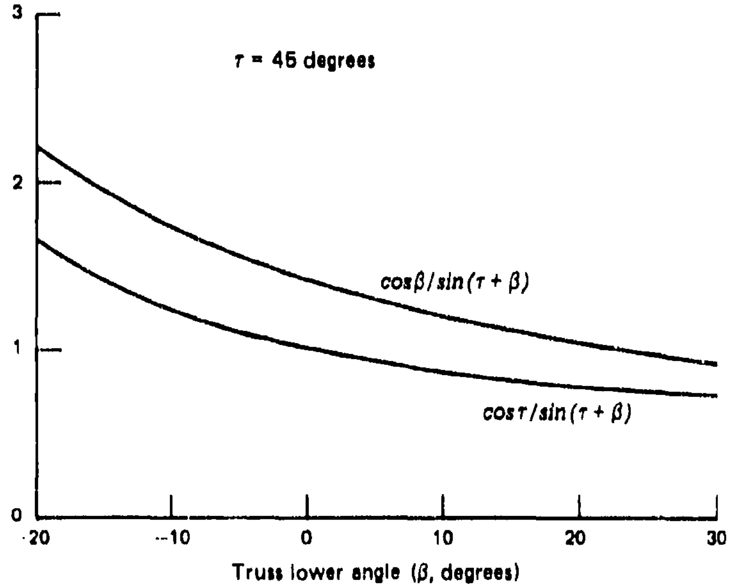

FIG. 100: VARIATION OF TRUSS GEOMETRY FACTORS

The geometry of a dirigible symmetrical truss outrigger is sketched in figure 34 of chapter 3. The loads on the elements are:

$$F_U = \frac{W_{LOD}}{2} \frac{\sin(\epsilon + \lambda)}{\sin\epsilon \sin\lambda} \quad ;$$

$$F_L = \frac{W_{LOD}}{2} \frac{\sin(\epsilon - \lambda)}{\sin\epsilon \sin\lambda} \quad . \qquad (218)$$

The load on the lower element is zero when λ is selected to be equal to ϵ. Then the upper element is vertical and the lower element is inclined at an angle above the horizontal of $90^o - 2\epsilon$. The load on the upper element is W_{LOD}. If the lower element is made identical to the upper element, the outrigger weight becomes:

$$W_{OUT} = \frac{2\phi w}{\sigma} W_{LOD} L_U \quad ; \qquad (219)$$

$$W_{OUT} = 0.0009 W_{LOD} L_U \quad .$$

The second form is for steel and a safety factor of 10.

For a cantilever outrigger (as on the ZPG-3W blimp) the weight, doubled for non-structural material, for a structural depth d is:

$$W_{OUT} = \frac{4\phi w}{\sigma} \frac{L_U}{d} W_{LOD} L_U \quad ; \qquad (220)$$

$$W_{OUT} = 0.0020 \, (L_U/d) \, W_{LOD} L_U \quad .$$

The second form is for a safety factor of 10 and aluminum density of 290 pounds per cubic foot and yield stress of 40,000 p.s.i. For the ZPG-3W the ratio L_U/d appears to have been 5, making the constant equal to 0.0100.

Outrigger weight data were obtained for only the ZPG-3W (table 20). The load weight consists of the dry engine, engine installation weight, the propeller weight W_{PRP}, the nacelle weight, and landing gear weight W_{GER}.

$$W_{LOD} = W_E + W_{NCON} + W_{CUL} + W_{LUB} + W_{PRP} + W_{NAC} + W_{GER} \quad . \qquad (221)$$

For the ZPG-3W data of table 20 the load without landing gear is 7,863 pounds. From table 32 the landing gear weight for the ZPG-3W was 1,190 pounds, so the load weight was 9,053 pounds. The ratio W_{OUT}/W_{LOD} of outrigger weight (2) to load weight was 0.097. From scaled sketches the ZPG-3W outrigger length appears to have been about 10.5 feet long. Then the weight ratio becomes $0.0092 L_{OUT}$. This is close to the 0.0100 value of equation (220) with L_U/d equal to 5.

For dirigibles, only the overall power plant weight data shown in table 21 were obtained. The power plant specific weights were quite large, starting with a relatively heavy engine that required a large installation weight.

TABLE 21

DIRIGIBLE PROPULSION PLANT WEIGHT DATA

	Airship			
	Los Angeles	Macon	Graf Zeppelin	Hindenburg
M.C. power (h.p.)	2,000	4,480	2,800	4,400
Power plant (lb.)	21,199	49,759	21,102	36,465
(lb./h.p.)	10.6	11.1	7.54	8.29

Source: Goodyear 1975, Vol. III, p. 19 (reference 8).

ELECTRIC PLANT

The electric plant component is defined as any special electric power system required for payload operation or other uses beyond normal ship operation. Formal data on weight and capacity for such power units and distribution systems were not obtained. A reasonable specific weight is 30 pounds per kilowatt. Then the weight W_{24} for the electric plant with a capacity E_{KW} is:

$$W_{24} = 30E_{KW} \tag{222}$$

FUEL AND FUEL SYSTEM WEIGHT ESTIMATION

A reference specific fuel consumption σ_R and reference lubricating oil consumption σ_{RO} were selected previously for the different engine types. It is convenient to consider that σ_R includes σ_{RO} for the calculations below. This reference value applies to a cruise at 75 percent of maximum continuous power for diesels and reciprocating engines, and at 90 to 100 percent of maximum continuous power for turboprops. Part-throttle variation of the specific fuel consumption σ influences off-design operations. Data for diesel engines were obtained from Wilkinson, 1942, p. 65 (reference 29). Curves for the other types of engine were obtained from Boeing, Vol. I, p. 5-32 (reference 6). The data are shown in figures 101 and 102. The lines in the figures are given by the following equations which were selected to approximate the data points.

$$\begin{aligned} \sigma/\sigma_R &= 0.02/(P/P_{MC}) + 0.05 + 0.04\,(P/P_{MC})^2 \text{ , diesel} \\ \sigma/\sigma_R &= 0.18/(P/P_{MC}) + 0.63 + 0.22\,(P/P_{MC})^2 \text{ , recip} \\ \sigma/\sigma_R &= 0.11/(P/P_{MC}) + 0.89 \text{ , turboprop} \end{aligned} \tag{223}$$

The approximation is adequate except for diesel engines near maximum continuous power.

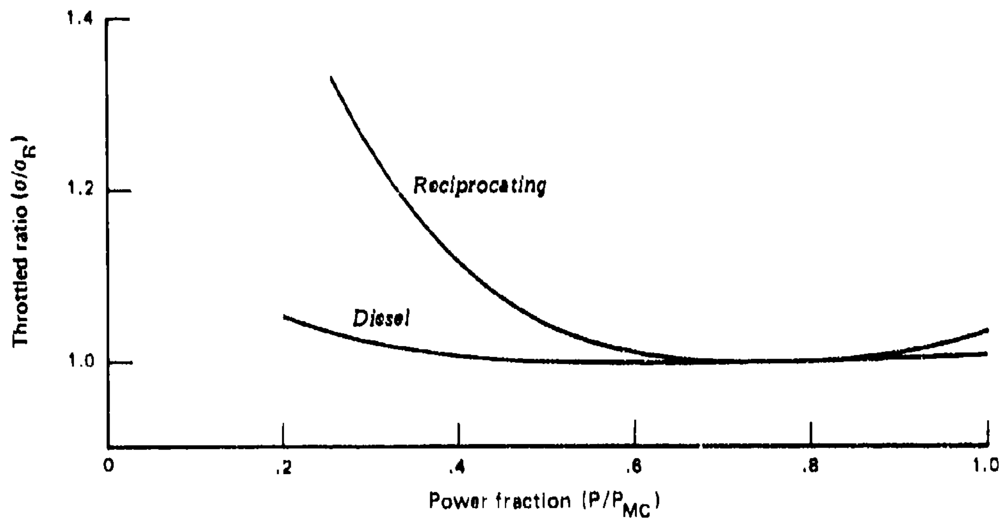

FIG. 101: ENGINE THROTTLED σ/σ_R RATIO

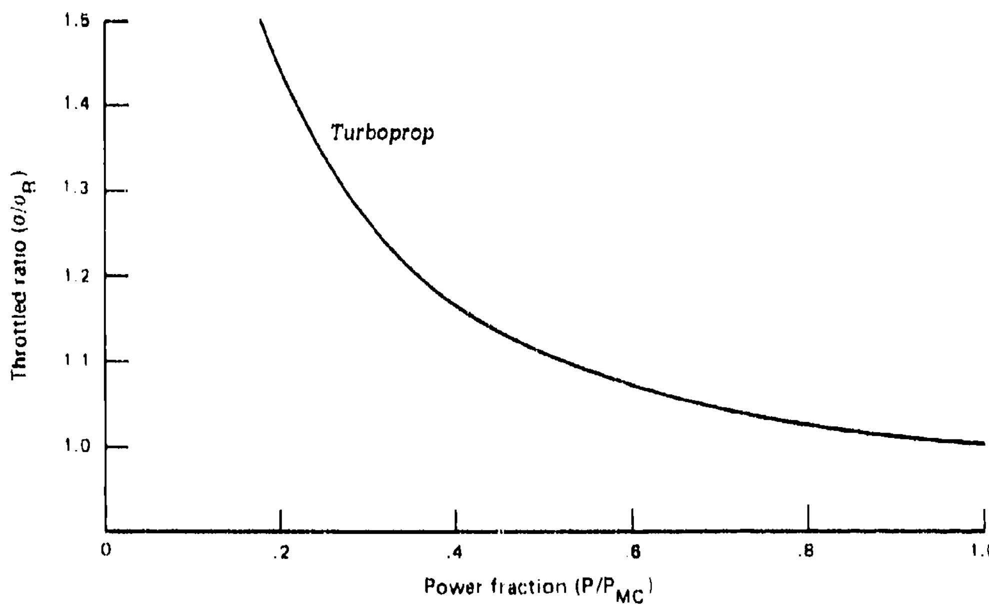

FIG. 102: ENGINE THROTTLED σ/σ_R RATIO

The design specific fuel consumption σ_D in operations is increased for some vehicles by an operational degradation fraction d as a design rule:

$$\sigma_D = \sigma(1+d) \quad . \tag{224}$$

A design rule for airship practice was not obtained. The degradation fraction can also be used to account for increases of σ due to engine installation losses.

The used, or usable, propulsion fuel weight W_{PUF} in pounds is equal to the product of σ_D, engine power P, and the operating time in hours. For a speed of V_K knots and range R nautical miles, the time is R/V_K. Thus:

$$W_{PUF} = \sigma_D PR/V_K \quad . \tag{225}$$

Ship's service electric power and payload equipment electric power may also require fuel. The electric useful fuel weight W_{EUF} for an average electric load E_{KW} with assumed engine specific fuel consumption of 0.60 pounds per horsepower hour and 90 percent generation efficiency is:

$$W_{EUF} = 0.89 E_{KW} R/V_K \quad . \tag{226}$$

The design useful weight W_{DUF} is the sum of the components:

$$W_{DUF} = W_{PUF} + W_{EUF} \quad . \tag{227}$$

An unavailable fuel fraction u for fuel in the bottom of tanks, and a reserve fuel fraction r to be usable at the end of the flight are usually selected as design rules. The initial fuel weight W_F is given by:

$$W_F = W_{DUF}/(1-u)(1-r) \quad . \tag{228}$$

This model does not consider an explicit allowance of fuel for initial climb.

For airships using aerodynamic lift L_A the sea level static (reference) fuel weight is designated W_{62}. It is given by:

$$W_{62} = W_F - L_A \quad . \tag{229}$$

If aerodynamic lift is zero, then W_{62} is equal to W_F.

For estimation of off-design operation at various altitudes, it is convenient to define the maximum sea level fuel weight W_{FMX} that is also needed for estimating fuel tank weight. At the design altitude z_D , where the atmospheric density ratio is σ_{ZD} , the buoyancy lift is equal to σ_{ZD} times the sea level static lift L_{ST} . Thus,

$$W_{FMX} = W_{62} + L_A + L_{ST}(1 - \sigma_{ZD}) \quad . \tag{230}$$

The usable fuel weight W_{FUZ} at altitude z and density ratio σ_Z is:

$$W_{FUZ} = (1 - U)(1 - r)(W_{FMX} - L_{ST}(1 - \sigma_Z)) \quad . \tag{231}$$

For off-design conditions, the range R^* is determined by setting the sum of propulsion useful fuel weight and electric useful fuel weight equal to W_{FUZ} . Using an asterisk on all symbols to indicate off-design range conditions, equations of the form of (225) and (226) give:

$$\sigma_D^* P^* \frac{R^*}{V_K^*} + 0.50 E_{KW}^* \frac{R^*}{V_K^*} = W_{FUZ} \quad ;$$

$$R^* = V_K^* W_{FUZ} / (\sigma_D^* P^* + 0.50 E_{KW}^*) \quad . \tag{232}$$

It is desirable to calculate the fuel use rate G_{PH} in gallons per hour for comparison with other vehicles. Fuel density in pounds per gallon varies with fuel type. A constant value of 6.67 pounds per gallon is used. Then:

$$G_{PH} = W_{DUF}(V_K/R)/6.67 \quad , \text{ design point} \quad ;$$

$$G_{PH} = W_{FUZ}(V_K^*/R^*)/6.67 \quad , \text{ off-design} \quad . \tag{233}$$

Data on fuel and fuel system and tank weight for a few historical airships are shown in table 22. Blimp data were obtained only for the ZPG-3W. Its fuel system weight appears to be rather large. The system included 5 slip tanks of about 240 gallons each, 2 main tanks of about 1,034 gallons each, and 1 combination (alternate ballast use) of about 400 gallons capacity. Perhaps the several relatively small tanks led to greater weight.

For the normal (buoyant lift) fuel, the fuel tank weight of the ZPG-3W is 40 percent of fuel weight. With aerodynamic-lift fuel, the tank weight is 14 percent of fuel weight. Tank capacity was estimated from data in the ZPG-3W Flight Handbook (reference 19) as 24,518 pounds. The tank weight is 9 percent of this estimate of installed tank capacity.

TABLE 22

FUEL AND FUEL TANK WEIGHT DATA

Airship	ZPG-3W	Los Angeles	Macon	Graf Zeppelin	Hindenburg
Fuel system	2,160				
Fuel, oil system		2,651	5,546	4,275	5,625
Normal fuel	5,372	40,000[a]	124,000	90,000	132,000
Aerodynamic fuel	15,872				
Tank capacity	24,518[b]				
Percentage[c]	40.2 13.6 8.8	6.6[a] (4.6)	4.5	4.8	4.3

Source: Goodyear 1975, Vol. III, pp. 33, 26, 19, and 20 (reference 8)

[a]U.S. helium operation. 58,000 pounds German hydrogen operation.

[b]From Flight Handbook (reference 19), including weight of 5 slip tanks.

[c]System weight relative to fuel weight.

The data for the dirigibles combined fuel and oil systems. It was assumed that the oil system contribution was small for the early dirigibles. The data for the Los Angeles correlate better if it is assumed that the German builders installed fuel tank capacity for the fuel that could be carried during operations using hydrogen as the lift gas. After it was delivered to the U.S. Navy, the Los Angeles was operated with helium and a reduced fuel-carrying capability. Fuel tank weight for the dirigibles varies from 4.3 to 4.8 percent of the fuel weight.

Fuel system weights for several types of vehicles are close to 5 percent of fuel weight. This estimate appears low for the blimp data point, but somewhat high for the dirigibles. For use in this model, the following equations for fuel tank weight W_{TNK} in terms of the maximum sea level fuel weight W_{FMX} were selected:

$$W_{TNK} = 0.070 W_{FMX} \text{ , blimps ;} \qquad (234)$$

$$W_{TNK} = 0.050 W_{FMX} \text{ , dirigibles .}$$

6. AIRSHIP WEIGHT AND VOLUME

Estimates of the weights of the components of the airship are investigated in this chapter. The weight groups and components selected for use in this airship model are shown in table 23. More detailed definitions are given later in the analysis. The two-digit items in the table are called components. The components of the hull group are considered in this chapter. The ship control group, the accommodations group, and special payload are also considered.

The design and construction margin (component 6.1) is an allowance for weight changes that occur during the later design and construction phases. It is estimated as a percentage of all other empty weight. Information concerning a standard value was not obtained.

GENERAL AIRSHIP WEIGHT COMPARISONS

Before analyzing the components it is desirable to review overall weight data for airships. Such data for the data sample airships are shown in table 24. The total weight W_T is defined (equation 22) at a reference altitude of sea level. It is equal to the product of standard sea level air weight density times the envelope volume.

TABLE 23

THE MODEL WEIGHT GROUPS AND COMPONENTS

1. Hull Group
   - 1.1 Basic hull
   - 1.2 Secondary structure
   - 1.3 Tail structure
   - 1.4 Gas system
2. Power Plant Group
   - 2.1 Main power plant
   - 2.2 Alternate power plant
   - 2.3 Propulsors
   - 2.4 Electric plant
3. Ship Control Group
   - 3.1 Steering and trim
   - 3.2 Nav/communications
   - 3.3 Ship facilities
   - 3.4 Ballast system
4. Accommodations
   - 4.1 Personnel and effects
   - 4.2 Personnel enclosures
   - 4.3 Personnel facilities
   - 4.4 Personnel stores
5. Payload Group
   - 5.4 Special payload
6. Other Weights
   - 6.1 Design margin
   - 6.2 Ship fuel
   - 6.3 Lift gas
   - 6.4 Air

TABLE 24

AIRSHIP GENERAL WEIGHTS

Airship	Total[a] weight (thous.lb.)	Static[a] lift (thous.lb.)	Aerodynamic[b] lift (percent)	Static[b] useful load (percent)	Fuel[c] weight (percent)
Goodyear Columbia	11.24	8.78	4.0	27.1	46.2
Goodyear America	15.52	11.90	3.6	30.7	49.3
U.S. Navy K-135	34.9	27.4	9.1	25.9	77.5
U.S. Navy ZPG-2	74.6	61.9	9.7	38.6	29.4
U.S. Navy ZPG-3W	113.9	94.6	11.1	40.6	14.1
U.S. Navy Shenandoah	175.1	126.5	0	36.4	60.7
U.S. Navy Los Angeles	214.1	153.1/168.0[d]	0	41.7/48.6[d]	62.6/70.9[d]
U.S. Navy Macon	565.9	403.5	0	41.4	74.3

---

[a] At sea level, standard reference altitude.

[b] Percent of static lift.

[c] Design, without dynamic lift, as percent of useful load.

[d] With hydrogen lifting gas as used by the German builders.

Source: Goodyear 1975, Vol. III, pp. 19, 25, 26, reference 8. Helium gas.

The static lift W_{ST} is also defined at standard sea level. It is (equation 24) the net lift when the lifting gas entirely fills, at sea level, the maximum available gas volume. Static lift is the maximum available buoyancy lift. For increasing operating altitude, the gas volume cannot be filled at sea level. Therefore, the buoyancy lift decreases as operating altitude increases.

Static lift is a convenient standard reference, but it is not a good reference for engineering analysis because it depends on gas type, gas purity, and gas volume fraction. The influence of gas type is indicated in table 24 by the helium/hydrogen static lift values for the Los Angeles. For hydrogen, the static lift is 10 percent greater than for helium.

Table 24 shows aerodynamic lift for blimps; historical dirigibles did not use aerodynamic lift except in flight. As a fraction of static lift, aerodynamic lift varied from about 4 to 11 percent. Aerodynamic lift was used to carry additional fuel.

The sea level static useful load is defined in equation (25) as static lift minus empty weight of the airship. Sea level static useful load is the maximum useful load capability. It is available only for sea level operations. Static useful load decreases rapidly as altitude increases (equation 26). Sea level static useful load is shown in table 24 as a fraction of static lift. It varied from 26 to 49 percent.

The design fuel weight without aerodynamic lift is also shown in table 24 as a fraction of sea level useful load. The fraction is around 50 percent for the small blimps; it decreases to 14 percent for the largest blimp. The large blimps used aerodynamic lift to carry additional fuel. The fuel weight ratio is greater than 50 percent for the dirigibles, which had relatively long cruise ranges.

This airship model assumes that blimp aerodynamic lift is used entirely for additional fuel. Thus, blimp range without aerodynamic lift should be relatively limited. The use of aerodynamic lift fuel then markedly increases the range (or endurance) for operations.

Prior development of vehicle concept models has shown that weight "data" can be taken only as a guide in estimating weights. The numbers given in any classification system depend on the phase of vehicle development and modification at which the numbers were recorded. The "data" also depend strongly on who assigns the items to the classification components. Therefore, the data are used only as a guide and to check the calculations.

HULL GROUP WEIGHT

The greatest engineering differences between blimps and dirigibles are in the hull group. Blimps have a pressurized structure so that the entire pressurization system is included in the basic hull component. The gas system component is not used for blimps. The rigid structure and cover were selected as the basic hull component for dirigibles. Gas cell and valve items were defined as the gas system component. Because the engineering analyses of hull weights for blimps and dirigibles are different, they are investigated separately. Blimps are considered first.

Blimps: Basic Hull Component Weight

Reasonably detailed weight data to support conceptual weight analysis were obtained for only the U.S. Navy ZPG-3W of the late 1950s. For the ZPG-3W the hull group components represent 25 percent of the total weight. The components are shown in table 25.

The envelope is the most important item for a pressurized structure. The critical loading for the envelope appears to be due to the gust moment, occurring near midships. Other moments include gas gradient moment, rigging moment, and aerodynamic lift moment. Here, only the maximum gust moment is considered as a measure of the critical loading.

If the envelope is visualized as a right cylinder of diameter D, and a material of thickness t_E, pressurized to an internal excess pressure δ_{pC} assumed constant throughout, then the consideration of forces on the left and right ends gives an approximation for the longitudinal stress σ_L in the material. The force on each end is $(\pi/4)D^2\delta_{pC}$ and produces the tension stress in a cross-section area of the material of $\pi D t_E$, so:

$$\sigma_L = \frac{\pi D^2 \delta_{pC}}{4} \frac{1}{\pi D t_E} = \frac{\delta_{pC} R}{2t_R} \quad . \tag{235}$$

Now visualize the pressurized cylinder supported at the ends, and subjected to a downward force near the center. The resultant bending moment leads to compression along the upper portions, with a maximum compression along the top. The maximum bending compression stress σ_{BC} for the maximum gust moment M_{GMX} and with the cross-sectional moment of area I equal to $\pi t_E R^3$ for the thin envelope circle, is:

$$\sigma_{BC} = M_{GMX} R/I = M_{GMX}/\pi t_E R^2 \quad . \tag{236}$$

To retain moderate pressurized structure rigidity the local resultant tension stress $(\sigma_L - \sigma_{BC})$ should not be negative (compressive resultant), so:

TABLE 25

BLIMP HULL GROUP WEIGHT DATA[a]

Item	ZPG-3W
Total weight	113946
1. Hull group	28068 (24.6)[b]
1.1 Basic hull	21201 (18.6)
Envelope	12690 (11.1)
Miscellaneous ·nvelope	2296 (2.0)
Suspension	1414 (1.2)
Ballonets	2211 (1.9)
Pressure group	2076 (1.8)
Air lines	514 (0.5)
1.2 Secondary struct	1559 (1.4)
Bow stiffeners and mooring	1559 (1.4)
1.3 Tail structure	5308 (4.7)
Tail group	3701 (3.2)
Fin suspension	377 (0.3)
Surface control group	1230 (1.1)
1.4 Gas system	(Integral with basic hull)

Source: Goodyear 1975, Vol. III, p. 33, reference 8.

[a]All weights are in pounds.

[b]The numbers in parentheses are percentages of total weight.

$$\sigma_L = \sigma_{BC} \quad ;$$

$$\delta_{pC} R/2t_E = M_{GMX}/\pi t_E R^2 \quad ; \tag{237}$$

$$\delta_{pC} = 2M_{GMX}/\pi R^3 \quad .$$

This relation defines the required excess pressure δ_{pC} . The circumferential tension stress σ_C on a longitudinal section of the envelope material, again assuming σ_{pC} constant, is equal to the product of δ_{pC} and projected area D per unit length, divided by the area $2T_E$ of material:

$$\sigma_C = \delta_{pC} D/2t_E = \delta_{pC} R/t_E \quad . \tag{238}$$

Comparison with equation (235) for σ_L shows that the approximation for σ_C is twice that for σ_L , so σ_C is critical.

Additional excess pressure contributions are considered in predesign phases. The reference excess pressure δ_{pC} at the center (axis) of the envelope is small, generally 1 to 3 inches of water, less than 1 percent of atmospheric pressure. The excess pressure changes as height changes inside the envelope because the pressure of interior lifting gas changes more slowly than the pressure of the external atmosphere. When this occurs, a larger δ_{pC} is needed. Further, on the midsection of the envelope in flight the flow produces underpressures (negative pressure coefficients). This further increases δ_{pC} locally. Finally, an increased excess pressure will be produced in unintended flight above gas maximum altitude. Its amount depends on rate of ascent, size of lift gas safety valving, and actual altitude.

These contributions are ignored here. From equation (238), the lineal load $\sigma_C t_E$ on the envelope material at the location of maximum gust moment is:

$$\sigma_C t_E = 2M_{GMX}/\pi R^2 \quad . \tag{239}$$

The distribution of gust moment is flat in the midship region where R is approximately constant, and goes to zero at bow and stern when R is zero. Thus, equation (239) gives a reasonably representative lineal load.

In predesign phases, a factor of safety is applied to obtain the design lineal load $(\sigma t)_D$. During World War II an envelope factor of safety of 5 was used, but the method used for estimating loads was not obtained. More recently, the literature cites an envelope factor of safety of 3 in connection with using all envelope pressure components listed above.

For use here, a pressure factor ϕ_p is defined to include load factor of safety and the detail moment and extra pressure items ignored above. Then,

$$(\sigma t)_D = \phi_p 2M_{GMX}/\pi R^2 \quad . \tag{240}$$

The specific weight w_{EM} of the envelope material per unit area is related to its lineal strength σt. The total envelope weight W_{EN} is equal to the product of an average specific weight $\overline{w}_{EM}$, and the hull wetted area A_{WH}:

$$W_{EN} = \overline{w}_{EM} A_{WH} \quad . \tag{241}$$

The specific weight of the envelope material must now be considered.

Blimp envelope materials have been woven fabric layers (cotton, rayon, nylon, dacron) with external and interior layers of bond sealant (rubber, neoprene) of 2- or 3-ply (fabric layers) construction. To some extent the combination of properties can be tailored for the specific area of application, as regards warp strength, fill direction strength, permeability to gas diffusion, wear resistance, service lift, and so forth. However, the characteristics of the basic materials used limit the trade-offs and combinations of properties that are possible. Some industrial companies have produced, developed, and incorporated new basic materials in envelope-type construction. Their principal market has been balloons, for which small-thickness envelope materials, not considered here, are needed. The developments are, however, applicable for blimp envelope material.

Only the specific weight and lineal strength properties are considered here. Data for the specific weight w_{EM} of the envelope material are shown in figure 103 as a function of lineal strength σt. For each type of material the specific weight appears to be a linear function of σt. Minimum fiber size leads to a minimum achievable specific weight w_{EMIN}. For conceptual analysis it is desirable to fit the discrete points in the figure for each material by an equation. For this purpose there is selected:

$$\begin{aligned} w_{EM} &= a_{EM} + b_{EM}(\sigma t) \\ w_{EMIN} &= c_{EM} \quad . \end{aligned} \tag{242}$$

The a_{EM} and b_{EM} for each type of material can be obtained from the linear equations shown in table 26. Conventional units for w_{EM} are ounces per square yead with strength σt in pounds per inch. For the conceptual model, units of pounds per square foot with strength in pounds per foot are needed. The selected equation for each type of material is shown in table 26 in both sets of units.

The following envelope materials are included in figure 103 and table 26.

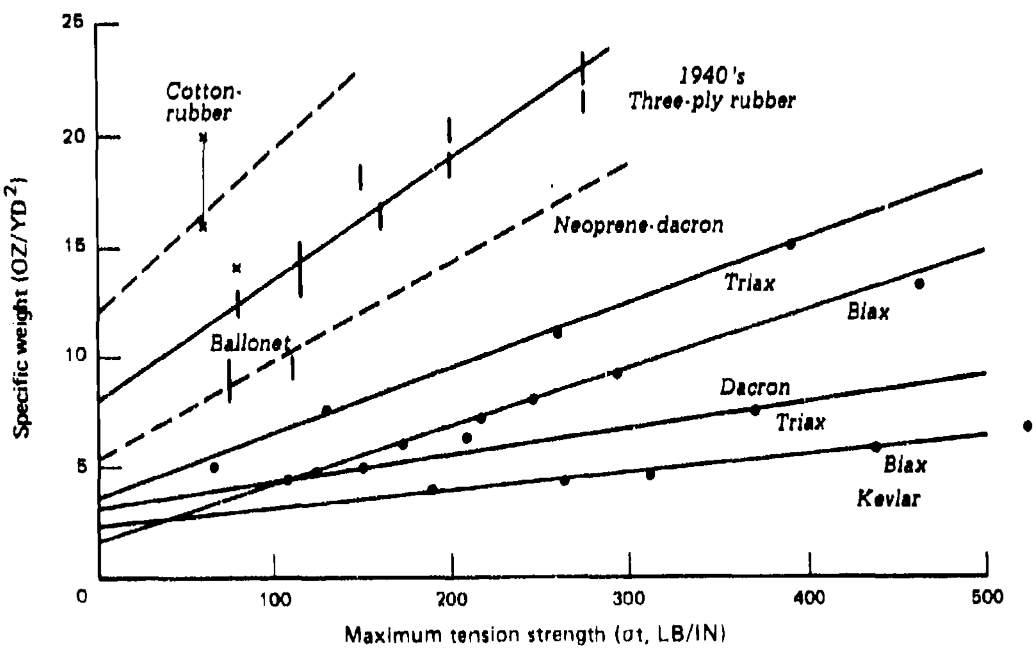

FIG. 103: ENVELOPE MATERIAL SPECIFIC WEIGHT

In the 1920s cotton rubber material was used. It was relatively heavy. The literature indicates there was little variation in lineal strength options. For historical interest, the material was fitted by a line 50 percent above that for 3-ply rubber material.

The material labeled 3-ply rubber is that used for the envelope and other components of the U.S. Navy blimps during World War II. The data source cites "cloth," but not the type of cloth. (It may have been nylon.) A layer of aluminum (foil) was used in some of the cases. The data bars in the figure indicate a ± 0.5 oz./yd.^{2} variability. A layer of paraffin, "not to exceed 0.5 oz./yd.^{2}" was specified for gas barrier and weather surfaces. The paraffin weight is not included in the data bars. The lowest 2 bars are for

TABLE 26

BLIMP ENVELOPE MATERIAL SPECIFIC WEIGHT VARIATION

Material	Specific weight oz/yd^2 & lb/in.	Specific weight[a] lb/ft^2 & lb/ft.	Minimum lb/ft^2
Cotton rubber[a]	14-20 oz/yd^2 at 60-80 lb/in	$.0834+47.7\sigma t/10^6$	.1111
3-ply rubber[b]	$8.0 + .0550\sigma t$	$.0556+31.8\sigma t/10^6$	.0625
Neoprene-Dacron bias 2-ply	$5.4+.0444\sigma t$	$.0375+25.7\sigma t/10^6$	.0625
Dacron[c] biaxial film	$1.6+.0264\sigma t$	$.0111+15.3\sigma t/10^6$	.0333
Dacron[c] triaxial film	$3.6+.0296\sigma t$	$.0250+17.1\sigma t/10^6$	.0347
Kevlar[c] biaxial film	$2.4+.0080\sigma t$	$.0167+4.63\sigma t/10^6$	.0278
Kevlar[c] triaxial film	$3.2+.0120\sigma t$	$.0222+6.94\sigma t/10^6$	.0313

[a]Burgess (p. 11, reference 7, copyright 1927) gives 14 oz/yd^2 at 80 lb/in. for blimps. Boeing (Vol. I, p. A-2-4, reference 6 gives early cotton rubber as 16-20 oz/yd^2 at 60 lb/in.

[b]From Goodyear "Descriptive Specifications", references 11-13.

[c]From Boeing, Vol. I, pp. A-6-4 and 5, reference 6.

ballonet, nonweather use. The other bars can be fitted reasonably by the line shown in the figure. The equation for the line is included in table 26.

Two-ply neoprene-dacron, with 1 cloth ply at a 45-degree bias relative to the other ply, was used for the envelopes of the U.S. Navy blimps of the 1950s. This composition has been used on Goodyear advertising blimps since then. The dashed line in figure 103 was selected to represent its specific weight.

It appears that a principal reason for going to 2-ply construction was ro reduce manufacturing operations and costs. This could be carried further on the basis of balloon material experience and research. And new polymer materials and polymer films, could be used. Four potential envelope materials are shown in figure 103 (Boeing, Vol. I, pp. A-1-1 to 6-7, reference 6).

These materials consist of 1 ply of cloth, with an outer film of ultraviolet stopping Tedlar polymer for service life, and film bond sealant of types of polyurethane polymer. The cloth may be woven normally, biaxially, with warp and fill, using the films to provide adequate shear strength. Or, the cloth may be woven in 3 directions, triaxially, so that it provides its own shear strength. The cloth can be dacron or a new high strength polymer Kevlar. The combinations of these 2 weaves and 2 materials give the 4 cases. These materials have not been used on airships; therefore, they are riskier than dacron-neoprene bias 2-ply material.

The data points for these new materials, which are for specific combinations of number, sizes, and plies, are shown in figure 103 and fitted by straight lines whose equations are included in table 26. The reference states that the lowest listed specific weight is expected to be the minimum for normal manufacturing and handling procedures. This minimum is listed in table 26 for use in the model.

As used in a blimp, the envelope material specific weight w_{EM} must be increased by an envelope material factor ϕ_{EM} to account for material seams, stress concentration reinforcement, aging, and so forth. The average specific weight $\overline{w}_{EM}$ is then:

$$\overline{w}_{EM} = \phi_{EM} w_{EM} \quad . \tag{243}$$

The literature did not contain information on values for ϕ_{EM} .

Estimation of ϕ_{EM} was therefore based on the weight data. The data (or estimated) values of the relevant items from previous tables and equations are listed in table 27. Substitution of the lineal load $(\sigma t)_D$ (with ϕ_p equals 3) from equation (240) into the specific weight equation (242) with the envelope material factor of equation (243) gives:

$$w_{EM} = \phi_{EM}(a_{EM} + b_{EM} 2(3) M_{GMX}/\pi R^3 \qquad (244)$$

TABLE 27

BLIMP ENVELOPE MATERIAL FACTOR CALCULATION

Item	ZPG-3W
Envelope weight (lb.)	12,690.
Hull wetted area (sq.ft.)	83,763.
Average $\bar{w}_{EM}$ (lb./sq.ft.	.1515
Average $\bar{w}_{EM}$ (oz./sq.yd.)	21.8
Maximum speed (kt.)	82.
Gust maximum moment (1000 ft./lb.)	2.214
Lineal load (lb./ft.)	2,135.
Lineal load (lb./in.	178.
Material factor ϕ_{EM}	1.64

For the ZPG-3W blimp with dacron-neoprene envelope, this relationship becomes:

$$21.8 \text{ oz./yd}^2 = \phi_{EM}(5.4 + 0.0444 \times 178) \quad . \qquad (245)$$

Hence, the apparent value for ϕ_{EM} is 1.64. This value is used for the airship concept model.

The estimation equation for blimp envelope weight is then:

$$W_{EN} = \phi_{EM} \mathrm{Max}(c_{EMIN}, (a_{EM} + b_{EM} \phi_p M_{GMX}/\pi R^3))A_{WH} \quad .$$

$$\phi_{EM} = 1.64 \;, \; \phi_p = 3.0 \quad . \qquad (246)$$

The "miscellaneous envelope" weight W_{MISEN} listed in table 25 is assumed to be envelope associated and proportional to the envelope weight. For the data of the table it is then:

$$W_{MISEN} = 0.18W_{EN} \quad . \tag{247}$$

The suspension system weight W_{SUS} should be related to the weight it supports. The sea level static lift W_{ST} of the ZPG-3W was 94,600 pounds (table 24). Its aerodynamic lift L_A was 10,500 pounds. It is assumed that only the hull group weight W_1 of table 25 is not supported. Then, an equation for W_{SUS} from this data is:

$$W_{SUS} = 0.018(W_{ST} + L_A - W_2) \quad . \tag{248}$$

The ballonets of blimps are relatively light fabric/film materials. The volume to be enclosed, from equation (30), is:

$$\nabla_{BB} = f_G(1 - \sigma_{ZBDMX})\nabla_E \quad . \tag{249}$$

Historical blimps of increasing size had increasing numbers N_{BB} (2 to 4) of ballonets. When the ballonets are approximated as hemispheres of radius R_{BB} the volume to be enclosed is:

$$\begin{aligned} \nabla_{BB} &= N_{BB}(2\pi/3)R^3_{BB} \quad ; \\ R_{BB} &= ((3/2\pi N_{BB})\nabla_{BB})^{1/3} \quad . \end{aligned} \tag{250}$$

Then the total ballonet area would be:

$$\begin{aligned} A_{BB} &= 2\pi N_{BB}R^2_{BB} \quad ; \\ A_{BB} &= 3^{2/3}(2\pi)^{1/3}N_{BB}^{1/3}\nabla_{BB}^{2/3} \quad ; \\ A_{BB} &= 3.84N_{BB}^{1/3}\nabla_{BB}^{2/3} \quad . \end{aligned} \tag{251}$$

The constant here was checked against data for the ballonet area in the "Descriptive Specifications" for the U.S. Navy G-type, K-type, and M-type blimps. The constant should be about 4.4. The variation of $N_{BB}^{1/3}$ for 2 and 4 relative to 3 is -13 percent and 10 percent. For the conceptual model a fixed value of 3 is selected.

$$A_{BB} = 4.40 N_{BB}^{1/3} \nabla_{BB}^{2/3} \;;$$
$$A_{BB} \simeq 6.35 \nabla_{BB}^{2/3} \quad . \qquad (252)$$

The weight W_{BB} of blimp ballonets is equal to the product of an average material specific weight w_{BM} and the ballonet area:

$$W_{BB} = \overline{w}_{BM} A_{BB} \quad . \qquad (253)$$

It appears that the average ballonet material specific weight is close to the minimum specific weight listed for different materials in table 26. For the ZPG-3W, ∇_{BB} from table 6 is 383,000 cubic feet. It had 4 ballonets, so the estimated area becomes 36,836 square feet. For 2,211 pounds (table 25), the aveage specific weight was 0.0600 pound per square foot, or 8.6 ounces per square yard. This is a little less than the minimum listed in table 26 for neoprene-dacron material. It is assumed that the type of material used for the envelope is used for the ballonet. Then:

$$W_{BB} = c_{EM} A_{BB} = 6.35 c_{EM} (f_G (1 - \sigma_{ZBDMX}) \nabla_E)^{2/3} \quad . \qquad (254)$$

It is assumed that pressure group weight and the air lines weight are proportional to the total weight. For the weights listed in table 25, this weight W_{PGAL} is then estimated as $0.023 W_T$.

The estimation equations for the weight W_{H} of the basic hull component for blimps, as selected above, are:

$$W_{H} = W_{EN} + W_{MISEN} + W_{SUS} + W_{BB} + W_{PGAL}$$
$$W_{en} = \phi_{EM} \mathrm{Max}(c_{EM} (a_{EM} + 2 b_{EM} \phi_p M_{GMX} / \pi R^2)) A_{WH}$$
$$\phi = 1.64 \; , \; \phi_p = 3.0 \qquad (255)$$
$$W_{MISEN} = 0.18 W_{EN}$$
$$W_{SUS} = 0.018 (W_{ST} + L_A - W_1)$$

and

$$W_{BB} = 6.35c_{EM}(f_G(1-\sigma_{ZBDMX})\nabla_E)^{2/3}$$

$$W_{PGAL} = 0.023W_T \quad .$$

<u>Blimps: Secondary Structure Component Weight</u>

The only contribution shown in table 25 for the secondary structure weight W_{12} is from bow stiffeners and mooring facilities for blimps. It is assumed to vary directly with total weight:

$$W_{12} = 0.014W_T \quad . \tag{256}$$

<u>Blimps: Tail Structure Component Weight</u>

Blimp tail structure consists of a metal (aluminum) frame of ribs and spars covered by a fabric material, mounted on reinforced portions of the blimp envelope and supported laterally by guy wires. For the ZPG-3W, from table 10, the tail area A_T is 5,200 square feet. The tail weight of 5,308 pounds from table 25 leads to 1.02 pounds per square foot, or 147 ounces per square yard. Thus, most of the weight must be from the metal framework. (Pressurized fins can also be used, but are not considered.)

Much of the tail structure design is probably governed by local loads and control surface loads. However, the overall tail structure must sustain the bending moment produced by an aerodynamic gust load and this loading is selected for estimating the tail weight. For 2 bending-resistance flanges of area A_F separated by a distance d, the area moment of inertia I is approximately $2A_F(d/2)^2$, so the bending stress σ_B in terms of the bending moment M_{BT} is:

$$\sigma_B = M_{BT}Y/I = M_{BT}(d/2)/2A_F(d/2)^2 \quad ;$$

$$\sigma_B = M_{BT}/A_F d \quad . \tag{257}$$

The weight W_{13} in terms of the flange area, fin maximum span b_F and 4 fins using material of density δ, is then:

$$W_{13} = \delta 4(2A_F)b_F = 8\delta M_{BT}b_F/\sigma_B d \quad . \tag{258}$$

The force on the fin caused by gust speed u_G is assumed to result from a sudden change of angle of attack of magnitude u_G/V. For a lift curve slope $C_{L\alpha}$ the force is:

$$F_{FIN} = (1/2)\,\rho V^2 (A_T/4)(u_G/V) C_{L\alpha} \quad . \tag{259}$$

Integration for moments for uniform spanwise loading shows that the maximum bending moment for guy wires attached at about 70 percent span is about $0.05F_{FIN}b_F$.

$$M_{BT} = 0.05F_{FIN}b_F \text{ , blimps} \quad . \tag{260}$$

Then the tail weight becomes:

$$W_{13} = \left(0.05C_{L\alpha}\frac{b_F}{d}\frac{\rho^{\delta}}{\sigma_B}\right)u_G V\, A_T b_F \quad . \tag{261}$$

The term in parentheses can now be obtained from the weight data. However, it is noted that $C_{L\alpha}$ decreases as b_F/c_F decreases, and that the distance d between flanges should be proportional to the thickness t of the airfoil. In terms of the fin thickness-chord ratio $(t/c)_F$ the term $0.05C_{L\alpha}b_F/d$ should be approximately proportional to $0.05(b_F/c_F)^2/(t/c)_F$ where $C_{L\alpha}$ is proportional to b_F/c_F. It appears that $(t/c)_F$ for historical blimps has been quite small, about 0.02. Hence, empirical correlations for weight may be invalid for significantly different b_F/c_F or $(t/c)_F$ cases.

The coefficient was calculated using W_{13} equal to 5,308 pounds (table 25), an assumed gust speed of 35 feet per second, design flight speed of 138 feet per second (82 knots from table 3), tail area of 5,200 square feet (table 10), and fin span of 31 feet (table 10). The result is:

$$W_{13} = 6.8\times10^{-6}u_G V A_T b_F \quad . \tag{262}$$

<u>Dirigibles: Basic Hull Component Weight</u>

Reasonably detailed weight data were obtained for 2 U.S. Navy and 2 German dirigibles, all from the 1930s. The components are shown in table 28. The hull group of dirigibles is about 25 percent of the total weight. This is the same as for blimps. About 60 percent of the hull group weight comes from the basic hull items.

TABLE 28

DIRIGIBLE HULL GROUP WEIGHT DATA[a]

Weight component	Los Angeles	Macon	Graf Zeppelin	Hindenburg
Total weight	214,127	565,908	321,190	585,025
1. Hull group	49889 (23.3)[b]	139165 (24.6)	89818 (28.0)	169157 (28.9)
1.1 Basic hull	27298 (12.7)	81532 (14.4)	53851 (16.8)	97663 (16.7)
Main frames	8776 (4.1)	37374 (6.6)	19980 (6.2)	43758 (7.5)
Inter frames	4824 (2.3)	12361 (2.2)	9724 (3.0)	15627 (2.7)
Longitudinals	11298 (5.3)	22867 (4.0)	19873 (6.2)	28129 (4.8)
Main/gas wire	2400 (1.1)	8930 (1.6)	4274 (1.3)	10149 (1.7)
1.2 Secondary structure	9620 (4.5	18076 (3.2)	14385 (4.5)	25653 (4.4)
Reinforcement[c]	1900 (ι.9)	4631 (0.8)	3313 (1.0)	5731 (1.0)
Hull and tail cover	7401 (3.5)	12606 (2.2)	10836 (3.4)	18753 (3.2)
Cover wires[c]				
Miscellaneous hull	319 (0.1)	839 (0.1)	236 (0.1)	1149 (0.2)
1.3 Tail structure	2750 (1.3)	14116 (2.5)	6998 (2.2)	16669 (2.8
1.4 Gas system	10221 (4.8)	25441 (4.5)	14584 (4.5	29172 (5.0)
Gas cells	8769 (4.1)	21769 (3.8)	12822 (4.0)	25524 (4.4)
Cell netting	671 (0.3)	570 (0.1)	715 (0.2)	1043 (0.2)
Gas valves	781 (0.4)	3102 (0.5)	1047 (0.3)	2605 (0.4)

[a] All weights are in pounds.

[b] Parentheses show weights as percentages of total weight.

[c] Cover wire weight included with reinforcements.

Source: Goodyear 1975, Vol. III, p. 20, reference 8.

The weight of the basic hull component comes from the metallic structure that defines a dirigible in contrast to a blimp: circular (polyhedral) main and intermediate frames, longitudinal stringers at the vertices of the polyhedral cross section, and wires that provide a rigid overall structure.

The main frames are defined as those that separate the gas cells (about 12) of lightweight material. The cells float upward and tend to expand longitudinally. Overall expansion increases as altitude increases. The lift force of the cells is applied to wire and netting, which transmits the force to the frames and longitudinals.

Longitudinal expansion of the gas cells is restrained by wires installed in the plane of each main frame. When all cells are inflated, the longitudinal cell expansion is balanced against the expansion of the adjacent cell. However, if 1 cell is deflated, a critical load on the main frame is applied by tension in the transverse wiring.

The weight W_{MF} of the main frames is proportional to the volume of structural material. The length of each frame is proportional to hull diameter D. The cross section for a given stress σ and wire tension force T_W must be proportional to T_W/σ. Considering the wires as catenaries, the wire tension is found to be proportional to D^3. Thus, W_{MF} would be proportional to D^4/σ. Data for D and the ratio W_{MF}/D^4 for the 4 dirigibles are shown in table 29. The average of the ratios gives:

$$W_{MF} = 1.26\text{x}10^{-4}D^4 \quad . \tag{263}$$

The main frames and several other items are loaded in compression. Elements of these structures are constructed as trusses loaded as columns. Such columns can fail in one of several modes. The probable critical mode is elastic buckling for which the failure stress is proportional to the square root of the yield stress σ_Y of the structural material. The aluminum used in the historical dirigibles had a yield strength of about 42,000 p.s.i. Substitution in equation (263) with a square root variation gives:

$$W_{MF} = 0.026D^4/\sqrt{\sigma_Y} \quad . \tag{264}$$

The intermediate frames are loaded in compression by shear wires, and in bending by gas pressure. Shear is produced by static load, including heaviness, and by the gust moment M_{GMX} which is estimated in chapter 4. Static load shear would give weight proportional to $W_T D$, and gust load shear would lead to weight proportional to M_{GMX}/LD. The data needed to calculate the gust moment are shown in table 29. The

TABLE 29

DIRIGIBLE BASIC HULL WEIGHT CALCULATIONS

	Los Angeles	Macon	Graf Zeppelin	Hindenburg
Hull length (ft.)	660	785	776	814
Hull diameter (ft.)	90.7	132.9	113.2	135.2
$10^4 W_{MF}/D^4$	1.30	1.20	1.22	1.31
Gust speed (f.p.s.)[a]	18.6	29.8	20.6	26.9
Max speed (kt.)	65.2	72.2	69.0	72.0
Max speed (f.p.s.)	110.0	121.9	116.5	121.5
Volume (1000 cu.ft.)	2,800	7,400	4,200	7,650
Gust moment (millions of ft.lb.)	2.71	10.95	4.90	10.45
$10^3 W_{IF}/W_T$	22.5	21.8	30.3	26.7
$10^3 W_{IF}/W_T D$	.248	.164	.268	.198
$W_{IF} LD/M_{GMX}$	107	118	174	165
$10^6 W_{LNG}/(W_T L^2/D)$	10.99	8.71	11.63	9.81
$10^4 W_{LNG}/(M_{GMX} L/D)$	5.72	3.53	5.91	4.47
$W_T L/M_{GMX}$	52.1	40.6	50.9	45.6
$10^6 W_{WIR}/W_T L$	17.0	20.1	17.1	21.3

[a]From end of chapter 4.

gust speed is from the end of chapter 4. Equation (152) was used, with sea level density. Three ratios of the intermediate frame weight are shown. The gust moment assumption gives consistent numbers for U.S. and German cases separately. This structure consists of compression members, so in terms of material yield stress σ_Y :

$$W_{IF} = 23,000(M_{GMX}/LD)/\sqrt{\sigma_Y} \quad . \tag{265}$$

The longitudinals are subjected to static and gust moment bending moments and to lateral bending by the gas cells. The static moment M_S distribution depends on the longitudinal distribution of gas cells, structure, propulsion, fuel and payload, but must be proportional to $W_T L$. Using longitudinals stress σ_{LNG} equal to M_y/I , with y proportional to D and I proportional to longitudinals cross-section areas A_{LNG} and D^2 , gives A_{LNG} proportional to $M/\sigma D$. For the static moment given above, W_{LNG} is proportional to $W_T L^2/\sigma D$. Calculated values of $W_{LNG}/(W_T L^2/D)$ for the data weights are shown in table 29. They vary from the average by -15 to +13 percent.

The gas cell bending moment is due to a locally applied load on the longitudinals, rather than an overall static moment or gust moment. However, if the longitudinal bending depth is proportional to D then again the structural weight is proportional to $ML^2/\sigma_{LNG}D$. The gas load w_G per axial foot of longitudinal is proportional to D for hydrostatic variation of gas pressure with height and again to D for circumferential area. For a continuous beam of length L_B loaded uniformly, the maximum bending moment is proportional to $w_G L_B^2$. But L_B is proportional to L , depending on the number of gas cells. Thus the gas bending moment M_G is proportional to D^2L^2 . With envelope volume, and hence total weight, proportional to LD^2 , it is seen that M_G has the same form as the static moment M_S . Thus W_{LNG} has the same form of variation for both cases.

If the maximum gust moment M_{GMX} were critical for the weight of the longitudinals, then W_{LNG} would be proportional to $M_{GMX}L/D$. Calculated values of $W_{LNG}/(M_{GMX}L/D)$ are shown in table 29. The calculated ratio varies considerably from -28 to 20 percent of the average.

It is possible that parts of longitudinals are critical for static and gas moments while other parts are critical for gust moment. With constants f and g :

$$W_{LNG} = fM_{GMX}(L/D) + gW_TL^2/D \quad ;$$

$$\frac{W_{LNG}}{M_{GMX}(L/D)} = f + g\,\frac{W_TL}{M_{GMX}} \quad . \tag{266}$$

The ratio W_TL/M_{GMX} is listed in table 29 and the variation of $W_{LNG}/(M_{GMX}L/D)$ as a function of W_TL/M_{GMX} is shown in figure 104. It is seen that the intercept f should be zero. The longitudinals are compression members, so for an assumed yield stress of 42,000 p.s.i. for the data, the line shown in figure 104 gives:

$$W_{LNG} = 2.11 \times 10^{-3}(W_TL^2/D)/\sqrt{\sigma_Y} \quad . \tag{267}$$

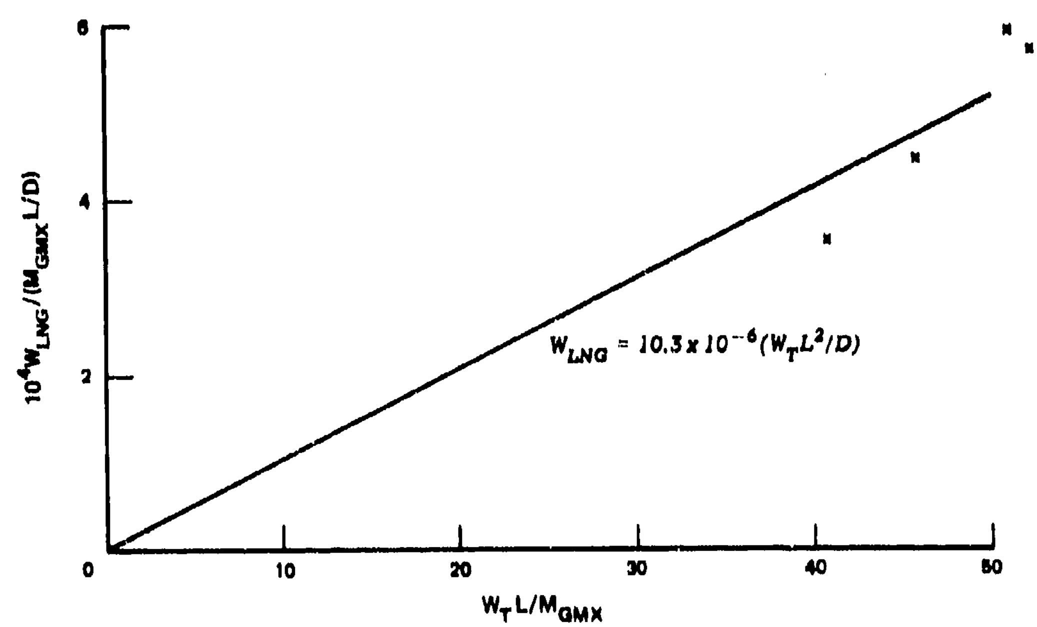

FIG. 104: LONGITUDINALS WEIGHT CORRELATION

The final contribution to the dirigible basic hull weight in table 28 is the main/gas wires. Main (shear) and gas cell wiring are combined in the available data. The loads in the main wiring are due to static load and gust moment shear forces. Considering only the static shear, assuming the shear to be proportional to W_T, and requiring the total wire area to be proportional to W_T/σ with wire length proportional to L, indicates that the wire weight W_{WIR} should be proportional to $W_T L/\sigma$. Values of the ratio $W_{WIR}/W_T L$ are shown in table 29. The wires are loaded in tension, so the wire yield stress does not require modification. However, it is convenient to use the wire stress σ_{REL} relative to the materials of the 1930s. With the average of the $W_{WIR}/W_T L$ ratios from table 29:

$$W_{WIR} = 19 \times 10^{-6} W_T L/\sigma_{REL} \quad . \tag{268}$$

A value of σ_{REL} of 1.1 is appropriate for 1976 steel wires. Kevlar polymer cable and rope would provide σ_{REL} values from 6 to 8 in 1976 technology.

The estimation equations for the weight W_{11} of the basic hull component for dirigibles, as selected above are:

$$\begin{aligned} W_{11} &= W_{MF} + W_{IF} + W_{LNG} + W_{WIR} \\ W_{MF} &= 0.026D^4/\sqrt{\sigma_Y} \\ W_{IF} &= 23{,}000\,(M_{GMX}/LD)/\sqrt{\sigma_Y} \\ W_{LNG} &= 2.11\times10^{-3}(W_T L^2/D)\sqrt{\sigma_Y} \\ W_{WIR} &= 18.9\times10^{-6} W_T L/\sigma_{WIR} \quad . \end{aligned} \tag{269}$$

Dirigibles: Secondary Structure Component Weight

The first item (bow and stern reinforcement) shown under secondary structure in table 28 also includes outer cover wiring. The reinforcement weight W_{RE} appears to be proportional to total weight W_T. The ratios W_{RE}/W_T are shown in table 30. Using the average ratio:

$$W_{RE} = 0.0093 W_T \quad . \tag{270}$$

TABLE 30

DIRIGIBLE SECONDARY STRUCTURE WEIGHT CALCULATIONS

	Los Angeles	Macon	Graf Zeppelin	Hindenburg
W_{RE}/W_T	.0089	.0082	.0103	.0098
C_P	.657	.680	.538	.655
C_S	.769	.793	.674	.773
Hull wetted area[a] (million sq.ft.)	144.543	259.976	186.045	267.237
Tail wetted area[b] (million sq.ft.)	.011	.029	.018	.024
$W_{COV}/(A_{WH}+A_{WT})$				
(lb./sq.ft.)	.0476	.0450	.0530	.0644
(oz./sq.yd.)	6.86	6.48	7.64	9.27
W_{MISH}/W_T	.0015	.0015	.0007	.0020

[a]Calculated from equation (39) with L and D from table 29.

[b]From table 10 and scaled sketches.

The cover weight, including hull and tail fins, should be proportional to the sum of hull wetted area and tail wetted area. The cover was made of a single-ply cloth of 2.7 to 4.5 ounce per square yard, with a 75 percent increase for seams, attachments, and dope (Burgess, page 267, reference 7). Hull wetted area, tail wetted area, and calculated cover specific weight are listed in table 30. The specific weight for the Hindenburg cover is 33 percent greater than the average for the other three dirigibles. Ignoring the Hindenburg value, the cover weight W_{COV} can be estimated as:

$$W_{COV} = 0.0485(A_{WH} + A_{TW}) \quad . \qquad (271)$$

This corresponds to a specific weight of 7 ounces per square yard for dirigibles of the 1925-1935 era. Polymer materials of 1976 could reduce W_{COV} by 50 percent.

The last item under secondary structure in table 29 is miscellaneous hull. Its weight W_{MISH} is very small and is approximated as proportional to total weight:

$$W_{MISH} = 0.0014W_T \quad . \tag{272}$$

The ratios W_{MISH}/W_T for each dirigible are shown in table 30.

The estimation equation for the weight W_{12} of the secondary structure for dirigibles can now be summarized:

$$\begin{aligned} W_{12} &= W_{RE} + W_{COV} + W_{COVW} + W_{MISH} \\ W_{RE} &= 0.0086W_T \\ W_{COV} &= 0.0485(A_{WH} + A_{TW}) \\ W_{COVW} &= 0 \text{ (no data for cover wires)} \\ W_{MISH} &= .0014W_T \quad . \end{aligned} \tag{273}$$

Dirigibles: Tail Structure Component Weight

The form of the previous approximate equation (261) for tail weight for blimps also applies to dirigibles. The dirigible tail is structurally attached to the frame longitudinal basic structure, and guy wires are not usually used. For a cantilever tail, the maximum bending moment occurs at the root and is approximately $0.50F_{FIN}b_F$; that is, 10 times the estimated moment for the blimp. However, the coefficient in the equation is also proportional to $1/(t/c)_F$. Further, it appears that dirigibles had $(t/c)_F$ values much larger than those of blimps.

It is possible that these changes may balance for historical blimps and dirigibles. Calculated values of the ratio $W_{13}/u_G VA_T b_F$ of tail weight to the bending stress parameters for the dirigibles are shown in table 31. The resultant ratios are nearly the same, and the average value is used. The tail structure is compression loaded aluminum so the yield stress is included in the equation:

$$W_{13} = 0.0019u_G VA_T b_F / \sqrt{\sigma_y} \text{, dirigibles.} \tag{274}$$

TABLE 31

DIRIGIBLE TAIL AND GAS SYSTEM WEIGHT CALCULATIONS

	Los Angeles	Macon	Graf Zeppelin	Hindenburg
b_F (ft.)	27	42	40	49
$10^6 W_{13}/u_G V_{MX} A_T b_F$	9.14	9.24	8.03	8.67
W_{GSCL}/A_{WH}	.0607	.0837	.0689	.0955
W_{NET}/W_T	.0031	.0010	.0022	.0018
W_{VAL}/W_T	.0036	.0055	.0033	.0045

[a]Gust speed and maximum speed from table 29.
Tail span and tail area from table 10 and sketches.

Dirigibles: Gas System Component Weight

The weight W_{GSCL} of the gas cells should be proportional to the area of the cells, with a low specific weight. The end area of each of N_C right cylindrical cells is proportional to $\pi D^2/4$. The circumferential area is somewhat less than the hull wetted area $C_S \pi LD$. For a material specific weight w_{CL} and a constant f , the weight of the gas cells can be written:

$$W_{GSCL} = w_{CL}(f\pi N_C D^2/4 + C_S \pi DL) \quad ;$$

$$\frac{W_{GSCL}}{C_S \pi DL} = w_{CL} + w_{CL} \frac{f}{4C_S} \frac{N_C}{L/D} \quad . \qquad (275)$$

This equation indicates that W_{GSCL}/A_{WH} may be a linear function of $1/(L/D)$ if f, C_S, and N_C are approximately constant.

Calculated values of W_{GSCL}/A_{WH} for the data dirigibles are listed in table 31, and shown as a function of $1/(L/D)$ in figure 105. The points scatter and do not permit selection of a line with a positive intercept.

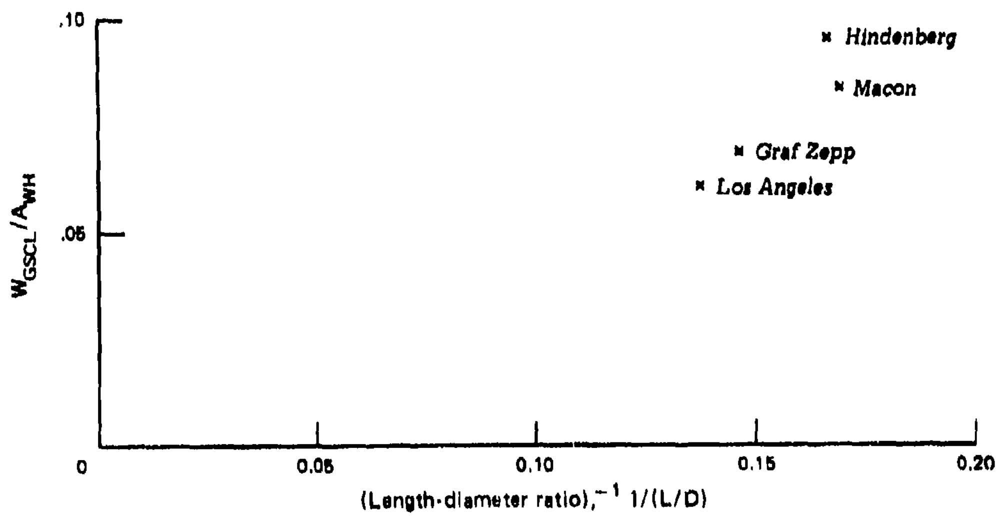

FIG. 105: VARIATION OF GAS CELL WEIGHT

It was therefore assumed that W_{GSCL}/A_{WH} is independent of L/D, that is, that N_C is proportional to L/D. The right side of equation (275) is then $2w_{CL}$. The average value of W_{GSCL}/A_{WH} in table 31 is .0772. When set equal to $2w_{CL}$, this gives an installed specific weight of 5.6 ounces per square yard. Then:

$$W_{GSCL} = 2w_{CL}A_{WH} \quad ;$$
$$w_{CL} = 0.0386, \text{ 1925 and 1935 era} \quad ; \qquad (276)$$
$$w_{CL} = 0.0140, \text{ 1976} \quad .$$

Polymer materials of 1976 would permit gas cells of 2 ounces per square yard or 0.0140 pounds per square foot, as shown.

The remaining two weight items in table 28 for the gas system are very small. They are assumed proportional to total weight. The ratios for the cell netting weight W_{NET} and gas value weight W_{VAL} are shown in table 31. Using the average:

$$W_{NET} = 0.0020W_T \quad ;$$
$$W_{VAL} = 0.0042W_T \quad . \qquad (277)$$

The weight W_{14} of the gas system component for dirigibles is:

$$W_{14} = W_{GSCL} + W_{NET} + W_{VAL} \quad . \qquad (278)$$

SHIP CONTROL GROUP WEIGHT

The weight data obtained for the ship control group defined in this airship model are for one blimp and four dirigibles. The items of the ZPG-3W blimp weight data that were assigned to the components of the ship control group are shown in table 32. The only item under steering weight W_{31} is the landing gear. Its weight is assumed to be proportional to the load weight with a safety factor. The load is the sum of total weight and maximum aerodynamic lift. For the ZPG-3W the aerodynamic lift is 10,500 pounds, so the load is 124,446 pounds. The landing gear weight should also be proportional to its length. For simplicity, the length was assumed to be equal to the sum of the length L_{GRC} of the car or centerline gear and twice the length L_{GRN} of the nacelle gear of blimps. From sketches, these lengths appear to be about 8 feet and 9 feet, respectively. For the 1190-pound landing gear weight of table 32, the steering component weight W_{31} becomes:

$$W_{31} = W_{GER}$$
$$W_{GER} = 0.00037(L_{GRC} + 2L_{GRN})(W_T + L_A) \quad . \qquad (279)$$

This equation is also used to estimate the weight of conceptual landing gear for dirigibles.

TABLE 32

BLIMP SHIP CONTROL GROUP WEIGHT DATA

Item	ZPG-3W
Total weight	113,946
3. Ship control group	12,747 (11.2)
3.1 Steering	1,190 (1.0)
Landing gear	1,190 (1.0)
3.2 Nav/communication	4,900 (4.3)
Instruments	580 (0.5)
Electronics group	4,320 (3.8)
3.3 Ship facilities	2,489 (2.2)
Access	414 (0.4)
Anti-ice	56 (0)
Electrical group	794 (0.7)
Auxiliary gear	795 (0.7)
Hydraulic group	430 (0.4)
3.4 Ballast	4,168 (3.7)
Ballast group	750 (0.7)
Minimum ballast[a]	3,418 (3.0)

[a] Estimated as discussed in text.

Source: Goodyear 1975, Vol. III, p. 33, reference 8. Weight in pounds.

The electronics group item weight under the navigation and communication component appears to be unreasonably large even though weights of military mission equipment were removed from the ZPG-3W data according to the source for the table. Instruments and basic ship control electronics for airships of the 1970s would be much different from those on the historical airships. However, the weight data for dirigibles (presented below) provide a better basis for analysis. The equations for navigation and communication weight W_{32} selected for dirigibles are therefore also used for blimps:

$$W_{32} = 0.0050W_T \ , \quad \text{before 1976 era;} \qquad (280)$$

$$W_{32} = 0.0025W_T \ , \quad \text{1976 era.}$$

To correlate with the ZPG-3W blimp, it is then necessary to assign an additional 4,320 pounds to payload.

The Ship Facilities component weight W_{33} includes several items. The access weight W_{ACCS} is:

$$W_{ACCS} = 0.004W_T \ . \qquad (281)$$

The small anti-icing weight is ignored. The ship's electric system weight W_{SLEC} is:

$$W_{SLEC} = 0.007W_T \ . \qquad (282)$$

The same coefficient is found below for dirigibles. The auxiliary gear item is not further defined in the source for the table. Its weight W_{AUX} is:

$$W_{AUX} = 0.007W_T \ . \qquad (283)$$

The hydraulic system weight W_{HYD} is:

$$W_{HYD} = 0.004W_T \ . \qquad (284)$$

Then, for blimps:

$$W_{33} = W_{ACCS} + W_{SLEC} + W_{AUX} + W_{HYD} \ . \qquad (285)$$

Normal operating ballast per se is not included in the weight data for either the blimps or dirigibles. It appears that ballast was considered to be part of the "useful" load. Here it was desired to include the minimum normal operating ballast weight in the ship control group.

The information obtained for selecting an estimate for minimum ballast was from the 1920s. Blakemore, 1927, p. 102 (reference 5) states that ballast for blimps varies from 4 to 7 percent of the static lift. And Burgess, 1927, p. 280 (reference 7) states that for dirigibles emergency ballast should be about 3 percent of static lift and that total ballast capacity should be not less than 15 percent of static lift.

For use here, the total weight was selected as reference for the minimum ballast weight. A minimum ballast of 3 percent of total weight was selected and is shown in tables 32 and 33. A ballast system (tanks, pipes, pumps) capacity of about 10 percent total weight should be provided.

Thus, the minimum ballast weight W_{MNB} is estimated as:

$$W_{MNB} = 0.03W_T \quad . \tag{286}$$

Referred to total weight, the weight W_{BALS} of the ballast system is:

$$W_{BALS} = 0.007W_T \quad . \tag{287}$$

Then the weight W_{34} of the ballast component for blimps is:

$$W_{34} = W_{BALS} + W_{MNB} \quad . \tag{288}$$

The data for ship control group weights for dirigibles are shown in table 33. Under the steering component weight W_{31} the mooring weight W_{MOR} is small and roughly proportional to total weight:

$$W_{MOR} = 0.006W_T \quad . \tag{289}$$

The control car weight W_{CCAR} increases slowly. To consider small dirigibles, the control car weight should vary. A 1/3 power variation approximates the data. The car structure is assumed to be loaded in compression, so the structural material yield stress is included in the equation.

$$W_{CCAR} = 4,700W_T^{1/3} / \sqrt{\sigma_Y} \quad . \tag{290}$$

The error for the Macon is +11 percent, but the other dirigibles vary only -2 to 3 percent. The controls weight W_{CONT} is approximately proportional to total weight:

$$W_{CONT} = 0.003W_T \quad . \tag{291}$$

TABLE 33

DIRIGIBLE SHIP CONTROL GROUP WEIGHT DATA[a]

Item	Los Angeles	Macon	Graf Zeppelin	Hindenburg
Total weight	214127	565908	321190	585025
3. Ship control group	19424(9.1)	51586(9.1)	29204(9.1)	51410(8.8)
3.1 Steering	3348(1.6)	6815(1.2)	3750(1.2)	7604(1.3)
Mooring	1399(0.7)	3425(0.6)	1453(0.5)	4168(0.7)
Control car	1399(0.7	1718(0.3)	1604(0.5)	1874(0.3)
Controls	550(0.3)	1672(0.3)	693(0.2)	1562(0.3)
3.2 Nav/communication	1151(0.5)	827(0.1)	1334(0.4)	3126(0.5)
Instruments	251(0.1)	255 (0)	267(0.1)	1043(0.2)
Radio, commun	900(0.4)	572(0.1)	1067(0.3)	2083(0.4)
3.3 Ship facilities	3551(1.7)	10615(1.9)	7379(2.3)	11667(2.0)
Gangways	2101(1.0)	8157(1.4)	3953(1.2)	6772(1.2)
Heat, vent	251(0.1)	535(0.1)	738(0.2)	728(0.1)
Electric syst	1199(0.6)	1923(0.3)	2688(0.8)	4167(0.7)
3.4 Ballast	11374(5.3)	33329(5.9)	16741(5.2)	29013(5.0)
Ballast system	950(0.4)	3430(0.6)	1229(0.4)	3126(0.5)
Water recovery	4000(1.9)	12922(2.3)	5876(1.8)	8336(1.4)
Minimum ballast[b]	6424(3.0)	16977(3.0)	9636(3.0)	17551(3.0)

[a] From Goodyear 1975, Vol. III, p. 20, reference 8. Weights in pounds.

[b] Estimated as 3 percent of total weight. See text.

Then, for dirigibles:

$$W_{31} = W_{CER} + W_{MOR} + W_{CCAR} + W_{CONT} \quad . \tag{292}$$

If landing gear is used, its weight is estimated by equation (279).

For the weight W_{32} of the navigation and communication component for dirigibles, the data shown in table 33 provide a reasonable basis for selecting estimation equations (in contrast) to the data for blimps in table 32. The ratios, relative to total weight, are low for the Macon, supporting descriptive histories of the Akron/Macon Navy operations that state that they had a limited electronics capability for working with the fleet and their onboard airplanes. Therefore, the data for the Macon are ignored here.

For the 1920s and 1930s the other dirigible data for instrument weight W_{INS} using an average coefficient are as follows:

$$W_{INS} = 0.0014W_T \text{ , dirigibles, 1930.} \tag{293}$$

Similarly, the radio and communication weight W_{RCOM} is:

$$W_{RCOM} = 0.0036W_T \text{ , dirigibles, 1930.} \tag{294}$$

Estimating W_{32} as the sum of these weights:

$$W_{32} = 0.005W_T \text{ , dirigibles, 1930.} \tag{295}$$

The weight of instruments and radio and communications could be considerably reduced in the 1976 era. The weight of inertial navigation systems for transoceanic operation and solid state electronic systems for operational and air traffic control should weigh about half as much as the data values for the Hindenburg. For 1976-era dirigibles, the weight estimate for W_{32} is selected as half that of the 1930 estimate:

$$W_{32} = 0.0025W_T \text{ , dirigibles, 1976 era.} \tag{296}$$

Appropriate corresponding cost estimate changes were not obtained.

As stated previously, these estimates of W_{32} for dirigibles were also selected for blimps because adequate reasonable alternative data for blimps were not obtained.

The weight W_{GNG} of the gangways of the dirigibles is analogous to the access weight for blimps. Perhaps W_{GNG} as horizontal gangways would be proportional to hull length L . Calculation shows this assumption is not valid. If the "gangway" weight includes the vertical access ladders used in historical dirigibles, the gangway weight might be more closely proportional to envelope volume, that is, to total weight. The percentages of total weight included in table 33, indicate that this is a better assumption. Using the average ratio for the four dirigibles:

$$W_{GNG} = 0.021W_T \quad . \tag{297}$$

The heat and ventilation weight W_{HVEN} for dirigibles was assigned to the ship facilities component partly because it is small and partly because accommodations for crew and passengers in dirigibles are internal to the hull envelope. (For the ZPG-3W blimp the air conditioning weight is relatively larger and was assigned to the accommodations group of this model.) For operation over oceans, and with the comfort standards of the 1930 era, perhaps little air conditioning was necessary. The average ratio of W_{HVEN} to total weight gives:

$$W_{HVEN} = 0.001W_T \quad . \tag{298}$$

The ship facilities electric power weight W_{SLEC} data for dirigibles, ignoring the Macon, give an average ratio to total weight that leads to:

$$W_{SLEC} = .007W_T \quad . \tag{299}$$

Finally, for dirigibles,

$$W_{33} = W_{ENG} + W_{HVEN} + W_{SLEC} \quad . \tag{300}$$

The Ballast system item weight W_{BALS} under the Ballast component for dirigibles in table 33 seems to indicate an increasing fraction of total weight for the two larger dirigibles. However, the average ratio is selected:

$$W_{BALS} = .005W_T \quad . \tag{301}$$

The water recovery item weight W_{WREC} is close to twice the engine horsepower P_{ENG} , except for the Macon. For the Macon the weight is 2.88 times the engine horsepower. The ratio of 2 is selected:

$$W_{WREC} = 2P_{ENG} \quad . \tag{302}$$

As discussed previously, the weight of minimum ballast is estimated as .03 times total weight:

$$W_{MNB} = .03W_T \quad . \tag{303}$$

Then the Ballast component weight W_{34} for dirigibles is:

$$W_{34} = W_{BALS} + W_{WREC} + W_{MNB} \quad . \tag{304}$$

ACCOMMODATIONS GROUP WEIGHT

The number N_{ACC} of accommodations is equal to the sum of the number N_{CRW} of crew and the number N_{PAS} of passengers:

$$N_{ACC} = N_{CRW} + N_{PAS} \quad . \tag{305}$$

For analysis purposes, estimates (not data) of N_{CRW} and N_{PAS} are shown in parentheses in table 34 for blimps, and in table 35 for dirigibles.

Estimation of the weight W_{41} of personnel and effects requires consideration of the weight W_{PERS} of the personnel. A weight of 160 pounds per person appears to have been used in the 1920s. The 1970s convention of the U.S. Navy (165 pounds) for displacement ships is selected for use here:

$$W_{PERS} = 165N_{ACC} \quad . \tag{306}$$

Calculated values for W_{PERS} based on this equation are shown in parentheses in tables 34 and 35.

Neither convention nor data were obtained concerning the weight W_{EFF} of personal effects. For the 1970s the U.S. Navy estimates 235 pounds per officer, 165 pounds per CPO, and 65 pounds per enlisted person for long-duration displacement. These are too large for airships. In addition, the personal effects weight should be a function of ship (flight) duration. The following estimation equations were selected to use in this model for various regimes of ship duration T_{DUR} :

TABLE 34

BLIMP ACCOMMODATIONS GROUP WEIGHT DATA[a]

Item	ZPG-3W
Total weight	113946
4. Accommodations group	
Crew	21
Passengers	0
4.1 Personnel effects	
Personnel	(3405)
Effects[b]	(840)
4.2 Personnel enclosures	5054(4.4)
Car	4570(4.0)
Car fairing	484(0.4)
4.3 Personnel facilities	3471(3.0)
Furnishing, equipment	2164(1.9)
Air conditioning	1307(1.1)
4.4 Personnel stores	

[a]All weights are in pounds.

[b]Assumed ZPG-3W design duration of 2 days.

Source: Goodyear 1975, Vol. III, p. 33, reference 8.

TABLE 35

DIRIGIBLE ACCOMMODATIONS GROUP WEIGHT DATA[a]

Item	Los Angeles	Macon	Graf Zeppelin	Hindenburg
Total weight	214127	565908	321190	585025
4. Accommodations group				
Crew	(25)	(65)		
Passengers	0	0		
Ship duration, days				
4.1 Personnel effects				
Personnel	(4125)	(10725)		
Effects[b]	(1250)	(3250)		
4.2 Personnel enclosures				
4.3 Personnel facilities				
Crew quarters	2499(1.2)	6450(1.1)	3205(1.0)	3645(0.6)
4.4 Personnel stores				

[a] All weights are in pounds.

[b] Assumed ZPG-3W design duration of 2, 3, 3, and 3 days.

Source: Goodyear 1975, Vol. III, p. 20, reference 8.

$$W_{EFF} = 0, \text{ when } T_{DUR} < 0.05 \text{ days};$$
$$W_{EFF} = 40N_{ACC}, \text{ when } 0.05 \le T_{DUR} < 2 ; \qquad (307)$$
$$W_{EFF} = (20+10T_{DUR})N_{ACC}, \text{ when } 2 \le T_{DUR} .$$

These equations are to be used for both blimps and dirigibles. Calculated values based on these equations are shown in parentheses in tables 34 and 35. Then:

$$W_{41} = W_{PERS} + W_{EFF} . \qquad (308)$$

Personnel enclosure weight W_{42} is intended to be principally only the enclosure weight W_{PEN}. Estimates were selected without adequate data, assuming light aluminum nonstructural enclosures:

$$W_{PEN} = 20N_{ACC}, \text{ when } T_{DUR} < 0.5 \text{ day};$$
$$W_{PEN} = 40N_{CRW} + 60N_{PAS}, \text{ when } 0.5 \le T_{DUR} . \qquad (309)$$

For up to 12 hours duration crew members are assumed to be at their work station. For more than 12 hours, separate living space, about equal to the work space, is required. Passengers are treated similarly, but for durations of 12 hours or more they are assumed to require more space than the crew members.

For blimps, the car and car fairing weights were assigned to the personnel enclosures component weight as shown in table 34. The ship duration for the ZPG-3W was greater than 12 hours, so equation (309) gives 840 pounds estimated personnel enclosure weight. The remaining car weight is 4,214 pounds. Its weight is estimated as proportional to the supported weight W_{SUP} (including the car), which was previously taken as 83,899 pounds for the ZPG-3W. Then:

$$W_{42} = W_{PEN} + .050W_{SUP} , \text{ blimps}. \qquad (310)$$

For dirigibles, the second term is omitted.

The personnel facilities component weight is intended to include work and living furniture, furnishings, and personnel equipment; heat, ventilation, and plumbing (HVP), with air conditioning when used; and lighting, fire protection, and emergency life vests and equipment. For airships, lighting has been assigned entirely to ship facilities. Data were not obtained for fire and emergency equipment. However, data for furnishings weight W_{FUR} and HVP weight are shown in table 34 for the ZPG-3W blimp. Specific definitions for the data were not obtained. It is assumed that the "furnishings and equipment" item is primarily related to personnel, and that "air conditioning" includes heat and ventilating systems. These weights should be functions of ship duration.

It is assumed that:

$$\left.\begin{aligned} W_{FUR} &= 20N_{ACC} \\ W_{HVP} &= 0 \end{aligned}\right\} \text{ when } T_{DUR} \leq 0.05 \text{ day}$$

$$\left.\begin{aligned} W_{FUR} &= 30N_{ACC} \\ W_{HVP} &= 10N_{ACC} \end{aligned}\right\} \text{ when } 0.05 < 0.5 \tag{311}$$

$$\left.\begin{aligned} W_{FUR} &= 100N_{ACC} \\ W_{HVP} &= 60N_{ACC} \end{aligned}\right\} \text{ when } 0.5 < T_{DUR}$$

The rationale is a sequence from a simple seat for very short durations, to a heavier seat, toilet facilities, and some air conditioning for intermediate durations. For long durations, bunk, bedding, wardroom, and cooking facilities must be added. The weight W_{43} of the personnel facilities component is:

$$W_{43} = W_{FUR} + W_{HVP} \quad . \tag{312}$$

Equations (311) for furnishings weights are to be used for dirigibles as well as blimps. The 1930 dirigibles had no personnel air conditioning; but this factor should be included for 1976-era dirigibles. Data for "crew quarters" weight for dirigibles are shown in table 35. Definition of the items included was not obtained.

For the estimated Los Angeles and Macon crews of 25 and 65, without personnel heat, ventilation, and plumbing, the estimates of equations (311) are consistent with the "crew quarters" weight data.

The weight W_{44} of the personnel stores component depends on the ship duration as well as the number of accommodations. U.S. Navy displacement ships carry 50 pounds plus 4.5 pounds of provisions per day per person. In addition, Navy ships carry 50 gallons of potable water per person for normal long ship durations. The allowances for provisions weight W_{PROV} and water weight W_{WA} for airships cannot be as large.

It is assumed that:

$$\left.\begin{aligned} W_{PROV} &= 0 \\ W_{WAT} &= 0 \end{aligned}\right\} \text{when } T_{DUR} \le 0.5 \text{ day}$$

$$\left.\begin{aligned} W_{PROV} &= 4.5N_{ACC} \\ W_{WAT} &= 8N_{ACC} \end{aligned}\right\} \text{when } 0.05 < T_{DUR} \le 0.5 \qquad (313)$$

$$\left.\begin{aligned} W_{PROV} &= 4.5T_{DUR}N_{ACC} \\ W_{WAT} &= 16T_{DUR}N_{ACC} \end{aligned}\right\} \text{when } 0.5 < T_{DUR}$$

The personnel stores weight is the sum of provisions and water weight:

$$W_{44} = W_{PROV} + W_{WAT} \quad . \qquad (314)$$

THE ITERATION PROCEDURE

An iterative calculation is used to estimate the total weight. A first estimate for the total weight is required to start the iteration. A constant could be used, but fewer steps of iteration are needed if at least the specified speed, range, and payload weight are considered. Many different equations would be adequate for this purpose. The one selected for this model is:

$$W_T = 1 + 4.3W_5 + 60(R/1000)(V_E/100)^3 \quad . \qquad (315)$$

Here W_5 is the weight of the conceptual payload group 5, R is the specified endurance range, and V_E is the endurance speed.

When the total weight has been recalculated on the basis of one estimate, the two values can be compared. If they are sufficiently close, say within 1 percent, the iteration is terminated. Otherwise, a new estimate must be made. The recalculated total weight could be used, but fewer iteration steps are required if the known estimates are used to calculate a new estimate.

For this purpose a numerical form of the Newton-Raphson method of mathematics is used. A function F is defined as the recalculated total weight W_{RT} minus the estimated total weight W_T :

$$F = W_{RT} - W_T \quad . \tag{316}$$

It is desired that F approach zero. Using the derivative F' of F with respect to W_T, a change of W_T equal to $-F/F'$ is required. The new estimate W_{TN} for total weight is then:

$$W_{TN} = W_T - F/F' \quad . \tag{317}$$

A first estimate for F' is needed. Calculations with the model indicate that a value of -0.6 is reasonable. When a second recalculation has been made, and thereafter, the derivative can be calculated numerically. Using a subscript L to denote the last previous values of F and W_T, the equations are:

$$F' = -0.60, \text{ after first calculations;}$$
$$F' = (F - F_L)/(W_T - W_{TL}), \text{ thereafter.} \tag{318}$$

PAYLOAD WEIGHT ESTIMATION

For this model, payload group 5 includes mission equipment hardware, or cargo, with all foundation and installation weight. Crew and passengers and their accommodations are considered separately under weight group 4. Auxiliary electric power required for payload must be specified; its weight is then included as electric plant component 2.3 . Ship fuel weight is considered as weight component 6.1 and normal operating ballast is included in weight component 3.4 .

The conventional sea level useful load for airships includes payload, crew, passenger accommodations, ballast, and ship's fuel. Although sea level useful load provides a general view of the capability of the airship, the fact that it decreases with increasing operating altitude and includes the essential crew, ballast, and ship's fuel can lead to confusion as to payload (or passenger) capability. Therefore, sea level useful load is not used directly in this model. It is calculated only for comparison with data for historical airships.

This model does not provide automatic consideration of payload such as payload shopping list with stored data for weight, installation weight, required deck area, investment cost, and installation cost.

The analyst must estimate the payload weight and installation weight separately and specify the sum for use by the model. Number of crew and passengers must also be estimated separately and specified.

REQUIRED VOLUME

The car size of a blimp must provide enough volume to contain all the items normally located in the car. For dirigibles, such items other than the control car and functions were historically located within the hull envelope. This required non-gas volume reduced the lift-gas volume and static lift.

It is necessary to estimate the required volume so that blimps and dirigible car size and dirigible internal volume can be considered. Overall volumes (envelope, ballonet, and dirigible gas cell clearance) were considered previously in chapter 3 on lift gases and geometry.

Here, the volume required for the components of airship weight is considered. The definitions of components for weight (table 23) are used for volumes.

A usual convention in vehicle analysis is to set the required volume for structure equal to zero. This convention is followed here, so the required volume V_1 for the structure group 1 is:

$$V_1 = 0 \ . \qquad (319)$$

With this convention, data on required volume are obtained including dimensions to enclosing structure. For airships, the density of internal solid structure is a few to several thousand times the density of air, so its required volume is negligible.

It is assumed that the power plants are located externally in nacelles so they do not require car or envelope volume.

An independent or auxiliary electric plant is assumed to be located internally. Volume data on airship electric plant installations were not obtained. On the basis of data for other types of vehicles an installed density of about 20 pounds per cubic foot is selected. Then:

$$V_{24} = 0.05W_{24} \ . \qquad (320)$$

Volume is required for several items of the ship control group. Data for airships were not obtained. The estimates below are based on data for other types of vehicles. The required volume V_{31} for the steering component 3.1 was selected to be zero for lack of data:

$$V_{31} = 0 \ . \qquad (321)$$

The volume V_{32} for the navigation and communication component 3.2 was considered to be that of the pilot control area, including controls, instruments, navigation, and radio. Also, this volume is estimated in terms of the deck area A_{32} required, with the volume obtained by multiplying A_{32} by an average deck height h_{DK}, as used previously in discussing the car size in chapter 3. The pilot control area probably increases slowly with ship size. The ZPG-3W appears to have had about 80 square feet including a radio operator's station in the pilot's compartment and a separate navigator's station. Under accommodations (equation 327) an area of 15 square feet is selected for each work station. Subtracting 3-15 from 80 leaves 35 square feet for the area A_{32}. For the ZPG-3W W_{32} weight estimated according to equation (280), the deck area is about 0.06 times the weight:

$$A_{32} = 0.06W_{32} \quad ;$$
$$V_{32} = h_{DK}A_{32} \quad . \qquad (322)$$

Ship facilities component volume V_{33} is required in the car and in the envelope. For auxiliary gear, ship electric system, and heat and ventilation a density of 20 pounds per cubic foot is appropriate. However, for the gangways of dirigibles considerable volume at a very low density is required. A density of 0.5 pounds per cubic foot is selected. Then:

$$V_{33} = 0.05W_{33} + 2W_{GNG} \quad . \qquad (323)$$

The double counting, with W_{GNG} included in W_{33}, is insignificant.

A reasonable installed density for the ballast system part of the volume V_{34} of the ballast component is again 20 pounds per cubic foot. This density is also reasonable for the water minimum ballast, because the water must be located in moderate size tanks longitudinally for trimming purposes. However, the water recovery item for dirigibles is located externally on the surface of the hull, so it does not require a significant volume. Thus:

$$V_{34} = .05W_{34} \text{ , blimps;}$$
$$W_{34} = .05(W_{BALS} + W_{MNB}) \quad . \qquad (324)$$

The required volume V_3 for the ship control group is the sum of the volumes for the components:

$$V_3 = V_{31} + V_{32} + V_{33} + V_{34} \quad . \tag{325}$$

For the accommodations group 4, the personnel, their effects, and the personnel facilities are defined to require zero volume because they are located within the personnel enclosures.

$$V_{41} = 0 \; ; \qquad V_{43} = 0 \quad . \tag{326}$$

For personnel enclosures it is desirable to express the required volume V_{42} in terms of deck area A_{42} and average deck height. From isometric general arrangement sketches in the ZPG-3W Flight Handbook it appears that there was about 15 square feet of work space (triple bunks) for each crew member. For comparison, U.S. Navy ship accommodations deck areas have been from 10 to 55 square feet per person. Assuming that deck area is proportional to the enclosures weights of equation (309) gives:

$$A_{42} = 15N_{ACC} \quad \text{when } T_{DUR} < 0.5 \text{ day;} \qquad A_{42} = 30N_{CRW} + 45N_{PAS} \; , \quad \text{when } 0.5 \leq T_{DUR} \quad . \tag{327}$$

For personnel stores volume V_{44} an installed density of 20 pounds per cubic foot is appropriate:

$$V_{44} = 0.05W_{44} \quad . \tag{328}$$

For the accommodations group:

$$V_4 = V_{41} + V_{42} + V_{43} + V_{44} \quad . \tag{329}$$

Payload volume requirements must be estimated by the user and are to be specified as special payload deck area. Estimated required deck area for payload equipment should be reduced by 15 square feet per person operating the equipment, that is, per work station, because this amount of deck area has been included in the work station accommodations deck area A_{42} in equations (327). When detailed information is not available, use of a payload deck area of about 30 square feet per 1,000 pounds of payload, reduced by crew station area, appears reasonable.

For payload cargo, the required deck area depends on the average loaded density and stacking height of the type of cargo being considered.

Fuel system volume is assumed to be included in V_{62} . Fuel is carried in several relatively small tanks in airships because fuel is used also for trim and as emergency ballast. The ZPG-3W had 5 slip tanks of 200 to 300 gallons capacity each. Slip tanks are constructed and installed such that they can be disengaged and dropped free of the airship instantly. They are designed, then, as quick release ballast units (including the tank weight) as well as fuel tanks connected in the fuel system. The ZPG-3W had one forward and one aft main fuel tank with a 1,150-gallon capacity. A seventh fuel tank was designed to be used either for fuel or for ballast water.

The result of using several tanks that are relatively small and designed in part for quick release is that the installed density appears to be much less than fuel density. For use in this model, an installed density of 20 pounds per cubic foot is selected, independent of type of fuel. Then:

$$V_{62} = .05W_{62} \quad . \qquad (330)$$

7. AIRSHIP INVESTMENT COST

The cost analysis presented in this chapter extends historical cost data to 1976 dollars. The analysis considers price indexes and learning rates. Estimates are made for engineering, prototype, and production costs. The cost of the lift gas is also considered. This chapter discusses only investment costs; operating costs are discussed in appendix F of volume II.

The analysis presented in this chapter provides only a first approximation that uses a constant specific cost (dollars per pound) for the empty weight of the airship. The importance of the constant specific cost approximation is that the effect of conceptual variations of hull material type, propulsion engine type, and so forth, on costs may not be adequately represented. When higher strength materials are used, the material specific cost usually increases. Similarly, when propulsion engines with a lower weight per horsepower are used the engine specific cost usually increases. The detailed cost data needed to include these variations were not found, so these relations are not included in this cost model.

An adequate conceptual investment cost model should also consider material costs and labor hours separately. The model should use a correct labor rate to convert labor hours into labor costs. These relations are also not considered in this investment cost model.

The most recent U.S. Navy blimps were constructed around 1960. The last U.S. Navy dirigible built was completed in 1933 in response to a contract signed in 1928. Since 1960 only Goodyear advertising blimps have been built in the United States. Cost data for these blimps were not found. To place the cost data that were available in proper perspective, that is, to make valid comparisons possible, it is necessary to transform the data by means of an appropriate price index.

An investigation of price indexes is presented first. This is followed by a discussion of learning factors for quantity production. Then production cost data are analyzed. Finally, research and development (R&D) cost, engineering cost, and prototype-increment cost are considered.

PRICE INDEX FOR AIRSHIPS

Several different series of price indexes are available. The Wholesale Price Index (WPI) is an index for general comparisons (references 21 and 22). There are three versions of the WPI: all commodities; all commodities excluding farm products and food; and machinery and equipment. Data for all three versions are shown in figure 106 where the 1947 to 1949 average is given an index of 100. The WPI indexes up to the end of World War II were almost constant and had much the same value. After World War II the indexes increased rapidly, and by 1950 the three versions began to diverge.

The lowest WPI line in figure 106 is for all commodities. The upper line is for machinery and equipment. The larger values for this case indicate that the WPI for machinery and equipment may be a desirable index for airships.

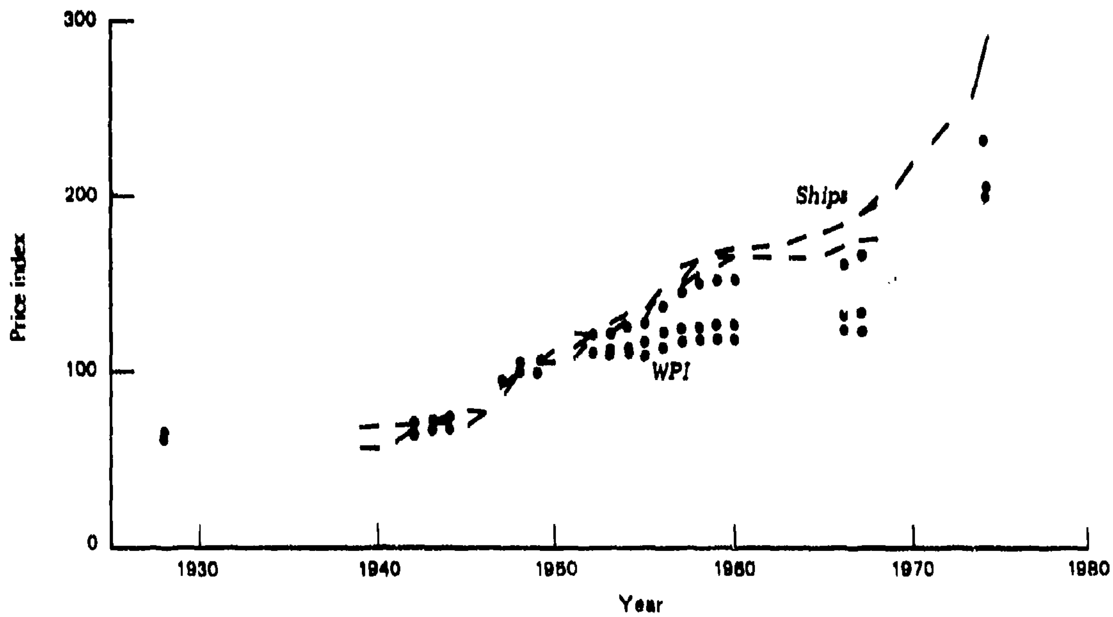

FIG. 106: HISTORICAL PRICE INDEX VARIATION

Price index data for three different surface ship cases, normalized to 1947-1949 equal an index of 100, are shown in figure 106 by short dash lines. The three cases are: a Bureau of Labor Statistics index for steel vessels; a Maritime Administration (MarAd) index for U.S. shipbuilding; and an index for U.S. Navy shipbuilding. Before the end of World War II the ship indexes corresponded to the WPI indexes. By about 1950 the ship indexes were higher than the WPI all-commodity index. The ship indexes were also higher than the WPI machinery and equipment index. This trend has continued through 1975.

Two other sets of indexes were considered: one of aircraft, ships and boats; the other of Gross National Product (GNP) and Federal Government Purchases (FGP). A pair of indexes for aircraft and ships and boats from 1929 to 1960 (reference 23) showed essentially identical variation and, when normalized to 1947-1949 equal 100, correspond to the scatter of the data points in figure 118 for those years. The final set considered included GNP deflator and FGP deflator indexes. The GNP deflator follows the WPI all-commodities index variation. The FGP, however, increases in the 1970s considerably above the ship indexes line in figure 106.

Technical vehicles such as airplanes and ships appear to be appropriate analogs for airships. With this assumption and using the above data, a price index series for airships was assumed and is shown in table 36. The data are from the machinery and equipment WPI until 1939, the average of the ship indexes until 1960, and the average of the MarAd and U.S. Navy indexes thereafter. The values for 1974 and 1975 reflect the rapid inflation for ships in those two years.

TABLE 36

ASSUMED PRICE INDEX FOR AIRSHIPS
(1947-49 = 100)

Year	Index	Year	Index
1925	73	1951	115
1926	71	1952	120
1927	67	1953	126
1928	66	1954	131
1929	65	1955	135
1930	61	1956	146
1931	54	1957	155
1932	50	1958	161
1933	51	1959	166
1934	56	1960	168
1935	56	1961	171
1936	57	1962	172
1937	61	1963	175
1938	58	1964	179
1939	58	1965	181
1940	64	1966	184
1941	65	1967	190
1942	69	1968	196
1943	71	1969	206
1944	73	1970	220
1945	74	1971	230
1946	76	1972	241
1947	89	1973	255
1948	102	1974	291
1949	108	1975	331
1950	109	1976	379

The variation of hourly earnings for manufacturing workers since 1925 is shown in figure 107 (references 24 and 25). From 1925 to the beginning of World War II, hourly earnings doubled while the price index remained constant. Since the beginning of World War II, hourly earnings have increased somewhat faster than the price indexes.

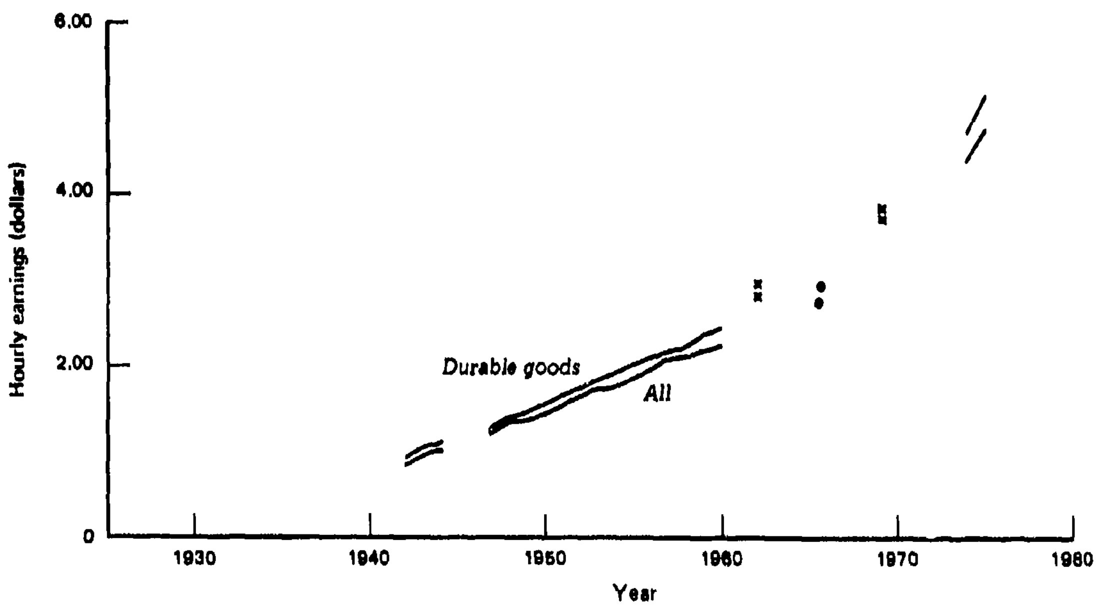

FIG. 107: HISTORICAL MANUFACTURING HOURLY EARNINGS

Airship production in 1976 would use less manual labor than was used in the 1930s. This would reduce the effect of the large increases in hourly wages since then.

LEARNING FACTORS

When a vehicle is produced in quantity, a significant decrease in the average production cost may occur. The result of quantity production is called "learning" and is usually primarily due to labor learning; that is, the required labor hours decrease. However, labor and material contributions can be added and the resultant average learning used. The influence of learning is important in this investigation for two reasons: it makes possible reducing the airship cost data to a common basis, and it permits estimating the influence of learning on the cost of future airships.

Learning factors F_{LN} are the ratio of the average cost or price per item to the cost or price of the first item. The learning factor is a function of the number N of items produced; it decreases as N increases. Two types of learning factors are defined: the unit average and the cumulative average. Both are defined in terms of the learning rate λ (in percent) and the production quantity N. The learning rate is the ratio of the unit cost obtained when the total quantity is doubled. The unit average learning factor is defined by:

$$F_{LN} = \left(\sum_{J=1}^{J=N} J^{\ln(\lambda/100)/\ln 2} \right) / N, \text{ unit average .} \quad (331)$$

The cumulative average learning factor is defined by:

$$F_{LN} = N^{\ln(\lambda/100)/\ln 2}, \text{ cumulative average.} \quad (332)$$

A comparison of the unit average and cumulative average learning factors is shown in figure 108 for an 85 percent learning rate. For production quantities greater than about 10, the cumulative average learning factor is approximately 20 percent less than the unit average learning factor. These 2 learning factors are useful for different vehicles. For surface ships, empirical data indicate that the cumulative average factor, with an appropriate learning rate, is preferred. For airplanes, the unit average factor is preferred.

The available historical data for the learning factor for airships do not state which cost factor was used. However, by analogy with airplanes, the unit average learning factor is selected for use in this volume.

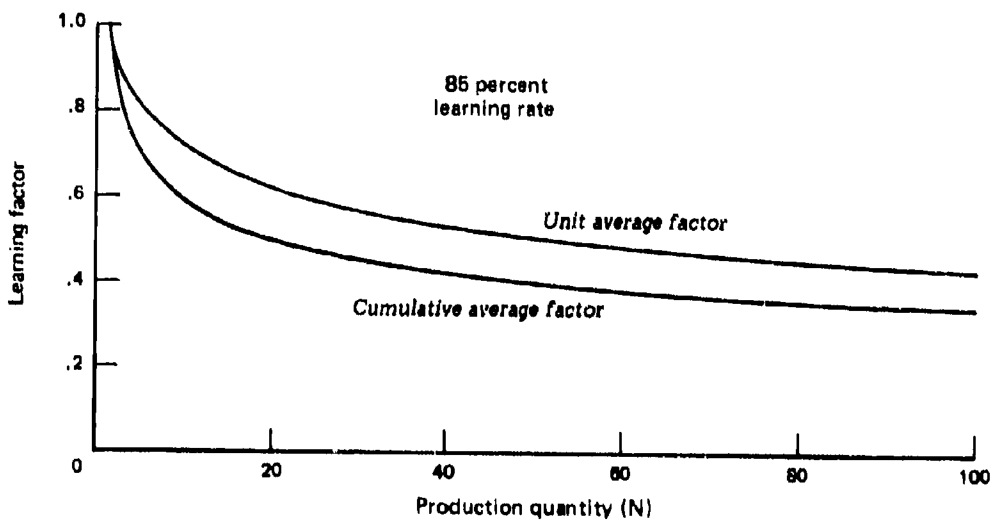

FIG. 108: COMPARISON OF LEARNING FACTORS

A learning rate λ of 85 percent is selected for estimating the influence of learning on the production cost of future airships:

$$\lambda = 85, \text{ unit average learning.} \tag{333}$$

Unit average cost factors for learning rates of 83 to 90 percent are also needed. These cost factors are listed in table 37. Inspection of table 37 shows that the definition of learning rate is such that a larger learning rate means less learning and larger learning cost factors. For a 100 percent learning rate there would be no learning at all.

TABLE 37

UNIT-AVERAGE PRODUCTION COST LEARNING FACTORS

Quantity	Factor			Quantity	Factor		
	Learning rate (%)				Learning rate (%)		
	83	85	90		83	85	90
1	1.000	1.000	1.000	20	.580	.620	.730
2	.915	.925	.950	25	.550	.592	.709
3	.858	.874	.915	30	.527	.570	.691
4	.816	.836	.889	35	.507	.551	.676
5	.782	.806	.868	40	.491	.536	.664
6	.755	.781	.850	(42)	.485	.530	.659
7	.732	.760	.835	60	.444	.490	.626
8	.712	.742	.822	80	.412	.460	.601
9	.694	.726	.810	(85)	.406	.454	.595
10	.679	.712	.799	100	.390	.438	.581
11	.665	.699	.790	120	.372	.420	.566
12	.652	.687	.781	140	.357	.406	.553
13	.640	.676	.773	160	.345	.393	.542
14	.630	.667	.766	180	.335	.383	.533
15	.620	.657	.759	200	.325	.374	.525
16	.611	.649	.752	250	.307	.355	.508
17	.602	.641	.746	300	.293	.341	.494
18	.595	.634	.741	350	.281	.329	.483
19	.587	.627	.735	400	.271	.319	.473

There are several ways in which the learning factors can be used. In particular, there is the question of how one or several preproduction items should be treated. If protytypes are markedly different from past items it may be desirable to treat the prototypes independently, as uniquely different from production items. However, it appears that the past airship protytype items were not markedly different. For such cases, it is convenient to consider a single preproduction prototype as the first production item (N=1), with an additional prototype production-cost increment (and associated research and development and/or engineering cost). This second approach is used in this investigation.

PRODUCTION COST FOR AIRSHIPS

Data on prototype and production costs for blimps are shown in table 38. The data for the 3 prototypes indicate a specific cost (dollars per pound) of about 90 in 1952 to 1955.

The production quantity shown does not include the prototype. In the case of the ZPG-2, the prototype (which was designated the ZPG-1) was significantly smaller in volume and empty weight than the production model. The production specific cost (per pound of empty weight) increased from 17 to 73 in then-year dollars from 1942 to 1960.

The data include learning rates defined only as "was derived on the basis of the prototype cost, the average production cost per unit, and the number of units produced." However, if the indicated learning rate for the ZPG-2 was for the cumulative average approach, the unit-one specific cost would be 28 percent greater than the prototype specific cost. It is therefore assumed that the indicated learning rates are based on a unit average. A learning rate of 85 percent was estimated for three cases in table 38 for which learning rate data were not available.

On this basis, learning factors were estimated for all 6 cases. For the first 2 cases, which were production lots of World War II K-ship blimps, it was assumed that there were sufficient changes in production techniques and/or production personnel that the learning factor from unit one (table 37) could be applied separately. That is, it was assumed that learning did not continue smoothly from the first production lot of 42 into the second production lot of 85. This appears to be reasonable because the resultant unit-one specific cost obtained is close to $33 per pound in both cases. The alternative assumption of a continuous run (at 85 percent learning) leads to a much greater unit-one specific cost for the second case.

For the third through fifth cases in table 38, the average cost per production unit after the prototype was used to estimate the learning factor relative to unit one. For an after-prototype production of N units, the total production cost is $(N+1)F_{L(N+1)}C_1$,

TABLE 38

BLIMP PROTOTYPE AND PRODUCTION COST DATA

Blimp	K-ship	K-ship	ZSG-4	ZS2G-1	ZPG-2	ZPG-3W
Prototype year			1954	1955	1952	
Volume (million cu.ft.)			.527	.650	.875	1.49
Empty weight (lb.)			24,366	28,203	40,152	67,566
Prod. cost (million $)			1.809	2.689	3.575	
Prod. cost ($/lb.)			74.24	95.34	89.05	
Production years	1942-1943	1943-1944	1954-1955	1955-1958	1953-1957	1959 1960
Quantity	42	85	14	17	15	(4)
Volume (million cu.ft.)	.425	.425	.527	.650	.975	1.490
Empty weight (lb.)	19,200	19,200	24,366	28,203	46,302	67,566
Prod. Cost (million $)			13.641	21.177	42.097	19.728
Prod. Cost ($/lb.	17.28	14.84	39.99	44.17	60.61	72.99
Learning rate (%)	(85)[a]	(85)	85	83	90	(85)
Learning factor	.530	.454	(.632)	(.571)	(.735)	.836
Unit-one ($/lb.)	32.60	32.69	63.28	77.36	82.46	87.31
Average price index	70	72	133	149	139	167
1976 inflation factor	5.41	5.26	2.85	2.54	2.73	2.27
1976 unit-one ($/lb.)	176.37	171.95	180.35	196.49	225.12	198.19
1976 prototype ($/lb.)			211.58	242.16	243.11	

[a] Parentheses indicate estimates.

Source: Goodyear 1975, Vol. III, p. 69, reference 8.

where C_1 is the cost of unit one. Subtracting the cost C_1 of the first vehicle and dividing by the production quantity N gives the average cost C_{AV} as:

$$C_{AV} = \left[\left(1 + \frac{1}{N}\right)F_{L(N+1)} - \frac{1}{N}\right]C_1 \quad . \qquad (334)$$

The estimated learning factors shown in table 38 for these cases is the numerical value of the square bracket in the above equation, using $F_{L(N+1)}$ from table 37.

The last case in table 38 is the ZPG-3W. The data do not separate the prototype vehicle from the production vehicles. It was assumed that prototype-increment cost was not large. The learning factor for a quantity of 4 was obtained from table 37.

The average price index for the years of construction shown in table 38 was obtained by using the price indexes of table 36 for the relevant years. The 1976 inflation factor for conversion of then-year dollars is equal to 379 divided by the average price index. The estimates that result for the 1976 unit-one specific cost vary from $172 to $225 per pound. Applying the inflation factor to the 3 prototype specific costs gives 1976 values of $212 to $243 per pound, as shown in the table.

A 1976 unit-one specific cost c_{P1} for production of blimps of $170 per pound is selected for use in the conceptual model:

$$c_{P1} = 170 \text{ , 1976 blimps.} \qquad (335)$$

For the unit average learning rate of 85 percent and a production quantity of 20, including the production prototype, the average specific cost becomes $105.40 per pound.

Dirigible Production Cost

Data for production cost for dirigibles in the United States are limited. The Macon was delivered to the U.S. Navy in 1933. The contractor's cost was $2,910,501, including some design costs (Goodyear 1975, Vol. III, p. 64, reference 8). The empty weight of the Macon was 236,493 pounds, which gives a specific cost of $12.31 per pound. For a learning rate of 85 percent, unit-two cost would be 85 percent of unit-one cost, or $14.48 per pound for unit one. Using the price indexes of table 36 of 50 for 1932 and 379 for 1976 gives an inflation factor of 7.58. Then the estimated Macon specific cost in 1976 becomes $109.76 per pound.

This is considerably smaller than $170 to $225 per pound specific production costs shown in table 38 for blimps. It may be due to the extensive use of manual labor in the Macon at a time when unemployment was high and labor rates were very low. For this conceptual model it is assumed that the specific production costs for blimps and dirigibles are identical and as selected above for blimps.

R&D, ENGINEERING, AND PROTOTYPE COSTS

Vehicle engineering development R&D or engineering development associated with a preproduction prototype is usually funded in connection with vehicle development. There is not a clear line between engineering development R&D and engineering; they are considered together here under the engineering heading. This usage of engineering includes technical design, engineering research, engineering development, component testing, and flight testing.

Prototype is used here for preproduction prototypes only. The prototype is the first of an intended production quantity -- the first expression of the engineering design in hardware. The prototype production operation usually involves more ad hoc hand-work and less production-facilitating equipment (that probably would need to be changed later). The cost for the prototype is usually greater than for the later production vehicles due to the lack of production equipment, the requirement for changes and improvements before proceeding to production, and more or less extensive testing of components, flight performance and characteristics.

An experimental prototype, or advanced development vehicle, is a vehicle intended for testing various engineering materials, components, propulsion plants, configurations, and so forth. There is no intent that an experimental prototype will proceed into production, though some concepts tested in an experimental prototype may be found to be desirable and used in later (preproduction) prototypes. Experimental prototypes of airships may be desirable, but they are not considered further in this investigation because the cost of an experimental prototype may be considerably greater than that of a (preproduction) prototype.

Data on engineering and prototype costs for blimps are shown in figure 109 (Goodyear, Vorachek, p. 14, reference 9). The reference states that costs are based on a limited production quantity, the engineering costs include design, static testing, flight testing, and technical data for a prototype vehicle, and that historically increasing specification compliance, testing, and documentation requirements may increase the costs. The production cost curve includes tooling fabrication, engineering services, and acceptance testing, but does not include electronics, engines, or payload costs. The curves indicate that engineering cost and prototype cost are each about twice the small-lot average production cost.

Additional data on engineering labor hours for blimps from Goodyear 1975 (Vol. III, p. 73, reference 8) are shown in table 39. The engineering hours data are for the entire program. An engineering specific hours of 20 is selected. In 1976 dollars, engineering direct labor is about $10 per hour, giving an engineering specific cost c_{ENG} of $200 per pound:

$$c_{ENG} = 200 \text{ , 1976 dollars.} \qquad (336)$$

This is about twice the previously selected average production specific cost of $105 per pound for a production quantity of 20, and thus consistent with the relative levels of engineering and production costs indicated by figure 109.

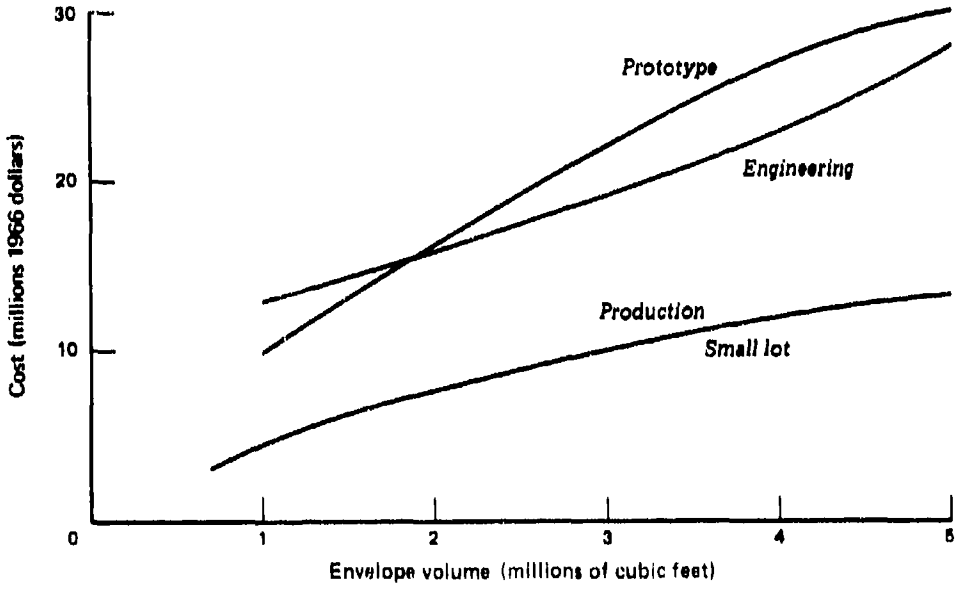

FIG. 109: COST ESTIMATES FOR BLIMPS

The data in figure 109 indicate a prototype production cost of about twice the average "small" lot production cost. For a learning rate of 85 percent and a production quantity of 10, the learning factor is 0.712, for which the prototype production ratio would be 2x0.712 = 1.424 relative to unit one; that is, the prototype production cost increment would be about 40 percent of the unit-one cost. For comparison, the 1976 prototype specific cost of $240 per pound estimated in table 38 for 2 of the 3 data cases is 141 percent of the selected unit-one specific cost of $170 per pound. The two approaches lead to consistent results.

TABLE 39

ENGINEERING HOURS DATA

Program	ZSG-4	ZS2G-1	ZPG-2	ZPG-3W
Volume (million cu.ft.)	.527	.650	.975	1.49
Empty weight (lb.)	24,366	28,203	46,302	67,566
Total quantity	15	18	16	4
Years	1954-5	1955-8	1953-7	1959-60
Design hours	317,322	409,664	315,033	616,721
Stress and weight analysis	66,990	109,686	88,896	84,428
Static test hours	16,542	55,223	78,999	141,695
Flight test hours	30,443	90,954	94,609	131,773
Production coordination	159,017	162,428	163,520	212,916
Total engineering hours	740,431	970,787	843,738	1,559,855
Engineering hours/lb.	30.4	34.4	18.2	23.1

Source: Goodyear 1975, Vol. III, p. 73 (reference 8).

Therefore, a 1976 prototype production specific cost c_{PIN} increment of \$70 per pound is selected.

$$c_{PIN} = 70 \text{ , 1976 dollars.} \qquad (337)$$

The cost data curves of figure 109 indicate a decreasing specific cost for increasing blimp envelope volumes. None of the other data obtained indicates any decrease of specific cost with increasing blimp volume; therefore, such decrease is not considered further in this investigation.

The cost of the initial shipfill of lift gas can be considered explicitly. Costs for hydrogen and helium are given in table 5 of chapter 3. For a gas volume ∇_G and 1976 dollars the lift gas cost C_{63} is:

$$C_{63} = 0.0047\nabla_G \quad \text{for hydrogen.}$$
$$C_{63} = 0.0547\nabla_G \quad \text{for helium.} \tag{338}$$

The initial lift gas cost is about 2 percent of the unit-one production cost. It is convenient to apply the production-quantity learning to the lift gas cost as well as to production cost.

LEVELS OF ENGINEERING, PROTOTYPE, AND PRODUCTION COSTS

To illustrate the results of the preceding analysis quantitatively, the magnitudes of the engineering, prototype increments, and unit-one production costs in 1976 dollars for four sizes of airships are shown in table 40. The data for volumes and empty weights are for historical airships.

The engineering cost was estimated as $200 per pound and unit one as $170 per pound.

For a quantity of one, the cost is the sum of the engineering, prototype increment, and unit-one cost. The costs for a quantity of one in table 40 are quite large because the engineering cost and prototype increment cost contributions are about 1.6 times the unit-one cost. This produces a total that is 2.6 times the unit-one cost.

The lower lines in table 40 show the average cost for total quantities of 10, 20, 40, and 100 blimps. As the quantity increases, production learning lowers the average production cost. The engineering and prototype increment cost is spread over the larger number of vehicles. For a quantity of 10, the average cost decreases by 66 percent from the cost for a quantity of one. Additional average cost reductions of about 20 percent occur when the quantity is increased from 10 to 20, 20 to 40, and 40 to 100.

TABLE 40

1976 INVESTMENT COST LEVELS FOR AIRSHIPS[a]
($ millions)

Airship type	Mayflower III	ZPG-2	ZPG-3W	Macon
Volume (million cu.ft.)	.200	.975	1.49	7.4
Empty weight (lb.)	6,400	38,006	56,582	236,493
Engineering cost	1.28	7.60	11.32	47.30
Prototype increment	.45	2.66	3.96	16.55
Unit-one cost	1.09	6.46	9.62	40.20
Cost for 1[b]	2.82	16.72	24.90	104.06
Average cost for 10[c]	.95	5.63	8.38	35.01
Average cost for 20[c]	.76	4.52	6.73	28.12
Average cost for 40[c]	.63	3.72	5.54	23.16
Average cost for 100[c]	.49	2.93	4.37	18.25

[a] Does not include initial lift gas cost.

[b] Sum of engineering, prototype increment, and unit one.

[c] Average includes engineering, prototype increment, and learning factor for 85 percent learning rate.

8. CONCEPTUAL AIRSHIP MODEL COMPUTER PROGRAM

This chapter presents the calculation procedure and computer program for the conceptual airship model. Because many calculations are required, using a computer facilitates these calculations. A computer program to handle the data is presented in appendix B.

The calculation approach consists of an iteration for technical design and a cost estimate for the design obtained. Figure 110 shows steps of the calculation procedure. Many of the boxes represent subroutines in a computer program.

The first step is to specify the problem, i.e., the design speed and range, ship type, and hull characteristics and construction materials, the power plant characteristics, the accommodations desired, and cost parameters.

An initial estimate for the total weight is then made, and the calculation proceeds as follows:

1. Estimate total weight by iteration.
   a. Calculate the airship dimensions.
   b. Calculate the propulsion power required.
   c. Calculate the fuel weight for the design mission.
   d. Calculate the component weights and sum with payload weight to obtain a recalculated total weight.
   e. Repeat (a) through (d) if recalculated total weight is significantly different from the estimate.
2. Calculate the investment cost.

The initial total weight estimate is made by the method presented in chapter 6. The dimensions are calculated by using the equations presented in chapter 3. The estimate of the propulsion power uses sustained speed. The required power is calculated by the method presented in chapters 4 and 5 in this volume. This is selected as the actual power unless the power plant size has been specified. Fuel weight is estimated as described in chapter 5.

It is now possible to calculate the revised total weight. For this purpose the equations selected in chapter 6 are used.

Next, the accuracy of the estimated total weight relative to the revised total weight can be calculated and tested against a specified desired percentage accuracy. If the desired accuracy has not been obtained the "No" arrow from the "Accurate?" box in figure 110 is followed. The estimated total weight is replaced by a revised total weight and the total weight calculation is repeated. The revised total weight is calculated using the numerical approximation to the Newton-Raphson method, as discussed at the end of chapter 6.

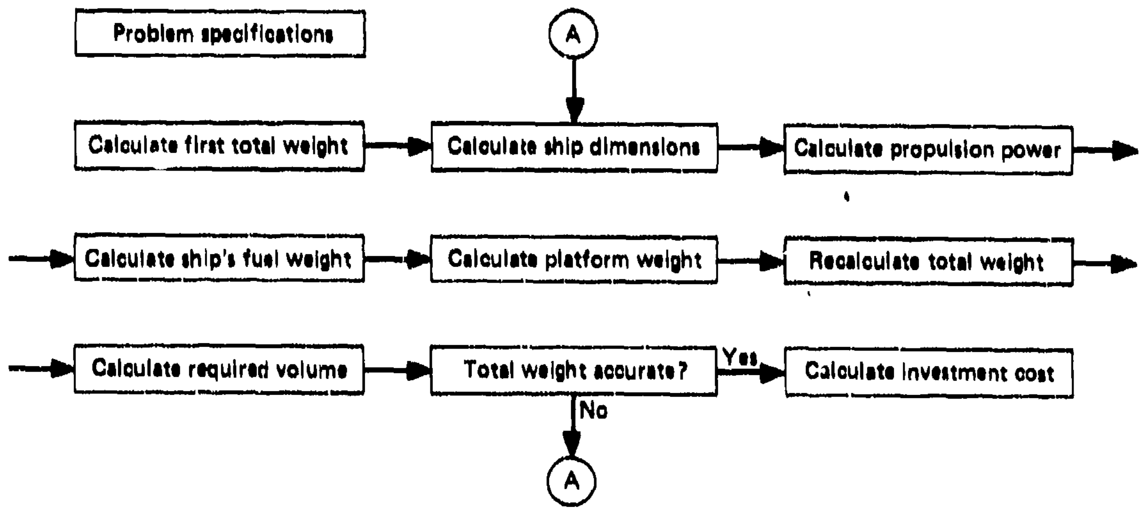

FIG. 110: THE CALCULATION PROCEDURE

The required volume for each component is calculated by using the estimation equations presented in chapter 6. The required volumes are summed, including the volume needed for payload. Finally, the investment cost for the ship can be calculated.

PROBLEM SPECIFICATIONS

The problem specifications are numbered for computer use. Blocks of the first 99 specifications are used to define the performance, geometry accommodations, power plant, specifications of costs, and calculation control.

The principal technical specifications are listed by number in table 41. The sustained speed is the speed at maximum continuous power. Endurance speed is the speed at which the specified endurance range is to be attained at the endurance altitude. Endurance speed is automatically reduced to be not greater than the sustained speed, if necessary.

TABLE 41

AIRSHIP MODEL TECHNICAL SPECIFICATIONS

1. Sustained speed (kt.)
2. Endurance speed (kt.)
3. Endurance range (mi.)
4. Endurance altitude (ft.)
5. Number officers
6. Number CPOs
7. Number enlisted
8. Ship duration (days)
9. Number passengers
10. Passenger duration (days)
11. Envelope length/diameter
12.
13. Envelope prismatic coeff.
14.
15.
16. Gas altitude margin (ft.)
17. Blimp ballonet altitude (ft.)
18. Lift gas purity (%)
19.
20. Design gust speed (f.p.s.)
21. Takeoff speed (kt.)
22. Takeoff angle of attack (deg.)
23.
24. Surface roughness (mils)
25. Cruise power ratio
26. Design construct.margin (%)
27. Special payload weight (klb.)
28. Special deck area (sq.ft.)
29.
30.
31. Electric power (kw.)
32.
33.
34. Size of main engines (h.p.)
35. Number of main engines
36.
37.
38.
39.
40.
41. Pages of technical print
42. Pages of cost print
43. Weight iteration tolerance (%)
44. Limit weight iterations
45.
46.
47.
48.
49.
50. Number of first ship

The crew can be specified separately in terms of officers, CPOs, and enlisted. However, the model does not treat them differently. The ship duration in days is used to select the accommodations required for the crew.

The number of passengers and passenger duration are used for estimating personnel and accommodations weights and volumes.

The envelope geometry is specified by its length-diameter ratio and prismatic coefficient.

Using a gas altitude margin also makes possible operation with decreased probability of loss of lift gas by automatic pressure relief valving of gas.

The blimp ballonet maximum altitude determines the relative size and weight of ballonets in blimps. It is usually specified as 10,000 feet.

Lift gas purity for design is conventionally specified as 94 percent. The design gust speed for structural design is 35 feet per second. This specification for airships in the 1920s and 1930s was much less than 35 feet per second (chapter 4).

The specification of takeoff speed is used with a special logic. If specified takeoff speed is zero, landing gear is not provided. When the takeoff speed specification is between zero and unity, the takeoff speed used in the calculation is the specified fraction of the sustained speed. If the takeoff speed specification is greater than unity, it is used as the takeoff speed.

The takeoff angle of attack specification also has a special logic. If the specification is zero (and the calculated takeoff speed is not zero), the maximum angle of attack attainable with the minimum length landing gear for envelope, car, and blimp propeller ground clearance is used. Otherwise, the specified takeoff angle of attack is used, and the landing gear length is increased if necessary.

The surface roughness specification is used to estimate friction drag. A value of 5 mils appears to be appropriate.

The cruise power ratio is the ratio of the endurance cruise engine power rating to the maximum continuous power rating. A value of 0.8 is usually used.

The design and construction margin is used to calculate a fractional increase of empty weight to account for design uncertainties. Conventions for its value were not obtained. It should be increased when new materials, design methods, or construction techniques are considered.

Special payload weight is to be used to specify equipment payload as one item. It is to be given in thousands of pounds.

Special payload deck area is used to estimate the volume required by the special payload. If special payload deck area is specified as zero, a typical payload area of 30 square feet per 1,000 pounds is automatically estimated. Otherwise, the specified special deck area is used directly.

The electric power specification is to be used for payload electric power requirements. Ship's service and operation electric power weight and volume are estimated independently.

When the specifications for size of main engines and number of main engines are both zero, 1 conceptual (rubber) engine of exactly the size required is provided. If the size of main engines is specified (equal, say, to that of an available engine), then the minimum number of engines that will provide at least the required power is provided.

If the size specification is zero and a nonzero specification of number of main engines is made, then that number of conceptual engines of exactly the size required is provided.

For blimps, the number of main engines should always be specified as 2.

When both the size and number of main engines are specified as nonzero, than a fixed power plant is used. The actual resulting sustained and endurance speeds available with the fixed power are calculated.

Specifications 41 through 44 are for calculation control. The amount of detail for technical and cost results that is printed by a computer can be specififed. The weight iteration accuracy is usually specified as 1 percent, with a limit of 9 weight iterations.

Computer calculations provide sequential numbering of the problems, starting with 1. If the first problem is desired to be other than number 1, specification 50 can be used.

Cost And Type Specifications

The cost and type specifications are listed by number in table 42. This group of specifications also includes specifications for automatically changing 1 specification, and for calculating off-design performance.

TABLE 42

AIRSHIP MODEL COST AND TYPE SPECIFICATIONS

51.	Year for dollar costs	76.	Ship type
52.	Production quantity	77.	
53.	Material inflation rate (percent)	78.	Main engine type
54.	Labor inflation rate (percent)	79.	
55.	Labor rate ($/hour)	80.	Propeller type
56.	D.E. labor rate ($/hour)	81.	Lift gas type
57.	Overhead rate (percent)	82.	
58.	D.E. overhead rate (percent)	83.	
59.	Profit rate (percent)	84.	
60.		85.	
61.		86.	Envelope material type
62.		87.	
63.		88.	
64.		89.	
65.		90.	
66.		91.	Off-design speed cases
67.		92.	First off-design speed
68.		93.	Increment off-design speed
69.		94.	Off-design altitude cases
70.		95.	First off-design altitude
71.	Number of cases	96.	Increment off-design altitude
72.	Variable for cases	97.	
73.	First variable value	98.	
74.	Variable increment	99.	
75.			

Specifications 51 through 59 are concerned with the investment cost calculation. The calculated costs are in dollars for the year specified. The production quantity is used for calculating the cumulative average learning factor. The material inflation rate and labor inflation rate are specified relative to 1976 as the reference year.

An automatic sequence of cases can be obtained by using specifications 71 through 74. If the number of cases is specified as 2 or greater, that number of cases will be calculated. The variable for the cases is to be given as the integer number of a specification or one of the coefficients defined below. The first value of the variable is its value for the first case. The sequence of values of the variable is then obtained by repeatedly adding the specified increment.

Several selections of types, defined by using integers, are provided in the specifications 76 through 86. The definitions of the integers are shown in table 43. Engine types and propellers are discussed in chapter 5. Lift gases are discussed at the beginning of chapter 3. Blimp envelope materials are discussed in chapter 6.

The off-design calculation specifications are used in the same manner as the automatic sequence specifications. The sequence of speeds is considered for each of the sequences of altitudes. Either of the sequences may consist of just one calculation.

Coefficients

The technical and cost estimating equations used in the conceptual airship contain many constants. It is desirable to be able to change these constants for sensitivity investigations and possible alternative concepts. Therefore, these constants can be specified. A standard set selected in the conceptual model investigation will normally be used.

The coefficients are used in the computer program as a 1-dimensional C array. However, they are specified for the computer program as a continuation of the 1-dimensional S array of the specifications discussed above. The equivalence if C(1) = S(301).

Because of the rapid development rate of the airship conceptual model, a formal definition list of coefficients has not been developed. Most of the constants are now built in and cannot be changed by using the specification array.

Calculation Results

The calculation results are obtained as computer printout. For each problem and case the specifications are printed in the form shown in figure 111. The first 75 specifications are printed at the top, in columns of 25 specifications. The abbreviated names match the definitions given in tables 41 and 42. The section in the middle of the right column refers to U.S. Navy end cost increment specifications that are not relevant for general use.

TABLE 43

NUMERICAL DEFINITION OF TYPES

Ship type

2. Blimp
3. Dirigible

Lift gas type

1. Helium
2. Hydrogen

Blimp envelope material

1. Cotton/rubber
2.
3. 3-ply rubber
4. Neoprene/Dacron
5.
6.
7. Biaxial Dacron (film)
8. Triaxial Dacron (film)
9. Biaxial Kevlar (film)
10. Triaxial Kevlar (film)

Main engine type

1. Diesel
2. Reciprocating
3. Turboprop

Propeller type

1.
2.
3.
4.

SHIP NUMBER 4 CASE NUMBER 1

SHIP SPECIFICATIONS

SUS SPD	80.00	DCMRGPCT	0.00	YEARCOST	1976.00
END SPD	80.00	SPCL PAY	3.50	NUM PROD	20.00
END RNGE	1000.00	SPCLDEKA	105.00	MAT FLAT	15.30
CRS ALT	4000.00	SPCL CG	0.00	LAB FLAT	0.00
OFFACCOM	1.00	FIX DIS	0.00	LAB RATE	6.34
CPOACCOM	2.00	ELECT KW	0.00	DE LABOR	8.95
ENLACCOM	5.00	SZ MNBLR	0.00	OVRHEAD	96.00
SHIPDAYS	0.50	NUMMNBLR	0.00	DEOVRHED	96.00
PASACCOM	0.00	SZ MNENG	0.00	PROFIT	10.00
PASSDAYS	0.00	NUMMNENG	2.00		0.00
L/D	5.00	SZ ALTNG	0.00	PLANS F	0.00
CONSTDIA	0.00	NUMALTNG	0.00	DEVEL L	0.00
PRISCOEF	0.65		0.00	DEVEL F	0.00
	0.00		0.00	STOKSP L	0.00
	0.00		0.00	STOKSP F	0.00
GASALTIN	0.00	PRT TPGS	1.00	TST IN L	0.00
BLMPHXZ	10000.00	PRT CPGS	0.00	TST IN F	0.00
GAS PURE	94.00	WTOL PCT	1.00	FUTURE L	0.00
GUST FPS	35.00	MX W ITS	9.00	FUTURE F	0.00
TOSPDKTS	0.60	VOL TOL	1.00		0.00
TO ALPHA	0.00	MX V ITS	2.00	MX CASES	3.00
RUFNSMIL	5.00		10.00	VARIABLE	3.00
DELTCF	0.00		10.00	FIRST	1000.00
	0.00		0.00	CHANGE	1000.00
CRS PRAT	0.80		0.00		0.00

SHIPTYPE BLIMP	LIFT GAS HELIUM	HULL MAT TRIKEVLR
MAINBOIL NONE	LANDGEAR RETRCTBL	
MAIN ENG TURBPROP	ALT ENG NONE	
MAINTRAN NONE	ALT TRAN NONE	
MAINPROP 4BLDPROP	ALT PROP NONE	TAILTYPE X-FORM

FIG. 111: ILLUSTRATION OF SHIP SPECIFICATIONS RESULTS

The type specifications 75 to 90 are converted to abbreviations for the name, and printed across the bottom of figure 111.

A summary of results is printed for each problem and case. An example is shown in figure 112. The upper half of the figure shows the general performance, geometry, weight, and cost results. The end cost increment results in the center of the page are relevant only for U.S. Navy airships. The iteration history shown at the bottom of the figure is useful to the analyst doing the calculations.

The abbreviated symbols used in the summary of results are defined in tables 44, 45, and 46.

An example of the calculated results of off-design performance is shown in figure 113. For information purposes, the speeds at each altitude are permitted to increase until the takeoff power is used, even though engine takeoff power can be used for only 5 to 30 minutes.

A summary of component results is shown in figure 114. The weight, volume, and total basic construction costs for each of the conceptual weight components and groups are provided. The contribution of each component and group as a percent of the total is included.

Additional detailed results on investment costs are available. They are of limited interest for the conceptual airship model because detailed cost estimating methods were not obtained for airships.

SHIP NUMBER 4 CASE NUMBER 1

SUMMARY OF RESULTS

MAX SPD	87.04	EMTY WT	10.17	YR COSTS	1976.00
MXSPDRNG	870.41	DCMARGIN	0.00	NO.PROD	20.00
ACT SSPD	87.04	SL USELD	10.67	ENDCOSTP	1.79
SUSPDRNG	870.41	STATLIFT	20.85	ENDFRSTF	1.79
ACT ESPD	80.00	TOTAL WT	25.73	ENDCOSTF	1.11
ENDRANGE	1000.00	DYN LOAD	4.99	ENDCOSTA	1.15
REQ SPOW	884.28	PAYLD WT	3.50		0.00
ACT SPOW	1061.69	SLUSE/ST	51.21	ENVOLKF3	336.01
REQ EPOW	'849.35	SHIPCREW	8.00	GSVOLPCT	100.00
ACT EPOW	849.35	NUM PASS	0.00	CRVOLKF3	2.05
	0.00		0.00	USVOLKF3	2.05
HULLNGTH	254.35		0.00		0.00
HULLDIAM	50.87	NACLDIAM	1.88	GALS/HR	73.11
CARLENTH	50.87	GERLENTH	7.02	ALPHADEG	2.34
CARWIDTH	5.04	TO ALPHA	7.68	STAT L/D	8.18
TOGRNRUN	0.00	FABLB/IN	87.92	LIFT/DRG	9.34
CHNG HCF	5.43	DYNRATIO	0.24	NEWTPRIM	-0.30
CHNG TCF	9.53	TALCOPCT	34.16	STRCOPCT	3.23
SSPDCD04	41.85	CAFCOPCT	6.61	NACCOPCT	0.66
PROP ETA	0.75	ENGCOPCT	3.89	NACINPCT	0.30

END COST INCREMENTS

	PROTO K$	FOLLOW K$		PROTO K$	FOLLOW K$
CONST PLANS	0	0	STOK SPARES	0	0
CHANGE ORDERS	0	0	DEVELOPMENT	0	0
SHP SYS ENG	0	0	LECTRN GROWTH	0	0
ESCALATION	0	0	ORDNCE GROWTH	0	0
TEST+INSTRUM	0	0	TOT INCREMENT	0	0
FUT CHAR CHG	0	0	END COST	1793	1112

ITERATION HISTORY

VOL IT	WT ITS	TOTWT KLBS	CALWT KLBS	VOLRAT PCT
1	6	25.7	25.7	

FIG. 112: SUMMARY OF RESULTS

TABLE 44

NAMES USED IN SUMMARY OF RESULTS
(Left-hand column)

MAX SPD	Ignore
MXSPDRNG	Ignore
ACT SSPD	Ignore
SUSPDRNG	Ignore
ACT ESPD	Differs from specified Endurance Speed if engines are specified.
ENDRANGE	Same as specified, to iteration accuracy.
REG SPOW	Sustained power required for specified sustained speed.
ACT SPOW	Includes cruise power ratio.
REQ EPOW	Endurance power required for specified endurance speed.
ACT EPOW	Differs from Required if engines are specified.
HULLNGTH	Envelope overall length (ft.).
HULLDIAM	Envelope maximum diameter (ft.).
CARLENTH	Car longitudinal length (ft.).
CARWIDTH	Car lateral width (ft.).
CHNG HCF	Roughness hull incremental friction coefficient x 10^4.
CHNG TCF	Roughness tail incremental friction coefficient x 10^4.
SSPDCD04	Total sustained speed drag coefficient x 10^4.
PROP ETA	Ignore

TABLE 45

NAMES USED IN SUMMARY OF RESULTS
(Center column)

EMTY WT	Empty weight, less ballast, people, stores, payload margin, fuel, gases (klb.).
DCMARGIN	Design, Construction margin weight (klb.).
SL USELD	Sea level reference useful load (klb.).
STATLIFT	Sea level reference static (buoyancy) lift (klb.).
TOTAL WT	Sea level envelope displacement (klb.).
DYN LOAD	Aerodynamic lift load (klb.).
PAYLD WT	Payload installed, enclosed, wired, weight (klb.).
SLUSE/ST	Ratio sea level useful load to static lift.
SHIPCREW	Total number of crew personnel.
NUM PASS	Number of passengers.
HULLWETA	Ignore
NACLFRTA	Ignore
NACL LEN	Ignore
STAT L/W	Ratio static lift to static lifting weight.
L/WRATIO	Ratio dynamic L/W to static L/W.
TALCDPCT	Tail drag coefficient as percent of hull.
CARCDPCT	Car drag coefficient as percent of hull.
ENGCDPCT	Nacelle, Internal, Outrigger CD as percent of hull.

TABLE 46

NAMES USED IN SUMMARY OF RESULTS
(Right-hand column)

YR COSTS	Year of dollars for investment costs.
No. PROD	Production quantity for learning.
ENDCOSTP	End overall cost for prototype M$.
ENDFRSTF	First follow ship cost M$
ENDCOSTF	Average follow ship cost for quantity M$.
ENDCOSTA	Average cost, total quantity M$.
ENVOLKF3	Envelope volume thousands, cubic feet.
GSVOLPCT	Gas volume, percent of envelope volume.
CRVOLKF3	Car volume, thousands cubic feet.
USVOLKF3	Ignore
GALS/HR	Gallons fuel at endurance speed per hour
ALPHADEG	Trimmed dynamic lift angle of attack deg
STAT LD	Ratio static lift to static drag.
LD RATIO	Ratio dynamic L/D to static L/D.
NEWTPRIM	Derivative of iteration Newton's function.
STRCDPCT	Nacelle Strut drag coefficient, percent of hull.
NACCDPCT	Nacelle drag coefficient, percent of hull.
NACINPCT	Nacelle Internal drag coefficient, percent of hull.

SHIP NUMBER 4 CASE NUMBER 1

OFF-DESIGN SPEED AND RANGE

ALT CASE	SPED CASE	ALT KFT	SPEED KNOTS	RANGE NMILE	ENDUR HOURS	PPOWR HP	GALS/ HOUR	USELOD KLBS
1	1	0.0	30	1586	52.9	265	24.7	10.7
1	2	0.0	40	2061	51.5	272	25.3	10.7
1	3	0.0	50	1979	39.6	354	32.9	10.7
1	4	0.0	60	1708	28.5	492	45.8	10.7
1	5	0.0	70	1422	20.3	689	64.2	10.7
1	6	0.0	80	1171	14.6	956	89.1	10.7
1	7	0.0	87	1098	13.2	1062	98.9	10.7
2	1	1.0	30	1532	51.1	257	23.9	10.1
2	2	1.0	40	1989	49.7	264	24.6	10.1
2	3	1.0	50	1910	38.2	343	32.0	10.1
2	4	1.0	60	1649	27.5	476	44.5	10.1
2	5	1.0	70	1373	19.5	669	62.3	10.1
2	6	1.0	80	1130	14.1	929	86.5	10.1
2	7	1.0	87	1041	12.4	1062	98.9	10.1
3	1	2.0	30	1479	49.2	250	23.2	9.5
3	2	2.0	40	1916	47.9	256	23.9	9.5
3	3	2.0	50	1840	36.8	333	31.1	9.5
3	4	2.0	60	1588	26.5	464	43.2	9.5
3	5	2.0	70	1322	18.9	650	60.5	9.5
3	6	2.0	80	1069	13.6	902	84.0	9.5
3	7	2.0	87	984	11.6	1062	98.9	9.5
4	1	3.0	30	1416	47.2	242	22.6	8.9
4	2	3.0	40	1839	46.0	249	23.2	8.9
4	3	3.0	50	1766	35.3	324	30.1	8.9
4	4	3.0	60	1524	25.4	450	41.9	8.9
4	5	3.0	70	1269	18.1	631	58.7	8.9
4	6	3.0	80	1045	13.1	875	81.5	8.9
4	7	3.0	87	927	10.8	1062	98.9	8.9
5	1	4.0	30	1355	45.2	235	21.9	8.3
5	2	4.0	40	1760	44.0	241	22.5	8.3
5	3	4.0	50	1690	33.3	314	29.3	8.3
5	4	4.0	60	1459	24.3	437	40.7	8.3
5	5	4.0	70	1215	17.4	612	57.0	8.3
5	6	4.0	80	1000	12.5	849	79.1	8.3
5	7	4.0	87	870	10.0	1062	98.9	8.3

FIG. 113: OFF-DESIGN PERFORMANCE

SHIP NUMBER 4 CASE NUMBER 1

DETAILED RESULTS

COMP	NAME	WEIGHT KLBS	WEIGHT PCT	VOLUME KFT3	VOLUME PCT	CTBAS K$	CTBAS PCT	MOMENT KFTTON
11	BASCSTRC	3.4	13.1	0.0	0.0	543	30.3	
12	SECSTRUC	0.4	1.4	0.0	0.0	58	3.2	
13	TAILSTRC	1.1	4.2	0.0	0.0	175	9.8	
14	GASYSTEM	0.0	0.0	0.0	0.0	0	0.0	
10	STRUCTUR	4.8	18.7	0.0	0.0	777	43.3	
21	MNPPLNT	1.9	7.3	0.0	0.0	302	16.9	
22	ALTPPLNT	0.0	0.0	0.0	0.0	0	0.0	
23	PROPULSR	0.5	2.0	0.0	0.0	82	4.6	
24	LECTPLNT	0.0	0.0	0.0	0.0	0	0.0	
20	PROPULSN	2.4	9.3	0.0	0.0	385	21.4	
31	STEERTRM	0.3	1.0	0.0	0.0	43	2.4	
32	NAV,COMM	0.1	0.2	0.1	0.0	10	0.6	
33	SHPFACIL	0.6	2.2	0.0	0.0	91	5.1	
34	BALLAST	1.0	3.7	0.0	0.0	154	8.6	
30	CONTROLS	1.8	7.2	0.1	0.0	299	16.7	
41	PERS,EFF	1.6	6.4	0.0	0.0	0	0.0	
42	PERSENCL	1.6	6.1	1.0	0.3	255	14.2	
43	PERSFACL	0.3	1.2	0.0	0.0	52	2.9	
44	PERSTORS	0.1	0.4	0.0	0.0	0	0.0	
40	ACCOMMS	3.6	14.2	1.0	0.3	307	17.1	
51	LECTRONS	0.0	0.0	0.0	0.0	0	0.0	
52	WEAPONS	0.0	0.0	0.0	0.0	0	0.0	
53	CARGO	0.0	0.0	0.0	0.0	0	0.0	
54	SPECIAL	3.5	13.6	0.8	0.2	0	0.0	
50	PAYLOAD	3.5	13.6	0.8	0.2	0	0.0	
61	DCMARGIN	0.0	0.0	0.0	0.0	0	0.0	
62	SHIPFUEL	2.3	9.1	0.1	0.0	0	0.0	
63	LIFT GAS	4.3	16.8	298.4	88.3	27	1.5	
64	AIR	2.9	11.2	37.6	11.1	0	0.0	
60	LOADS	9.5	37.1	336.1	99.4	0	0.0	
	TOTAL	25.7	100.0	338.1	100.0	1793	100.0	

11.29	0.47	0.27	0.11
31.03	2.48	0.91	0.37
26.85	2.10	0.93	0.37
26.13	1.96	0.80	0.35
26.21	1.98	0.90	0.34
26.24	1.99	0.90	0.34

FIG. 114: SUMMARY OF COMPONENT RESULTS

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APPENDIX A

LIST OF SYMBOLS

A_{32}	Deck area for Nav/communications (sq.ft.), equation 322.
A_{42}	Deck area for personnel enclosures (sq.ft.), equation 327.
A_{BB}	Blimp ballonet total area (sq.ft.), equations 251 and 252.
A_{CRF}	Car frontal area (sq.ft.), equations 54 and 55.
A_{EL}	Elevator area (sq.ft.), table 14.
A_F	Average exposed fin area (sq.ft.), equation 44.
A_F	Fin flange area (sq.ft.), equations 257 and 258
A_{CBLF}	Cable frontal area (sq.ft.), equation 89.
A_{FNC}	Nacelle frontal area (sq.ft.), equations 185, 192, 199, 205.
A_{GRF}	Landing gear frontal area (sq.ft.), equation 80

A_{HT} Horizontal tail area (sq.ft.), table 14.

A_{LNG} Dirigible longitudinals cross section area (sq.ft.), before equation 266.

A_{OUTF} Outrigger frontal area (sq.ft.), equations 66, 67, 68, 69.

A_R Drag reference area (sq.ft.), equation 81.

A_T Area of tail, all fins (sq.ft.), equation 46.

A_{TW} Tail wetted area (sq.ft.), equation 47.

A_{WH} Wetted hull area (sq.ft.), equations 2, 39, 43.

A_W Wetted area for friction drag (sq.ft.), equation 83.

Æ Aspect ratio

$Æ_F$ Fin effective aspect ratio, equation 49.

a	Constant in form for C_L equations, equation 100.
a	Parameter for takeoff distance, equation 177.
a_{EM}	Constant for on envelope material weight, equation 242.
a_{LT}	Coefficient for lift of tail (per radian), equation 102.
B	Number of blades per propeller.
b	Constant in form for C_L equations, equation 100.
b	Propeller blade width (feet), equation 161.
b_{EM}	Constant for envelope material weight, equation 242.
b_F	Maximum exposed span of fin (feet), equation 44.
b_{LT}	Coefficient for lift of tail (per sq.radian), equation 102.

C_1 Production cost of first blimp (dollars), equation 334.

C_{63} Cost for initial lift gas (dollars), equation 338.

C_{ABV} Clearance above propeller disk to top of blimp car (feet), equation 60.

C_{AV} Average cost of blimps (dollars), equation 334.

C_{B20} Basic construction cost for 20 blimps (dollars).

C_D Drag coefficient, equation 81.

C_{DO} Zero lift drag coefficient,

C_{DCBL} Cable drag coefficient for blimps, equation 90.

C_{DCR} Car drag coefficient, equation 92.

C_{DF} Friction drag coefficient, equation 83.

C_{DFH} Hull friction drag coefficient, equation 86 and 87.

C_{DFOUT} Outrigger friction drag coefficient, equation 97.

C_{DFT} Tail friction drag coefficient, equation 86 and 88.

C_{DFN} Nacelle friction drag coefficient, equation 86 and 94.

C_{DGR} Landing gear drag coefficient, equation 98.

C_{DH} Hull zero-lift drag coefficient, equation 87.

C_{DL} Lift drag coefficient, referred to $V_E^{2/3}$, equation 99.

C_{DLO} Lift drag coefficient, zero elevator.

$C_{DLØT}$ Tail increment of zero-elevator lift drag coefficient, equations 112.

C_{DLOT1} Tail 1 increment of zero-elevator lift drag coefficient, equation 110.

C_{DLOT2} Tail 2 increment of zero-elevator lift drag coefficient, equation 110.

C_{DLB} Lift drag coefficient for body alone, equations 109 and 112.

C_{DLE} Elevator increment of lift drag coefficient, equations 111 and 112.

C_{DNCE} Nacelle external drag coefficient, equation 94.

C_{DNCI} Nacelle internal drag coefficient, equation 95.

C_{DOUT} Outrigger drag coefficient, equation 96 and 97.

C_{DS} Sustained speed drag coefficient, equation 180.

C_{DT} Tail zero-lift drag coefficient, equation 88.

C_{DTIN} Tail interference drag coefficient, equation 91.

C_{DX} Cross sectional drag coefficient of car, equation 92.

C_{GRD} Ground clearance of propeller (feet), equation 70.

C_L Lift coefficient, referred to $v_E^{2/3}$, equation 99.

C_{L0BT1} Zero-elevator lift coefficient for body plus tail 1, equation 100.

C_{L0BT2} Zero-elevator lift coefficient for body plus tail 2, equation 100.

C_{L0T} Zero-elevator lift coefficient for tail.

C_{L0T1} Zero-elevator lift coefficient for tail 1, equation 101.

C_{L0T2} Zero-elevator lift coefficient for tail 2, equation 101.

C^*_{LOT}, $C^*_{LOT}1$, $C^*_{LOT}2$ Lift coefficients based on horizontal fin area, equation 103.

C_{LA} Average propeller lift coefficient, equation 162.

C_{LB} Lift coefficient for body alone, equations 100 and 108.

C_{LE} Lift coefficient for elevator deflection, equation 107.

C_{LTO} Lift coefficient during takeoff (constant).

$C_{L\alpha}$ Lift coefficient slope, equation 180.

C_M Pitching moment coefficient, equations 113 and 121.

C_{MB} Body moment coefficient, equation 114.

C_{MMG} Maximum gust moment coefficient, equations 144 to 150.

C^*_{MMG} Maximum gust moment coefficient at speed V^*, equation 151.

C_p Prismatic coefficient, equation 37.

C_P Propeller power coefficient, equal $(J/C_{SP})^5$.

C_{PRP} Propeller clearance from car or envelope (feet), equation 60

C_S Hull wetted surface coefficient, equations 39 and 43.

C_{SP} Speed power coefficient, equation 156.

C^*_{SP} Modified speed power coefficient, equation 164.

c Parameter for takeoff distance, equation 177.

c_{ENG} Specific cost for engineering (dollars), equation 336.

c_F Average fin chord (feet), equation 48.

c_{OUT} Outrigger chord (feet), equations 67, 68.

c_{P1} Specific production cost for first airship (dollars) equation 335.

c_{PIN} Prototype production specific cost (dollars), equation 337.

$\mathcal{D}$ Airship aerodynamic drag (pounds), equation 81

D Airship hull maximum diameter (feet), equation 38.

D_0 Zero lift drag of airship (pounds), equation 2.

D_L Lift drag (pounds), equations 6, 99, 129.

D_{NC} Diameter of nacelle (feet), equations 56 and 58.

D_P Diameter of propeller (feet).

D_{POPT} Optimum propeller diameter (feet), equal Vn/J_{OPT}

D_{TB} Diameter of outrigger tubes (feet), equations 66, 67, 69.

d Fuel degradation fraction, equation 224.

d Structural depth (ft.), equations 220, 257.

E_{KW} Average electric load (kilowatts), equation 222.

E^*_{KW} Off-design electric load (kilowatts), equation 232.

F Newton function (lb.), equation 316.

F' Derivative of Newton function, equation 318.

F_2 Last previous value of Newton function (lb.), equation 318.

F_{FIN} Fin factor for takeoff clearance, equation 73.

F_{FIN} Fin load force (lb.) equation 259.

F_{GR} Gear distance factor, gear to fin corner, equation 74.

F_L Force on lower element of outrigger (pounds), equation 214 and 218.

F_{LN} Learning factor for production of NAIRSHIPS, equations 331 and 332.

F_U Force on upper element of outrigger (pounds), equations 214 and 218.

f Fraction of hull length for pitching moment, equation 115.

f Function for takeoff distance, equation 179.

f Constant in equation 266.

f Constant in equation 275.

f_G Maximum gas fraction (of envelope volume), equations 32 and 33.

$f(\xi)$	Similarity function, equation 40.
G_{PH}	Fuel use rate (gallons per hour), equation 233.
g	Gravity acceleration (ft./sec.^{2}), equation 171.
g	Constant in equation 266.
H	Airship heaviness (pound), equation 171.
h	Engine height (feet).
h_{DK}	Car deck height (feet), equation 50.
h_{OVR}	Overhead height for equipment (feet), equation 50.
h_{OVRMX}	Maximum overhead for blimp car (feet), equation 50.
I	Cross-sectional moment of area (ft^4)
J	Summation integer, equation 331 and 332.
J	Propeller advance ratio, equation 157

J_{OPT}	Optimum propeller advance ratio, equation 165.
K	Lift drag parameter, referred to $V_E^{2/3}$, equation 122.
K*	Lift drag parameter, referred to A_{WH}, equation 175.
k_S	Sand roughness height (feet), equation 86.
$\mathcal{L}$	Aerodynamic lift (pounds), equations 99.
L	Airship hull length (feet), equation 36.
L	Engine length (feet).
L_2	Length of second blimp desk (feet), equation 50.
L_A	Aerodynamic lift of airship (pounds), equations 5 and 128.
L_B	Buoyant lift (pounds) equation 1 and continuous beam length, before equation 266.
L_C	Car length (feet), equations 54 and 55.

L_C Reynolds number component length (feet), equation 82.

L_{GRC} Length of car landing gear (feet), equations 71, 72, 77, 78, 79.

L_{GRN} Length of nacelle gear (feet), equations 71, 72, 77.

L_{NC} Length of nacelle (feet), equations 57 and 59.

L_{OUT} Length of dirigible outrigger structure (feet), equation 62.

L_{OUT1} Length of blimp upper outrigger structure (feet), equation 61.

L_{OUT2} Length of blimp lower outrigger structure (feet), equation 61.

L_U Length of upper outrigger structure (feet), equations 219 and 220.

(L/D) Hull envelope length-diameter ratio

$(L/D)_{ENG}$ Engine length-diameter ratio, equations 186, 193, 199, and 205.

$(L/D)_{NC}$ Nacelle length-diameter ratio, equation 57.

M Pitching moment (ft.lb.), equation 113.

M Bending moment (ft.lb.).

M_{BT} Bending moment on tail fin (ft.lb.), equations 257, 260.

M_G Gas bending moment (ft.lb.), before equation 266.

M_{GMX} Maximum gust moment (ft.lb.), equations 144 to 152.

M_S Dirigible longitudinals static moment (ft.lb.), before equation 266.

M_{TPR} Propeller rotational tip Mach number, figure 72.

N Number produced, equations 331 and 332.

N_{ACC} Number of accomodations, equation 305.

N_{BB} Number of blimp ballonets, equations 250, 252.

N_C Number of dirigible gas cells, equation 275.

N_{CRW} Number of crew, equation 305.

N_{ENG} Number of engines installed.

N_{PAS} Number of passengers, equation 305.

n	Propeller rotation rate (revolutions per second).
P^*	Off-design propulsion power (horsepower), equation 232.
P_{CR}	Engine cruiser power (horsepower) equations 188, 195, 201, 207.
P_E	Engine power (horsepower), equation 154.
P_E^*	Engine power (foot-pounds per second), equation 153.
P_{ENG}	Total installed engine power (horsepower), equation 302.
P_{EQ}	Equivalent power of turboprop engine (horsepower), figure 94.
P_G	Fractional purity of left gas, equation 21.
P_{MC}	Engine maximum continuous power rating (horsepower).
P_{SH}	Shaft power(horsepower), figure 94.
P_{TO}	Engine takeoff power rating (horsepower), equations 187, 194, 200, 206.

p	Installed specific weight of engine system (lb./hp.).
p	Atmospheric pressure (lb./sq.ft.), equation 19.
p_B	Base value of p (lb./sq.ft.), equation 20.
R	Maximum radius of airship envelope (feet), equation 40.
R	Range of airship (feet).
R^*	Off-design range of airship (n.mi.), equation 232.
R_{NM}	Range of airship (n.mi.).
R_{BB}	Hemispherical radius of ballonets (feet), equations 250 and 251.
R_N	Reynolds number, equation 82.
R_P	Power ratio, equation 174.
R_{TSO}	Thrust ratio to zero speed thrust, equation 174.

r	Radial coordinate of body of revolution (feet) equation 40.
r	Reserve fuel fraction, equation 228.
r_{CL}	Average radial netting clearance for dirigibles (feet), equations 34 and 36.
s	Structural weight fraction, of L_{BO}, equation 16.
T	Propulsive thrust (lb), equation 153.
T	Temperature of atmosphere (^{O}R), equation 19.
T_B	Base value of temperature (^{O}R), equation 20.
T_S	Sustained (maximum continuous) thrust (pounds), equation 174.
T_{SO}	Sustained thrust at zero airspeed (points), equation 174.
T_{TO}	Takeoff thrust (pounds), equation 173.
T_{TO0}	Takeoff thrust at zero airspeed (pounds), equation 174.

T_W Dirigible main frame wire tension force (lb.), equation 264.

t_E Blimp envelope material thickness (feet), equation 239.

t_{POUT} Pylon outrigger frontal thickness (feet), equation 68

(t_{POUT}/L_{OUT1}) Pylon outrigger thickness to length ratio, equation 68.

$(t/c)_F$ Fin thickness-chord ratio, equation 45.

$(t/c)_{OUT}$ Outrigger thickness-chord ratio, equations 67, 68.

u Unavailable fuel fraction, equation 228.

u_G Gust velocity (ft./sec.), equations, 145 to 152.

u_{GD} Design gust velocity (ft./sec.),

V Airspeed of airship (Sect. per second).

V_1 Required volume for hull group (cu.ft.), equation 319.

V_2 Required volume for power plant group (cu.ft.)

V_{24} Required volume for electric plant (cu.ft.), equation 320.

V_3 Required volume for ship control group (cu.ft.), equation 325.

V_{31} Required volume for steering and trim (cu.ft.), equation 321.

V_{32} Required volume for Nav/communications (cu.ft.), equation 322

V_{33} Required volume for ship facilities (cu. ft.), equation 323.

V_{34} Required volume for ballast system (cu.ft.), equation 324.

V_4 Required volume for accomodations (cu.ft.), equation 329.

V_{41} Required volume for personnel (cu.ft.), equation 326.

V_{42} Required volume for personnel enclosures (cu.ft.), equation 327.

V_{43} Required volume for personnel facilities (cu.ft.), equation 326.

V_{44} Required volume for personnel stores (cu.ft.), equation 328.

V_5 Required volume for payload group (cu.ft.).

V_{54} Required volume for special payload (cu.ft.).

V_6 Required volume for other weights (cu.ft.).

V_{61} Required volume for design margin (cu.ft.).

V_{62} Required volume for ship fuel (cu.ft.), equation 330.

V_{63} Required volume for lift gas (cu.ft.),

V_{64} Required volume for air (cu.ft.),

V^* Gust design speed (ft./sec.), equation 151.

V_{CR} Cruise speed (ft./sec.).

V_D Design speed (ft./sec.), equations 150, 151.

V_G Ground speed during takeoff (ft./sec.), equation 171.

V_K — Air speed of airship (knots).

V_{MX} — Maximum airship speed for gust load (ft./sec.), equations 144 to 152.

V_S — Airship sustained airspeed (ft./sec.).

V_{TO} — Takeoff speed of airship (ft./sec.), equations 172 and 177.

V_{TPR} — Propeller rotational tip speed (ft./sec.), equations 159 and 160.

V_W — Wind speed during takeoff (ft./sec.), equations 172 and 177.

W_1 — Weight for hull group (lb.).

W_{11} — Weight for basic hull (lb.), equations 255 and 269.

W_{12} — Weight for secondary structure (lb.), equations 256 and 273

W_{13} — Weight for tail structure (lb.), equations 258, 262, and 274.

W_{14} — Weight for gas system (lb.), equation 278.

W_2	Weight for power plant group (lb.).
W_{21}	Weight for main power plant (lb.).
W_{22}	Weight for alternate power plant (lb.).
W_{23}	Weight for propulsors (lb.), equation 169.
W_{24}	Weight for electric plant (lb.), equation 222.
W_3	Weight for ship control group (lb.).
W_{31}	Weight for steering and trim (lb.), equations 279 and 292.
W_{32}	Weight for Nav/communications (lb.), equations 280, 295, and 296.
W_{33}	Weight for ship facilities (lb.), equations 285 and 300.
W_{34}	Weight for ballast system (lb.), equations 288 and 304.
W_4	Weight for accomodations (lb.)

W_{41} Weight for personnel and effects (lb.), equation 308.

W_{42} Weight for personnel enclosures (lb.), equation 310.

W_{43} Weight for personnel facilities (lb.), equation 312.

W_{44} Weight for personnel stores (lb.), equation 314.

W_5 Weight for payload group (lb.).

W_{54} Weight for special payload (lb.)

W_6 Weight for other weights (lb.).

W_{61} Weight for design margin (lb.).

W_{62} Weight for ship fuel (lb.), equation 229.

W_{63} Weight for lift gas (lb.).

W_{64} Weight for air (lb.).

W_{AO} Total weight of air in hull at sea level (lb.), equation 29.

W_{ACCS} Weight of blimp access component (lb.), equation 281.

W_{AUX} Weight of blimp auxiliary gear (lb.), equation 283.

W_{BALS} Weight of ballast system (lb.), equations 287 and 301.

W_{BB} Weight of blimp ballonets (lb.), equations 254 and 255.

W_{CCAR} Weight of dirigible control car (lb.) equation 290.

W_{CONT} Weight of dirigible controls (lb.), equation 291.

W_{COV} Weight of dirigible cover (lb.), equations 271 and 273.

W_{COVW} Weight of Dirigible cover wire (lb.), equation 273.

W_{CUL} Weight of cooling system (lb.), equation 211.

W_{DUF} Weight of design useful fuel (lb.), equation 227.

W_E — Empty weight of airship (lb.), equation 25

W_E — Engine dry weight (lb.), equations 183, 184, 191, 198, 204.

W_{EFF} — Weight of personal effects (lb.), equation 307

W_{EN} — Total blimp envelope weight (lb.), equations 241, 246, and 255.

W_{EUF} — Electric useful fuel weight (lb.) equation 226.

W_F — Fuel weight (lb.), equation 228.

W_{FMX} — Maximum sea level fuel weight (lb.), equation 230.

W_{FUR} — Weight of furnishings (lb.), equation 311.

W_{FUZ} — Weight of usable fuel at altitude (lb.), equation 231.

W_{GER} — Weight of loading gear (lb.), equation 279.

W_{GNG} — Weight of dirigible gangways (lb.), equation 297.

W_{GO} Weight of lift gas in hull at sea level (lb.), equation 29, 124

W_{GSCL} Weight of dirigible gas cells (lb.), equation 276.

W_{HVEN} Weight of dirigible heat and ventilation (lb.), equation 298.

W_{HVP} Weight of heat, ventilation, and plumbing systems (lb.), equation 311.

W_{HYD} Weight of blimp hydraulic system (lb.), equation 284.

W_{IF} Weight of dirigible intermediate frames (lb.), equations 265 and 269.

W_{INS} Weight of dirigible instruments (lb.), equation 293.

W_{L} Weight of lower element of outrigger (lb.), equation 216.

W_{LNG} Weight of dirigible longitudinals (lb.), equations 266 and 269.

W_{LOD} Downward load or outrigger (lb.), equation 221.

W_{LUB} Lubricating oil weight (lb.), equation 212.

W_{MF} Weight of dirigible main frames (lb.), equations 264 and 269.

W_{MISEN} Blimp miscellaneous envelope weight (lb.), equations 247 and 255.

W_{MIS} Dirigible miscellaneous hull weight (lb.), equation 272 and 273.

W_{MNB} Weight of minimum ballast (lb.), equations 286 and 303.

W_{MOR} Weight of dirigible mooring system (lb.), equation 289.

W_{NAC} Engine nacelles weight (pounds), equation 213.

W_{NCON} Engine control system weight (lb.), equation 210.

W_{NET} Weight of dirigible cell netting (lb.), equation 277.

W_{OUT} Weight of each outrigger (lb.), equations 217, 219, and 220.

W_{PAY} Fixed payload weight (lb.), equation 16.

W_{PEN} Weight of personnel enclosures (lb.), equation 309.

W_{PERS} Weight of personnel (lb.), equation 306.

W_{PGAL} Pressure group and air lines weight (lb.), equation 255.

W_{PP} Propulsion plant weight (lb.), equations 14 and 18.

W_{PROP} Propeller weight (lb.), equation 169.

W_{PROV} Weight of provisions (lb.), equation 313.

W_{PUF} Propulsion useful fuel weight (lb.), equation 225.

W_{RCOM} Weight of dirigible radio and communications (lb.), equation 295.

W_{RE} Weight of dirigible reinforcements (lb.), equations 270 and 273.

W_{REG} Reduction gear weight (lb.), equation 169.

W_{RT} Recalculated total weight (lb.), equation 316.

W_{SLEC} Weight of electric system (lb.), equations 282 and 299.

W_{ST} Static lift, sea level operation (lb.), equation 24.

W_{SUP} Supported weight (lb.), equation 248.

W_{SUS} Blimp suspension system weight (lb.), equations 248 and 255.

W_T Total weight of airship, zero aerodynamic lift (lb.), equation 22.

W_{TL} Last estimate for total weight (lb.), equation 318.

W_{TN} New estimate for total weight (lb.), equation 317.

W_{TNK} Fuel tank weight (lb.), equation 234.

W_{TO} Takeoff weight (lb.).

W_U Weight of upper element of outrigger (lb.), equation 215.

W_{US} Useful load at sea level (lb.), equation (25)

W_{USZ} Useful load at altitude z (lb.), equation 26.

W_{VAL} Weight of dirigible gas valves (lb.), equation 277.

W_{WAT} Weight of potable water (lb.), equation 313.

W_{WIR} Weight of dirigible wires (lb.), equations 268 and 269.

W_{WREC} Weight for dirigible water recovery (lb.), equation 302.

w Weight density of atmosphere (lb./cu. ft.), equation 19.

w Material density

w_B Base value of weight density (lb./cu. ft.), equation 20.

w_B Specific (unit) lift of lift gas (lb./cu.ft.), table 5

w Engine width or diameter (feet).

w_C Car width (feet), equations 54 and 55.

w_{BM} Average ballonet material specific weight.

w_{CL}	Dirigible gas cell material specific weight (lb./sq.ft.), equation 276.
w_{EM}	Specific weight of envelope material (lb./sq.ft.), equations 242.
$\bar{w}_{EM}$	Average installed specific weight of envelope material (lb./sq.ft.), equations 241 and 244.
w_{EMIN}	Minimum specific weight of envelope material (lb./sq.ft.), equations 242.
w_G	Gas load per axial foot (lb./ft.), before equation 266.
w_{GO}	Sea level weight density of lift gas (lb./cu.ft.), equation 21.
x	Distance along takeoff runway (feet), equation 171.
x_{50}	Take off distance to 50 foot altitude (feet), equation 170.
x_G	Takeoff ground run distance (feet), equation 171, 178, 181.
y	Distance to extreme fiber (ft.), before equation 266.

z Altitude above sea level (feet).

z_{BDMX} Design maximum altitude of blimp (feet).

z_D Design cruise altitude (feet), equation 230.

z_{OP} Specified operating altitude (feet), equation 28.

z_{MRG} Gas-altitude margin (feet), equation 28.

α Angle of attack for aerodynamic lift (radian's)

α^o Angle of attack for aerodynamic lift (degrees)

α_{MRG} Takeoff angle of attack margin (radians), equation 76.

α_P Propeller activity factor, equation 161.

α_{TO} Takeoff angle of attack (radians), equations 77, 79, 180.

α_{TOMX} Maximum takeoff angle of attack (radians), equation 76.

α_{TOS} Specified takeoff angle of attack (radians), equations 77, 79.

β Coefficient for λ_B (ft./sec^2), equation 135.

β Propeller blade angle at .75 maximum radius (degrees), equations 167 and 168.

β Bottom outrigger angle (radians), equation 65.

β_{OPT} Optimum propeller blade angle (degrees), equation 165.

γ Coefficient for λ_{AA} (sec^2/ft.), equations 10 and 135.

δ Structural material density (lb./cu.ft.), equation 258.

δ_E Elevator deflection angle (radians), equation 107.

δ°_E Elevator deflection angle (degrees).

δ_{ET} Trimmed elevator deflection angle (radians), equation 121.

δ_{PC} Blimp internal excess pressure (lb./sq.ft.), equation 237.

ϵ Engine angle (radians), equation 64.

η Isolated propeller efficiency, equation 168.

η_E Envelope propeller efficiency.

η_{EMX} Maximum envelope propeller efficiency, equation 163.

η_M Propeller efficiency at M_{TPR}, figure 72.

η_P Propulsive efficiency, equations 153, 155.

θ_{MX} Maximum takeoff pitch angle (radians), equation 75.

λ Hull length ratio, equation 181.

λ Learning rate (percent), equations 331-333.

λ_A Aerodynamic lift-drag ratio, equation 136, 139.

λ_{AA} Aerodynamic lift alone lift-drag ratio, equations 9 and 132.

λ_{AMX}	Maximum aerodynamic lift-drag ratio, equation 140.
λ_B	Buoyant lift-drag ratio, L_B/D_O, equations 3, 126.
λ_V	Vehicle lift-drag ratio, equations 11, 141 and 142.
λ_{VMX}	Maximum vehicle lift-drag ratio, equations 12, and 143.
μ	Viscosity of atmosphere (lb.sec/sq.ft.), equation 19.
μ	Half-angle of dirigible outrigger (radians), equation 63.
μ	Takeoff rolling friction coefficient, equations 171 and 177.
ρ	Mass density of atmosphere (slug/cu.ft.), equation 19.
ρ_B	Base value of ρ (slug/cu.ft.), equation 20.
σ	Structural stress (lb./sq.ft.).
σ	Specific fuel consumption (lb./hp.hr.), equation 223.
σ^*	Off-design specific fuel consumption (lb./sq.ft.), equations 232.

σ_B Bending stress in tail fins (lb./sq.ft.), equation 257.

σ_{BC} Blimp maximum bending compression stress (lb.ft.^{2}), equation 236.

σ_C Circumferential tension stress (lb./ft.^{2}), equation 238.

σ_D Design specific fuel consumption (lb. fuel.hp.hr.) 300 equation 224.

σ_L Longitudinal stress in envelope material (lb./sq.ft.), equation 235.

σ_{LNG} Dirigible longitudinals stress (lb./sq.ft.), before equation 266.

σ_R Reference specific fuel consumption (lb./hp.hr.), equations 189, 196, 202, 208.

σ_{REL} Wire stress relative to 1930s, equation 268 and 269.

σ_{RO} Reference specific oil consumption (lb./hp.hr.), equations 190, 197, 203, 209.

σt Lineal strength of envelope material (lb./ft.).

$(\sigma t)_D$ Design lineal load (lb./ft.), equations 240.

σ_Y — Yield stress of structural material (lb./sq.ft.), equations 264,

σ_z — Atmospheric density ration at altitude, equation 19.

σ_{zD} — Density ratio at design cruise altitude, equation 230.

τ — Top outrigger angle (radians), equation 65.

ϕ — Factor for takeoff drag, equation 175.

ϕ_1 — Factor for pitching moment, equation 115 and 118.

ϕ_2 — Factor for pitching moment, equation 115 and 118.

ϕ_E — Factor for elevator moment effectiveness, equation 115.

ϕ_{EM} — Installed envelope material factor, equation 243,

ϕ_P — Blimp envelope pressure factor of safety, equation 246.

χ — Wetted area ratio, equation 180.

ψ — Parameter for takeoff distance, equation 178.

∇_{BB}	Blimp ballonet volume (cu.ft.), equations 30 and 250.
∇_{CEN}	Car envelope volume (cu.ft.), equations 32 and 53.
∇_{CL}	Clearance volume for dirigibles (cu.ft.), equation 35.
∇_{E}	Envelope volume of airship (cu.ft.).
∇_{G}	Design volume of lift gas (cu.ft.), equation 338.
∇_{GMX}	Maximum gas volume (cu.ft.)
∇_{RC}	Required car volume (cu.ft.).
∇_{USE}	Useful hull volume of dirigibles (cu.ft.), equation 33.
ω	Wind speed ratio, equation 177.
ω	Lift ratio, aerodynamic lift to sea level buoyant lift, equations 8, 131,
ω_{AOPT}	Optimum ω for maximum λ_A, equations 140.
ω_{VOPT}	Optimum ω for maximum λ_V, equations 13, 143.

APPENDIX B

COMPUTER PROGRAM LISTING

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      PROGRAM AIRSHIP
      COMMON/DATA/P(10,500),S(800),Q(100),IT(100),C(500)
      EQUIVALENCE(S(800),C(500))
      TYPE REAL L,LD,NACLL,NACLD,NACLLD,NACFRA,NACLCD,NACINT,JETA,LABRAT
      COMMON/CONST/G,GAMMA,PI,RHOAIR,RHOWAT,SPDFPS,TON,VISWAT,VOLWAT
      COMMON/TYPES/JSHIP,JMBOIL,JMENG,JMTRAN,JMPROP,JGAS,JHMAT,JMCONF
      COMMON/TYPES2/JTAIL,JGEAR
      COMMON/ACC/NOFF,NCPO,NENL,SHPDUR,NTRP,TRPDUR,NCREW,NACCOM
      COMMON/GEOM1/L,B,H,F,D,CP,CX,CB,CW,LD,BH,DEKHT,NCOMPS
      COMMON/GEOM2/HULLWA,FINA,FINB,FINC,FINAR,FINTC,TAILA,TAILWA
      COMMON/GEOM6/PROPC,TOSPC,TOALF,GERLC,GERLN
      COMMON/GEOM3/CARLEN,CARWID,       CAROVR,OVRMAX,SECLEN,CARFRT
      COMMON/GEOM4/STRTC,STRTL,STRTTC,STRTWA,NACLL,NACLD,NACLLD,NACFRA
      COMMON/PPLNT/SZMBLR,NMBLR,SZMENG,NMENG,SZAENG,NAENG
      COMMON/OPOW/VKTS,HULLD(4),ETA(4),POWR(4),PSACT,PEACT,JOP
      COMMON/PRNTD2/SRTCD4,NCLCD4,NCINT4,ENGCD4,DRGZRO,DRGLIF,ALFPRT
      COMMON/WATE/W(6,5),FIXDIS,TOTWT,PLATWT,STLIFT,EMTWT,SLUSLD,CRUSLD
      COMMON/WATE2/WMNB,WGNG,WBALS,FUELMX,WPROPS
      COMMON/DRGSPC/HEVI,SURUF,TERA,DELTCF,GSTSPD,DYLODD
      COMMON/AIRGAS/TEMRAT,DENRAT,ETAP
      COMMON/VOL/V(6,5),ENVOL,GSFRAC,CARVOL,USEVOL,VR
      COMMON/HIST1/MXVIT,HNWT(9),HTOTWT(9),HCALWT(9),HF(9)
      COMMON/COST1/YRCOST,NPROD,FLATR,LABRAT,DELABR,OVRRAT,DEOVER,PROFIT
      COMMON/COST2/CPLAN(3),CTIN(3),CFUT(3),CSTOK(3),CDEV(3)
      COMMON/PRINT1/ICONST,ITECH,ICOST,NSHIP,NCASE,CALWT,PSREQ,PEREQ
      COMMON/OFF2/OFFEND(10,10),OFFPOW(10,10),OFFGPH(10,10),OFFUSE(10)
      COMMON/OFF1/MXSPD,MXALT,NALT,OFFALT(10),OFFSPD(10),OFFRNG(10,10)
      COMMON/PRINT2/VMXACT,VMXRNG,VSACT,VSRNG,VEACT,VERNG,GPHR
      DIMENSION SPDMX(20)
      COMMON/CONTROL/NWT,FP,STATLW,DYLW
      NSHIP=0          $ DO 2 I=1,800
    2 S(I)=0           $ PI=3.14159      $ G=32.174        $ SPDFPS=1.6878
C                 ADDITIONAL PROBLEMS START HERE
    3 NSHIP=NSHIP+1  $ CALL DATA2(S,60,IND)                $ IF(IND) RETURN
      NCASE=0  $ IF(S(71).LE.1.) GO TO 7     $ NAUTO=S(72)
    6 NCASE=NCASE+1  $ S(NAUTO)=S(73)+(NCASE-1)*S(74)
C                 ADDITIONAL CASES START HERE
    7 TON=C(1)         $ GAMMA=C(2)      $ VISWAT=C(3)     $ RHOAIR=C(4)
      RHOWAT=GAMMA/G  $ VOLWAT=TON/GAMMA
      SUSSPD=S(1)      $ DCMAPG=S(26)    $ YRCOST=S(51)    $ JSHIP=S(76)
      ENDSPD=S(2)      $ SPCLPA=S(27)    $ NPROD=S(52)     $ JMBOIL=S(77)
      RANGE=S(3)       $ SPCLDK=S(28)    $ FLATM=S(53)     $ JMENG=S(78)/10.
      CRSALT=S(4)      $ SPCLCG=S(29)    $ FLATL=S(54)     $ JMTRAN=S(79)
      NOFF=S(5)        $ FIXDIS=S(30)    $ LABRAT=S(55)    $ JMPROP=S(80)
      NCPO=S(6)        $ ELECKW=S(31)    $ DELABR=S(56)    $ JGAS=S(81)
      NENL=S(7)        $ SZMBL1=S(32)    $ OVRRAT=S(57)    $ JGEAR=S(82)
      SHPDUR=S(8)      $ NMBLR1=S(33)    $ DEOVER=S(58)    $ JAENG=S(83)
      NTRP=S(9)        $ SZMNG1=S(34)    $ PROFIT=S(59)    $ JATRAN=S(84)
      TRPDUR=S(10)     $ NMENG1=S(35)                      $ JAPROP=S(85)
      LD=S(11)         $ SZANG1=S(36)    $ CPLAN(2)=S(61)  $ JHMAT=S(86)
      CONSTD=S(12)     $ NAENG1=S(37)    $ CDEV(1)=S(62)
      CP=S(13)         $ SPECPD=S(38)    $ CDEV(2)=S(63)
                                           CSTOK(1)=S(64)
                                           CSTOK(2)=S(65)  $ JTAIL=S(90)
      GSZIN=S(16)      $ ITECH=S(41)     $ CTIN(1)=S(66)   $ MXSPD=S(91)
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      BLMXZ=S(17)     $ ICOST=S(42)      $ CTIN(2)=S(67)   $ FSTSPD=S(92)
      GSPURE=S(18)    $ WTOL=S(43)       $ CFUT(1)=S(68)   $ CNGSPD=S(93)
      GSTSPD=S(19)    $ MXWIT=S(44)      $ CFUT(2)=S(69)   $ MXALT=S(94)
      TOSPD=S(20)     $ VOLTCL=S(45)                       $ FSTALT=S(95)
      TOALFS=S(21)    $ MXVIT=S(46)      $ MXCASE=S(71)    $ CNGALT=S(96)
      SURUF=S(22)     $ GMBMIN=S(47)     $ NAUTO=S(72)
      DELTCF=S(23)    $ GMBTOL=S(48)     $ FIRST=S(73)
                        FSTSHP=S(49)     $ CHNGE=S(74)
      CRSRAT=S(25)
      JMCONF=S(78)-10.*JMENG
      IF(TOSPD.LT.1.) TOSPD=TOSPD*SUSSPD
      IF(S(28).EQ.0) SPCLOK=30.*S(27)
      IF(MXWIT.GT.9) MXWIT=9             $ IF(MXVIT.GT.9) MXVIT=9
      DO 8 I=1,MXVIT    $ HNWT(I)=0
    8 HTOTWT(I)=HCALWT(I)=HF(I)=0
C             PEOPLE, PAYLOAD AND FIRST ESTIMATE OF TOTAL WEIGHT
      NWT=0     $ NVOL=0     $ GSFRAC=1.     $ IF(JSHIP.EQ.3) GSFRAC=.93
      DEKHT=8.        $ OVRMAX=5.        $ SZMENG=500.     $ NMENG=2
      NCREW=NOFF+NCPO+NENL $ NACCOM=NCREW+NTRP
      TOTWT=FIXDIS    $ IF(TOTWT.NE.0) GO TO 22
      W(5,5)=W(5,4)=SPCLPA $ V(5,5)=V(5,4)=DEKHT*SPCLOK
      TOTWT=1.+4.3*W(5,5)+6E-8*FANGE*ENDSPD**3
C             ADDITIONAL VOLUME ITERATIONS START HERE
   21 NVOL=NVOL+1      $ SUMFP=0
C             ADDITIONAL HEIGHT ITERATIONS START HERE
   22 NWT=NWT+1        $ IF(TOTWT.LE.0.) GO TO 96
      ENVOL=TON*TOTWT/(RHOAIR*G)
      Z=CRSALT+GSZIN        $ TEMRAT=1.-6.876E-6*Z$ DENRAT=TEMRAT**4.256
      GSDEN0=.01057  $ IF(JGAS.EQ.2) GSDEN0=.00532
      GSDEN0=GSDEN0*GSPURE/100.+RHOAIR*G*(1.-GSPURE/100.)
      STLIFT=GSFRAC*(RHOAIR*G-GSDEN0)*ENVOL/TON
      W(6,3)=GSFRAC*GSDEN0*DENRAT*ENVOL/TON
      W(6,4)=(1.-DENRAT*GSFRAC)*TOTWT
      V(6,3)=TON*W(6,3)/GSDEN0            $ V(6,4)=TON*W(6,4)/(RHOAIR*G)
      D=(ENVOL/((PI/4.)*CP*LD))**(1./3.)            $ L=LD*D
      CSURF=(1.+.90/(LD**2))*CP**(2./3.)            $ HULLWA=CSURF*PI*L*D
      FINA=.30*(CP**(1./3.))*((ENVOL/LD)**(2./3.))        $ TAILA=4.*FINA
      IF(JTAIL.EQ.3) FINA=(4./3.)*FINA$ FINB=.60*D/(LD**(1./3.))
      FINC=FINA/FINB $ FINAR=2.*(FINB**2)/FINA           $ TAILWA=2.*TAILA
      FINTC=.02        $ IF(JSHIP.EQ.3) FINTC=.10
      IF(JSHIP.EQ.3) GO TO 26
      CARWID=4.       $ CAROVR=0        $ SECLEN=0        $ CARENV=0
      CARLEN=MAX1F(12.,CARVOL/(CARWID*DEKHT))
      IF(CARLEN.LE..2*L) GO TO 24       $ CARLEN=.2*L
      CARWID=MAX1F(4.,CARVOL/(CARLEN*DEKHT))
      IF(CARWID.LE..15*D) GO TO 24      $ CARWID=.15*D
      CAROVR=CARVOL/(CARLEN*CARWID)-DEKHT
      IF(CAROVR.LE.OVRMAX) GO TO 24     $ CAROVR=OVRMAX
      SECLEN=(CARVOL-CARLEN*CARWID*(DEKHT+CAROVR))/(CARWID*DEKHT)
   24 CARFRT=CARWID*(DEKHT+CAROVR) $ IF(SECLEN.NE.0) CARFRT=CARWID*DEKHT
      CARENV=(CARLEN*CAROVR+SECLEN*DEKHT)*CARWID
      GSFRAC=1.-CARENV/ENVOL            $ GO TO 28
   26 CARLEN=12.      $ CARWID=4.       $ CARFRT=1.*DEKHT*CARWID
      CLRRAD=.006*D  $ CLRVCL=CLRRAD*HULLWA
      GSFRAC=1.-(CLRVOL+USEVOL)/ENVOL
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 28 GERLC=0  $ GERLN=0   $ CPPP=2.  $ IF(JSHIP.EQ.3) CPRP=4.
    GERLEN=0
    OUTL=.5*(PROPD-NACLD)+CPRP       $ IF(TOSPD.EQ.0) GO TO 30
    PHIFIN=0 $ IF(JTAIL.EQ.2) PHIFIN=.293  $ IF(JTAIL.EQ.3) PHIFIN=.5
    ALFMRG=3.        $ CABV=2.          $ CGRD=3.         $ PHIGER=.50
    GERLN=CGRD+.5*(PROPD-NACLD)         $ GERLC=CABV+PROPD+CGRD-DEKHT
    BOTNAC=CABV+.5*(PROPD+NACLD)        $ IF(GERLC.GE.CGRD) GO TO 290
    GERLC=CGRD       $ GERLN=DEKHT+CGRD-BOTNAC
290 THETMX=(180./PI)*ATANF((GERLC+DEKHT+.5*PHIFIN*D)/(PHIGER*L))
    IF(TOALFS.EQ.0) GO TO 292$ IF(TOALFS.LE.(THETMX-ALFMRG)) GO TO 291
    GERLN=PHIGER*L*TANF(PI*(TOALFS+ALFMRG)/180.)-.5*PHIFIN*D-BOTNAC
    GERLC=BOTNAC+GERLN-DEKHT
291 TOALF=TOALFS     $ GO TO 293
292 TOALF=THETMX-ALFMRG
293 XN=BOTNAC+GERLN         $ XC=DEKHT+GERLC
 30 JOP=1            $ VKTS=SUSSPD     $ CALL DRAGPOWR  $ PSREQ=POWR(1)
    JOP=2            $ VKTS=ENDSPD     $ CALL DRAGPOWR  $ PEREQ=POWR(2)
    POW=PSREQ        $ IF(PSREQ.LT.PEREQ/CRSRAT) POW=PEREQ/CRSRAT
              SZ=SZMNG1  $ N=NMENG1$ IF(SZ.NE.0.AND.N.NE.0) GO TO 32
    IF(SZ.NE.0.AND.N.EQ.0) GO TO 31
    IF(N.EQ.0) N=1          $ SZ=POW/N $ GO TO 32
 31 N=POW/SZ $ IF(POW/SZ.GT.N) N=N+1
 32 PSACT=N*SZ  $ SZMENG=SZ  $ NMENG=N
    POW=PEREQ        $ IF(PEREQ.GT.CRSRAT*PSACT) POW=CRSRAT*PSACT
              SZ=SZANG1  $ N=NAENG1$ IF(SZ.NE.0.AND.N.NE.0) GO TO 34
    IF(SZ.NE.0.AND.N.EQ.0) GO TO 33
    IF(N.EQ.0) N=1          $ SZ=POW/N $ GO TO 34
 33 N=POW/SZ $ IF(POW/SZ.GT.N) N=N+1
 34 PEACT=N*SZ  $ SZAENG=SZ  $ NAENG=N
    BOYPP=(DRGZRO/(DRGZRO+DRGLIF))*W(2,5)
   1+(DRGZRO/(DRGZRO+.5*DRGLIF))*(W(6,2)+DYLODO)
    AIRPP=(DRGLIF/(DRGZRO+DRGLIF))*W(2,5)
   1+(DRGLIF/(DRGZRO+.5*DRGLIF))*(W(6,2)+DYLODO)
    BOYSST=(W(1,5)+W(3,4)+BOYPP)/STLIFT
    AIRSST=(W(3,1)+AIRPP)/DYLODO
C              ESTIMATE THE FUEL WEIGHT
    GO TO(41,42,43,44,45),JMENG
 41 SFCCON=.37       $ SFCPAR=0           $ GO TO 50
 42 SFCCON=(.6+.0046*SZMENG)/(1+.01*SZMENG)      $ SFCPAR=0  $ GO TO 50
 43 SFCCON=.35       $ SFCPAR=0           $ GO TO 50
 44 SFCCON=.31       $ SFCPAR=0           $ GO TO 50
 45 SFCCON=(.75+.001*SZMENG)/(1+.002*SZMENG)    $ SFCPAR=0  $ GO TO 50
 50 SFCDEG=C(93)/100.     $ UNFUEL=C(94)/100.    $ RESFUL=C(95)/100.
    USFUEL=(1+SFCDEG)*(SFCCON*POWR(2)+SFCPAR*PSACT)*RANGE/(ENDSPD*TON)
    USFUEL=USFUEL+.60*(ELECKW/.746)*(SHPOUR*24.)/TON

    W(6,2)=USFUEL/((1-UNFUEL)*(1-RESFUL))-DYLODO
    FUELMX=W(6,2)+DYLODO+STLIFT*(1-DENRAT)
    GPHR=TON*USFUEL*ENDSPD/(RANGE*6.67)
C              RECALCULATE THE TOTAL WEIGHT AND ITERATE
    VKTS=SUSSPD
    Z=BLMXZ                 $ TEMRAT=1.-6.876E-6*Z$ DENRAT=TEMRAT**4.256
    CALL WEIGHT     $ EMTWT=PLATWT-W(4,1)-W(4,4)-WMNB
    W(6,1)=(DCMAPG/100.)*EMTWT
    W(6,5)=W(6,1)+W(6,2)+W(6,3)+W(6,4)
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      CALWT=PLATWT+W(5,5)+W(6,5)
      SLUSLD=STLIFT-W(6,1)-EMTWT
      HTOTWT(NVOL)=TOTWT     $ HCALWT(NVOL)=CALWT   $ HNWT(NVOL)=NWT
      IF(FIXDIS.NE.0) GO TO 56          $ FNEWT=CALWT-TOTWT
      FPCAL=(FNEWT-FM1)/(TOTWT-WTM1)   $ FPSUM=FPSUM+MIN1F(0,FPCAL)
      IF(NWT.EQ.1) FPSUM=-.30          $ FP=FPSUM/NWT
      WTDIF=ABSF(FNEWT)/(TOTWT*ABSF(FP))          $ GO TO 57
   56 W(5,5)=TOTWT-PLATWT-W(6,5)
C              CALCULATE THE REQUIRED VOLUME AND ITERATE
   57 CALL VOLUME     $ VA=FNVOL+CARVOL
      V(6,5)=V(6,1)+V(6,2)+V(6,3)+V(6,4)
      VR=V(1,5)+V(2,5)+V(3,5)+V(4,5)+V(5,5)+V(6,5)
      CARVOL=V(2,5)+V(3,5)+V(4,5)+V(5,5)+V(6,2)
      USEVOL=V(2,5)+V(3,5)+V(4,5)+V(5,5)+V(6,2)
      FM1=FNEWT         $ WTM1=TOTWT
      TOTWT=MAX1F(.2*TOTWT,TOTWT-FNEWT/FP)    $ IF(NWT.LT.6) GO TO 22
      IF(WTDIF.GT.WTOL/100.AND.NWT.LT.MXWIT) GO TO 22
C              ACTUAL SPEEDS AND RANGES
      Z=CRSALT+GSZIN          $ TEMRAT=1.-6.876E-6*Z$ DENRAT=TEMRAT**4.256
      VMXACT=SUSSPD  $ JOP=4    $ DO 60 NVMAX=1,9
      VKTS=VMXACT     $ CALL DRAGPOHR   $ RATPOW=POWR(4)/PSACT
   60 VMXACT=VMXACT/(RATPOW**.5)
      VMXRNG=TON*USFUEL*VMXACT/((1+SFCDEG)*(SFCCON*POWR(4)+SFCPAR*PSACT)
     1)
      VSACT=SUSSPD    $ JOP=4    $ DO 62 NVSACT=1,9
      VKTS=VSACT      $ CALL DRAGPOWR   $ RATPOW=POWR(4)/PSACT
   62 VSACT=VSACT/(RATPOW**.5)
      VSRNG=TON*USFUEL*VSACT/((1+SFCDEG)*(SFCCON*POWR(4)+SFCPAR*PSACT))
      VEACT=ENDSPD    $ JOP=4     $ DO 64 NVEACT=1,9
      VKTS=VEACT       $ CALL DRAGPOWR  $ RATPOW=POWR(4)/PEACT
   64 VEACT=VEACT/(RATPOW**.5)
      VERNG=TON*USFUEL*VEACT/((1+SFCDEG)*(SFCCON*POWR(4)+SFCPAR*PSACT))
C              OFF-DESIGN RANGE AND SPEED
      IF(MXSPD.LT.1.AND.MXALT.LT.1) GO TO 140
      IF(MXSPD.GT.10) MXSPD=10            $ IF(MXALT.GT.10) MXALT=10
      IF(MXSPD.GT.0.AND.MXALT.EQ.0) MXALT=1
      IF(MXSPD.EQ.0.AND.MXALT.GT.0) MXSPD=1        $ NALT=0
C              ADDITIONAL OFF-DESIGN CASES START HERE
  110 NSPD=0     $ NALT=NALT+1     $ OFFALT(NALT)=FSTALT+(NALT-1)*CNGALT
      SPDMX(NALT)=SUSSPD     $ DO 115 NVPOS=1,9
      Z=OFFALT(NALT)+GSZIN $ TEMRAT=1.-6.876E-6*Z$ DENRAT=TEMRAT**4.256
      IF(JSHIP.EQ.2.AND.Z.GT.BLMXZ) GO TO 135
      VKTS=SPDMX(NALT)        $ JOP=4      $ CALL DRAGPOWR
      RATPOW=POWR(4)/PSACT $ SPDMX(NALT)=SPDMX(NALT)/SQRTF(RATPOW)
  115 CONTINUE          $ JMXSPD=0
  120 NSPD=NSPD+1      $ IF(JMXSPD.NE.0) GO TO 135
      OFFSPD(NSPD)=FSTSPD+(NSPD-1)*CNGSPD
      IF(OFFSPD(NSPD).LE.SPDMX(NALT)) GO TO 122
      JMXSPD=1          $ OFFSPD(NSPD)=SPDMX(NALT)
  122 VKTS=OFFSPD(NSPD)      $ JOP=4      $ CALL DRAGPOWR
      ZMXFUL=FUELMX-STLIFT*(1-DENRAT)
      ZUSFUL=(1-UNFUEL)*(1-RESFUL)*ZMXFUL
      OFFEND(NALT,NSPD)=ZUSFUL/(((1.+SFCDEG)/TON)*(SFCCON*POWR(4)
     1+SFCPAR*PSACT)+.60*(FLECKW/.746)/TON)
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```
      OFFRNG(NALT,NSPD)=OFFSPD(NSPD)*OFFEND(NALT,NSPD)
      IF(ZUSFUL.LE.0) OFFEND(NALT,NSPD)=0
      OFFPOW(NALT,NSPD)=POWF(4)
      OFFGPH(NALT,NSPD)=TON*ZUSFUL/(6.67*OFFEND(NALT,NSPD))
      OFFUSE(NALT)=SLUSLD-STLIFT*(1.-DENRAT)
  130 IF(NSPD.LT.MXSPD) GO TO 120
  135 IF(NALT.LT.MXALT) GO TO 110
C                 ESTIMATE THE INVESTMENT COST
  140 CALL INVEST    $ CALL PRINT     $ GO TO 100
   96 PRINT 98,NSHIP,NCASE $ GO TO 100
   98 FORMAT(1H1,6X*SHIP NUMBER*I4,5X*CASE NUMBER*I4/7X
     1*NEGATIVE TOTAL WEIGHT IN ITERATION*//7X*PROBLEM DELETED*)
  100 IF(MXCASE.LE.1) GO TO 3          $ IF(NCASE.LT.MXCASE) GO TO 6
      GO TO 3          $ END

*    SINGLE-BANK COMPILATION.
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      SUBROUTINE DRAGPOWR
      COMMON/DATA/P(10,500),S(800),Q(100),IT(100),C(500)
      EQUIVALENCE(S(800),C(500))
      TYPE REAL L,LD,NACLL,NACLD,NACLLD,NACFRA,NACLCD,NACINT,JETA,LABRAT
      COMMON/CONST/G,GAMMA,PI,RHOAIR,RHOWAT,SPDFPS,TON,VISWAT,VOLWAT
      COMMON/TYPES/JSHIP,JMBOIL,JMENG,JMTRAN,JMPROP,JGAS,JHMAT,JMCONF
      COMMON/TYPES2/JTAIL,JGEAR
      COMMON/PPLNT/SZMBLR,NMBLR,SZMENG,NMENG,SZAENG,NAENG
      COMMON/GEOM1/L,B,H,F,D,CP,CX,CB,CW,LD,BH,DEKHT,NCOMPS
      COMMON/GEOM2/HULLWA,FINA,FINB,FINC,FINAR,FINTC,TAILA,TAILWA
      COMMON/GEOM3/CARLEN,CARWID,       CAROVR,OVRMAX,SECLEN,CARFRT
      COMMON/GEOM4/STRTC,STRTL,STRTTC,STRTWA,NACLL,NACLD,NACLLD,NACFRA
      COMMON/GEOM6/PROPD,TOSPD,TOALF,GERLC,GERLN
      COMMON/AIRGAS/TEMRAT,DENRAT,ETAP
      COMMON/DPOW/VKTS,HULLD(4),ETA(4),POWR(4),PSACT,PEACT,JOP
      COMMON/WATE/W(6,5),FIXDIS,TOTWT,PLATWT,STLIFT,EMTWT,SLUSLD,CRUSLD
      COMMON/WATE2/WMNB,WGNG,WBALS,FUELMX,WPROPS
      COMMON/VOL/V(6,5),ENVOL,GSFRAC,CARVOL,USEVOL,VR
      COMMON/DRGSPC/HEVI,SURUF,TERA,DELTCF,GSTSPD,DYLODD
      COMMON/PRNTD1/CHCFH4,CHCFT4,CD04,ETA4,HULCD4,TALCD4,CBLCD4,CARCD4
      COMMON/PRNTD2/SRTCD4,NCLCD4,NCINT4,ENGCD4,DRGZRO,DRGLIF,ALFPRT
      TYPE REAL NCLCD4,NCINT4
      GO TO 10
C               FUNCTION DEFINITION
    2 REY=RHO*VFPS*CFL/VISCOS  $ CF0=.028/REY**.14          $ CF1=CF0
      DO 4  I=1,9 $ CFX=1./(CF0*REY)   $ RUFR=RUF/CFL
      ZIN=.86/RUFR**.86     $ CF1=.0586/(ALOG10(CF1*REY))**2
      CF2=.0586/(ALOG10(CFX+ZIN/(1.+80.*((CF0**.5)*RUFR*CFX)**1.5)))**2
      CFDIF=ABS(CF2/CF0-1.)$ CF0=CF2
    4 IF(CFDIF.LE..001) GO TO 6
    6 CF=CF2+DELTA             $ GO TO(30,40,50,60),K
C               CALCULATIONS
   10 VFPS=VKTS*SPDFPS       $ RHO=RHOAIR*DENRAT
      VISCOS=5.1691E-7*(TEMRAT**1.5)/(TEMRAT+.3831)
      STDRUF=SURUF/12000.   $ DELTA=DELTCF
      NACLLD=3.
      GO TO(21,22,23,24,25),JMENG
   21 NACFRA=NMENG*.04*SZMENG/(1+.003*SZMENG)
      IF(JMCONF.EQ.2) NACFRA=NMENG*.17*SZMENG/(1+.008*SZMENG)
      IF(JMCONF.EQ.3) NACFRA=NMENG*.04*SZMENG/(1+.003*SZMENG)$ GO TO 29
   22 NACFRA=NMENG*.21*SZMENG/(1+.040*SZMENG)
      IF(JMCONF.EQ.2) NACFRA=NMENG*.17*SZMENG/(1+.008*SZMENG)
      IF(JMCONF.EQ.3) NACFRA=NMENG*.0076*SZMENG   $ GO TO 29
   23 NACFRA=NMENG*1.0*SZMENG/(1+.008*SZMENG)     $ GO TO 29
   24 NACFRA=NMENG*1.0*SZMENG/(1+.008*SZMENG)     $ GO TO 29
   25 NACFRA=NMENG*.12*(SZMENG)**.5               $ GO TO 29
   29 NACLD=(4.*NACFRA/(PI*NMENG))**.5$ NACLL=NACLLD*NACLD
      IF(NACLL.GE.1.3*GERLN) GO TO 28 $ NACLL=1.3*GERLN
   28 STRTTC=.20
      IF(JOP.EQ.1) STRTL=2.+.5*(PROPD-NACLD)
      STRTC=1.*STRTL $ STRTWA=4.*NMENG*STRTL*STRTC
      K=1          $ CFL=L        $ RUF=STDRUF       $ GO TO 2
   30 HULLCD=(1.+1.5/LD**1.5+7.0/LD**3)*CF
      IF(JOP.EQ.1) CHCFH4=1E4*(CF-CF1)
      K=2          $ CFL=FINC  $ RUF=1.*STDRUF    $ GO TO 2
```

```
40 TAILCD=(1.+2.*FINTC+60.*FINTC**4)*CF*TAILWA/HULLWA
  1+4.*(FINTC**3)*FINC**2/HULLWA
   CABLCD=0 $ IF(JSHIP.EQ.2) CABLCD=.36E-3*(FINB/HULLWA)
  1*(GSTSPD*VFPS*TAILA)**.5
   TAILCD=TAILCD+CABLCD
   IF(JOP.EQ.1) CHCFT4=1E4*(CF-CF1)
   CARCD=.15*CARFRT/HULLWA
   K=3       $ CFL=STRTC $ RUF=1.0*STORUF             $ GO TO 2
50 STRTCD=((1.+2.*STRTTC+60.*STRTTC**4)*CF*STRTWA+(STRTTC**3)
  1*STRTC**2)/HULLWA
   K=4       $ CFL=NACLL $ RUF=1.0*STORUF             $ GO TO 2
60 NACLCD=(3.*NACLLD+4.5/NACLLD**.5+21./NACLLD**2)*CF*NACFRA/HULLWA
   NACINT=.05*NACFRA/HULLWA          $ NACLCD=NACLCD+NACINT
   GEARCD=.75*(GERLN**2)/(12.*HULLWA)
   IF(JGEAR.EQ.2.AND.GERLN.LT.1.3*NACLL) GEARCD=0
   CD0=HULLCD+TAILCD+CARCD+STRTCD+NACLCD+GEARCD
   DYPRES=.5*RHO*(VFPS**2)  $ IF(JOP.EQ.1) DRGZRO=DYPRES*HULLWA*CD0/
  1TON
   V23=ENVOL**(2./3.)
62 ALB=.160 $ BLB=1.05  $ FLINT=1.6$ TARAT=.5*TAILA/V23
   TARAT=1.2*TARAT
   ALT=FLINT*.5*PI*FINAR*TARAT
   BLT=FLINT*4.*(FINAR**.5)*EXPF(-.82*FINAR)*TARAT
   AMB=1.55 $ BMB=1.40               $ ARM=.45*L/SQRTF(V23)
   ALPHA=(PI*TOALF/180.)*(TOSPD/VKTS)**2
   CLB=ALB*ALPHA+BLB*ALPHA**2        $ CLOT=ALT*ALPHA+BLT*ALPHA**2
   TRIM=((AMB-.82*(FINAR**.5)*ARM*ALT)*ALPHA
  1-(BMB+ARM*BLT)*ALPHA**2)/(ARM*.37*ALT*(1.+ALPHA))
   CLE=.37*ALT*TRIM*(1.+ALPHA)       $ CL=CLB+CLOT+CLE
   DYLODD=.5*RHO*(VFPS**2)*V23*CL/TON
   ALFPRT=180.*ALPHA/PI
   CDLB=ALB*ALPHA**2+.9*BLB*ALPHA**3
   CDLOT=.8*ALT*ALPHA**2+BLT*ALPHA**3
   CDLE=CLE*(.5*TRIM+1.6*ALPHA)      $ CDL=(CDLB+CDLOT+CDLE)*V23/HULLWA
   IF(JOP.EQ.1) DRGLIF=DYPRES*HULLWA*CDL/TON
   IF(JOP.NE.1) CDL=.5*CDL
   HULLD(JOP)=.5*RHO*(VFPS**2)*HULLWA*(CD0+CDL)
   NPROPS=NMENG    $ RPM=900.        $ A2B=40000.      $ CLA=.30
   FABC=(.0070+.0035*((A2B**(1./3.))*(CLA**1.5)))/CLA
   SPECPD=S(38)  $ IF(SPECPD.NE.0) PROPD=SPECPD
   PROPP=550.*S(34)      $ IF(PROPP.NE.0) GO TO 70    $ ETA1=.5
   DO 85 NETA=1,9 $ PROPP=(VFPS/ETA1)*(HULLD(JOP)/NPROPS)
70 CSP=VFPS*(RHOAIR*DENRAT*(FABC/.0889)/(PROPP*((RPM/60.)**2)))**.2
   IF(JOP.NE.1) GO TO 75$ IF(SPECPD.NE.0) GO TO 75
   ADOPT=.45*CSP+.12*CSP**2          $ PROPD=VFPS/((RPM/60.)*ADOPT)
   BETA=15.5*CSP  $ GO TO 80
75 AD=VFPS/((RPM/60.)*PROPD)
   BETA=(AD/CSP+.060*(CSP**2)-.45)/(.011+.00090*(CSP**2))
   BETA=MAX1F(.001,BETA)
80 ETA2=(1.-FABC)*CSP/((.40+.017*(BETA**1.2))*(1.+(11.46*CSP/BETA)**3
  1))
   FETA=ETA2-ETA1         $ FCAL=(FETA-F1)/(ETA1-ETAM1)
   FPE=MIN1F(-1.,FCAL)
   ETADIF=ABSF(FETA)/(ETA1*ABSF(FPE))      $ F1=FETA  $ ETAM1=ETA1
   ETA1=MAX1F(.15,ETA1-FETA/FPE)
```

```
      IF(S(34).NE.0) GO TO 90            $ IF(ETADIF.LE..01) GO TO 90
   85 CONTINUE
   90 TIPSPD=PI*(RPM/60.)*PROPD
      ETAP=ETA1
      IF(JOP.NE.1) GO TO 95
      WPROPS=NPROPS*.00126*(A2B**.375)*(TIPSPD**.5)*(SZMENG**.12)
     1*(PROPD**1.76)/TON
      CD04=1E4*CD0           $ ETA4=ETAP              $ HULCD4=1E4*HULLCD
      TALCD4=100.*TAILCD/HULLCD          $ CARCD4=100.*CARCD/HULLCD
      SRTCD4=100.*STRTCD/HULLCD          $ NCLCD4=100.*NACLCD/HULLCD
      NCINT4=100.*NACINT/HULLCD
      ENGCD4=100.*(STRTCD+NACLCD)/HULLCD
   95 POWR(JOP)=(HULLD(JOP)*VFPS/ETAP)/550.
      RETURN    $ END

*    SINGLE-BANK COMPILATION.
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```
      SUBROUTINE WEIGHT
      COMMON/DATA/P(10,500),S(800),Q(100),IT(100),C(500)
      EQUIVALENCE(S(800),C(500))
      TYPE REAL L,LD,NACLL,NACLD,NACLLD,NACFRA,NACLCD,NACINT,JETA,LABRAT
      COMMON/CONST/G,GAMMA,PI,RHOAIR,RHOWAT,SPDFPS,TON,VISWAT,VOLWAT
      COMMON/TYPES/JSHIP,JMBOIL,JMENG,JMTRAN,JMPROP,JGAS,JHMAT,JMCONF
      COMMON/TYPES2/JTAIL,JGEAR
      COMMON/PPLNT/SZMBLR,NMBLR,SZMENG,NMENG,SZAENG,NAENG
      COMMON/ACC/NOFF,NCPO,NENL,SHPDUR,NTRP,TRPDUR,NCREW,NACCOM
      COMMON/GEOM1/L,B,H,F,D,CP,CX,CB,CW,LD,BH,DEKHT,NCOMPS
      COMMON/GEOM2/HULLWA,FINA,FINB,FINC,FINAR,FINTC,TAILA,TAILWA
      COMMON/GEOM6/PROPD,TOSPD,TOALF,GERLC,GERLN
      COMMON/GEOM3/CARLEN,CARWID,      CAROVR,OVRMAX,SECLEN,CARFRT
      COMMON/GEOM4/STRTC,STRTL,STRTTC,STRTWA,NACLL,NACLD,NACLLD,NACFRA
      COMMON/DPOW/VKTS,HULLD(4),ETA(4),POWR(4),PSACT,PEACT,JOP
      COMMON/WATE/W(6,5),FIXDIS,TOTWT,PLATWT,STLIFT,EMTWT,SLUSLD,CRUSLD
      COMMON/WATE2/WMNB,WGNG,WBALS,FUELMX,WPROPS
      COMMON/DRGSPC/HEVI,SURUF,TERA,DELTCF,GSTSPD,DYLODD
      COMMON/AIRGAS/TEMRAT,DENRAT,ETAP
      COMMON/VOL/V(6,5),ENVOL,GSFRAC,CARVOL,USEVOL,VR
      COMMON/WTPRNT/SIGT
      PLATWT=0          $ DO 2 I=1,4
    2 W(I,5)=0          $ VFPS=SPDFPS*VKTS
      GSTMOM=.07*GSTSPD*VFPS*(RHOAIR*DENRAT/2.)*L*ENVOL**(2./3.)
      IF(JSHIP.EQ.3) GO TO 30
      GO TO(11,12,13,14,15,16,17,18,19,20),JHMAT
   11 ENMMIN=.111       $ ENMINT=.0834     $ ENMSLP=47.7E-6  $ GO TO 21
   12 ENMMIN=.111       $ ENMINT=.0834     $ ENMSLP=47.7E-6  $ GO TO 21
   13 ENMMIN=.0625      $ ENMINT=.0556     $ ENMSLP=31.8E-6  $ GO TO 21
   14 ENMMIN=.0625      $ ENMINT=.0375     $ ENMSLP=25.7E-6  $ GO TO 21
   15 GO TO 21
   16 GO TO 21
   17 ENMMIN=.0333      $ ENMINT=.0111     $ ENMSLP=15.3E-6  $ GO TO 21
   18 ENMMIN=.0347      $ ENMINT=.0250     $ ENMSLP=17.1E-6  $ GO TO 21
   19 ENMMIN=.0278      $ ENMINT=.0167     $ ENMSLP=4.63E-6  $ GO TO 21
   20 ENMMIN=.0313      $ ENMINT=.0222     $ ENMSLP=6.94E-6  $ GO TO 21
   21 PRSFAC=3.0        $ ENMFAC=1.64
      SIGT=PRSFAC*2.*GSTMOM/((PI/4.)*D**2)
      WEN=ENMFAC*MAX1F(ENMMIN,ENMINT+ENMSLP*SIGT)*HULLWA/TON
      WMISEN=.18*WEN           $ WSUPTD=STLIFT+DYLODD-W(1,5)
      WSUSP=.018*WSUPTD        $ WPGAL=.023*TOTWT
      WBNET=(6.35*ENMMIN*(GSFRAC*(1-DENRAT)*ENVOL)**(2./3.))/TON
      W(1,1)=WEN+WMISEN+WSUSP+WBNET+WPGAL           $ W(1,2)=.014*TOTWT
      W(1,3)= 7.5E-6*GSTSPD*VFPS*TAILA*FINB/TON    $ W(1,4)=0
      GO TO 40
   30 GSTMOM=(33./28.)*GSTMOM           $ SIGREL=1
      SIGREL=2.00
      WMNF=1.26E-4*(D**4)/(SIGREL*TON)$ WINTF=.022*TOTWT/SIGREL
      WLNG=10.3E-6*TOTWT*(L**2)/(D*SIGREL)
      WWIR=18.9E-6*TOTWT*L/SIGREL       $ W(1,1)=WMNF+WINTF+WLNG+WWIR
      WBS=.0086*TOTWT          $ WCOV=.0485*(HULLWA+2.*TAILA)/(SIGREL*TON)
      WCOVW=0                  $ WMISH=.0015*TOTWT
      W(1,2)=WBS+WCOV+WCOVW+WMISH
      W(1,3)= 7.0E-6*GSTSPD*VFPS*TAILA*FINB/TON
      WGSCL=(.0386/SIGREL)*2.*HULLWA/TON           $ WNET=.0020*TOTWT
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      WVAL=.0042*TOTWT       $ W(1,4)=WGSCL+WNET+WVAL
   40 GO TO(41,42,43,44,45),JMENG
   41 WENG=PSACT*(4.0+.020*SZMENG)/(1+.010*SZMENG)      $ GO TO 50
   42 WENG=PSACT*(3.5+.015*SZMENG)/(1+.012*SZMENG)      $ GO TO 50
   43 WENG=PSACT*1.0           $ GO TO 50
   44 WENG=PSACT*6.0           $ GO TO 50
   45 WENG=PSACT*(.8+.002*SZMENG)/(1+.005*SZMENG)       $ GO TO 50
   50 WKUL=.19*PSACT $ WLUB=0            $ WSTRT=.15*PSACT
      WNACL=NMENG*1.9*PI*NACLD*NACLL
      WLOD=WENG+WKUL+WLUB+WNACL+W(2,3)+GERWT      $ WOUT=.01*STRTL*WLOD
      W(2,1)=(WENG+WKUL+WSTRT+WNACL+WOUT)/TON+.07*FUELMX
      W(2,3)=WPROPS
      W(2,4)=.03*S(31)

      IF(JSHIP.EQ.3) GO TO 70
      GERWT=.00027*(2.*GERLN+GERLC)*(TOTWT+DYLODD)
      IF(TOSPD.EQ.0) GERWT=0
      IF(JGEAR.EQ.2.AND.GERLN.LT.1.3*NACLL) GERWT=(4./3.)*GERWT
      W(3,1)=GERWT    $ W(3,2)=.0025*TOTWT
      WACCS=.004*TOTWT       $ WSLEC=.007*TOTWT     $ WAUX=.007*TOTWT
      WHYD=.004*TOTWT        $ WBALS=.007*TOTWT     $ WMNB=.030*TOTWT
      W(3,3)=WACCS+WSLEC+WAUX+WHYD      $ W(3,4)=WBALS+WMNB
      GO TO 80
   70 WMOR=.006*TOTWT        $ WCCAR=(23./TON)*(TOTWT*TON)**(1./3.)
      WCCAR=.005*TOTWT
      WCONT=.003*TOTWT       $ WINS=.0014*TOTWT     $ WRCOM=.0036*TOTWT
      GERWT=.00027*(2.*GERLN+GERLC)*(TOTWT+DYLODD)
      IF(TOSPD.EQ.0) GERWT=0
      IF(JGEAR.EQ.2.AND.GERLN.LT.1.3*NACLL) GERWT=(4./3.)*GERWT
      W(3,1)=WMOR+WCCAR+WCONT+GERWT    $ W(3,2)=WINS+WRCOM
      WGNG=.012*TOTWT        $ WHVEN=.001*TOTWT     $ WSLEC=.007*TOTWT
      WBALS=.005*TOTWT       $ WWREC=2.0*PSACT/TON $ WMNB=.03*TOTWT
      WWREC=0
      W(3,3)=WGNG+WHVEN+WSLEC              $ W(3,4)=WBALS+WWREC+WMNB
C            ACCOMODATIONS GROUP
   80 WPERS=165.*NACCOM/TON              $ WEFF=0
      IF(SHPDUR.GT..05) WEFF=40.*NACCOM/TON
      IF(SHPDUR.GT.2.) WEFF=(20.+10.*SHPDUR)*NACCOM/TON
      W(4,1)=WPERS+WEFF      $ W(4,2)=20.*NACCOM/TON
      IF(SHPDUR.GT..5) W(4,2)=(40.*NCREW+60.*NTRP)/TON
      IF(JSHIP.EQ.2) W(4,2)=W(4,2)+.055*WSUPTD
      IF(SHPDUR.LE..05) GO TO 84         $ IF(SHPDUR.LE..5) GO TO 82
      WPROV=4.5*SHPDUR*NACCOM/TON        $ WWAT=16.*SHPDUR*NACCOM/TON
      WFUR=100.*NACCOM/TON $ WHVP=60.*NACCOM/TON $ GO TO 86
   82 WPROV=4.5*NACCOM/TON $ WWAT=8.*NACCOM/TON
      WFUR=30.*NACCOM/TON  $ WHVP=10.*NACCOM/TON $ GO TO 86
   84 WPROV=0              $ WWAT=0
      WFUR=20.*NACCOM/TON  $ WHVP=0              $ GO TO 86
   86 W(4,3)=WFUR+WHVP     $ W(4,4)=WPROV+WWAT
      DO 91 I=1,4     $ DO 90 J=1,4
   90 W(I,5)=W(I,5)+W(I,J)
   91 PLATWT=PLATWT+W(I,5)
      RETURN    $ END

*     SINGLE-BANK COMPILATION.
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```
      SUBROUTINE VOLUME
      COMMON/DATA/P(10,500),S(800),Q(100),IT(100),C(500)
      EQUIVALENCE(S(800),C(500))
      TYPE REAL L,LD,NACLL,NACLD,NACLLD,NACFRA,NACLCD,NACINT,JETA,LABRAT
      COMMON/CONST/G,GAMMA,PI,RHOAIR,RHOWAT,SPDFPS,TON,VISWAT,VOLWAT
      COMMON/TYPES/JSHIP,JMBOIL,JMENG,JMTRAN,JMPROP,JGAS,JHMAT,JMCONF
      COMMON/TYPES2/JTAIL,JGEAR
      COMMON/PPLNT/SZMBLR,NMBLR,SZMENG,NMENG,SZAENG,NAENG
      COMMON/ACC/NOFF,NCPO,NENL,SHPDUR,NTRP,TRPDUR,NCREW,NACCOM
      COMMON/GEOM1/L,B,H,F,D,CP,CX,CB,CW,LD,BH,DEKHT,NCOMPS
      COMMON/GEOM2/HULLWA,FINA,FINB,FINC,FINAR,FINTC,TAILA,TAILWA
      COMMON/GEOM6/PROPD,TOSPD,TOALF,GERLC,GERLN
      COMMON/GEOM3/CARLEN,CARWID,        CAROVR,OVRMAX,SECLEN,CARFRT
      COMMON/GEOM4/STRTC,STRTL,STRTTC,STRTWA,NACLL,NACLD,NACLLD,NACFRA
      COMMON/CPOW/VKTS,HULLD(4),ETA(4),POWR(4),PSACT,PEACT,JOP
      COMMON/WATE/W(6,5),FIXDIS,TOTWT,PLATWT,STLIFT,EMTWT,SLUSLD,CRUSLD
      COMMON/WATE2/WMNB,WGNG,WBALS,FUELMX,WPROPS
      COMMON/DRGSPC/HEVI,SURUF,TERA,DELTCF,GSTSPD,DYLODD
      COMMON/AIRGAS/TEMRAT,DENRAT,ETAP
      COMMON/VOL/V(6,5),ENVOL,GSFRAC,CARVOL,USEVOL,VR
      DO 5 I=1,4     $ DO 5 J=1,5
    5 V(I,J)=0
      V(2,4)=.05*W(2,4)*TON
      V(3,2)=.10*DEKHT*W(3,2)*TON
      V(3,3)=(.05*W(3,3)+2.*WGNG)*TON
      V(3,4)=.05*W(3,4)*TON
      IF(JSHIP.EQ.3) V(3,4)=.05*(WBALS+WMNB)*TON
      V(4,2)=15.*DEKHT*NACCOM
      IF(SHPDUR.GT..5) V(4,2)=DEKHT*(30.*NCREW+45.*NTRP)
      V(4,4)=.05*W(4,4)*TON          $ V(6,2)=.05*W(6,2)*TON
      DO 95 I=1,4     $ DO 95 J=1,4
   95 V(I,5)=V(I,5)+V(I,J)
      RETURN    $ END

*     SINGLE-BANK COMPILATION.
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```
      SUBROUTINE INVEST
      COMMON/CATA/P(10,500),S(800),Q(100),IT(100),C(500)
      EQUIVALENCE(S(800),C(500))
      TYPE REAL L,LD,NACLL,NACLD,NACLLD,NACFRA,NACLCD,NACINT,JETA,LABRAT
      TYPE REAL MXPLNL,MXCHGL,MXCHGF
      COMMON/CONST/G,GAMMA,PI,RHOAIR,RHOWAT,SPOFPS,TON,VISWAT,VOLWAT
      COMMON/TYPES/JSHIP,JMBOIL,JHENG,JMTRAN,JMPROP,JGAS,JHMAT,JMCONF
      COMMON/TYPES2/JTAIL,JGEAR
      COMMON/PPLNT/SZMBLR,NMBLR,SZMENG,NMENG,SZAENG,NAENG
      COMMON/ACC/NOFF,NCPO,NENL,SHPDUR,NTRP,TRPDUR,NCREW,NACCOM
      COMMON/GEOM1/L,B,H,F,D,CP,CX,CB,CW,LD,BH,DEKHT,NCOMPS
      COMMON/GEOM2/HULLWA,FINA,FINB,FINC,FINAR,FINTC,TAILA,TAILWA
      COMMON/GEOM6/PROPD,TOSPC,TOALF,GERLC,GERLN
      COMMON/GEOM3/CARLEN,CARWID,       CAROVR,OVRMAX,SECLEN,CARFRT
      COMMON/GEOM4/STRTC,STRTL,STRTTC,STRTWA,NACLL,NACLD,NACLLD,NACFRA
      COMMON/DPOW/VKTS,HULLD(4),ETA(4),POWR(4),PSACT,PEACT,JOP
      COMMON/WATE/W(6,5),FIXDIS,TOTWT,PLATWT,STLIFT,EMTWT,SLUSLD,CRUSLD
      COMMON/WATE2/WMNB,WGNG,WBALS,FUELMX,WPROPS
      COMMON/DRGSPC/HEVI,SURUF,TERA,DELTCF,GSTSPD,DYLODD
      COMMON/AIRGAS/TEMRAT,DENRAT,ETAP
      COMMON/COST1/YRCOST,NPROD,FLATR,LABRAT,DELABR,OVRRAT,DEOVER,PROFIT
      COMMON/COST2/CPLAN(3),CTIN(3),CFUT(3),CSTOK(3),CDEV(3)
      COMMON/COST3/CCHNG(3),CSYS(3),CESC(3),CLECG(3),CORDG(3),TOTEND(3)
      COMMON/COST4/FLNLAB,FLNMAT,FLNDEL,FLNDEM,HR(6,5),CM(6,5),HCS(6,5)
      COMMON/COS5/CMCS(6,5),HDE(6,5),CMDE(6,5),HT(6,5),CTL(6,5),CTM(6,5)
      COMMON/COST6/CPRFT(6,5),CBAS(6,5),CGFM(6,5),CTB(6,5)
      COMMON/COST7/HLN(6),CMLN(6),HCSLN(6),CMCSLN(6),HDELN(6),CMDELN(6)
      COMMON/COST8/HTLN(6),CTLLN(6),CTMLN(6),CPFTLN(6),CBLN(6),CTBLN(6)
      COMMON/COST9/HRS,CMS,HCSS,CMCSS,HDES,CMDES,HTS,CTLS,CTMS,CPRFTS
      COMMON/CO10/CBS,CGFMS,CTBS,HRLNS,CMLNS,HCSLNS,CMCSLS,HDELNS,CMDELS
      COMMON/COST11/HTLNS,CTLLNS,CTMLNS,CPFTLS,CBLNS,CGFMLS,CTBLNS
      COMMON/COST12/CENDP,CENDF,CENDF1,CENDAV
C              INITIALIZE THE COST QUANTITIES
      DO 2 I=1,4      $ DO 1 J=1,5
      HR(I,J)=CM(I,J)=HCS(I,J)=CMCS(I,J)=HDE(I,J)=CMDE(I,J)=HT(I,J)=0
    1 CTL(I,J)=CTM(I,J)=CPRFT(I,J)=CBAS(I,J)=CGFM(I,J)=CTB(I,J)=0
      HLN(I)=CMLN(I)=HCSLN(I)=CMCSLN(I)=HDELN(I)=CMDELN(I)=HTLN(I)=0
    2 CTLLN(I)=CTMLN(I)=CPFTLN(I)=CBLN(I)=CTBLN(I)=0
      FLAT=(1.+(FLATR/100.))**(YRCOST-1976.)
      FDELAB=C(401)/100.    $ FDEMAT=C(402)/100.
      FCSLAB=C(403)/100.    $ FCSMAT=C(404)/100.
      OVTRM=1.+OVRRAT/100.              $ DETRM=1.+DEOVER/100.
C             CALCULATE THE LEARNING FACTORS
      RLNLAB=C(437)  $ RLNMAT=C(438)   $ RLNDEL=C(439)   $ RLNDEM=C(440)
      I=1        $ RLN=RLNLAB
    4 FLNT=0     $ DO 5 N=1,NPROD         $ EX=-ALOG(100./RLN)/ALOG(2.)
    5 FLNT=FLNT+N**EX        $ GO TO(6,7,8,9),I
    6 FLNLAB=FLNT/NPROD     $ I=2       $ RLN=RLNMAT      $ GO TO 4
    7 FLNMAT=FLNT/NPROD     $ I=3       $ RLN=RLNDEL      $ GO TO 4
    8 FLNDEL=FLNT/NPROD     $ I=4       $ RLN=RLNDEM      $ GO TO 4
    9 FLNDEM=FLNT/NPROD
C              COMPONENT HOURS AND MATERIAL
      HR(1,1)= 6000.*W(1,1)              $ CM(1,1)=17000.*W(1,1)
      HR(1,2)= 6000.*W(1,2)              $ CM(1,2)=17000.*W(1,2)
      HR(1,3)= 6000.*W(1,3)              $ CM(1,3)=17000.*W(1,3)
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      HR(1,4)= 6000.*W(1,4)                $ CM(1,4)=17000.*W(1,4)
      HR(2,1)= 6000.*W(2,1)                $ CM(2,1)=17000.*W(2,1)
      HR(2,2)= 6000.*W(2,2)                $ CM(2,2)=17000.*W(2,2)
      HR(2,3)= 6000.*W(2,3)                $ CM(2,3)=17000.*W(2,3)
      HR(2,4)= 6000.*W(2,4)                $ CM(2,4)=17000.*W(2,4)
      HR(3,1)= 6000.*W(3,1)                $ CM(3,1)=17000.*W(3,1)
      HR(3,2)= 6000.*W(3,2)                $ CM(3,2)=17000.*W(3,2)
      HR(3,3)= 6000.*W(3,3)                $ CM(3,3)=17000.*W(3,3)
      HR(3,4)= 6000.*W(3,4)                $ CM(3,4)=17000.*W(3,4)
      HR(4,2)= 6000.*W(4,2)                $ CM(4,2)=17000.*W(4,2)
      HR(4,3)= 6000.*W(4,3)                $ CM(4,3)=17000.*W(4,3)
      CM(6,3)=.055*TON*W(6,3)/.01057   $ IF(JGAS.EQ.2) CM(6,3)=0
C               COST CALCULATIONS FOR EACH COMPONENT
      PRODUCT=1./(1.+C(411)/100.)
      IF(JSHIP.EQ.4) PRODUCT=1./(1.+C(416)/100.)
      SUPHRS=C(412)   $ IF(JSHIP.EQ.4) SUPHRS=C(417)
      YRDLAB=C(413)   $ IF(JSHIP.EQ.4) YRDLAB=C(418)
      YRDMAT=C(414)   $ IF(JSHIP.EQ.4) YRDMAT=C(419)
      DO 72 I=1,6     $ DO 72 J=1,4
      HR(I,J)=(1.+SUPHRS/100.)*(1.+YRDLAB/100.)*HR(I,J)/PRODUCT
      CM(I,J)=(1.+YRDMAT/100.)*CM(I,J)
      HCS(I,J)=FCSLAB*HR(I,J)              $ CMCS(I,J)=FCSMAT*CM(I,J)
      HDE(I,J)=FDELAB*HR(I,J)              $ CMDE(I,J)=FDEMAT*CM(I,J)
      HT(I,J)=HR(I,J)+HCS(I,J)+HDE(I,J)
      CTL(I,J)=OVTRM*LABRAT*(HR(I,J)+HCS(I,J))+DETRM*DELABR*HDE(I,J)
      CTM(I,J)=CM(I,J)+CMCS(I,J)+CMDE(I,J)
      CPRFT(I,J)=(PROFIT/100.)*(CTL(I,J)+CTM(I,J))
      CBAS(I,J)=CTL(I,J)+CTM(I,J)+CPRFT(I,J)
   72 CTB(I,J)=CBAS(I,J)+CGFM(I,J)
C               SUMS FOR EACH GROUP
      K=5             $ DO 74 I=1,6        $ DO 74 J=1,4
      HR(I,K)=HR(I,K)+HR(I,J)              $ CM(I,K)=CM(I,K)+CM(I,J)
      HCS(I,K)=HCS(I,K)+HCS(I,J)           $ CMCS(I,K)=CMCS(I,K)+CMCS(I,J)
      HDE(I,K)=HDE(I,K)+HDE(I,J)           $ CMDE(I,K)=CMDE(I,K)+CMDE(I,J)
      HT(I,K)=HT(I,K)+HT(I,J)              $ CGFM(I,K)=CGFM(I,K)+CGFM(I,J)
      CTL(I,K)=CTL(I,K)+CTL(I,J)           $ CTM(I,K)=CTM(I,K)+CTM(I,J)
      CPRFT(I,K)=CPRFT(I,K)+CPRFT(I,J)
      CBAS(I,K)=CBAS(I,K)+CBAS(I,J)
      CTB(I,K)=CTB(I,K)+CTB(I,J)
   74 CGFM(I,K)=CGFM(I,K)+CGFM(I,J)
      IF(NPROD.LE.1) GO TO 78
      K=5         $ DO 76 I=1,6
      HLN(I)=FLNLAB*HR(I,K)                $ CMLN(I)=FLNMAT*CM(I,K)
      HCSLN(I)=FLNLAB*HCS(I,K)             $ CMCSLN(I)=FLNMAT*CMCS(I,K)
      HDELN(I)=FLNDEL*HDE(I,K)             $ CMDELN(I)=FLNDEM*CMDE(I,K)
      HTLN(I)=HLN(I)+HCSLN(I)+HDELN(I)
      CTLLN(I)=OVTRM*LABRAT*(HLN(I)+HCSLN(I))+DETRM*DELABR*HDELN(I)
      CTMLN(I)=CMLN(I)+CMCSLN(I)+CMDELN(I)
      CPFTLN(I)=(PROFIT/100.)*(CTLLN(I)+CTMLN(I))
      CBLN(I)=CTLLN(I)+CTMLN(I)+CPFTLN(I)
   76 CTBLN(I)=CBLN(I)+CGFM(I,K)
C               SUMS LESS DC MARGIN
   78 HRS=HRLNS=CMS=CMLNS=HCSS=HCSLNS=CMCSS=CMCSLNS=HDES=HDELNS=CMDES=0
      CMDELS=HTS=HTLNS=CTLS=CTLLNS=CTMS=CTMLNS=CPRFTS=CPFTLS=CBS=0
      CBLNS=CGFMS=CGFMLS=CTBS=CTBLNS=0
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```
      K=5        $ DO 82 I=1,6
      HRS=HRS+HR(I,K)                   $ HRLNS=HRLNS+HLN(I)
      CMS=CMS+CM(I,K)                   $ CMLNS=CMLNS+CMLN(I)
      HCSS=HCSS+HCS(I,K)                $ HCSLNS=HCSLNS+HCSLN(I)
      CMCSS=CMCSS+CMCS(I,K)             $ CMCSLS=CMCSLS+CMCSLN(I)
      HDES=HDES+HDE(I,K)                $ HDELNS=HDELNS+HDELN(I)
      CMDES=CMDES+CMDE(I,K)             $ CMDELS=CMDELS+CMDELN(I)
      HTS=HTS+HT(I,K)                   $ HTLNS=HTLNS+HTLN(I)
      CTLS=CTLS+CTL(I,K)                $ CTLLNS=CTLLNS+CTLLN(I)
      CTMS=CTMS+CTM(I,K)                $ CTMLNS=CTMLNS+CTMLN(I)
      CPRFTS=CPRFTS+CPRFT(I,K)          $ CPFTLS=CPFTLS+CPFTLN(I)
      CBS=CBS+CBAS(I,K)                 $ CBLNS=CBLNS+CBLN(I)
      CGFMS=CGFMS+CGFM(I,K)             $ CGFMLS=CGFMLS+CGFM(I,K)
      CTBS=CTBS+CTB(I,K)
   82 CTBLNS=CTBLNS+CTBLN(I)
      IF(NPROD.LE.1.) CBLNS=CBS         $ IF(NPROD.LE.1.) CTBLNS=CTBS
C              CALCULATE THE DC MARGIN COST
      SUMC=W(1,5)+W(2,5)+W(3,5)+W(4,2)+W(4,3)+W(5,5)
      CRAT=W(6,1)/SUMC
      HR(6,1)=HR(6,5)=CRAT*HRS          $ HLN(6)=CRAT*HRLNS
      CM(6,1)=CM(6,5)=CRAT*CMS          $ CMLN(6)=CRAT*CMLNS
      HCS(6,1)=HCS(6,5)=CRAT*HCSS       $ HCSLN(6)=CRAT*HCSLNS
      CMCS(6,1)=CMCS(6,5)=CRAT*CMCSS    $ CMCSLN(6)=CRAT*CMCSLS
      HDE(6,1)=HDE(6,5)=CRAT*HDES       $ HDELN(6)=CRAT*HDELNS
      CMDE(6,1)=CMDE(6,5)=CRAT*CMDES    $ CMDELN(6)=CRAT*CMDELS
      HT(6,1)=HT(6,5)=CRAT*HTS          $ HTLN(6)=CRAT*HTLNS
      CTL(6,1)=CTL(6,5)=CRAT*CTLS       $ CTLLN(6)=CRAT*CTLLNS
      CTM(6,1)=CTM(6,5)=CRAT*CTMS       $ CTMLN(6)=CRAT*CTMLNS
      CPRFT(6,1)=CPRFT(6,5)=CRAT*CPRFTS
      CPFTLN(6)=CRAT*CPFTLS             $ CGFM(6,1)=CGFM(6,5)=0.
      CBAS(6,1)=CBAS(6,5)=CRAT*CBS      $ CBLN(6)=CRAT*CBLNS
      CTB(6,1)=CTB(6,5)=CBAS(6,1)+CGFM(6,1)
      CTBLN(6)=CBLN(6)+CGFM(6,5)
C              SUMS WITH DC MARGIN
      I=6        $ K=5
      HRS=HRS+HR(I,K)                   $ HRLNS=HRLNS+HLN(I)
      CMS=CMS+CM(I,K)                   $ CMLNS=CMLNS+CMLN(I)
      HCSS=HCSS+HCS(I,K)                $ HCSLNS=HCSLNS+HCSLN(I)
      CMCSS=CMCSS+CMCS(I,K)             $ CMCSLS=CMCSLS+CMCSLN(I)
      HDES=HDES+HDE(I,K)                $ HDELNS=HDELNS+HDELN(I)
      CMDES=CMDES+CMDE(I,K)             $ CMDELS=CMDELS+CMDELN(I)
      HTS=HTS+HT(I,K)                   $ HTLNS=HTLNS+HTLN(I)
      CTLS=CTLS+CTL(I,K)                $ CTLLNS=CTLLNS+CTLLN(I)
      CTMS=CTMS+CTM(I,K)                $ CTMLNS=CTMLNS+CTMLN(I)
      CPRFTS=CPRFTS+CPRFT(I,K)          $ CPFTLS=CPFTLS+CPFTLN(I)
      CBS=CBS+CBAS(I,K)                 $ CBLNS=CBLNS+CBLN(I)
      CGFMS=CGFMS+CGFM(I,K)             $ CGFMLS=CGFMLS+CGFM(I,K)
      CTBS=CTBS+CTB(I,K)                $ CTBLNS=CTBLNS+CTBLN(I)
C            END-COST INCREMENTS AND END COSTS
      CSTMRG=C(415)  $ IF(JSHIP.EQ.4) CSTMRG=C(420)
      FPLNL=C(421)          $ MXPLNL=C(422)          $ FSYSL=C(423)
      FSYSF=C(424)   $ IF(JSHIP.EQ.4) FSYSL=C(425)
      FCHGL=C(427)          $ MXCHGL=C(428)          $ FCHGF=C(429)
      MXCHGF=C(430)         $ FLECL=C(431)           $ FLECF=C(432)
      FORDL=C(433)          $ FORDF=C(434)           $ FESCL=C(435)
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      FESCF=C(436)
      CPLAN(1)=MIN1F((FPLNL/100.)*CBS,MXPLNL)
      CPLAN(3)=CPLAN(2)     $ CSYS(3)=(FSYSF/100.)*(CBS+CPLAN(3))
      CSYS(1)=(FSYSL/100.)*(CBS+CPLAN(1))
      CSYS(2)=(FSYSF/100.)*(CBLNS+CPLAN(2))
      CDEV(3)=CDEV(2)
      CCHNG(1)=MIN1F((FCHGL/100)*CBS,MXCHGL)
      CCHNG(2)=MIN1F((FCHGF/100.)*CBLNS,MXCHGF)
      CCHNG(3)=MIN1F((FCHGF/100.)*CBS,MXCHGF)
      CLECG(1)=(FLECL/100.)*CGFM(6,1) $ CLECG(2)=(FLECF/100.)*CGFM(6,1)
      CORDG(1)=(FORDL/100.)*CGFM(6,2) $ CORDG(2)=(FORDF/100.)*CGFM(6,2)
      CLECG(3)=CLECG(2)     $ CORDG(3)=CORDG(2)
      CESC(1)=(FESCL/100.)*(CBS+CPLAN(1)+CSYS(1))
      CESC(2)=(FESCF/100.)*(CBLNS+CPLAN(2)+CSYS(2))
      CESC(3)=(FESCF/100.)*(CBS+CPLAN(3)+CSYS(3))
      CTIN(3)=CTIN(2)       $ CSTOK(3)=CSTOK(2)    $ CFUT(3)=CFUT(2)
      DO 88 I=1,3
   88 TOTEND(I)=CPLAN(I)+CCHNG(I)+CESC(I)+CLECG(I)+CORDG(I)
     1+CSYS(I)+CDEV(I)+CTIN(I)+CSTOK(I)+CFUT(I)
      CENDP=CTBS+TOTEND(1) $ CENDF=CTBLNS+TOTEND(2)
      CENDF1=CTBS+TOTEND(3)
      CENDP=(1.+CSTMRG/100.)*(CENDP-CESC(1)-CFUT(1))+CESC(1)+CFUT(1)
      CENDF=(1.+CSTMRG/100.)*(CENDF-CESC(2)-CFUT(2))+CESC(2)+CFUT(2)
      CENDF1=(1.+CSTMRG/100.)*(CENDF1-CESC(3)-CFUT(3))+CESC(3)+CFUT(3)
      CENDAV=(NPROD*CTBLNS+TOTEND(1)+(NPROD-1)*TOTEND(2))/NPROD
      RETURN    $ END

*    SINGLE-BANK COMPILATION.
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      SUBROUTINE PRINT
      COMMON/DATA/P(10,500),S(800),Q(100),IT(100),C(500)
      EQUIVALENCE(S(800),C(500))
      TYPE REAL L,LD,NACLL,NACLC,NACLLD,NACFRA,NACLCD,NACINT,JETA,LABRAT
      COMMON/CONST/G,GAMMA,PI,RHOAIR,RHOWAT,SPDFPS,TON,VISWAT,VOLWAT
      COMMON/TYPES/JSHIP,JMBOIL,JMENG,JMTRAN,JMPROP,JGAS,JHMAT,JMCONF
      COMMON/TYPES2/JTAIL,JGEAR
      COMMON/PPLNT/SZMBLR,NMBLR,SZMENG,NMENG,SZAENG,NAENG
      COMMON/ACC/NOFF,NCPO,NENL,SHPDUR,NTRP,TRPDUR,NCREW,NACCOM
      COMMON/GEOM1/L,B,H,F,D,CP,CX,CB,CW,LD,BH,DEKHT,NCOMPS
      COMMON/GEOM2/HULLWA,FINA,FINB,FINC,FINAR,FINTC,TAILA,TAILWA
      COMMON/GEOM6/PROPD,TOSPD,TOALF,GERLC,GERLN
      COMMON/GEOM3/CARLEN,CARWID,      CAROVR,OVRMAX,SECLEN,CARFRT
      COMMON/GEOM4/STRTC,STRTL,STRTTC,STRTWA,NACLL,NACLD,NACLLD,NACFRA
      COMMON/DPOW/VKTS,HULLD(4),ETA(4),POWR(4),PSACT,PEACT,JOP
      COMMON/WATE/W(6,5),FIXDIS,TOTWT,PLATWT,STLIFT,EMTWT,SLUSLD,CRUSLD
      COMMON/WATE2/WMNB,WGNG,WBALS,FUELMX,WPROPS
      COMMON/DRGSPC/HEVI,SURUF,TERA,DELTCF,GSTSPD,DYLODD
      COMMON/AIRGAS/TEMRAT,DENRAT,ETAP
      COMMON/PRNTD1/CHCFH4,CHCFT4,CD04,ETA4,HULCD4,TALCD4,CBLCD4,CARCD4
      COMMON/PRNTD2/SRTCD4,NCLCD4,NCINT4,ENGCD4,DRGZRO,DRGLIF,ALFPRT
      TYPE REAL NCLCD4,NCINT4
      COMMON/VOL/V(6,5),ENVOL,GSFRAC,CARVOL,USEVOL,VR
      COMMON/HIST1/MXVIT,HNWT(9),HTOTWT(9),HCALWT(9),HF(9)
      COMMON/COST1/YRCOST,NPROD,FLATR,LABRAT,DELABR,OVRRAT,DEOVER,PROFIT
      COMMON/COST2/CPLAN(3),CTIN(3),CFUT(3),CSTOK(3),CDEV(3)
      COMMON/COST3/CCHNG(3),CSYS(3),CESC(3),CLECG(3),COPDG(3),TOTEND(3)
      COMMON/COST4/FLNLAB,FLNMAT,FLNDEL,FLNDEM,HR(6,5),CM(6,5),HCS(6,5)
      COMMON/COS5/CMCS(6,5),HDE(6,5),CMDE(6,5),HT(6,5),CTL(6,5),CTM(6,5)
      COMMON/COST6/CPRFT(6,5),CBAS(6,5),CGFM(6,5),CTB(6,5)
      COMMON/COST7/HLN(6),CMLN(6),HCSLN(6),CMCSLN(6),HDELN(6),CMDELN(6)
      COMMON/COST8/HTLN(6),CTLLN(6),CTMLN(6),CPFTLN(6),CBLN(6),CTBLN(6)
      COMMON/COST9/HRS,CMS,HCSS,CMCSS,HDES,CMDES,HTS,CTLS,CTMS,CPRFTS
      COMMON/CO10/CBS,CGFMS,CTBS,HRLNS,CMLNS,HCSLNS,CMCSLS,HDELNS,CMDELS
      COMMON/COST11/HTLNS,CTLLNS,CTMLNS,CPFTLS,CBLNS,CGFMLS,CTBLNS
      COMMON/COST12/CENOP,CENCF,CENDF1,CENDAV
      COMMON/OFF1/MXSPD,MXALT,NALT,OFFALT(10),OFFSPD(10),OFFRNG(10,10)
      COMMON/OFF2/OFFEND(10,10),OFFPOW(10,10),OFFGPH(10,10),OFFUSE(10)
      COMMON/PRINT1/ICONST,ITECH,ICOST,NSHIP,NCASE,CALWT,PSREQ,PEREQ
      COMMON/PRINT2/VMXACT,VMXRNG,VSACT,VSRNG,VEACT,VERNG,GPHR
      DIMENSION NS(100),NTYP(15),NCOMP(6,5),SR(60),NSR(60)
      DIMENSION WPCT(6,5),VPCT(6,5),CPCT(6,5)
      COMMON/CONTROL/NWT,FP,STATLW,DYLW
      COMMON/WTPRNT/SIGT
C           SET THE SPECIFICATION NAMES
    1 IF(FIXDIS.NE.0) CALWT=TOTWT
      NS(1)=8HSUS SPD      $ NS(26)=8HDCMRGPCT   $ NS(51)=8HYEARCOST
      NS(2)=8HEND SPD      $ NS(27)=8HSPCL PAY   $ NS(52)=8HNUM PROD
      NS(3)=8HEND RNGE     $ NS(28)=8HSPCLDEKA   $ NS(53)=8HMAT FLAT
      NS(4)=8HCPS ALT      $ NS(29)=8HSPCL CG    $ NS(54)=8HLAB FLAT
      NS(5)=8HOFFACCOM     $ NS(30)=8HFIX DIS    $ NS(55)=8HLAB RATE
      NS(6)=8HCPOACCOM     $ NS(31)=8HELECT KW   $ NS(56)=8HDE LABOR
      NS(7)=8HENLACCOM     $ NS(32)=8HSZ MNBLR   $ NS(57)=8HOVRHEAD
      NS(8)=8HSHIPDAYS     $ NS(33)=8HNUMMNBLR   $ NS(58)=8HDEOVRHED
      NS(9)=8HPASACCOM     $ NS(34)=8HSZ MNENG   $ NS(59)=8HPROFIT
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      NS(10)=8HPASSDAYS    $ NS(35)=8HNUMMNENG    $ NS(60)=8H
      NS(11)=8HL/D         $ NS(36)=8HSZ ALTNG    $ NS(61)=8HPLANS F
      NS(12)=8HCONSTDIA    $ NS(37)=8HNUMALTNG    $ NS(62)=8HDEVEL L
      NS(13)=8HPRISCOEF    $ NS(38)=8H            $ NS(63)=8HDEVEL F
      NS(14)=8H            $ NS(39)=8H            $ NS(64)=8HSTOKSP L
      NS(15)=8H            $ NS(40)=8H            $ NS(65)=8HSTOKSP F
    2 NS(16)=8HGASALTIN    $ NS(41)=8HPRT TPGS    $ NS(66)=8HTST IN L
      NS(17)=8HDLMPMXZ     $ NS(42)=8HPRT CPGS    $ NS(67)=8HTST IN F
      NS(18)=8HGAS PURE    $ NS(43)=8HWTOL PCT    $ NS(68)=8HFUTURE L
      NS(19)=8HGUST FPS    $ NS(44)=8HMX W ITS    $ NS(69)=8HFUTURE F
      NS(20)=8HTOSPDKTS    $ NS(45)=8HVOL TOL     $ NS(70)=8H
      NS(21)=8HTO ALPHA    $ NS(46)=8HMX V ITS    $ NS(71)=8HMX CASES
      NS(22)=8HRUFNSMIL    $ NS(47)=8H            $ NS(72)=8HVARIABLE
      NS(23)=8HDELTCF      $ NS(48)=8H            $ NS(73)=8HFIRST
      NS(24)=8H            $ NS(49)=8H            $ NS(74)=8HCHANGE
      NS(25)=8HCRS PRAT    $ NS(50)=8H            $ NS(75)=8H
      NS(76)=8HSHIPTYPE    $ NS(81)=8HLIFT GAS    $ NS(86)=8HHULL MAT
      NS(77)=8HMAINBOIL    $ NS(82)=8HLANDGEAR    $ NS(87)=8H
      NS(78)=8HMAIN ENG    $ NS(83)=8HALT ENG     $ NS(88)=8H
      NS(79)=8HMAINTRAN    $ NS(84)=8HALT TRAN    $ NS(89)=8H
      NS(80)=8HMAINPROP    $ NS(85)=8HALT PROP    $ NS(90)=8HTAILTYPE
C             SET THE TYPE NAMES
    3 NTYP(1)=8HBALLOON    $ IF(JSHIP.EQ.2) NTYP(1)=8HBLIMP
      IF(JSHIP.EQ.3) NTYP(1)=8HDIRIGIBL
      NTYP(2)=8HNONE
      GO TO(101,102,103,104,105),JMENG
  101 NTYP(3)=8HDIESLHO    $ IF(JMCONF.EQ.2) NTYP(3)=8HDIESLRAD
      IF(JMCONF.EQ.3) NTYP(3)=8HDIESLVEE       $ GO TO 110
  102 NTYP(3)=8HRECIPHO    $ IF(JMCONF.EQ.2) NTYP(3)=8HRECIPRAD
      IF(JMCONF.EQ.3) NTYP(3)=8HRECIPVEE       $ GO TO 110
  103 NTYP(3)=8HOILSTEAM   $ GO TO 110
  104 NTYP(3)=8HSTIRLING   $ GO TO 110
  105 NTYP(3)=8HTURBPROP
  110 NTYP(4)=8HNONE
      NTYP(5)=8H2BLDPROP   $ IF(JMPROP.EQ.3) NTYP(5)=8H3BLDPROP
      IF(JMPROP.EQ.4) NTYP(5)=8H4BLDPROP
      NTYP(6)=8HHELIUM     $ IF(JGAS.EQ.2) NTYP(6)=8HHYDROGEN
      NTYP(7)=8H           $ NTYP(8)=8HNONE       $ NTYP(9)=8HNONE
      NTYP(7)=8HFIXED      $ IF(JGEAR.EQ.2) NTYP(7)=8HRETROTBL
      NTYP(10)=8HNONE      $ NTYP(11)=8H          $ NTYP(12)=8H
      NTYP(11)=8HCOTNRUBR  $ IF(JHMAT.EQ.3) NTYP(11)=8H3PLYRUBR
      IF(JHMAT.EQ.4) NTYP(11)=8HNPRENDAC
      IF(JHMAT.EQ.7) NTYP(11)=8HBIAXDAC
      IF(JHMAT.EQ.8) NTYP(11)=8HTRIAXDAC
      IF(JHMAT.EQ.9) NTYP(11)=8HBIXKEVLR
      IF(JHMAT.EQ.10) NTYP(11)=8HTRIKEVLR
      NTYP(13)=8H          $ NTYP(14)=8H
      NTYP(15)=8HCRUCFORM  $ IF(JTAIL.EQ.2) NTYP(15)=8HX-FORM
      IF(JTAIL.EQ.3) NTYP(1  =8HINVERT Y
C               PRINT THE SPECIFICATIONS
      IF(NCASE.NE.0) GO TO 6      $ PRINT 7,NSHIP     $ GO TO 10
    6 PRINT 8,NSHIP,NCASE
    7 FORMAT(1H1,10X*SHIP NUMBER*I4)
    8 FORMAT(1H1,10X*SHIP NUMBER*I4,5X*CASE NUMBER*I4)
    9 FORMAT(1H )
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10 PRINT 11         $ DO 12 J=1,25
11 FORMAT(1H0,32X*SHIP SPECIFICATIONS*/)
12 PRINT 13,NS(J),S(J),NS(J+25),S(J+25),NS(J+50),S(J+50)
13 FORMAT(1H ,10X,3(A8,F11.2,2X))
   PRINT 9          $ DO 14 J=1,5
14 PRINT 15,NS(J+75),NTYP(J),NS(J+80),NTYP(J+5),NS(J+85),NTYP(J+10)
15 FORMAT(1H ,10X,3(A8,1X,A8,4X))
C          PRINT THE CONSTANTS
   IF(ICONST.NE.1.) GO TO 21   $  IF(NCASE.GT.1) GO TO 21
   PRINT 7,NSHIP          $ PRINT 17
17 FORMAT(1H0,29X*SHIP CONSTANTS*/)
   DO 18 I=1,50       $  J=50+I  $  K=100+I  $  M=150+I  $ N=200+I
18 PRINT 19,I,C(I),J,C(J),K,C(K),M,C(M),N,C(N)
19 FORMAT(4X,5(I3,1X,E9.2,2X))
   PRINT 7,NSHIP          $ PRINT 17
   DO 20 I=251,300    $  J=50+I  $  K=100+I  $  M=150+I  $ N=200+I
20 PRINT 19,I,C(I),J,C(J),K,C(K),M,C(M),N,C(N)
C          SET DATA FOR SUMMARY OF RESULTS
21 SR(1)=VMXACT         $ SR(21)=EMTWT          $ SR(41)=YRCOST
   SR(2)=VMXRNG         $ SR(22)=W(6,1)         $ SR(42)=NPROD
   SR(3)=VSACT          $ SR(23)=SLUSLD         $ SR(43)=CENDP/1E6
   SR(4)=VSRNG          $ SR(24)=STLIFT         $ SR(44)=CENDF1/1E6
   SR(5)=VEACT          $ SR(25)=CALWT          $ SR(45)=CENCF/1E6
   SR(6)=VERNG          $ SR(26)=DYLODD         $ SR(46)=CENDAV/1E6
   SR(7)=PSREQ          $ SR(27)=W(5,5)         $ SR(47)=0.
   USFRAC=100.*SLUSLD/STLIFT
   SR(8)=PSACT          $ SR(28)=USFRAC         $ SR(48)=ENVOL/1000.
   SR(9)=PEREQ          $ SR(29)=NCREW          $ SR(49)=100.*GSFRAC
   SR(10)=PEACT         $ SR(30)=NTRP           $ SR(50)=CARVOL/1000.
   SR(11)=0.            $ SR(31)=0.             $ SR(51)=USEVOL/1000.
   SR(12)=L             $ SR(32)=PROPD          $ SR(52)=0.
   SR(13)=D             $ SR(33)=NACLD          $ SR(53)=GPHR
   SR(14)=CARLEN        $ SR(34)=GERLN          $ SR(54)=ALFPRT
   SR(15)=CARWID        $ SR(35)=TOALF          $ SR(55)=STLIFT/DRGZRO
   SR(16)=0             $ SR(36)=SIGT/12.       $ SR(56)=DYLODD/DRGLIF
   SR(56)=(STLIFT+DYLODD)/(DRGZRO+DRGLIF)
   SR(17)=CHCFH4        $ SR(37)=DYLODD/STLIFT$ SR(57)=FP
   SR(18)=CHCFT4        $ SR(38)=TALCD4         $ SR(58)=SRTCD4
   SR(19)=CD04          $ SR(39)=CARCD4         $ SR(59)=NCLCD4
   SR(20)=ETA4          $ SR(40)=ENGCD4         $ SR(60)=NCINT4
   NSR(1)=8HMAX  SPD    $ NSR(21)=8HEMTY WT     $ NSR(41)=8HYR COSTS
   NSR(2)=8HMXSPDRNG    $ NSR(22)=8HDCMARGIN    $ NSR(42)=8HNO.PROD
   NSR(3)=8HACT SSPD    $ NSR(23)=8HSL USELD    $ NSR(43)=8HENDCOSTP
   NSR(4)=8HSUSPDRNG    $ NSR(24)=8HSTATLIFT    $ NSR(44)=8HENDFRSTF
   NSR(5)=8HACT ESPD    $ NSR(25)=8HTOTAL WT    $ NSR(45)=8HENDCOSTF
   NSR(6)=8HENDRANGE    $ NSR(26)=8HDYN LOAD    $ NSR(46)=8HENDCOSTA
   NSR(7)=8HPEQ SPOW    $ NSR(27)=8HPAYLD WT    $ NSR(47)=8H
   NSR(8)=8HACT SPOW    $ NSR(28)=8HSLUSE/ST    $ NSR(48)=8HENVOLKF3
   NSR(9)=8HREQ EPOW    $ NSR(29)=8HSHIPCREW    $ NSR(49)=8HGSVOLPCT
   NSR(10)=8HACT EPOW   $ NSR(30)=8HNUM PASS    $ NSR(50)=8HCRVOLKF3
   NSR(11)=8H           $ NSR(31)=8H            $ NSR(51)=8HUSVOLKF3
   NSR(12)=8HHULLNGTH   $ NSR(32)=8HPROPDIAM    $ NSR(52)=8H
   NSR(13)=8HHULLDIAM   $ NSR(33)=8HNACLDIAM    $ NSR(53)=8HGALS/HR
   NSR(14)=8HCARLENTH   $ NSR(34)=8HGERLENTH    $ NSR(54)=8HALPHADEG
   NSR(15)=8HCARWIDTH   $ NSR(35)=8HTO ALPHA    $ NSR(55)=8HSTAT L/D
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      NSR(16)=8HTOGRNRUN    $ NSR(36)=8HFABLB/IN   $ NSR(56)=8HLIFT/DRG
      NSR(17)=8HCHNG HCF    $ NSR(37)=8HDYNRATIO   $ NSR(57)=8HNEWTPRIM
      NSR(18)=8HCHNG TCF    $ NSR(38)=8HTALCDPCT   $ NSR(58)=8HSTRCDPCT
      NSR(19)=8HSSPDCD04    $ NSR(39)=8HCARCDPCT   $ NSR(59)=8HNACCDPCT
      NSR(20)=8HFPOP ETA    $ NSF(40)=8HENGCDPCT   $ NSR(60)=8HNACINPCT
C              PRINT THE SUMMARY OF RESULTS
      IF(NCASE.NE.0.) GO TO 22          $ PRINT 7,NSHIP      $ GO TO 23
   22 PRINT 8,NSHIP,NCASE
   23 IF(NWT.EQ.9) PRINT 25
   25 FORMAT(1H ,10X*RESULT MAY BE INVALID, 9 WEIGHT ITERATIONS*)
      IF(FP.GE.-.05) PRINT 27,FP
   27 FORMAT(1H ,10X*RESULT SENSITIVE OR INVALID, NEWTON,PRIME IS*F6.2)
      PRINT 31           $ DO 32 J=1,20
   31 FORMAT(1H0,32X,*SUMMARY OF RESULTS*/)
   32 PRINT 33,NSR(J),SR(J),NSR(J+20),SR(J+20),NSR(J+40),SR(J+40)
   33 FORMAT(1H ,10X,3(A8,F11.2,2X))
      PRINT 9
C              PRINT THE END-COST INCREMENTS
      PRINT 35,CPLAN(1),CPLAN(2),CSTOK(1),CSTOK(2),CCHNG(1),CCHNG(2),
     1CDEV(1),CDEV(2),CSYS(1),CSYS(2),CLECG(1),CLECG(2),CESC(1),CESC(2),
     2CORDG(1),CORDG(2),CTIN(1),CTIN(2),TOTEND(1),TOTEND(2),
     3CFUT(1),CFUT(2),CENDP,CENDF
   35 FORMAT (1H0,31X*END COST INCREMENTS*//27X*PROTO*2X*FOLLOW*19X
     1*PROTO*2X*FOLLOW*/29X*K$*6X*K$*22X*K$*6X*K$*/11X*CONST PLANS*2X,
     2-3P,2(F8.0),3X*STOK SPARES*2X,2(F8.0)/
     311X*CHANGE ORDERS*2(F8.0),3X*DEVELOPMENT*2X,2(F8.0)/
     411X*SHP SYS ENG*2X,2(F8.0),3X*LECTRN GROWTH*2(F8.0)/
     511X*ESCALATION*3X,2(F8.0),3X*ORDNCE GROWTH*2(F8.0)/
     611X*TEST+INSTRUM*1X,2(F8.0),3X*TOT INCREMENT*2(F8.0)/
     711X*FUT CHAR CHG*1X,2(F8.0),3X*END COST*5X,2(F8.0)/)
C              PRINT THE ITERATION HISTORY
      PRINT 37           $ DO 38 I=1,9
   37 FORMAT(1H0,32X,*ITERATION HISTORY*//11X*VOL*2X*WT*3X*TOTWT*4X
     1*CALWT*2X,6X,     2X*VOLRAT*3X,3X, 2X,5X,   2X,6X,     /12X*IT*1X
     2*ITS*4X*KLBS*5X*KLBS*3X,4X,  5X*PCT*10X,4X,  4X,3X)
      IF(HNWT(I).EQ.0.) GO TO 40
   38 PRINT 39,I,HNWT(I),HTOTWT(I),HCALWT(I)
   39 FORMAT(11X,I2,F4.0,1X,F9.1,F9.1)
C              PRINT OFF-DESIGN PERFORMANCE
   40 IF(MXSPD.LT.1.AND.MXALT.LT.1) GO TO 50
      IF(NCASE.NE.0.) GO TO 41          $ PRINT 7,NSHIP  $ GO TO 42
   41 PRINT 8,NSHIP,NCASE
   42 PRINT 43
   43 FORMAT(1H0,28X*OFF-DESIGN SPEED AND RANGE*//12X*ALT*2X*SPED*2X
     1*ALT*1X*SPEED*1X*RANGE*2X*ENDUR*2X*PPOWR*2X*GALS/*2X*USELOD*/11X
     2*CASE*2X*CASE*2X*KFT* 1X*KNOTS*1X*NMILE*2X*HOURS*4X*HP*4X
     3*HOUR*3X*KLBS*)
      DO 46 NALT=1,MXALT    $ DO 46 NSPD=1,MXSPD
      IF(NSPD.EQ.1) PRINT 9$ IF(OFFRNG(NALT,NSPD).EQ.0) GO TO 46
   44 PRINT 45,NALT,NSPD,OFFALT(NALT),OFFSPD(NSPD),OFFRNG(NALT,NSPD),
     1OFFEND(NALT,NSPD),OFFPOW(NALT,NSPD),OFFGPH(NALT,NSPD),OFFUSE(NALT)
   45 FORMAT(1H ,11X,I2,4X,I2,1X,-3PF5.1,1X,0PF4.0,   2(1X,F6.0,1X,F6.1)
     1,2X,F6.1)
   46 CONTINUE
C              SET THE COMPONENT NUMBERS AND NAMES
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50 IF(ITECH.LT.1.AND.ICOST.LT.1.) GO TO 100
   NCOMP(1,1)=8HBASCSTRC               $ NCOMP(1,2)=8HSECSTRUC
   NCOMP(1,3)=8HTAILSTRC               $ NCOMP(1,4)=8HGASYSTEM
   NCOMP(1,5)=8HSTRUCTUR               $ NCOMP(2,1)=8HMNPPLNT
   NCOMP(2,2)=8HALTPPLNT               $ NCOMP(2,3)=8HPROPULSR
   NCOMP(2,4)=8HLECTPLNT               $ NCOMP(2,5)=8HPROPULSN
   NCOMP(3,1)=8HSTERTRM                $ NCOMP(3,2)=8HNAV,COMM
   NCOMP(3,3)=8HSHPFACIL               $ NCOMP(3,4)=8HBALLAST
   NCOMP(3,5)=8HCONTROLS               $ NCOMP(4,1)=8HPERS,EFF
   NCOMP(4,2)=8HPERSENCL               $ NCOMP(4,3)=8HPERSFACL
   NCOMP(4,4)=8HPERSTORS               $ NCOMP(4,5)=8HACCOMMS
   NCOMP(5,1)=8HLECTRONS               $ NCOMP(5,2)=8HWEAPONS
   NCOMP(5,3)=8HCARGO                  $ NCOMP(5,4)=8HSPECIAL
   NCOMP(5,5)=8HPAYLOAD                $ NCOMP(6,1)=8HDCMARGIN
   NCOMP(6,2)=8HSHIPFUEL               $ NCOMP(6,3)=8HLIFT GAS
   NCOMP(6,4)=8HAIR                    $ NCOMP(6,5)=8HLOADS
C              PRINT THE DETAIL TECHNICAL RESULTS
   IF(ITECH.LT.1) GO TO 60
   IF(NCASE.NE.0.) GO TO 51            $ PRINT 7,NSHIP     $ GO TO 52
51 PRINT 8,NSHIP,NCASE
52 PRINT 53          $ TOTPCT=100.
53 FORMAT(1H0,33X*DETAILED RESULTS*//11X*COMP*3X*NAME*3X,2(*WEIGHT*1X
  1),1X,2(*VOLUME*1X),2(*CTBAS*1X)   *MOMENT*/26X*KLBS*4X*PCT*4X
  2*KFT3*4X*PCT*4X*K$*3X*PCT*2X*KFTTON*)
   DO 54 I=1,6       $ DO 54 J=1,5     $ K=10*I+J $ IF(J.EQ.5) K=10*I
   WPCT(I,J)=100.*W(I,J)/CALWT         $ VPCT(I,J)=100.*V(I,J)/VR
   CPCT(I,J)=100.*CTB(I,J)/CTBS
   PRINT 55,K,NCOMP(I,J),W(I,J),WPCT(I,J),V(I,J),VPCT(I,J),
  1CTB(I,J),CPCT(I,J)
54 IF(J.EQ.5) PRINT 9
55 FORMAT(1H ,11X,I2,2X,A8,F8.1,F6.1,-3PF8.1,0PF6.1,-3PF7.0,0PF6.1)
   PRINT 56,CALWT,TOTPCT,VR,TOTPCT,CTBS,TOTPCT
56 FORMAT(16X*TOTAL*3X,F8.1,F6.1,-3PF8.1,0PF6.1,-3PF7.0,0PF6.1)
C              PRINT THE DETAIL COSTS WITHOUT LEARNING
60 IF(ICOST.LT.1.) GO TO 100
   IF(NCASE.NE.0) GO TO 62             $ PRINT 7,NSHIP     $ GO TO 64
62 PRINT 8,NSHIP,NCASE
64 PRINT 65
65 FORMAT (1H0,26X*DETAIL COSTS WITHOUT LEARNING*//11X*COMP*3X*NAME*
  13X,3(*TOTAL*2X)*PROFIT*1X*BASIC*4X*GFM*2X*TOTAL*/25X*HOURS*2X
  2*LABOR*1X*MATFRIAL*1X*COST*2X*CONST*3X*COST*2X*BASIC*/
  325X*THOUS*5X*K$*5(5X*K$*))
   DO 68 I=1,6       $ DO 68 J=1,5     $ K=10*I+J $ IF(J.EQ.5) K=10*I
   PRINT 67,K,NCOMP(I,J),HT(I,J),CTL(I,J),CTM(I,J),
  1CPRFT(I,J),CBAS(I,J),CGFM(I,J),CTB(I,J)
67 FORMAT(1H ,11X,I2,2X,A8,-3PF6.0,6(F7.0))
68 IF(J.EQ.5) PRINT 9
   PRINT 69,HTS,CTLS,CTMS,CPRFTS,CBS,CGFMS,CTBS
69 FORMAT(1H ,15X*TOTAL*3X,-3PF6.0,6(F7.0))
C              PRINT GROUP COSTS WITH,WITHOUT LEARNING
   IF(NPROD.LE.1) GO TO 90  $ IF(ICOST.LT.2.) GO TO 100
   IF(NCASE.NE.0) GO TO 70             $ PRINT 7,NSHIP     $ GO TO 72
70 PRINT 8,NSHIP,NCASE
72 PRINT 73          $ DO 74  I=1,6    $ K=5              $ M=10*I
73 FORMAT (1H0,18X,*FOLLOWSHIP GROUP TOTALS WITH, WITHOUT LEARNING*//
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  111X*COMP*3X*NAME*3X*LABOR*2X*MATER*3X*C S*4X*C S*2(4X*D+E*),3X
  2*TOTAL*/23X,3(2X*HOURS*3X*COST*),2X*HOURS*/22X,3(3X*THOUS*4X*K$*),
  33X*THOUS*)
74 PRINT 75,M,NCOMP(I,K),HR(I,K),CM(I,K),HCS(I,K),
  1CMCS(I,K),HDE(I,K),CMDE(I,K),HT(I,K),HLN(I),CMLN(I),HCSLN(I),
  2CMCSLN(I),HDELN(I),CMDELN(I),HTLN(I)
75 FORMAT(1H ,11X,I2,2X,A8/16X*WITHOUT*  ,-3P,7(F7.0)/
  116X*WITH*3X,7(F7.0))
   PRINT 77,HRS,CMS,HCSS,CMCSS,HDES,CMDES,HTS,HRLNS,CMLNS,HCSLNS,
  1CMCSLS,HDELNS,CMDELS,HTLNS
77 FORMAT(1H ,11X*TOTAL*/16X*WITHOUT*   -3P,7(F7.0)/16X
  1*WITH*3X,7(F7.0))
   PRINT 79       $ DO 80 I=1,6     $ K=5          $ M=10*I
79 FORMAT(1H0,10X*COMP*3X*NAME*3X*TOTAL*1X*TOTLAB*1X*TOTMAT*2X
  1*PROFIT*1X*BASIC*3X*GFM*1X*TOT BAS*/25X*HOURS*6(3X*COST*)/
  225X*THOUS*6(5X*K$*))
80 PRINT 81,M,NCOMP(I,K),HT(I,K),CTL(I,K),CTM(I,K),
  1CPRFT(I,K),CBAS(I,K),CGFM(I,K),CTB(I,K),HTLN(I),CTLLN(I),CTMLN(I),
  2CPFTLN(I),CBLN(I),CGFM(I,K),CTBLN(I)
81 FORMAT(1H ,11X,I2,2X,A8/16X*WITHOUT*   -3P,7(F7.0)/
  116X*WITH*3X,7(F7.0))
   PRINT 83,HTS,CTLS,CTMS,CPFFTS,CBS,CGFMS,CTBS,HTLNS,CTLLNS,
  1CTMLNS,CPFTLS,CBLNS,CGFMLS,CTBLNS
83 FORMAT(1H ,11X*TOTAL*/16X*WITHOUT*   -3P,7(F7.0)/16X
  1*WITH*3X,7(F7.0))
   PRINT 85,NPROD,FLNLAB,FLNDEL,FLNMAT,FLNDEM
85 FORMAT(1H0,10X*PRODUCTION QUANTITY*1X,I4/11X*LABOR LEARNING FACTOR
  1*1X,F5.3,5X*D+E LABOR LRNG FACTOR*3X,F5.3/11X*MATERIAL LRNG FACTOR
  2*2X,F5.3,5X*D+E MATRL LRNG FACTOR*3X,F5.3)
C              PRINT THE BASIC, CONST SERV AND DES-ENG HOURS AND COSTS
90 IF(ICOST.LT.3.) GO TO 100
   IF(NCASE.NE.0) GO TO 92          $ PRINT 7,NSHIP     $ GO TO 94
92 PRINT 8,NSHIP,NCASE
94 PRINT 95
95 FORMAT (1H0,17X*HOURS, COSTS FOR BASIC, CONST SERVICES, DES-ENG*//
  111X*COMP*3X*NAME*3X*LABOR*1X*MATERL*2X*CSERV*2X*CSMAT*1X*DESENG*
  2     2X*DEMAT*/23X,3(2X*HOURS*3X*COST*)/22X,3(3X*THOUS*4X*K$*)/)
   DO 98 I=1,6    $ DO 98 J=1,5     $ K=10*I+J $ IF(J.EQ.5) K=10*I
   PRINT 97,K,NCOMP(I,J),HR(I,J),CM(I,J),HCS(I,J),
  1CMCS(I,J),HDE(I,J),CMDE(I,J)
97 FORMAT(1H ,11X,I2,2X,A8,-3P,F6.0,5(F7.0))
98 IF(J.EQ.5) PRINT 9
   PRINT 99,HRS,CMS,HCSS,CMCSS,HDES,CMDES
99 FORMAT(1H ,15X*TOTAL*3X,-3P,F6.0,5(F7.0))
100 RETURN    $ END
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*   SINGLE-BANK COMPILATION.