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TECHNICAL REPORT - SDC 641-2-9

HUMAN FACTORS IN THE DESIGN OF AIRSHIPS
(Human Engineering Systems Studies)

Dunlap and Associates, Inc.
10 East 49th St., N. Y., N. Y.
30 June 1950

SDC Human Engineering Project 20-F-2
Contract N8 onr-641, T.O. II
Project Designation NR-784-002

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DEPARTMENT OF THE NAVY
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PORT WASHINGTON, L.I., N.Y

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Ralph C. Channell
Project Director

- -

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Acknowledgments

Dr. J. Orlansky acted as assistant project director and H. Jacobs as principal investigator. The data were collected and analyzed with R. C. Channell and J. Fucigna and the report was prepared with the assistance of A. Cleven, D. Huggins, and J. Weigandt.

Grateful appreciation is expressed to those whose efforts materially facilitated the work on this project: the personnel in the Navy Department (Code Aer-AC-7), Fleet Air Wing 1, Weeksville, North Carolina, and Lakehurst, New Jersey, and especially Commanders W. J. Keim and H. S. Graves.

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SUMMARY

This study was conducted to determine personnel requirements and optimum equipment design and arrangement for ASW airships. The problem was to increase airship effectiveness in anti-submarine combat by improving the efficiency of human performance.

Information with respect to airship-types, operations, and tactics was obtained by interviews with LTA personnel. The basic data of this investigation consist of observer samplings, sound recordings, and motion pictures of the activities of airship crewmen during simulated anti-submarine missions. The critical characteristics of airship performance were determined by analytical evaluations. These findings were used to specify personnel requirements and to improve the particular man-man and man-machine linkages crucial to combat success. Finally, human engineering researches and principles of work simplification were examined to derive recommendations. Detailed suggestions are presented in Chapter V of this report, and are briefly summarized below.

Summary of Recommendations

1. Optimum Crew

2K-type Airship	3K-type Airship	N-type Airship
Command Pilot	Command Pilot	Command Pilot
Co-Pilot	Co-Pilot	Co-Pilot
Navigator	Navigator	Navigators (2)
Electronics Operator (Radar) Electronics Operator (Relief-radio-utility) or Electronics Operator (Radar) Electronics Operator (Undesignated) Electronics Operator (Relief-radio-utility)	Electronics Operator (Radar) Electronics Operator (Sonar) Electronics Operator (RCM) Electronics Operator (Infra-red) Electronics Operator (Relief-utility)	Electronics Operators (2) (Radar) Electronics Operators (2) (Sonar) Electronics Operators (2) (RCM) Electronics Operators (2) (Infra-red) Electronics Operators (2) (Relief-technicians-lookouts)
Flight Mechanic		Flight Mechanic (cook- look-out- utility)

For missions which do not require maximum endurance, one or more relief operators should be added to the optimum crew. Electronics operators and equipment should be eliminated on missions which require greater than normal endurance. Where tactical considerations do not require that certain equipment be used, both equipment and operator should be removed.

2. Airship Design

Work stations should be arranged so that operators of electronic equipment are grouped closely about the navigator. The radar station should be next to the navigator. The sonar station should be located where sound intensity is least. Specific layout proposals are presented for the 2K-, 3K- and N-type airships. The following stations should be located within the ASW Plot:

Stations

2K-type Airship	3K-type Airship	N-type Airship
Navigation	Navigation	Navigation
Radar	Radar (radio)	Radar (radio)
Radio	RCM	RCM
or	Sonar	Sonar
Radar	Infra-red	Infra-red
Electronics	Relief	Relief
(Undesignated)	Service	
Radio		

The ASW Plot should be sound-treated and light-sealed. The general illumination for this compartment should be at a brightness level of 0.1 footlambert. A local brightness level of 1.0 footlambert should be made available at all work stations. Red lighting should be provided for night operations, should it be necessary to protect dark adaptation.

All work stations should be designed so that equipment units are easily removable. Equipment should be arranged in panels. Primary detection scopes should be directly before and 6-8 inches from the operators' eyes. Primary instrument controls should be touch-coded and located within 20 inches of the operator and less than 14 inches above the work table. Secondary equipment units should be located overhead or at a remote station. All generators, dynamotors, and inverters should be located outside the ASW Plot.

Cathode ray tubes should be equipped with signal generators for determining optimum screen brightness. Target information should be obtained by range and bearing cursors with counter-type indicators, with repeaters at the navigator's station. The frequency of auditory signals (sonar, sonobuoy, infra-red, RCM) should be selected to minimize the masking influence of airship noise.

Remote controls for LF radio equipment and CW keys should be located at all electronics stations and the relief operator's station. Switch boxes should be provided at all stations so that operators can select ICS, LF radio, or equipment auditory signals for earphones. One ICS circuit should connect all personnel and another only the pilots and navigator. Microphones should be mounted on adjustable arms and actuated by foot pedals. Operators' chairs should be contoured, have foot and elbow rests, be adequately padded and mounted to minimize vibration. Only the navigator's chair should swivel. Seating dimensions are given.

Consideration should be given to measures which can reduce noise and vibration. These include maximum propeller tip clearance, minimum propeller tip velocity, rearward location of nacelles, noise filters on exhausts, stiff panels in plane of propellers, and as few air leaks as possible within the car.

3. Work Station Design and Equipment Distribution

Sketches of recommended work station designs are incorporated in the report. The proposed distribution of equipment is summarized below:

Navigation Station (3K-, 2K- and N-type):

Instrument panel, drift sight, sonobuoy release switch, sea-marker release switch, MAD indicator, directional sonobuoy indicator-plotter, radar repeater, ground stabilization control, loran, and radio compass.

Radar Station (3K- and N-types):

Radar indicator, radar controls, IFF controls, antenna reel control, LF receivers, LF transmitter, VHF transceiver and remote radio controls.

Radar Station (2K-type):

Radar indicator, radar controls, IFF controls.

Radio Station (2K-type):

Antenna reel control, LF receivers, LF transmitter, VHF transceiver.

Sonar Station (3K- and N-types):

Sonar indicator, sonar controls, sonobuoy receiver, sonobuoy recorder, bathy-thermograph recorder, and radio remote controls.

Infra-red Station (3K- and N-types):

Infra-red indicator, infra-red control unit, radio remote controls.

<u>Countermeasures Station (3K- and N-types):</u>

Radar detector indicator, radar detector remote control unit, azimuth indicator, pulse analyzer indicator-control, radio remote control, and optimum bias tester.

<u>Relief Station (3K-type):</u>

Reclining chair, radio remote controls.

<u>Service Station (2K- and 3K-types):</u>

Food lockers, warming oven, coffee urn, sink.

I. INTRODUCTION

A. Statement of the Problem

A study has been made of the ASW airship in order to determine the most efficient design and arrangement of equipment,from the point of view of operator and crew efficiency, and the minimum number of crew members needed for short and long range flights.

The main objectives of the investigation were to determine what the airship is supposed to do, how it is accomplished now, and how it can be improved. Attention was directed primarily to the flow of information between various men and between men and machines. Specific man-man and man-machine relationships are defined as ''linkages;'' all the linkages taken as a whole are defined as the airship ''system.'' The specific questions which the investigators have tried to answer are:

1. How many operators and work stations are required for maximum airship effectiveness?

2. What must be the design and arrangement of equipment at each work station for efficient operator performance?

3. How should work stations be arranged for maximum crew efficiency?

4. How should the interior of the airship car be designed to facilitate sustained performance?

This study has been limited to ZPN, ZP2K, and ZP3K types of anti-submarine airships. The M-type airship serves primarily as an airborne CIC and, therefore, has not been specifically covered by this report. Both the K- and N -types are designed for anti-submarine operations. The K-type is smaller and more maneuverable, but has only a fraction of the endurance of the N-type which should be capable of remaining aloft for sixty hours or more. The 2K-type airship represents a modification of the older K-type and contains only that equipment which was available at the time of conversion. The 3K- and N-types are still in the planning or construction stages. Both of these will contain the most recent equipment and must perform the same combat functions; the design and arrangement of equipment and work stations in each ASW Plot should be almost identical. The N-type, however, will possess a larger crew because of the need for relief personnel.

B. Procedures

In making this study, the investigators were first indoctrinated in airship terminology, equipment, operations and crew duties at the Naval Air Station, Lakehurst, New Jersey. Visits were made to NAF, Philadelphia, Pennsylvania, and the Goodyear Aircraft Co., Akron, Ohio, to examine the ZP2M and ZPN airships under construction. Design proposals for the XZP3K airships were examined and the operation of new equipment units was discussed with technical personnel in the Navy at Washington, D. C., and Sands Point, Long Island, N. Y.

Data pertaining to airship operations and the activities of crewmen were obtained by means of direct observations, motion pictures, sound recordings, and discussions with airship personnel.

1. Observers were stationed in the airship car to record the activities of mechanics and riggers. Observations were made, during anti-submarine exercises, aboard ZP2K airships based at Weeksville, N. C. Activity samples were taken at 30 second intervals during normal patrols and at 15 second intervals during hunting and tracking maneuvers.

2. Photographic activity samples were taken continuously during a six hour period on a simulated anti-submarine mission, conducted by two ZP2K-type airships flying out of Weeksville, N. C.

3. Sound recordings were made of all messages transmitted over the intercommunication circuit and the voice radio, during simulated anti-submarine flights on ZP2K-type airships. In order to coordinate communication data with activity observations, film footage and timer readings were entered periodically on the recordings.

Techniques of analytical evaluation were employed to determine performance specifications for the airship system. This was done by determining the effect of specific linkages on "the probability of success" for each stage of combat. The results of the analyses permitted the investigators to estimate:

1. The overall effectiveness of airship performance on various anti-submarine missions and during each of several tactical phases.

2. The linkages which exert direct influence on the probability of success.

3. The human requirements for the critical linkages, i.e., speed and accuracy of response, sensitivity to enemy stimuli, and sustained performance for a period of time.

Finally, it was necessary to determine to what extent critical system linkages fulfill the necessary performance requirements and to devise ways to improve those which are unsatisfactory. Human engineering researches were reviewed in order to derive recommendations for improving linkage performances. From our investigation, personnel requirements were determined and station and equipment designs were developed for the several airship types. These designs were tested with small scale models of equipment units.

II. RESULTS

A. Description of Airship Operation

The airship's role in anti-submarine warfare consists essentially of four tactical missions: the seeking out and destruction of submarines in open ocean areas, the exclusion of submarines from certain protected sea lanes, the denial to submarines of access to harbors and fleet anchorages, and the protection of coastal areas.

The immediate purpose of each type of mission may be different, but certain patterns of combat activity are similar to all. These patterns or combat phases differ in their tactical purpose and are characterized by specific types of airship, personnel, and equipment activity. All phases may not be required on any one mission and they may occur in any sequence. For example, an enemy submarine might be detected by aircraft, surface vessels, or another airship. The airship's mission would then be to follow up the initial contact and destroy the submarine. The airship, in this case, would not have to engage in a "search phase." Direct observations and discussions of airship tactics indicated that five important phases--in some combination--comprise every anti-submarine mission. These phases have been defined as searching, approaching, hunting, tracking, and attacking. It is assumed that an airship must be designed so that it can perform each of these phases effectively:

> Searching: The objective is to establish initial contact with submarines. The airship may be required to patrol small or large ocean areas with, or without, the assistance of other airships, HTA, or surface craft. Contact may be made by visual sighting, reports from other craft, radar, RCM, infra-red, or sonar.
>
> Approaching: This involves following a course which will join the enemy in the shortest possible time. Contact development and attack-weapons must be readied. Since the target may be expected to counter-detect and submerge, part of the approach may be blind. In this case, the point of submergence must be estimated.
>
> Hunting: After arrival at the estimated point of submergence it is necessary to locate the submarine. Detection devices such as sonobuoys, sonar, MAD, or infra-red can be used for this task. Hunting activities generally center about the estimated point of submergence.
>
> Tracking: A submarine is tracked by obtaining a series of running underwater "fixes" on it by means of directional

sonobuoys, MAD, or sonar. This permits estimation of course, speed, and future position to set up the attack.

Attacking: The attack can be launched when the submarine's position, course, and speed are known. In order to insure positive weapon action, speed, course, and altitude at launching must be carefully considered.

B. Airship Effectiveness

In this report the effectiveness of airship operations has been evaluated in terms of the probability of success. This criterion represents the percentage of opportunities during which the airship is expected to succeed at a given task. For example, if one out of every two submarines entering the search radius is detected, then the "probability of success" during the search phase is said to be 50%. Overall effectiveness is no better than performance during the least efficient phase. More important, total effectiveness is the product--rather than the average--of the efficiency during each component phase. Illustrative cases are given in Table 1. For example, if searching, approaching, hunting, tracking, and attacking are 90% effective, then total effectiveness is only 59% (.90 to the fifth power).

Table 1. Influence of phase success on mission success

Stage of Mission	Examples 1	2	3
Search: Submarines entering swept area which are detected.	90%	70%	5%
Approach: Detected targets successfully entrapped by sonobuoy pattern.	90	70	30
Hunt: Entrapped targets successfully located by sonobuoys.	90	70	70
Track: Located targets successfully tracked by MAD.	90	70	60
Attack: Tracked targets which are destroyed.	90	70	70
RESULT: Submarines entering swept area which are destroyed.	59.0%	16.8%	0.45%

The success of each phase is a function of the coordinated performance of the crew and the equipment. A careful analysis has, therefore, been made of the various man-machine and man-man relationships, or linkages, involved in the five most important phases. In each case, two questions were raised: Is this linkage important to combat success? How should this linkage be designed to maximize airship effectiveness?

C. Critical Linkages

The primary purpose of the analyses was to derive quantitative estimates of the influence of the various linkages on the probability of combat success. Instead of including all the details of the analyses, the results have been summarized for each phase and specific computations are presented to emphasize the nature and importance of certain conclusions.[1] The findings made it possible to determine the critical linkages, to estimate present levels of performance, and to discover how improvement could be introduced. The results are summarized below for each phase, along with a brief description of the tactical procedures.

1. Search Phase

Searching effectiveness depends upon the quality of the detection equipment and operator ability and performance. The relationship between airship search effectiveness and operator performance has been computed mathematically for a particular type of radar employed against snorkel targets (Figure 1). This figure shows that the probability of target detection approaches a maximum when the chances of recognizing a single scope-blip are about 10 to

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[1] The analytical techniques which underlie the findings presented in this section and Figures 1, 3 and 6 have been adapted from the computational methods employed by Operations Evaluation Group (cf. 26, 28, 30). In operational analysis the normal procedure is to begin with equipment and system characteristics, from which are computed tactical procedures. The procedure has been reversed here. Starting with a given tactical maneuver and known equipment performance data (29), the expected success of a specific phase is determined as a function of the system's performance characteristics. Airship performance data collected during the course of this investigation permitted estimation of the present level of effectiveness. This approach resulted in the three findings which were prerequisite to the design investigation: where improvement is needed; what type of improvement is needed; and how badly improvement is needed.

The mathematical analyses, which are necessarily involved, are to be considered in a later report. In general they are based on certain operation assumptions with regard to airship speed and altitude, submarine speed, equipment operation, and tactical maneuvering.

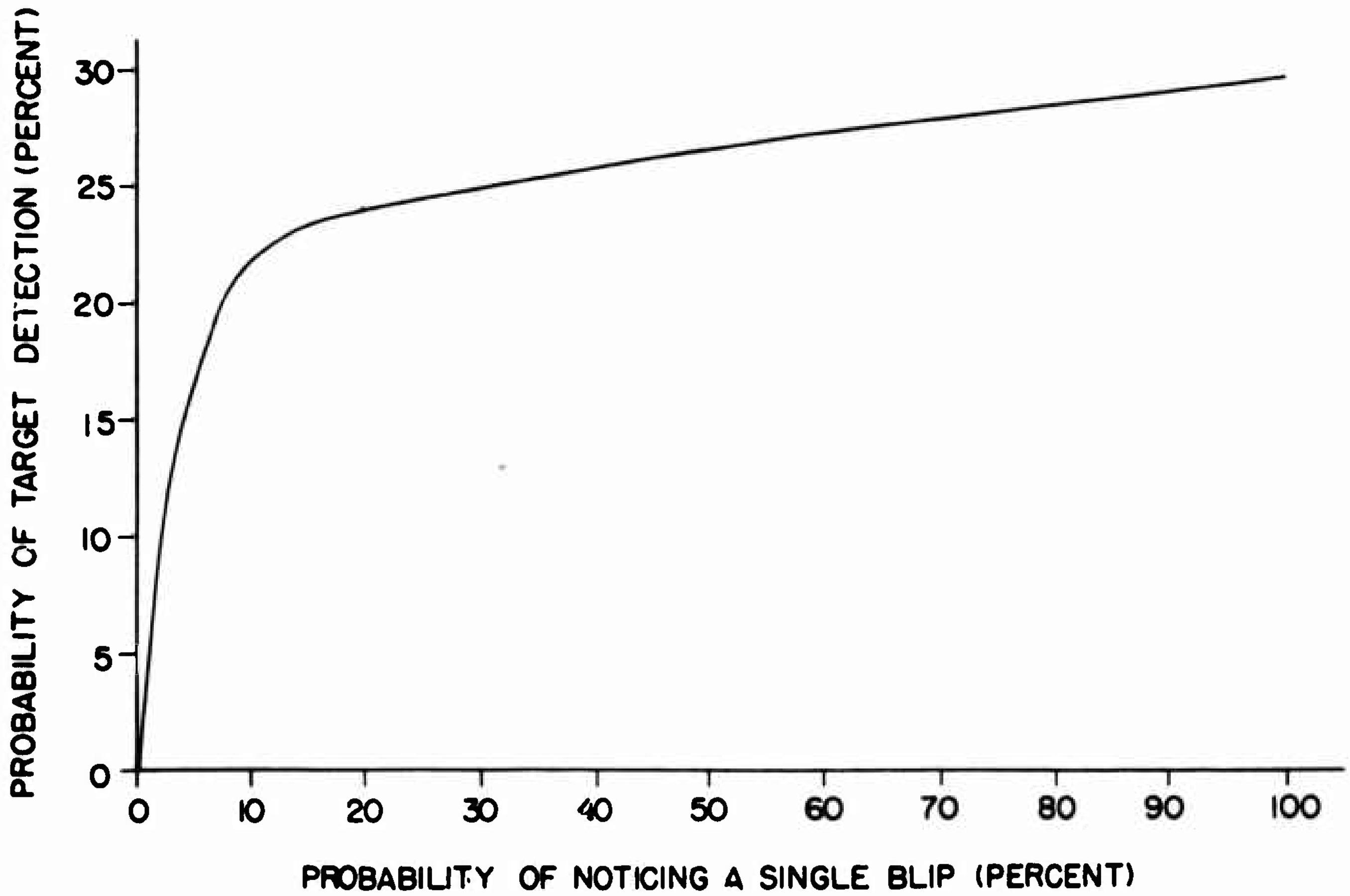

Figure 1. Searching effectiveness: relationship between probability of radar operator's noticing single scope blip and probability of target detection (snorkelling submarine within 20 miles).

This curve was derived from probability theory as applied to the problem of detection by the Operations Evaluation Group (cf. 30). The probability of detecting a target on any one radar scan depends on the type of target, the range, the characteristics of the radar, and the ability of the operator. The probability of detecting a target while it is within radar range is determined by the number of scans which can be made on it. This is a function of the scanning rate and the relative course and speed of target and observer. Since the courses of airship and submarine are assumed to be distributed randomly, the probability of detection must be integrated over all courses.

In this manner, the probability of detecting a submarine located within a 20-mile-wide band on each side of the airship was found to be

$$P = \frac{1}{20}\int_{-\infty}^{\infty}\left[\ 1 - \exp\left\{\frac{1}{wT}\int_{-\infty}^{\infty} \ln[\ 1-p_0\,\psi^n(\sqrt{x^2 + y^2}\ )\ dy\ ]\right\}\right]dx$$

where w = average relative speed of airship and submarine;
T= antenna rotation rate;
p_0= probability that operator will detect a radar blip;
ψ= blip-scan ratio.

Computations were based on cruising speeds of 50 knots for the airship and 15 knots for the submarine, an antenna rotation rate of 12 RPM, and blip-scan data reported for airborne radar operating against snorkel targets.

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20 percent. If the operator is able to notice less than 10 percent of the scope signals, the probability of detection will vary almost directly with the level of operator performance. Studies made by the Operations Evaluation Group indicated that, with snorkel targets, airborne radar operators are able to notice only about 2% of all scope-blips (28). For all practical purposes, therefore, any impairment in radar operator performance will produce an almost proportionate decrease in airship effectiveness. It can be assumed that this finding will hold also for the operation of infra-red and RCM equipment.

The activity analysis revealed that the radar operator had his eyes on the scope only about half the time because of inattentiveness or preoccupation with other duties (radio, log, ICS, etc.).[2] Even while watching the display, however, his attention was divided. He was required to detect radar signals and monitor radio code simultaneously. For dim blips retained only briefly on the radar scope (snorkel targets), the likelihood of detecting a signal varies directly with the proportion of time which the operator spends watching his scope. It is evident, therefore, that an operator who watches his scope 50% of the time will have only half as great a probability of noticing a particular signal than if he were watching continuously. The airship system, therefore, is operating at considerably less than 50% of its potential effectiveness during search.

The general conclusion follows that loss in efficiency on the part of operators of primary detection equipment will result in a corresponding decrease in the number of submarines detected. Some of the factors which can impair operator performance are visual fatigue, loss of visual adaptation, improper adjustment of equipment, and lack of attentiveness.

The effectiveness of searching is also influenced by accuracy of navigation. Failure to know the precise position of the airship at all times impairs the coverage of assigned patrols, reduces the effective patrol time available, and lessens the value of contact reports. Therefore, the design and layout of navigation equipment and the navigator's working conditions should be such as to provide for the most effective performance. The linkage-design requirements for present airships during the search phase are summarized in Figure 2.

2. Approach Phase

The approach phase begins with the moment of detection and involves "homing in" to a position close enough to attack. In most cases, the submarine can be expected to detect the approaching airship in ample time to

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[2] Data on the activities and performances of airship crewmen were collected during the field study. The results of this aspect of the investigation are presented in the Appendix.

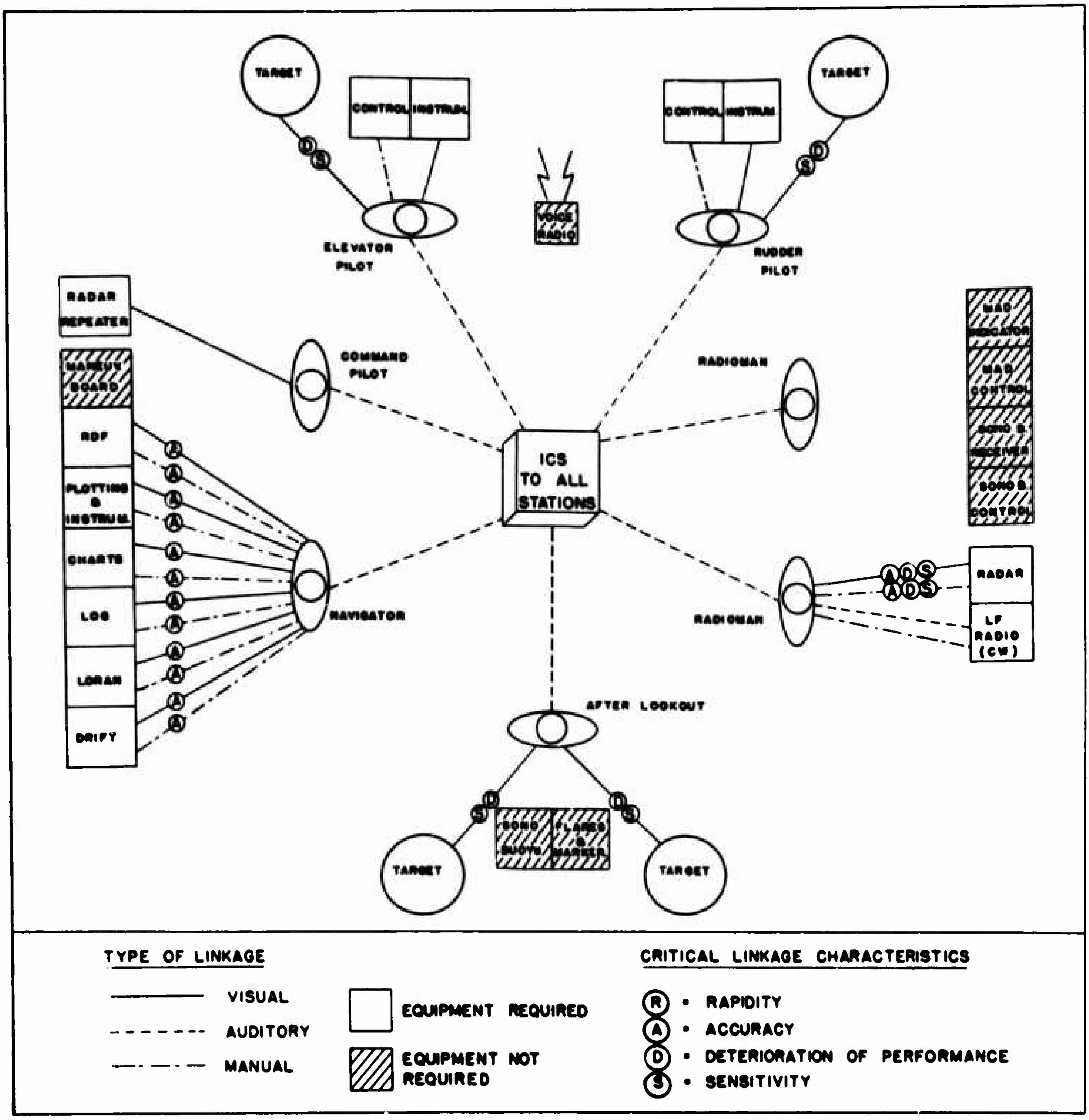

Figure 2. Linkage chart for the search phase of the present airship system (2K-type). The critical linkage chracteristics are indicated only for those linkages critical to the combat success of this phase.

submerge. Therefore, the airship will usually have to estimate the point of submergence and relocate the position of the submarine with sufficient accuracy to launch an attack.

The process of target relocation or contact development is carried out with close-in detection apparatus. With present airships, this requires laying a pattern of sonobuoys about the estimated point of submergence in the hope of entrapping and later locating the submarine. The probability of success in this action is related to the accuracy with which the actual point of submergence can be identified, and the distance traversed by the submerged submarine.

Analysis revealed that the chances of entrapment are not significantly affected by the speed with which the airship responds once a contact has been made. The probability of entrapment is, however, critically affected by range and angular errors made by the airship in locating and marking the point of submergence. This relationship is illustrated by the family of curves in Figure 3. This chart demonstrates the seriousness of the homing problem. For example, a range error of 5% and an angular error of 5° in locating the point of submergence will cause a 50% reduction in the probability of entrapment.

Table 2 indicates how range and bearing errors are introduced by the various man-man and man-machine linkages through which information flows during the homing operation. Estimates are given in Table 3 of present system performance times and errors which were determined on the basis of laboratory studies of specific man-machine problems, and recorded observations during ASW flights summarized in the Appendix (Table A). The results of the analysis indicated a probable range error of 7% and an angular error of 4°. Reference to Figure 3 suggests that an airship possessing these performance characteristics would have only a 30% probability of successfully entrapping a submarine. The linkage design requirements for the approach phase are summarized in Figure 4.

3. Hunting Phase

The objective of hunting is to relocate the position of a previously detected submerged target with enough accuracy to permit immediate launching of attack weapons or to bring into use short range, highly accurate detection devices (such as MAD) in order to determine the target's track. In either event, the success of later operations requires accurate location of the target.

The probability of making a sonobuoy contact depends on the ability of the sound operator to recognize target noises and the amount of time given to monitoring each buoy. Effective listening time is reduced by the time lost in tuning each buoy. Our studies show that a skilled operator can monitor a given sonobuoy every five to seven seconds. At least two of these seven seconds

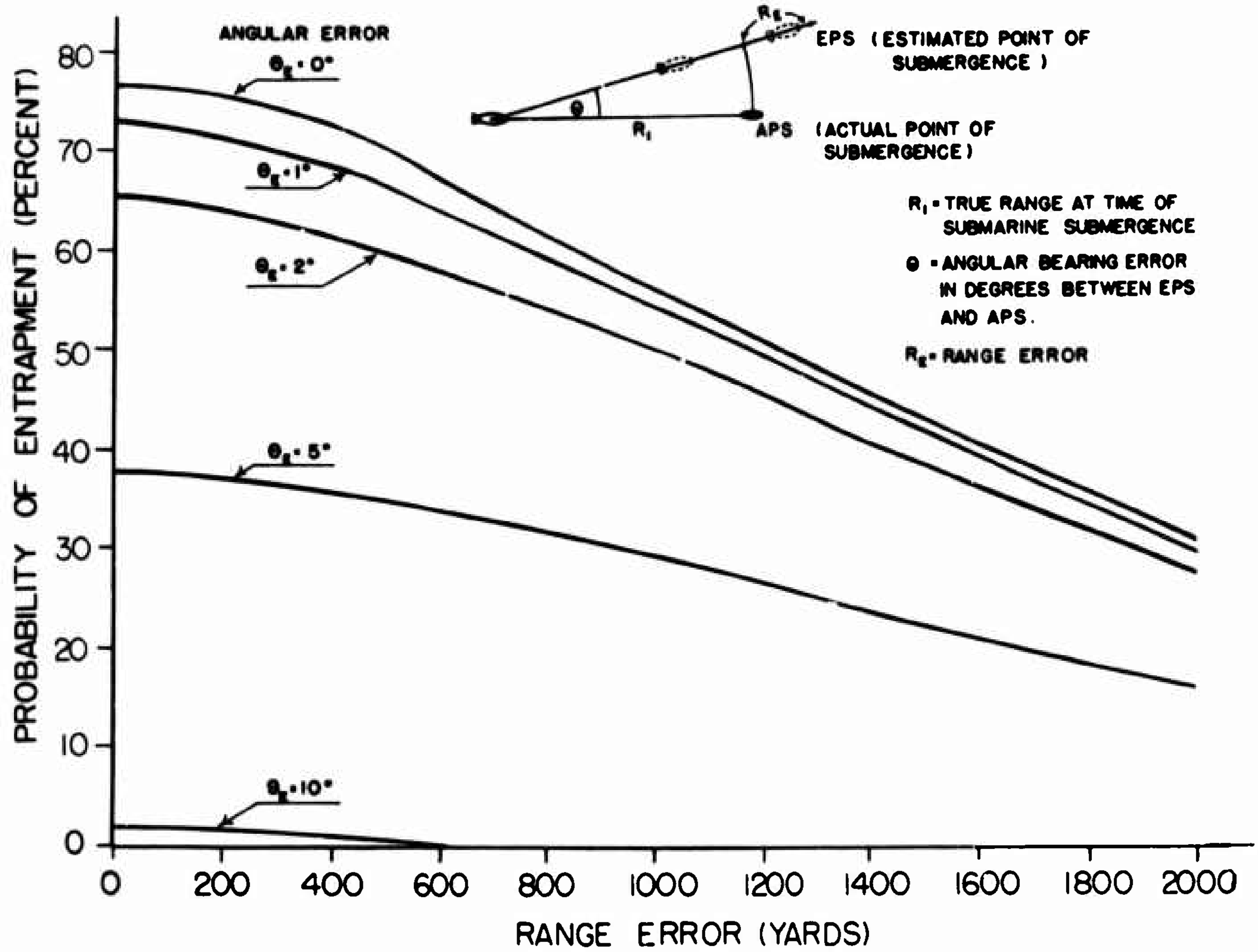

Figure 3. Probability of entrapping a submarine within a sonobuoy circle plotted as a function of bearing and range errors in marking the point of submergence. For this case the true range at time of submergence equals ten miles.

Sometime after the airship detects and commences homing, the submarine can be expected to counter-detect, submerge, and attempt to escape underwater. Depending on its course and speed, the submarine can have reached a position anyplace within a circular area by the time the airship has dropped its sonobuoy pattern. The radius of this circle is determined by the distance which the submarine can travel during the time required for the airship to reach the estimated point of submergence and complete its sonobuoy pattern. The probability of entrapment is the proportion of the submarine's circle of escape which is contained within the sonobuoy circle. This probability is influenced by the error between the estimated and actual points of submergence.

In computing the probability, the radius of the sonobuoy circle was taken as 1500 yards; airship homing speed, 60 knots; and submarine speed, 4 knots.

Table 2. Errors introduced by component linkages during DR homing

System Element	Error resulting from	Error Type: Range	Error Type: Bearing
A. Radar-Operator Linkage	1. Error in radar presentation	X	X
	2. Error in measuring range and bearing	X	X
	3. Delay in noticing disappearance of blip	X	
B. Radar Operator-Navigator Linkage	1. Delay in reporting range to navigator	X	
C. Navigator-Clock Linkage	1. Delay in recording time	X	
	2. Error in measuring time	X	
D. Navigator-Drift Sight	1. Error in measuring wind	X	X
	2. Delay in measuring drift		X
E. Navigator-Air speed Indicator	1. Uncorrected errors in air speed indication	X	
	2. Errors in measuring air speed	X	
F. Navigator	1. Error in computing influence of wind on speed	X	
	2. Error in computing influence of wind on course		X
	3. Time delay in computing course to steer (compass correction)		X
G. Navigator-Pilot	1. Time delay in reporting course and speed to steer	X	X
	2. Time delay in reporting arrival 1500 yards short of EPS	X	
H. Pilot	1. Failure to maintain constant speed	X	
	2. Failure to steer precise course		X
I. Pilot-Rigger	1. Time delay in ordering release of first sonobuoy	X	

Table 3. Range and bearing errors introduced by system element errors and time delays

Errors and Time Delays	True Speed Error (Knots)	Time Delay (Seconds)	Range Error (Yards)	Bearing Errors (Degrees)
Error in radar presentation				± 1
Error in measuring bearing				± 1
Error in measuring range			± 500	
Delay in noticing blip disappearance		10	+ 330	
Delay in reporting range and bearing to navigator		7.5	+ 250	
Delay in recording time of blip disappearance		6	+ 200	
Error in measuring time		±3	± 100	
Error in measuring wind	± 2		± 650	
Error in measuring drift				± 3
Uncorrected errors in airspeed indication	± 2		± 650	
Error in measuring speed	± 1		± 330	
Delay in reporting arrival 1500 yds. short of EPS		5	+ 160	
Uncorrected compass error				± 2
Delay in ordering release of first sonobuoy		3	+ 100	
Probable Error of Entire System			1400	4°
Resultant Probability of Entrapment = 30%				

Note: Time delays in information flow and speed errors (resulting from inaccurate air speed and wind measurements) have been converted into range errors on the basis of a homing speed of 60 knots and a homing range of 10 miles. Mean values have been given for constant errors which vary from zero in the positive direction; probable values have been given for variable errors (which may be negative or positive). The probable overall errors in range and bearing have been computed by means of standard statistical techniques (Chapanis, 5).

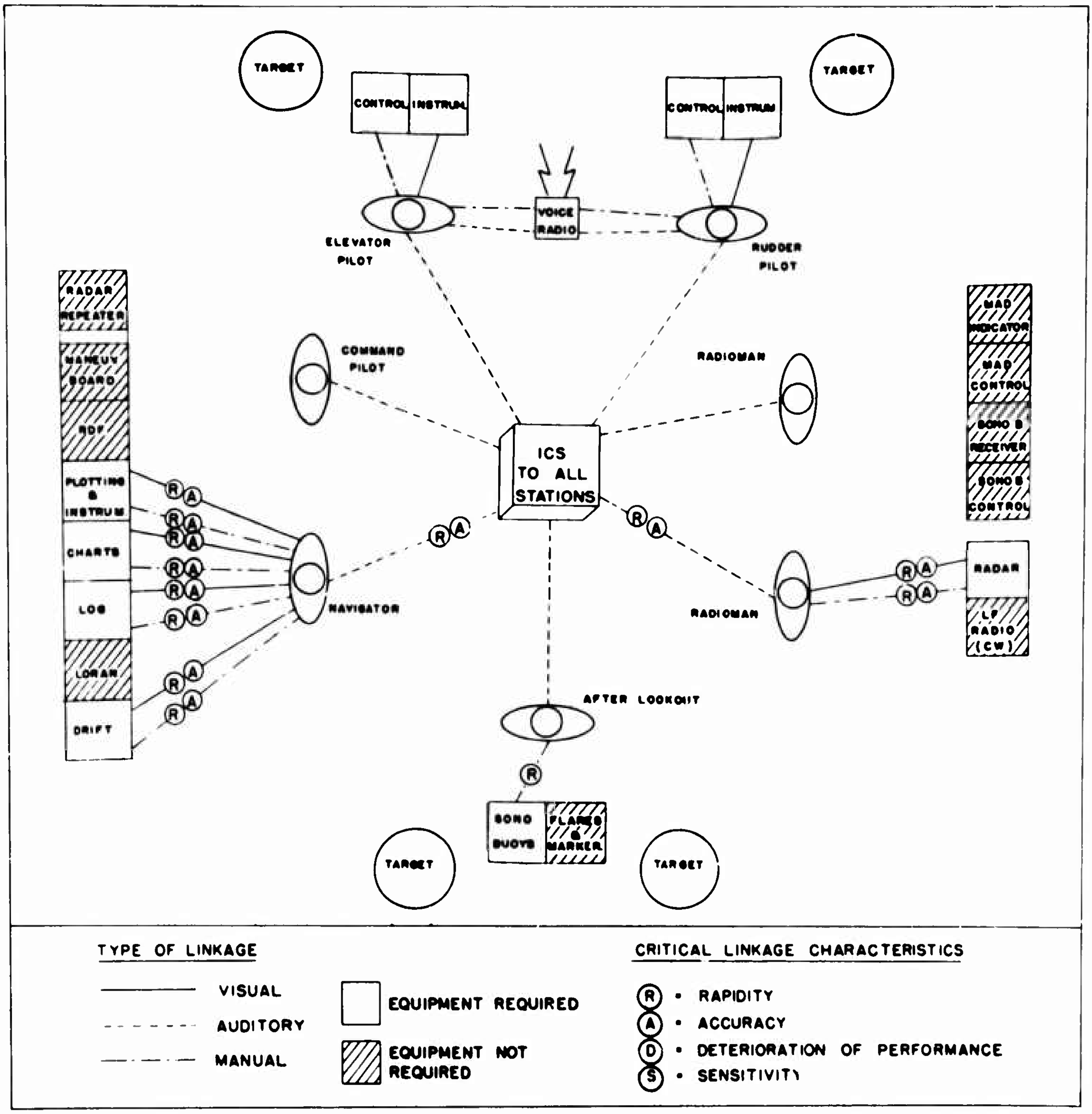

Figure 4. Linkage chart for the approach phase of the present airship system (2K-type). The critical linkage characteristics are indicated only for those linkages critical to the combat success of this phase.

are consumed in the required manual tuning of the receiver. This reduces the effective listening time by about 30% and lowers the probability of success. The accuracy of the sonobuoy receiver-operator linkage is also important. In order to judge the target's position with respect to one or more sonobuoys, it is necessary to interpret properly the absolute and relative strength of target noises. The linkage design requirements for the hunting phase are given in Figure 5.

4. Tracking

The purpose of tracking is to determine the course and speed (track) of the submarine after its underwater position has been determined. It may be utilized to permit direct attack by the airship or to assist the attack of surface ships.

At the present time, tracking is performed by flying a series of small circles above the suspected position of the submarine in an effort to establish contact through magnetic airborne detection. Once contact is established, it must be maintained by reorienting the tracking circle following each contact. The last contact is used as the center for a given tracking circle. It is necessary to make two or more such contacts before the approximate track of the submarine can be estimated.

Analysis of this operation revealed that the primary determinant of tracking success is the accuracy with which the submarine's position can be marked on each contact. The error between the marked (estimated) and the true positions of the submarine is a function of the time required to release a marker after the MAD indicator presents a contact signal.

The relationship between the probability of tracking success and the reaction time of the airship system is illustrated in Figure 6. Inspection of these curves reveals that effectiveness drops off sharply as reaction time is increased. If the time delay can be reduced to less than five seconds, an eight-knot submarine can be tracked effectively.

The reaction time of the airship for this operation is the sum of many component time delays. These delays are introduced at the linkages

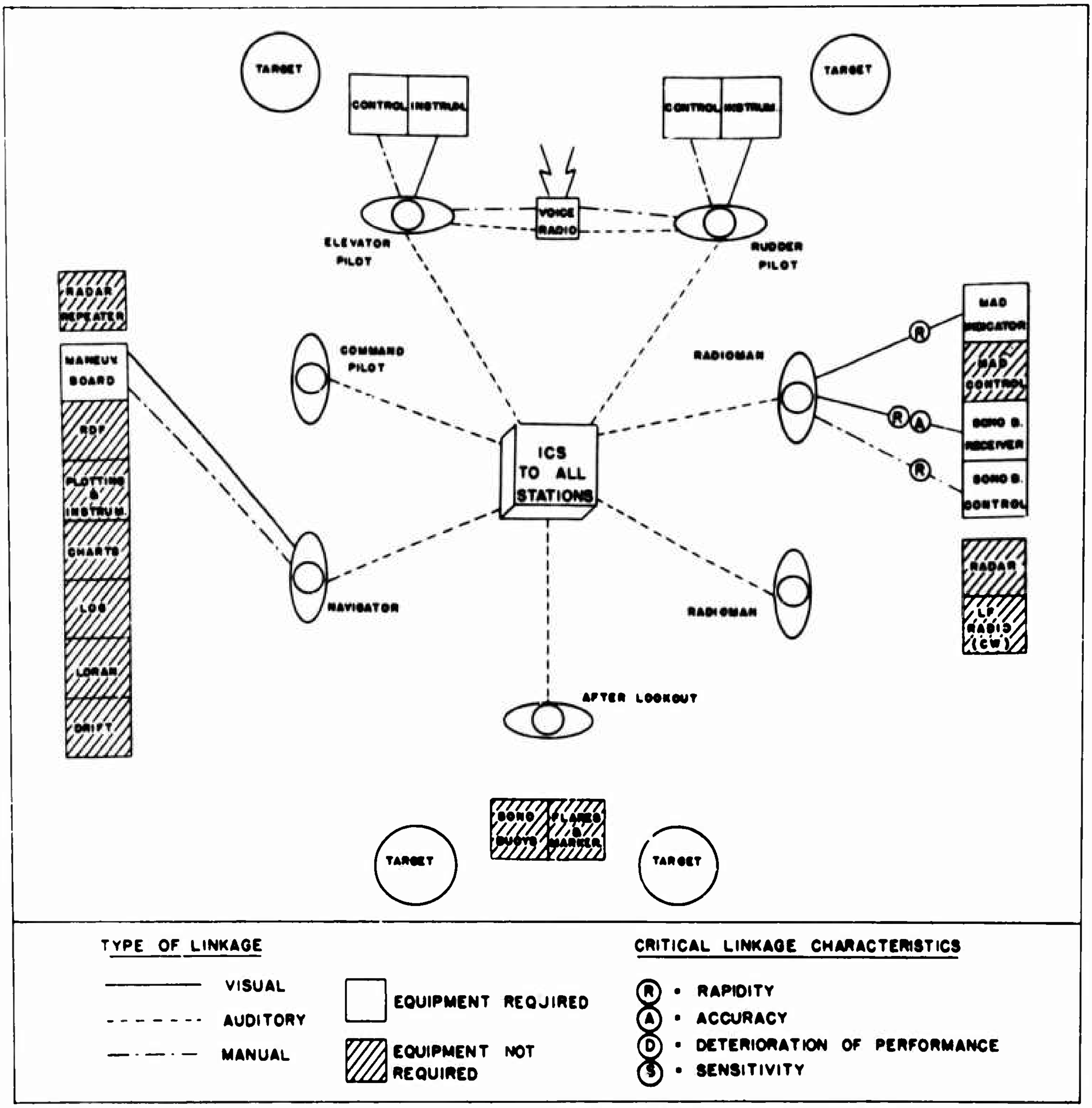

Figure 5. Linkage chart for the hunting phase of the present airship system (2K-type). The critical linkage characteristics are indicated only for those linkages critical to the combat success of this phase.

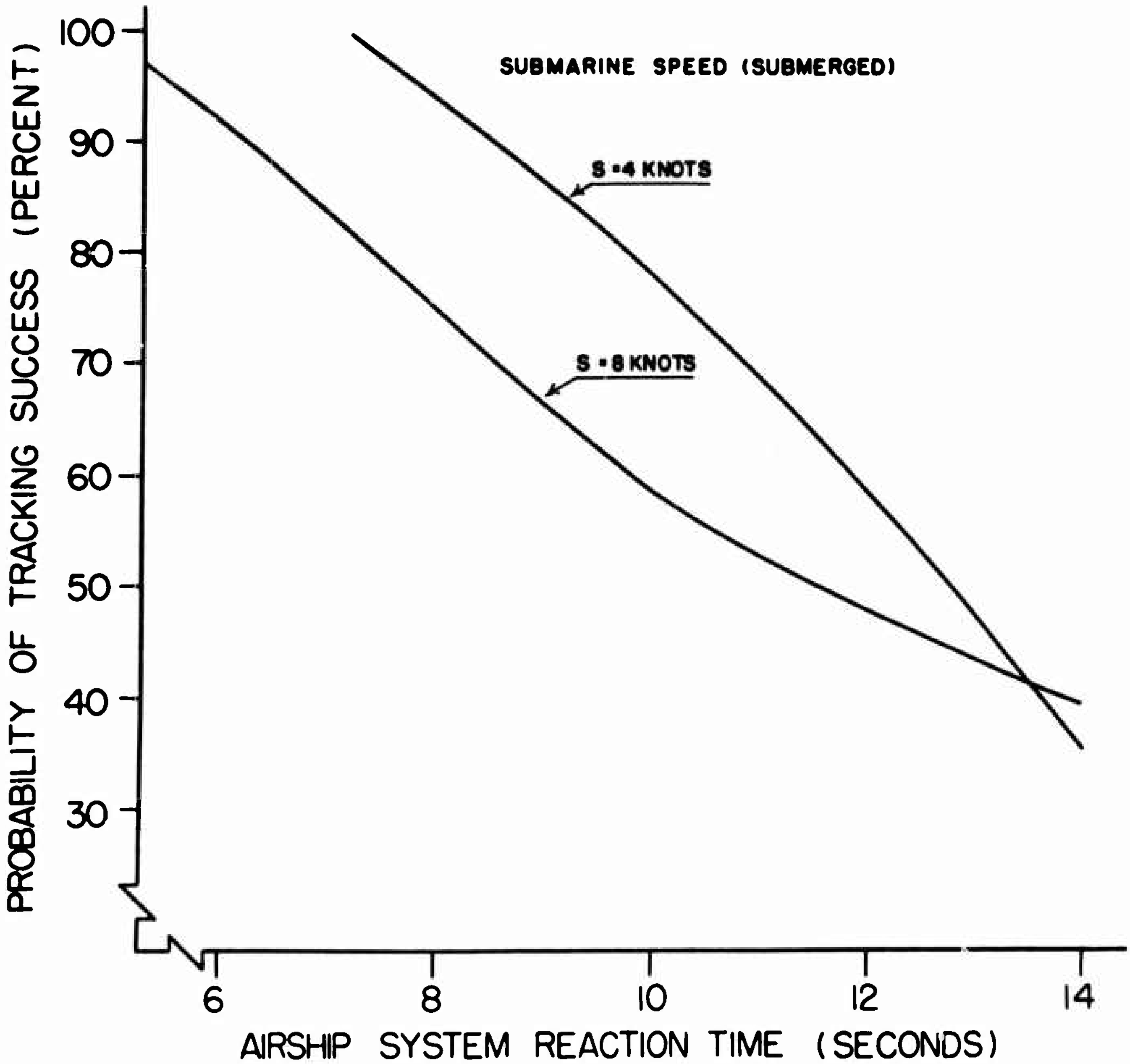

Figure 6. Tracking success as a function of airship reaction time. Tracking success is represented by the probability of obtaining two MAD contacts on a submerged submarine. Reaction time is measured from the moment of contact until sea marker is released.

The probability of tracking success depends on the likelihood that the submarine will be contained within each successive MAD circle. From the time a contact is made until a new circle is established, the submarine can travel some distance on any random course. The likelihood that it will be encircled depends on the accuracy with which its position was marked, its speed, MAD sweep width, and the radius of the tracking circle.

The computations leading to the above curves were based on an airship speed of 65 knots, a tactical radius of 350 yards, and MAD characteristics published by the NDRC (cf. 29).

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through which information flows:

Linkage	Operation
MAD Indicator-Operator	MAD indicator presents signal MAD operator notices signal MAD operator interprets signal and decides it is real.
MAD Operator-Pilot	MAD operator picks up microphone MAD operator sounds contact alarm Pilot hears alarm.
Pilot-Marker Release	Pilot presses marker release button Marker drops from chute.
Pilot-Flying Controls	Pilot initiates new tracking circle.

Performance times recorded on ASW flights indicate that the total time required for this series of operations on the K-type airship is greater than 10 seconds. As Figure 6 reveals, the probability of tracking success with a 10 second delay is less than 80% for a four-knot submarine and less than 60% for an eight-knot submarine. Figure 7 summarizes the linkage design requirements for the tracking phase.

5. Attack Phase

The attack phase represents the culmination of anti-submarine warfare. The airship must have succeeded in <u>all</u> of the previous maneuvers in order to make the attack possible. <u>If failure occurs at any point, the entire mission will be in vain.</u>

The airship will rarely surprise a submarine on the surface. Occasionally, it will be close enough to a diving submarine to launch a direct attack. Most often, the submarine will have vanished completely before attack can be initiated. The weapon available for this task is the homing torpedo.

The success of a homing-weapon attack is dependent upon the distance

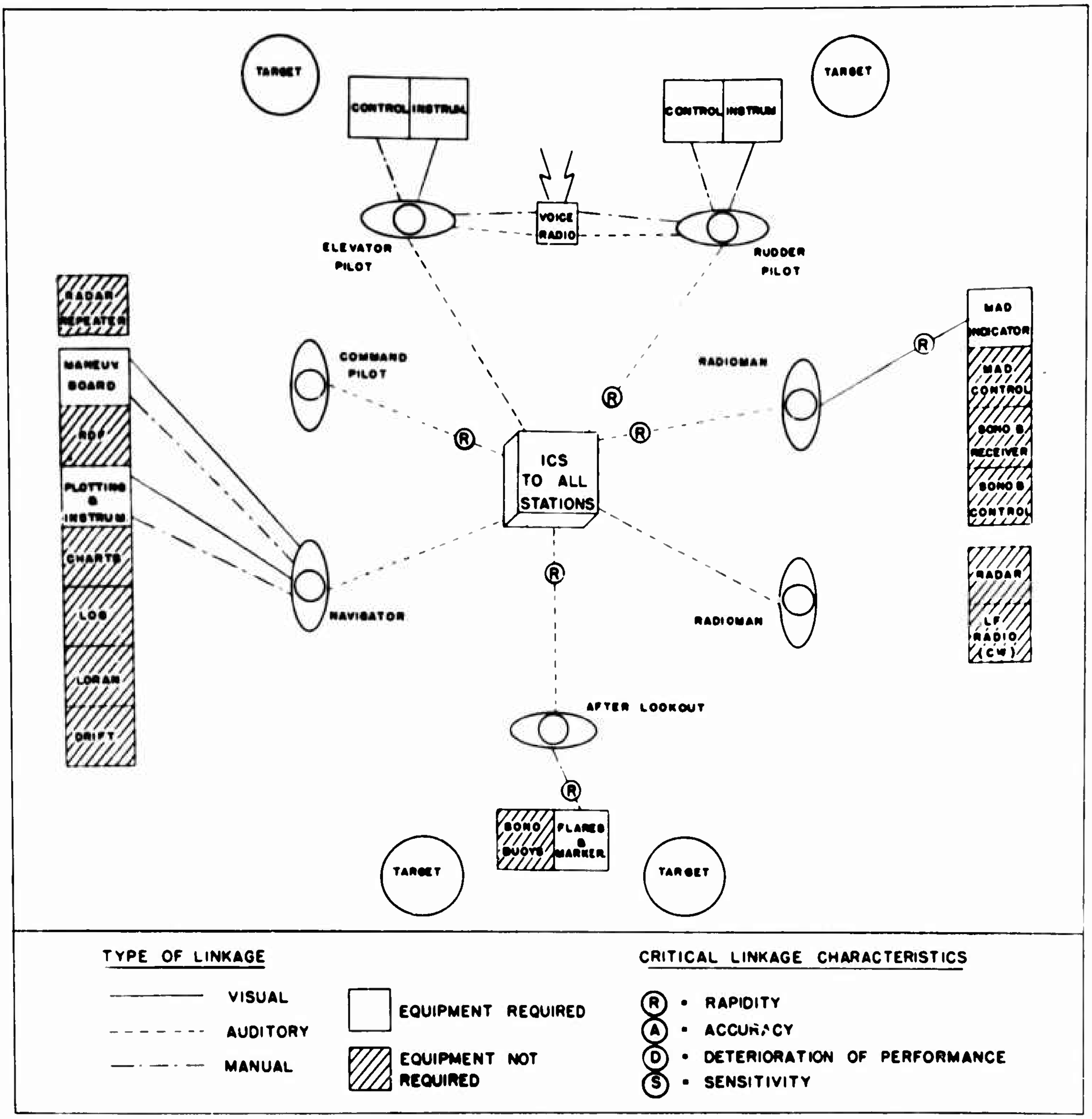

Figure 7. Linkage chart for the tracking phase of the present airship system (2K-type). The critical linkage characteristics are indicated only for those linkages critical to the combat success of this phase.

between the point of launching and the actual position of the underwater target. The greater the launching error, the more time the submarine has to employ defensive measures. It is apparent that the effectiveness of airship attack is related to tracking accuracy. Thus, the reaction time of the airship to MAD contacts is important to both tracking and attack.

Several other requirements exist for the successful launching of airborne homing weapons. In order to ensure proper water entry, airship altitude, speed, and course must conform with certain predetermined requirements. In particular, the course must be such that drift is limited to 5^{o}. In addition, the weapon should preferably be launched on a closing course with the target. This means that the proper course of approach must be furnished by the navigator almost immediately after the last fix. The linkage design requirements for the final phase, attack, are given in Figure 8.

D. Summary of Analytical Results

Airship operation depends upon the interactions of individuals with their equipment (man-machine), as well as upon the exchange of information between individuals (man-man). The results of the analyses just examined were designed to determine how the performances of man-man and man-machine linkages influence the combat effectiveness of airships. In general, it was found that the performance of particular linkages may influence the probability of success in any of several ways.

1. Speed of Response: the rate at which information flows through the linkage;

2. Accuracy: the amount of distortion in information transmitted through a linkage;

3. Sensitivity: the ability of a linkage to respond to enemy stimuli;

4. Performance Maintenance: the ability of a linkage to maintain a high level of performance over a long period of time.

Available linkage performance data, collected in the present investigation and in special evaluation studies, were applied to indicate the probable level of present airship performance and the need for improvement. Although the analyses were based on the currently designed airship system, the findings and conclusions are applicable as well to the design of future airships. The linkages which have a critical influence on airship effectiveness are

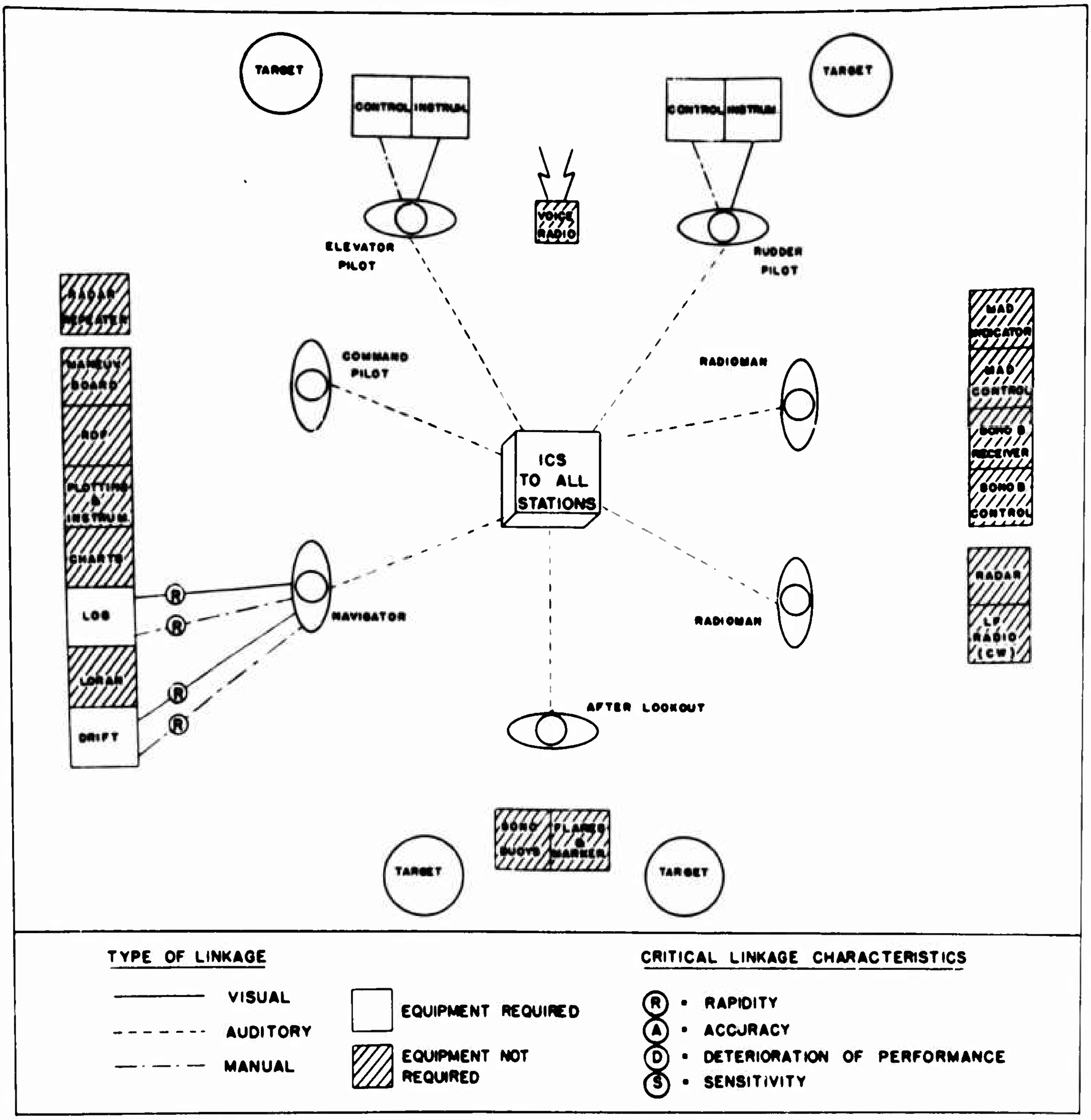

Figure 8. Linkage chart for the attack phase of the present airship system (2K-type). The critical linkage characteristics are indicated only for those linkages critical to the combat success of this phase.

summarized in Table 4. This body of linkage performance specifications forms the essential findings of the analytic aspect of the present investigation. Improvement in total airship performance will be effected by developing design specifications which will fulfill these performance requirements. This question, of improved design and layout of equipment, is considered in the next section of this report.

Table 4. Summary of airship linkage performance requirements

Linkage	Type of Linkage	Performance Requirements
Navigator-		
Clock	Visual	Speed, accuracy
Drift sight	Visual-manual	Speed, accuracy
Log	Visual-manual	Speed, accuracy
Computers and instruments	Visual-manual	Speed, accuracy
Course indicator	Visual	Accuracy
Charts, plotting board	Visual-manual	Accuracy
Airspeed indicator	Visual	Accuracy
Pilot	Audio	Speed
MAD Operator-		
MAD	Visual	Speed
Pilot	Audio	Speed
Radar Operator-		
Radar	Visual-manual	Speed, accuracy, sensitivity, performance maintenace
Navigator	Audio	Speed
RCM Operator-		
RCM	Audio-visual-manual	Accuracy, sensitivity, performance maintenance
Sonar Operator-		
Sonar	Audio-visual-manual	Accuracy, sensitivity, performance maintenance
Sonobuoy Operator-		
Sonobuoy receiver	Audio-visual-manual	Accuracy, sensitivity
Pilot -		
Rigger	Audio	Speed
Infra-red Operator-		
Infra-red	Visual, manual	Sensitivity, performance maintenance

III. DESIGN AND ARRANGEMENT OF EQUIPMENT

In order to translate the critical linkage-performance requirements (Table 4) into specific design recommendations, the relevant human engineering researches were reviewed. To a large extent, the problems are focused on two major areas: navigator and electronics stations. These two station-groups are, therefore, considered first. This is followed by an evaluation of factors which are general in nature and apply to all equipment regardless of its locus; e.g., lighting, noise, panel-layouts. In some instances, problems arise only at a given station. As a practical compromise, these are considered in connection with the treatment of the particular station.

A. Navigator's Station

1. Navigator-Instrument Linkages

The probability of success in DR homing operations is severely affected by the accuracy of information on heading, speed, wind, and elapsed time. These factors also determine general navigational performance and, therefore, the effectiveness of searching. This was demonstrated by Carter and Dudek, in a study of performance on standardized navigational flights (3). Under current practice, navigators observe clock time and elapsed time on wrist watches. This involves two quantitative observations (beginning and end of run) and one computation.

The use of a timer would eliminate the initial reading as well as the computational step. Research by Grether (11) indicates that the interpretation time required to read a two-pointer type instrument dial is about five seconds. A counter-type indicator, on the other hand, requires less than one second for interpretation. A counter-type timer (reading only minutes and seconds) would be expected to save five seconds for the initial observation, more than four seconds for the final observation, and the time required for the intermediate arithmetic. Since the airship homes at about 65 knots, a five second delay in measuring initial time is equivalent to a range error of 180 yards. In addition, experiments by Grether (11) and Long (16) revealed that a counter-type instrument resulted in 1/10 to 1/20 as many gross errors as various dial-type instruments. As a general policy, therefore, more rapid and accurate readings will be obtained with counter-type indicators; e.g., navigation clock, airspeed indicator, and gyro course indicator.

An additional source of observational error is inherent in the nature of certain instruments, especially those concerned with air speed and compass heading. Although airships do not generally experience the extreme fluctuations in altitude, pressure, and temperature to which aircraft are subject, it is worth noting that an increase of 500 feet altitude, 0.5 inches mercury pressure, and 10°C. temperature together produces an air speed error of almost three knots. On operational flights for this investigation, the only correction applied by the navigator to either air speed or compass heading was that for magnetic variation. The navigator's station, therefore, should include a temperature meter, a pressure altimeter, a calibration curve for indicated air speed, and a graph of compass deviations.

As demonstrated in the second chapter, speed of acquiring drift information is especially vital just prior to weapon launching. In addition, the activity analyses indicated that 20% of the navigator's time is devoted to this task during search patrol. In order to measure drift on present airships, the navigator must arise, open the window, and lean over. This time-consuming task cannot be performed under black-out at night. An interior illuminated sight should be installed in such a position that readings may be taken without gross body movements. This should be mounted on the floor immediately adjacent to the navigator so that he could be seated and use it comfortably.

Analysis of navigator flight logs revealed drift errors averaging about 3°. The gyro stabilized Air Force type drift sight has been installed in some of the recently modified ZP2K airships and it is supposed to reduce drift sight errors to less than 1°. Navigators do not use it, however, and prefer the Wiley sight. On one airship, the gyro-sight was entirely removed. The reasons for this failure to use the new drift sight should be studied so that, if necessary, improvements in design can be made.

2. Navigator-Pilot-Rigger Linkages

Current operating procedure calls for the navigator to tell the pilot when to drop the first sonobuoy. The pilot in turn orders the rigger to drop the sonobuoy. These messages are passed over the ICS. The time delay of eight seconds (equivalent to a range error of about 260 yards) could be shortened by having the navigator communicate directly with the rigger. The optimum arrangement would be to install an automatic sonobuoy dispenser with release buttons at both the navigator's and the pilots' stations. This would permit the navigator to release the first three buoys in a nine buoy pattern (to establish the pattern axis) and the pilot to release the remaining ones.

3. Navigator-MAD Linkage

Observations made on the ASW airship exercises indicated that the MAD indicator was watched intermittently by either the radio-radar operator or navigator during hunting and tracking operations. The indicator, actually observed only about 50% of the time, was mounted at an acute angle of observation, several feet from either man. Under night illumination (red lighting) the visual contrast of the red ink trace on a white background is markedly reduced. With the present arrangement, it is estimated that the time required to recognize and interpret a given MAD signal is over five seconds. An additional five seconds or more are consumed before the sea marker is released and the contact reported. A bomb release has been installed so that it will automatically drop a weapon or marker when a MAD signal of sufficient strength has been received. This device is unsatisfactory because it cannot differentiate weak signals from "noise."

It is proposed that the MAD indicator be mounted in a perpendicular position close to the operator who is to observe it. It should emit an auditory signal when any possible contact occurs. The tracing ink should be black. The MAD operator should be provided with a single button which would simultaneously release a sea marker and sound an alarm (in the pilot's compartment and over ICS). This would permit the operator to interpret the signal, mark the position of the contact with minimum delay, and inform the pilot to commence a new tracking circle.

Reference to Figure 6 (p.21) indicates that when the system reaction time is less than five seconds, the probability of tracking success is independent of the lateral position of the submarine (within the swept band). Information now provided on the lateral position of the target would, therefore, be superfluous. As a consequence, the reward for upgrading these linkages would be an improvement in effectiveness. In addition, there would be a saving in weight of 170 lbs., since one comparator and one entire MAD could be eliminated. This saving in weight can provide fuel for an additional hour's flight-time or an extra crewman.

4. <u>Navigator-Computers-Plotting Instrument Linkage</u>

The time required to manipulate navigational computers and instruments (e.g., protractors, pencils, dividers) is important. For optimum probability of success, some computations may have to be performed in a matter of seconds. Since the navigator spends about 40% of his time in plotting, a reduction in the time required to manipulate instruments can have a valuable load-easing influence.

These particular linkage times can be modified by redesigning the computational methods and/or aids, and by modifying the design of the work station. It was observed that airship navigators were continually troubled by having to rummage underneath charts, search the work table, or look on the floor in order to find pencils, dividers, computers, scratch paper, etc. This difficulty can be appreciably reduced by proper prepositioning of working tools. This calls for the installation of clips, holders, chains, etc.

5. Navigator-Log Linkage

When some problems in DR navigation (such as homing, tracking, etc.) arise suddenly, the navigator must have instantly the most recent information on wind velocity, drift, observed compass errors, etc. These are now recorded in a log (or record) more to comply with regulations than in anticipation of use. A permanent and prominently mounted data board should permit the navigator to obtain rapidly the necessary information.

B. Electronic Stations

1. Visual-Operator Linkages

Man-machine functions will be no better than the weaker of the two components. Equipment can be so designed and located that maximum use is made of the human capacities.

Reaction time increases sharply when an individual is required to discriminate and respond to more than one stimulus. An experiment by Mackworth (17) indicated that operators performing a visual discrimination task (similar to scope monitoring) experienced a 12% reduction in effectiveness when required simultaneously to discriminate and respond to auditory stimuli. Investigation of airship communications revealed that messages were being sent over the ICS about 20% of the time. This means that electronic operators should not be required to guard all internal commu-ications, but should hear only those messages intended for them. Further, no secondary activity should be permitted; e.g., keeping log, tuning radio, adjusting VHF, eating at station. Christensen's study (6) revealed that radar operators on arctic weather reconnaissance missions spent an average of 24% of their time making knob and switch adjustments. For the particular radar employed (APQ-13), 63% of all adjustments were made with four controls. These were receiver gain, antenna tilt, receiver tuning, and scope azimuth knob. The principal controls, therefore, should be identifiable by touch and located for convenient operation so that the operator need not remove his eyes from the scope. Selector switches on the microphones themselves or at some convenient position at the pilot's and navigator's work stations should be employed to permit specific communication with electronic operators.

An important finding in our study is that the detection of snorkel targets on visual displays is critically dependent upon the attention and alertness of the operator (Figure 1). It is apparent that operator performance is highly dependent on selection and training. But tasks and equipment can be so organized that the crew operates more effectively. The analysis of crew activity during the search phase revealed that the radar operator devoted full attention to the radar display less than 60% of the time. Similar evidence was collected by Christensen (6) who showed that radar operators on arctic missions actually had their eyes on the PPI about 45% of the time, during half of which time they were engaged in simultaneous auxiliary activities. The probability of detecting a given signal, and thus overall airship effectiveness, was reduced 40-46%. Performance with regard to radar, infra-red, RCM, and sonar displays should be improved, therefore, by reducing distractive influences, minimizing auxiliary activities which require removal of eyes from the scope, and providing close supervision to prevent obvious inattention (reading, talking, sleeping, etc.). The layout of work stations should permit the ASW Plot officer (navigator) to maintain visual contact with all electronics operators. Windows or portholes should not be located next to electronics stations, nor should there be ash trays at these stations.

The accuracy with which the target ranges and bearings are reported by the radar operator at the time of the submarine's submergence strongly influences the probability of success during DR homing. Range and bearing errors can be reduced by introducing a movable range trace with range counter and coupling a bearing counter dial to the bearing cursor control. A study made by Chapanis (4) indicates that the time required to read range and bearing information from radar-bearing and range-dials averages about 3.5 seconds. The substitution of direct-reading counter-type dials decreased reading time by about 50%. An additional advantage of our proposal is that it would permit direct remote indication of range and bearing at the navigator's station. This would eliminate about five seconds delay in reading and transmitting radar information, would provide numbers directly for computational reference, and would keep homing information flowing to the navigator without continuous audio communication. The delay in transmitting target information to the navigator can be minimized by positioning the navigation and radar stations so that visual, tactual, and vocal communication is possible in order to avoid circuiting this information through the ICS.

Another important consideration in operator performance is related to the observation of visual displays such as radar scopes. A review of the literature suggests the importance of such factors as scope brightness, distance from eye, signal length and thickness, etc.

The effectiveness of visual displays, such as radar scopes, is influenced by the distance from the eye. With no background "noise," the advantage of a 6-inch viewing distance over a 24-inch distance is equivalent to more than 8 db. of signal power for a dim scope and more than 5 db. for a moderately bright scope (Bartlett et al., 1). This means that, for optimum effectiveness, indicator scopes should be positioned at a distance of about 6 inches; if hoods or shields are employed, their length should be proportioned accordingly.

Observations during airship operations revealed that screen brightness is controlled haphazardly, varying from very bright to extremely dim. Screen brightness and video gain are interdependent variables which tend to compensate for each other in determining the visibility of radar signals (Garner et al., 9). It is crucial to recognize that there is great variation in signal visibility (on a noise-free, P-7 phosphor screen with CRT grid bias or brightness (Williams et al., 22). Optimum visibility is dependent on video gain, noise, and the response curve of the phosphor (which changes with time). Since all of these values change with use and operating conditions, it is impossible to set the optimum bias for a given tube by meters alone.

It is recommended, therefore, that provision be made for the determination of optimum bias by each operator every time he uses the scope. This could be accomplished psychophysically by employing an attenuable artificial signal. The operator would simply reduce the signal gradually while varying the brightness control to find the optimum setting. The control would then be set for maximum sensitivity so that the weakest possible signal can be detected.

Visibility has been found to improve appreciably as the thickness of the blip on the scope increases and slightly with increased radial distance of the signals from the scope center. Radar presentation ranges should be designed on the basis of the target to be detected. In the case of snorkel targets, which are unlikely to present a scope signal at ranges greater than 20 miles, the minimum suitable scale should be provided so that signals will have maximum thickness and will first appear on the scope near its periphery. An increased signal length from 1° to 5° reduced threshold visibility by 5 decibels (Bartlett et al., 1). It is suggested, therefore, that the possibility of increasing signal length by increasing the beam width of the signal should be investigated.

2. Auditory-Operator Linkages

The sonobuoy operator, at present, must look at a dial in order to tune his receiver. Evidence was cited that a skilled operator requires seven seconds to monitor a single buoy, approximately two seconds of which must be devoted to tuning. With two seconds thus wasted on each unit, each buoy of a nine buoy pattern could be monitored less than 8% of the time. The wastage-interval could be reduced by replacing the mechanical-visual, dial-type tuner with the necessary number of pre-tuned push button switches. This modification would eliminate the need for visual reference and would also permit the operator to coordinate monitoring activity with airship position by observing sonobuoy echoes on a radar scope, compass heading of airship, etc.

The effectiveness of the sonar, sonobuoy receiver, RCM, and infrared gear depends upon the ability of the operators to recognize auditory signals. Therefore, work conditions impairing such tasks should be remedied. Here, the masking effects of noise are crucial.

The primary sources of noise on airships (propellers, engines, exhausts, etc.) are identical with those of airplanes. The noise spectrum of an airship, therefore, is probably about the same as that of a typical two-engine aircraft, with the greatest sound intensities occurring at the lower frequencies (Beranek et al., 2). Submarine cavitation noises and most other auditory signals have most of their energy concentrated at the middle and higher frequencies. Masking is most effective when the frequency of signal and masking noise coincide, but serious masking will occur when the signal and masking noise differ in frequency, if the sound is loud enough. As reported, low frequencies at high intensity successfully mask high frequency signals (Fletcher, 8). To be effective, therefore, sound-reduction must apply to the entire spectrum. Standard sound absorbing materials such as acoustic-celotex can be effective over the entire spectrum, but the lightest weight is 1.5 lbs. per square foot.[3] This would require about 200 lbs. of additional weight in order to construct a soundproof compartment for the sonar operator alone. It is recommended, therefore, that a sound-absorbing shield should be installed only in the area of the sonar operator's head. Also, a research program should be initiated to develop earphones which afford greater protection from the ambient noise.

The ambient noise intensity may vary as much as 10 decibels, depending on the location of the sonar or sonobuoy stations within the airship (Beranek et al., 2). It has been found that propeller noise is loudest in the vertical plane of the propeller itself, louder behind than in front of this plane. Sound intensities are lowest along the center line of the car. In view of these facts, it is recommended that the sonar station be located as far forward of the propeller plane as possible and close to the center line of the car. Also, as a general principle, the sound contour of each airship type should be determined prior to layout design.

Masking interference can also be influenced by the characteristics of the signal. For each noise spectrum, some signal frequencies will be more easily discriminated than others. A research program should be established to determine what are the optimum characteristics of listening and echo-ranging signals for the operation of airship-borne sound equipment. The performance of the sonobuoy operator would be aided if the auditory detection could be supplemented with a visual signal. Finally, research should be directed to the development of a display which would simultaneously present the signals from all sonobuoys.

C. General Factors

In addition to the design problems specific to given stations, there are important considerations which apply to the airship as a whole. The factors

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3 Light-weight sound insulating materials have been developed for aircraft but are effective only in the high frequency portion of the spectrum. Recommendations for its use are made in the next section.

to be considered are: illumination, noise, vibration, panel layout and operator seating, and food service.

1. Illumination

Proper lighting has general significance in addition to its effect upon the performance of operators at specific gear (e.g., radar scopes). Inadequate illumination will not only decrease the accuracy of instrument reading, but will also result in such serious indirect effects as eyestrain and fatigue. These, in turn, will further impair performance. As a matter of fact, it is almost impossible to consider general illumination separately from instrument lighting since they are intimately related.

Research on visual performance under varying conditions of illumination indicates that white light should be employed under daylight conditions when the problem of dark adaptation is not involved. At night, dark adaptation may be important so that red lighting should be made available.

Williams and Hanes in their study of visibility on cathode-ray tubes found that ambient illumination up to about the brightness of the scope field gave a slight advantage over darkness; beyond this point a very rapid loss in visibility results from increasing intensity (24). They also reported that the lowest contrast thresholds and the shortest detection times occurred when the scope and adapting illuminations were equal or very nearly so (23). Within the range of ordinary room illumination, the level of adaptation of the eye is not a significant factor in radar detection. The weakest signal can be detected readily even after adaptation to as much as six millilamberts of illumination. However, adaptation to 2000 millilamberts (about the brightness of blue sky away from the sun) may cause a delay of up to three minutes in the detection of a dim pip; this means that a signal of 25 db. above threshold is required in order to detect it immediately.

The implication of these findings to airship design is important. Adaptation to a 2000 millilambert light source occurs in less than two minutes. Should an operator gaze out the window once an hour for just two minutes, the probable rate of detection suffers about 10%. Therefore, the ASW Plot should be blacked out at all times; the general level of illumination should be about 0.1 foot-lambert. Where local lighting is required (navigation station), proper shielding should be provided. Shiny or bright reflecting surfaces should be eliminated and the interior of the room should be painted dull rather than glossy.

The most effective visual performance is obtained if the ratio of task to background brightness is 1:1! this ratio should never exceed 10:1. For these reasons, whether the lighting is white or red, it is recommended that illumination at the navigation station and other work stations (where local lighting may be required occasionally for copying radio-code), should be 1.0 foot-lambert. Although some authorities recommended 25 foot-lamberts for illumination of the work task, the end effect on performance is affected slightly when one foot-lambert is used. In addition, the use of the latter value makes it possible not to violate the other important principle that the brightness contrast (ratio) shall not exceed 10:1. For more detailed examination of the researches in this field see Orlansky et al. (19). To achieve these lighting requirements it will probably be necessary to employ compartment lights (dome), local work station lighting, and specific instrument lighting.

2. Noise

Noise not only creates a special problem for operators of sound equipment but it may also impair the efficiency of all personnel. The problems specific to the sound operators considered in the previous section dealt largely with minimizing the masking of instrument signals. Here, the acoustic problems considered are those of impaired auditory sensitivity, speech intelligibility and fatigue, and they apply to personnel located throughout the airship.

Research has established that subjects exposed to aircraft noise suffer temporary but serious losses in hearing. Thirty minutes exposure to such sounds effected an impairment of more than 30 decibels. As exposure time increases, there is a greater loss of auditory sensitivity which spreads to the lower frequencies. Recovery from one-half hour exposure required about four hours and longer exposures prolonged recovery times (cf. Stevens et al., 21).

The detection performance of four equipment units, i.e., sonar, sonobuoy receiver, RCM, and infra-red, depends upon the ability of airship operators to recognize auditory signals and submarine cavitation noises. More important, these sounds are in the higher frequencies and the hearing losses noted above occur predominantly in this same band of the acoustic spectrum. Since watch rotation among operators is anticipated, it would be desirable to protect the auditory sensitivity of all operators. If noise protection can be accomplished, therefore, it should extend to the entire compartment rather than to one specific station.

Noise can also have a detrimental effect on communications. A serious problem exists when verbal intercommunications and voice radio messages cannot be heard or are misunderstood. There are further disadvantages when personnel, particularly in the ASW Plot, cannot converse with each other without shouting. Quantitative studies on speech intelligibility were performed at the Harvard Psycho-Acoustic Laboratory (21), which clearly demonstrated that the intelligibility of speech can be doubled if the high frequencies of the aircraft sound spectrum are eliminated. This is true even if the overall sound intensity remains the same.

The performance of psychomotor tasks and higher mental processes is somewhat impaired by noise. Slightly greater reaction times and more errors resulted when subjects were required to perform certain tasks at aircraft noise levels. This performance is achieved at the expense of greater effort. Subjective feelings of fatigue, irritability, annoyance, and discomfort are greatly intensified by a noisy environment. These subjective feelings are much less severe for low than for high frequency sounds (cf. 21).

For our consideration, the vital fact of the above researches is that high frequency noise is very effective in masking speech, impairing auditory sensitivity, or intensifying subjective fatigue. There are two ways to alleviate these effects: decrease the overall noise level and attenuate the high frequency components of the noise spectrum. Unfortunately, the most common method of noise reduction, sound absorption, is impractical. Since the efficiency of a sound absorbing material is roughly proportional to its weight, its application to the airship is impractical.

Fortunately, special light weight sound insulating materials have been developed in recent years which are extremely effective in attenuating the high frequency components of the noise-spectrum. Some of these products weigh as little as 0.1 lb. per square foot, yet are capable of reducing the sound level of frequencies above 1200 cps. by as much as 40 decibels. It is recommended, therefore, that these materials be used to soundproof the entire compartment (at the expense of an increase in weight of about 60 lbs.). The following benefits would accrue:

> There would be considerable reduction in the masking of submarine noise signals. The auditory sensitivity of the sonar operator would not suffer during off-watch periods. The masking of auditory signals at other work stations (RCM, infra-red) would be decreased. The auditory sensitivity of other operators would be protected since they may be called upon to operate the sonar or sonobuoy equipment. Direct verbal communication should be possible within the ASW Plot. The efficiency of ICS communications would be improved. Operator discomfort and subjective fatigue would be diminished. These materials also exhibit some thermal insulating properties.

Sound insulation is only one way of attacking the noise problem. The design and arrangement of the airship and its equipment deserve equal attention. The most important sources of noise on airships are the propellers, the exhausts, the engines, the auxiliary power unit, generators, dynamotors, inverters, and rattling or vibrating objects. Although detailed procedures cannot be elaborated, some specific recommendations can be offered. In the absence of other engineering restrictions or requirements, the following general considerations should cover design decisions:

Maximize fuselage-propeller tip clearance. Increasing fuselage-propeller tip clearance from 10 to 20 inches can reduce the over-all noise level by 3 db.

Provide for minimum propeller-tip velocities. Each 100 fps. increase in tip velocity increases the noise level by 2-1/2 db.

Provide light weight acoustic filters for engine exhausts.

Locate engine nacelles as far to the rear of the car as possible.

Locate all blowers, generators, dynamotors, inverters, etc. outside the ASW Plot. The importance of this step is indicated by the fact that future airships will contain more than 15 generators, inverters, dynamotors, and blowers, all of which contribute greatly to the level of high frequency sounds.

Make every effort to eliminate loose, vibrating floors, panels, fixtures, etc. On the present K-type airship, extreme annoyance is created by the vibration of the plexiglass window next to the navigator's station.

Ventilating and heating air-intake ducts should be placed in the area of lowest sound level and should have acoustic filters.

Not only is it desirable to treat noise at its source, but much can be accomplished simply by attenuating it as it is transmitted through the car structure. Noise transmission losses are also determined by the design of the airship car. The following recommendations are offered in this respect:

Provision should be made for rigid wall sections near the propeller plane.

Windows and hatches should not be placed near the loudest noise zones.

The car itself and the ASW Plot in particular should be sealed against air leaks which, around windows or doors, contribute much to high-frequency noise intensity. If the car interior has inadequate noise absorbing power, the leakage of noise through a crack as small as 0.01 inches may bring the noise within the car to the same level as that outside. This requires the application of liberal quantities of trim.

3. Vibration

Vibration is noted for its effect on human performance. Extensive research on the physiological effects of exposure to vibration was conducted by Coermann in Germany (7). It was discovered that visual acuity and reflex responses were impaired by prolonged exposure to excessive vibration. Other studies have shown that subjective feelings of physical discomfort and fatigue increase with vibration and are accompanied by loss of operational efficiency (Zand, 25). Complaints of eyestrain, headaches, distortion of depth perception, general fatigue, and exhaustion by navigators and pilots on transoceanic flights were markedly diminished after instrument panels and navigation tables were remounted to reduce vibration (McFarland, 18).

Many of the recommendations made to reduce noise will also attenuate vibration. This is particularly true in the case of propeller design and location. The following specific suggestions should also be helpful:

> Shock-mountings for all instruments, instrument panels, indicators and work tables; seating designed to minimize vibration; rubber foot pads, arm rests, etc. to prevent vibration transmission through the feet, arms, elbows, etc.

4. Panel Layouts and Operator Seating

The arrangement of controls and displays in equipment panels can affect the development of fatigue in operators. Work simplification studies (cf. 20, 13) have led to the adoption of six general design principles:

> All controls and displays should be located within a practical working distance from the operator. Within this working area, each control and display should be located where it may be most efficiently used. The more important and more frequently used items should be given the preferred positions on the panel. Controls and displays should be grouped in patterns that make for the easiest operation and observation from the point of view of the operator. No one part of the body should be overloaded with work that could be assigned to other body parts. Any possible confusion of controls or displays by the operator should be avoided by proper design or placement.

The practical limits of the work space can best be determined from anthropometric data The results of one study with Navy pilots, on the limits of reach, represent the maximum distances which 97% of the sample could reach (Figure 9). These data can be used to specify the distance within which all primary controls must be placed.

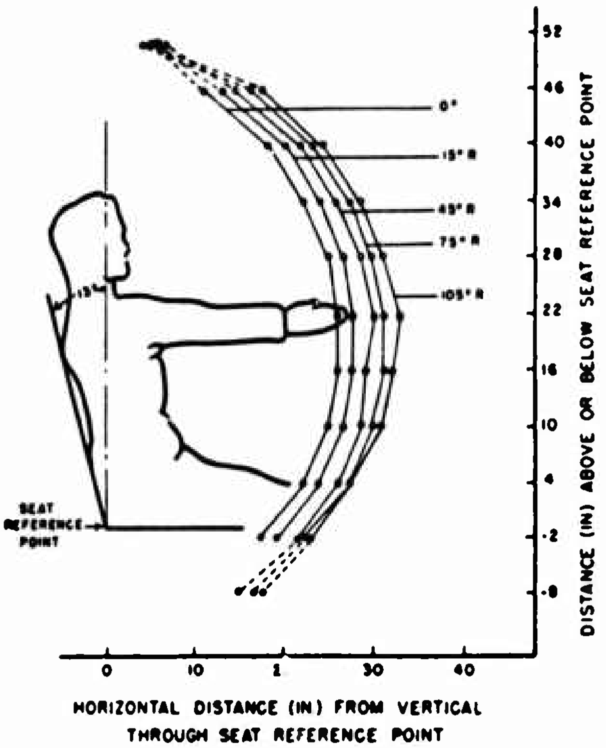

Figure 9. Maximum distances which can be reached by 97% of a sample of Navy pilots at angles from 0 degrees to 105 degrees to the right of the midline. [After King et al. (13)]

Having established the practical limits of the working area, it is necessary to determine the optimum position of the controls. In general, the best position for most hand-operated controls is considered to be between shoulder and waist height. Visual displays should be placed at eye height in front of the operator, in order to be seen most accurately and with least effort.

Other design dimensions for the seated position, as suggested by anthropometric data (27) are listed in Table 5; they are averages for a population of adult males.

A work station seat must satisfy three requirements: it must support the operator in such a position that he can most effectively employ all controls and displays; it must minimize the development of postural fatigue, and it should reduce the transmission of airship vibrations to the operator.

Table 5. Anthropometric data required for work station design

	Inches
Height of seat from floor	19
Distance from seat to elbow	10
Distance from seat to shoulder	24
Distance from seat to eyes	31

From these data, the following design dimensions in inches are suggested: height of work tables above floor should be 29; height (above tables) of primary visual displays, 21; height (above tables) of primary controls, 0-14.

Specifications for seating must include dimensions, design and cushioning. For maximum comfort, the chair must fit the user. The dimensions must be based on anthropometric body-size measurements. Major dimensions derived from such measurements (27) are presented in Table 6.

Table 6. Recommended seating dimensions (in inches)

	Dimension	Adjustment Required
Height of seat above floor	19	$\pm$ 2
Seat length	19	
Seat width	21	
Back height	24	
Height of arm rests	9.5	
Shoulder breadth	20	

For maximum comfort and least fatigue, seating design must meet the following objectives (14, 18):

The operator should be supported over a large area to get the smallest unit pressure on the flesh. The most comfort-able surface contour and pressure distribution on the loaded cushion should be obtained. Minimum muscular exertion should be required to maintain equilibrium. The front edge of the seat should not press against the underside of the legs and interfere with circulation.

Seat and back cushions which can fulfill these requirements and provide the necessary protection against vibration have been developed (Jackman, 12). These cushions were constructed of fiberglass batts which weigh only 5 lbs. Arm rest cushions should not be overlooked. Seats should be rubber shock isolated at all points of attachment, easily removable and slide mounted on tracks. Only the navigator's seat should be of the swivel type. Foot rests and rubber foot pads should be provided.

5. Food Service

Three methods have been suggested for feeding airship crews on long missions: serve one or more fully prepared hot meals on each flight; serve one or more pre-cooked, frozen, and reheated meals; and serve only sandwiches or other ready-to-eat meals.

For each case, there is some penalty involved in the weight of food and equipment, and in the man-hours of activity required for service. This problem was discussed with LTA personnel. In general it was felt that hot meals were desirable because they gave the men something to look forward to, served to break up the monotony of long flights, and helped minimize feelings of tiredness.

There has been little research to determine objectively the influence of the type, frequency, and content of meals on the performance of monotonous tasks. The feelings expressed by airship crewmen, however, would seem to warrant the serving of at least one hot meal on each mission.

IV. PERSONNEL REQUIREMENTS

There remains one final problem related to the design and layout of equipment. What is the most desirable size of crew to operate the airship at maximum effectiveness? This concern is the subject of the present section.

If the operation of combat equipment and the performance of operating tasks were the only determinants of crew size, there should be provided enough men to handle all equipment, sufficient relief personnel to assure high-level human performance, and an adequate service crew to meet the needs of the operating personnel. This is essentially the way a ship or shore establishment is operated. Other equally important considerations, however, make this impractical.

Additional crew may add to combat effectiveness but, at the same time, their weight reduces flight endurance. The duration of the flight is affected by total weight and the addition of an extra crewman invokes a fuel penalty. The weight of one man, plus his personal equipment, is approximately equivalent to an hour's flying time. Curtailment in endurance will be reflected in a decrease in the potential number of submarines destroyed. The size of the crew, therefore, will be determined by overall combat performance, which in turn is measured by performance effectiveness and the period during which it can be maintained.

Since the airship must be designed for maximum overall performance, the arrangement of equipment and work stations must provide for operation by an "optimum crew." Actually, the optimum crew will vary with the type and duration of mission. The design and arrangement of work stations, however, must be based on an "optimum crew" selected to meet the most general operational requirements and yet possess sufficient flexibility to meet specific tactical requirements. The general operational requirements assumed for design purposes are:

1. The airship must be prepared to carry out all phases of combat.
2. Almost all of the activity on missions will consist of searching operations.
3. Missions for K-type airships will average 13 hours; the N-type, 60 hours.

Under operating conditions, these requirements, and consequently size of crew, may vary from mission to mission. If tactical plans call for airships to operate in teams or to perform only certain types of work, certain equipment units, operators, and/or entire work stations might not be needed. Under these circumstances, additional endurance or armament would probably be desirable. If greater endurance is required, then certainly men and/or equipment must be sacrificed. If a shorter mission is planned, additional relief personnel or equipment operators would be more profitable than excess fuel.

Equipment and work stations, therefore, must be arranged for optimum crew, but should provide sufficient flexibility to meet tactical operating demands. This means that some equipment, chairs, and work stations should be mounted so that they can be easily and quickly removed.

A. Minimum Crew

The determination of "minimum" crew is a preliminary step to finding the optimum crew. The "minimum" crew required for combat performance is determined by the number of tasks which must be performed simultaneously. The latter, in turn, are specified by the nature and amount of human attention required to operate the weapons, equipment units, instruments, controls, and work stations installed in the airship. Since equipment operation varies with combat activity, there must be sufficient crew to operate all equipment required during any one phase. The human requirements for the operation of each piece of equipment which is, or will be, installed in airships are shown in Figure 10. The patterns of equipment utilization throughout the various phases of the combat cycle for the 2K-, 3K-, and N-type airships are shown in Figure 11. From these there have been derived the minimum personnel required to operate all equipment units within the ASW Plot.

1. 3K-type Airship

Four electronic operators with an officer-navigator can manage all equipment required during each phase of the combat cycle if the equipment is distributed to the various watch stations according to the schedule shown in Table 7. This proposal calls for four major equipment stations plus a navigation station. This distribution will permit suitable operation of all equipment according to tactical demands by a "minimum" crew. Each operator would be assigned one major unit of equipment. In addition, radiophone and key-jacks would be provided at each station to allow monitoring of radio signals in one of two ways: by an operator whose equipment is not required during a particular patrol, or by an operator who is simultaneously guarding a primary detection device. The first situation would occur, for example, when tactical consideration precludes the reduced speed needed for towed sonar, demands radar silence, or limits use of RCM or infra-red. On the other hand, should it be necessary to employ simultaneously all

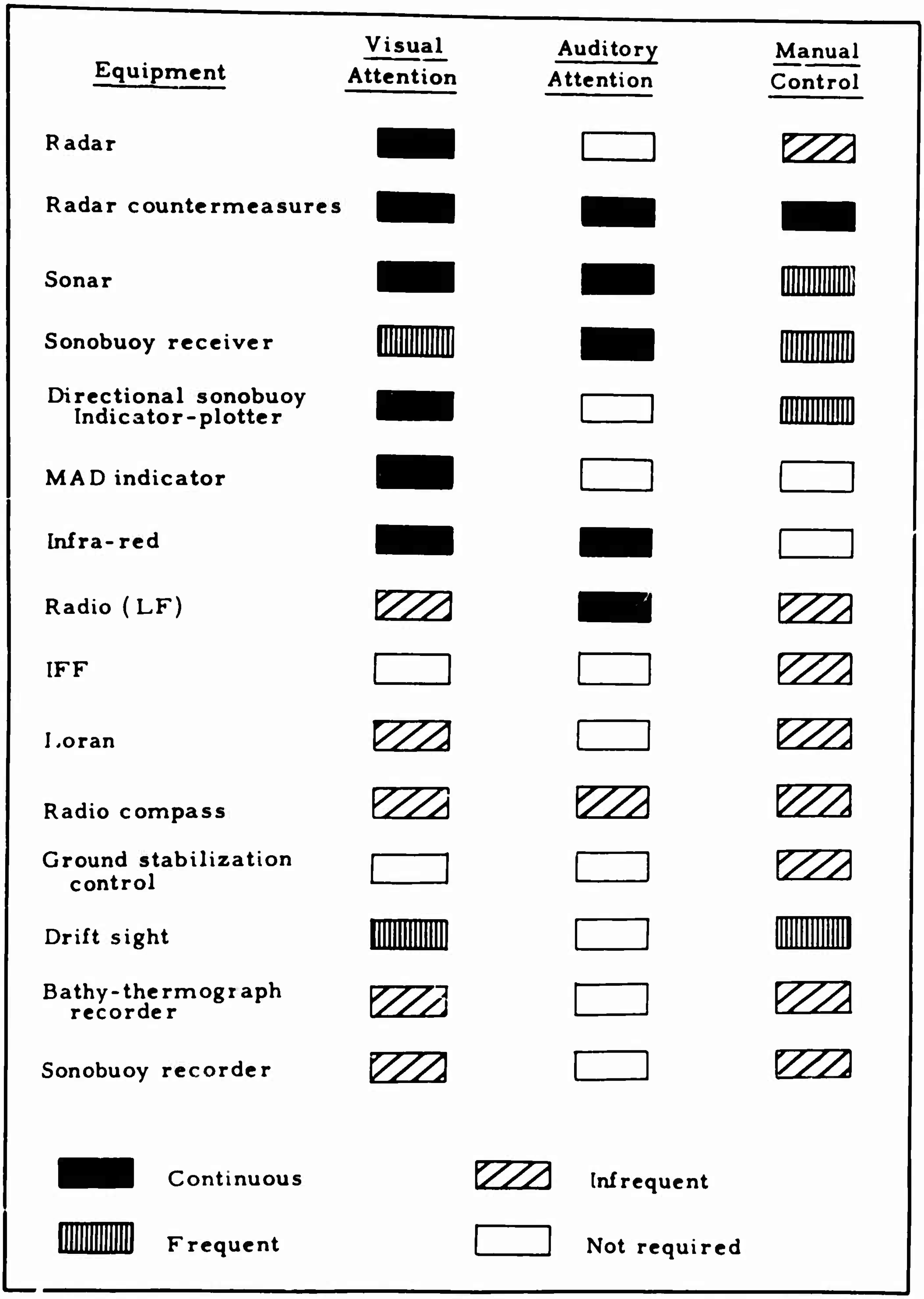

Figure 10. Human requirements for the operation of airship equipment.

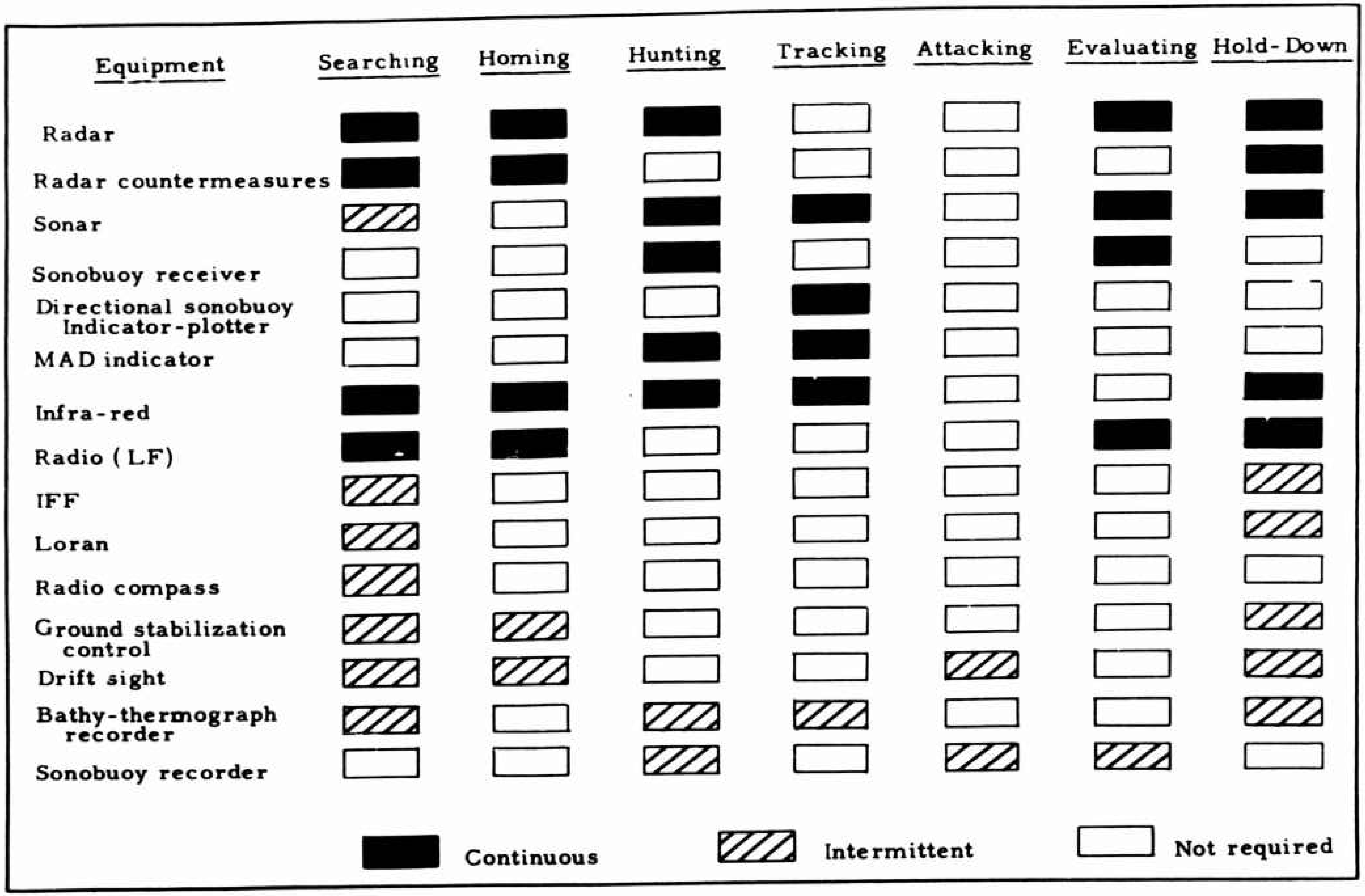

Figure 11. Probable intensity of equipment utilization during various phases of the combat cycle.

Table 7. Proposed distribution of equipment for minimum personnel operation on the 3K- and N-type airships

	Combat Phase						
	Searching	Homing	Hunting	Tracking	Attacking	Eval.	Hold-down
Navigator:							
Drift sight	X	X					X
Radio compass	X						X
GSC	X	X					X
Loran	X						
Directional SB Ind. Plotter				X			
MAD			X	X		X	X
Operator 1:							
Radar	X	X	X			X	X
IFF	X						
(Radio)	(X)	(X)					
Operator 2:							
RCM	X	X				X	X
(Radio)	(X)	(X)					
Operator 3:							
Sonar	X	X	X	X		X	X
Sonobuoy Rec.			X			X	
Directional SB Rec.				X			
(Radio)	(X)	(X)					
Bathy-thermograph Recorder	X		X				
Wire Recorder			X	X	X	X	
Operator 4:							
Infra-red	X	X	X	X		X	X
(Radio)	(X)	(X)					

primary detection devices, one of the operators could monitor radio messages while guarding a visual display (radar or infra-red). The latter alternative would, however, cause some reduction in detection performance.

2. N-type Airship

Since the combat equipment and tactical operating procedures will be essentially the same for 3K- and N-type airships, the personnel required to operate the ASW Plot should be the same. However, a complete relief crew is essential since the N-type may have to operate continuously for days or weeks. This would require two officer-navigators and eight electronics watch operators.

3. 2K-type Airship

The 2K-type carries only a portion of the equipment which is planned for future airships. This 2K-type, now in operation, employs only radar detection. Future models may carry one or more additional detection equipment units. Table 8 shows the minimum personnel requirements and the necessary distribution of equipment for either the present or modified 2K-type. If radar is the only detection device installed, a navigator and two electronics operators are required. Another operator and work station will be needed if an additional detection unit is added (RCM, infra-red).

B. Optimum Crew

It is useful to consider the effect of adding or subtracting a man from the number of "minimum" crew members. In every case, the primary criterion is the net gain in overall performance.

It is assumed that the effective endurance of a 2K-type or 3K-type airship with "minimum" crew complement is 13 hours and that of an N-type, 60 hours. Effective endurance implies sufficient reserve to allow for anticipated emergencies. Since the weight of one man, plus personal equipment, is the equivalent of about one hour's endurance, the addition of one man reduces the available patrol time of K-type airships from 13 hours to 12 hours--a reduction in potential overall combat achievement of 7.7%. For N-type airships the reduction is from 60 to 59 hours--or 1.7%. For a net gain to exist there must be a greater resultant performance improvement.

Some of the possible changes in the composition of the basic crew are:

1. Reduction in the number of electronics operators,

2. Addition of relief electronics operators,

Table 8. Proposed distribution of equipment for minimum personnel operation on the 2K-type airship

	Searching	Homing	Hunting	Tracking	Attacking	Evaluating	Hold-down
Navigator:							
Drift Sight	X	X					
Radio Compass	X						
Loran	X						
Directional SB Ind.-Plot.				X			
MAD Indicator			X	X		X	X
Operator 1:							
Radar	X	X	X			X	X
IFF	X						
(Radio)	(X)	(X)					
Operator 2:							
Radio	X	X					
Sonobuoy Receiver			X	X		X	
Wire Recorder			X	X	X	X	

3. Addition of after-visual lookout,

4. Addition of utility personnel,

5. Addition of flight mechanics.

1. Reduction in the Number of Electronics Operators

There are four primary detection devices and each requires continuous undivided visual attention. In addition, three units (sonar, RCM, and infra-red) require continuous auditory attention. For the 3K- and N-type airships, the four electronics stations and the radio must be operated by four men. Should one of these operators be relieved from his electronics station, he would still be needed to monitor the radio. For the elimination of an operator to be profitable, the value of an additional hour of flight would have to be greater than the contribution which some combination of equipment units can make during an entire mission. For a 3K-type airship this means that 13 equipment-hours must be less important than a 7.7% (1/ 13) increase in endurance. For the N-type, 60 equipment hours would have to be less useful than a 1.7% (1/60) increase in endurance. It is, therefore, recommended that the optimum crew contain no fewer electronics operators than the number specified for minimum crew operations.

Changes in equipment operating demands may change minimum crew requirements. Chief among these would be the development of self-indicating devices which would not require continuous visual or auditory monitoring.

2. Addition of Relief Electronics Operators

Operators who monitor visual displays for a long time suffer some progressive loss in ability to detect scope signals (Lindsley et al., 15). According to Mackworth (17), the loss in function is about 15% for the first half hour, 10% for the next, and 1% for each of the subsequent periods. If an operator is permitted to rest and then return to the job, his performance returns to its initial peak and deteriorates again at about the same rate. Performance decrement curves were constructed from these data for two conditions: a) for electronics operators with no relief; and b) for electronics operators relieved for 30 minutes every two and one-half hours--by adding one relief operator. Since our analysis revealed that probability of detection is almost directly proportional to the ability of an operator to notice a scope signal (cf. p.12), the expected number of detections per mission is proportional to the area under the performance decrement curve.

The results indicated that the expected performance improvement with relief for the 3K-type airship is about the same as the loss resulting from curtailed endurance. Therefore, the optimum crew should contain a relief operator who can also serve as cook or perform other utility functions. For the N-type airship, the contribution of a relief operator would clearly exceed the cost of adding an additional man to the crew. For this reason, the optimum crew should contain two relief operators (one for each watch section).

3. Addition of After-Visual Lookout

Detection performance might be improved in one of two ways: 1) by adding an after-visual lookout to the airship crew for a greater number of visual detections, or 2) by removing a lookout in favor of the greater number of detections which the airship could make with an additional hour of flying time. The gain in adding a crewman to serve as an after-visual lookout has been determined by comparing the computed expected improvement in detection performance with the cost of curtailed endurance.[4] Expected performance was calculated in terms of the number of detections per unit time for airships which would and would not have an after-lookout. The total number of expected detections per mission was then calculated for a standard (minimum crew) mission and for a modified (minimum crew plus lookout) mission. Without a lookout, the expected rate of detection for a target density of .00001 (one target per 100,000 square miles) was computed as .0197 per hour. With an after-lookout, the expected rate of detection came to .0199 per hour.

The results, as shown in Table 9, indicate that the K-type with an additional hour of searching time in place of the after-lookout would produce, in the long run, more detections; this estimate is probably conservative.

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4 The theoretical considerations and calculations involved in the solution of this problem were derived from techniques used in operational analysis (cf. 30). The computations and methodology are intended for separate publication (cf. footnote 1). The following primary assumptions were made:

a. Detection of a submarine can be accomplished by forward-visual lookouts (two pilots) scanning a forward sector 180°, and after-visual lookout (when present) scanning the rear sector of 180°, or radar.
b. The submarine can detect the airship first, visually or by radar, and submerge to deprive the airship of detection opportunity.
c. The after-lookout is deprived of a detection opportunity if the pilot or the radar operator detects the submarine first.

Table 9. Detection effectiveness with and without a visual lookout

	Maximum Hours of Over-Ocean Flight Endurance			
	No Lookout 13 hrs.	Lookout 12 hrs.	No Lookout 13 hrs.	Lookout 12 hrs.
Expected no. of detections	.256	.239	1.20	1.20
Percentage improvement without lookout	7.1%		0.0%	

Consideration was not given to the impaired effectiveness of visual lookouts at night nor to the fact that certain portions of the flight are the least profitable (because of fatigue and inattentiveness). With additional electronic detection devices (sonar, infra-red) the usefulness of the visual lookout would be further decreased. It is evident, therefore, that the K-type optimum crew should not have an after-visual lookout.

For N-type airships, the performance improvement resulting from either an extra hour of endurance or an after-lookout would be about the same. For this reason, a lookout who can perform other important services (e.g., mechanic, cook) would be a desirable addition.

4. Addition of Utility Personnel

On present airships, our study showed that the two flight riggers during normal operations actually serve as cooks. The activity sample indicated that during such operations 44% of the available rigger man-hours were occupied with cooking and cleaning, 27% were spent as rudder pilot, and 29% were idle. During combat exercise, 81% of the available man-hours were spent as lookout or gunner, 6% loading or standing by markers, flares and sonobuoys, and 13% in idleness.

With an automatic pilot, there would be no demand for additional pilot relief. Airship gunnery is obsolete. This means that cooking, flare or sonobuoy handling, and infrequent in-flight repairs must justify the inclusion of riggers or similar utility crewmen. Interviews with airship pilots have indicated that only very minor repairs can be made during flight. Reference to Figure 11 (p.46) discloses that personnel can be released from equipment operating jobs during hunting and tracking phases to load flares and sonobuoys.

The primary reason for adding a utility man to the minimum crew would be for cooking or some newly developed utility function (such as winch tending for sonar operations, refueling, etc.). If pre-cooked frozen meals are used, both of these tasks could be handled by the relief electronics operator. Such meals could be stored in a light-weight insulated cabinet and heated in a few minutes.

5. <u>Addition of Flight Mechanics</u>

The primary duty of the flight mechanic is watching instruments. The flight mechanic's panel was guarded continuously during searching and cruising operations. However, the mechanics actually made control adjustments only 10% of the time and most of these were of a minor nature. The remainder of their time was largely devoted to inactivity or eating. The pilots can be assigned to watch an additional half-dozen engine instruments since the automatic pilot would take care of many of their duties during flight. This is particularly true with respect to those instruments requiring check rather than quantitative readings.

The combat functions of the flight mechanics are relatively insignificant. While one man stands watch at the panel, the other serves as an auxiliary after-lookout and utility man. Although the mechanic will not be needed on future airships, he is still useful on present K- and 2K-types. Since he does not require relief, the second mechanic is not needed for the optimum crew.

V. SUMMARY OF RECOMMENDATIONS

The primary purpose of this investigation was to derive recommendations with respect to airship design in order to obtain maximum performance on anti-submarine missions.

It was first necessary to determine the influence of human performance on airship operation in order to specify the nature of performance--man and machine--required for maximum effectiveness. Airship data collected on anti-submarine missions indicated the extent to which present and anticipated performance satisfies these requirements.

Finally, human engineering design data were applied to derive recommendations for design and arrangement of airship equipment and work stations in order to obtain maximum combat performance. This final section is a summary of all of the specific recommendations contained in the two previous chapters. The order of presentation is as follows:

A. Optimum Crew

B. Layout and Design

1. General Airship Design
2. Design of the Airship Car and the ASW Compartment
3. Layout of Work Stations
4. Design of Work Stations

    a. General Recommendations
    b. Specific Work Station Design

        (1) Navigator's Station
        (2) Radar Station
        (3) Radio Station
        (4) Sonar Station
        (5) Countermeasures Station
        (6) Infra-red Station
        (7) Relief Operator Station
        (8) Service Station

A. Optimum Crew

The optimum crew requirements, summarized in Table 10, are designed to meet general tactical needs. The optimum crew size must vary, however, with specific mission requirements. On long endurance missions, additional fuel is required. The weight resulting from personnel and equipment must, therefore, be reduced. On short endurance missions, add relief electronic operators. Whenever possible, eliminate unnecessary work stations, equipment units, and operators and add relief operators or additional fuel and/or armamen

B. Layout and Design

1. General Airship Design

In order to reduce noise and vibration, maximize car-propeller tip clearance and minimize propeller tip velocities. Locate engine nacelles as far to the rear of the car as possible and provide light-weight acoustic filters for engine exhausts.

2. Design of the Airship Car and the ASW Compartment

To reduce distraction and minimize noise and vibration within the airship car do not have windows or hatches within the ASW Plot. Restrict the number and size of hatches in the after section of the car to the minimum needed for lookout or other purposes. Separate the ASW Plot from the forward and after sections of the airship by light-locks. Treat the ASW Plot acoustically by covering all surfaces with sound insulating material. (Use material for this purpose equivalent in acoustical properties and weight to Fiberglass AA). Apply trim about all doors and cracks. Have sound-treated doors which fit snugly in their frames at both ends of the ASW Plot. Eliminate loose floor-plates, panels and fixtures which may vibrate in flight. Place ventilating and heating air-intake ducts in an area of lowest sound level and provide them with acoustic filters. Provide rigid car wall sections near the propeller plane. Locate hatches away from the loudest noise zones. Seal the airship and the ASW Plot, in particular, against air leaks.

In order to provide good visibility, illuminate the ASW Plot by overhead, non-glare lighting. Use white light during daylight hours and red at night. Provide a general room illumination brightness of approximately 0.1 foot-lambert. Eliminate all bright reflecting surfaces and use paint with a dull finish on the interior of the ASW Plot.

3. Layout of Work Stations

Specific recommended layouts for the 2K-, 3K-, and N-type airships are presented in Figures 12 and 13.

Table 10. General optimum crew requirements

2K-type Airship	3K-type Airship	N-type Airship
Command Pilot	Command Pilot	Command Pilot
Co-Pilot	Co-Pilot	Co-Pilot
Navigator	Navigator	Navigators (2)
Electronics Operators (2 or 3) Radar Relief-radio-utility or Radar Undesignated Relief-radio-utility	Electronics Operators (5) Radar Sonar RCM Infra-red Relief-utility	Electronics Operators (10) Radar (2) Sonar (2) RCM (2) Infra-red (2) Relief-technicians-lookouts (2)
Flight Mechanic		Flight Mechanic (cook-lookout-utility)

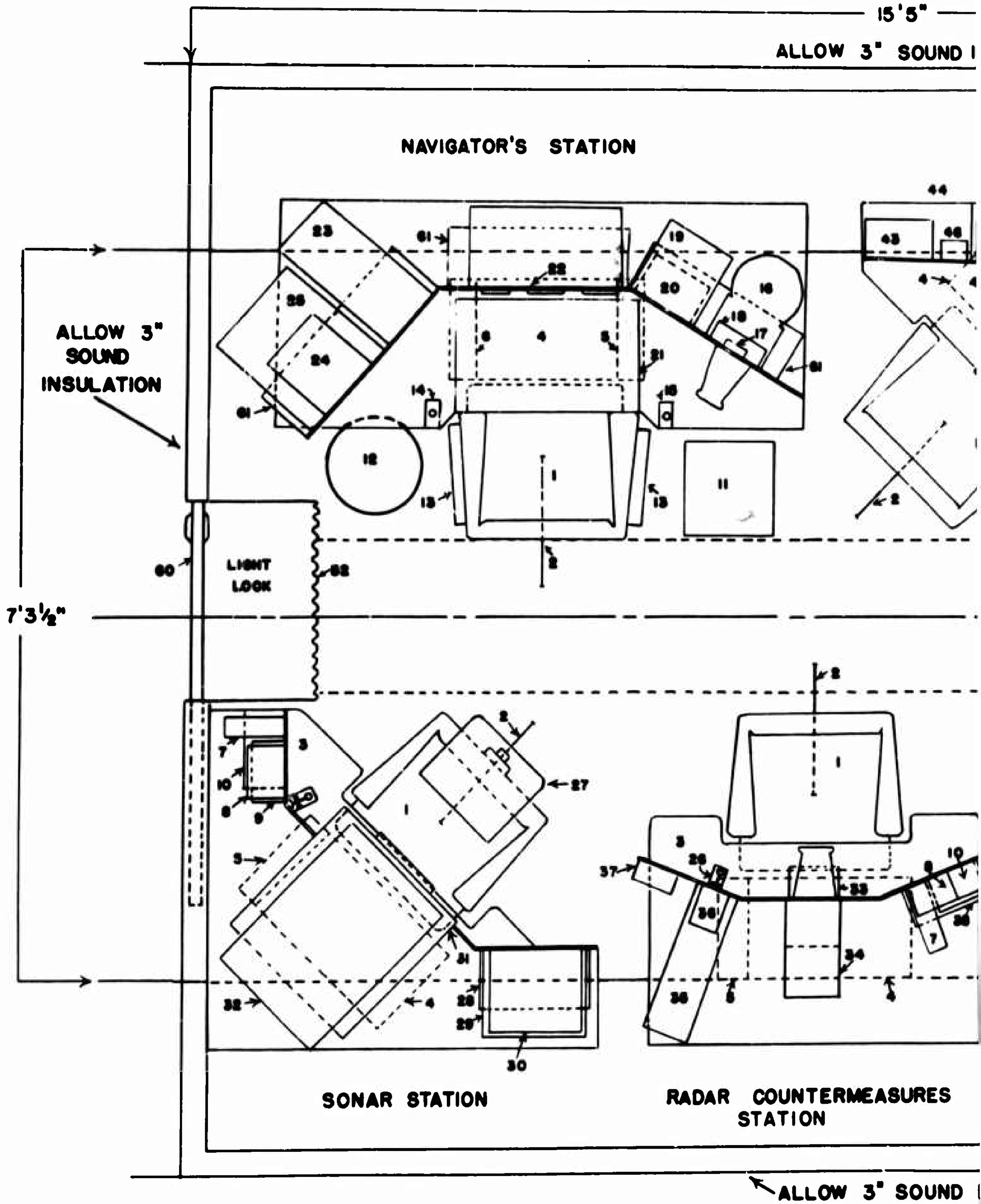

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Figure 12. Proposal for the layout of equipment in the
N-type would not have a service station. (

A

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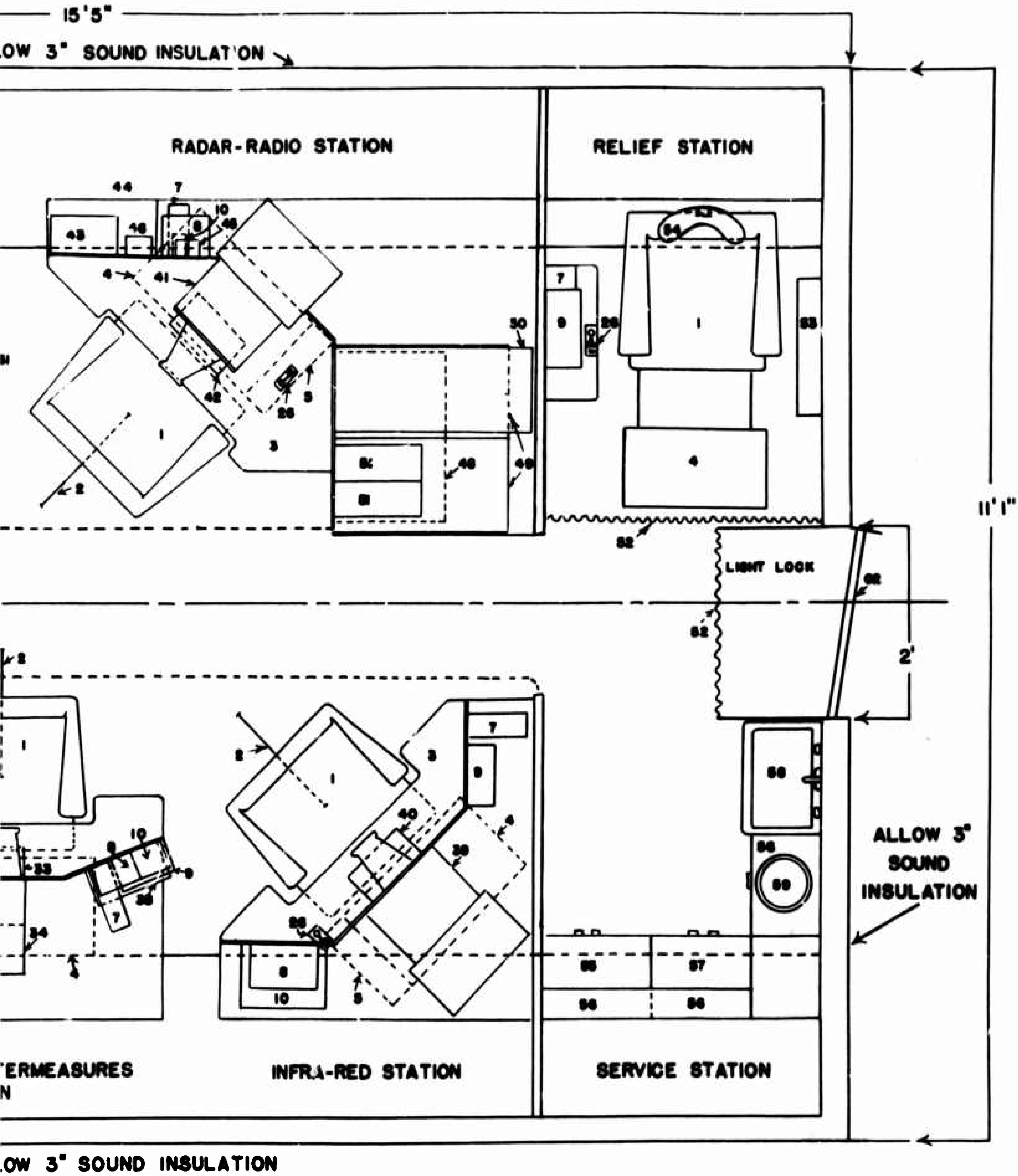

SCALE 1" = 1'

.pment in the ASW Plot of the 3K- and N-type airships. The
:e station. (The key to equipment numbering is given on p. 58).

B

Equipment Numbering Key

1.	Chair	
2.	Track	
3.	Table	
4.	Foot rest	
5.	Microphone pedal switch--general ICS circuit	
6.	Microphone pedal switch--pilot-navigator circuit	
7.	Jackbox	
8.	Optimum bias tester	
9.	Radio remote control	
10.	Earphone switch box	
11.	Sonobuoy indicator-plotter	AN/ARR-26
12.	Drift sight	
13.	Chart rack	
14.	Sonobuoy release switch with safety cover	
15.	Marker switch and contact alarm with safety cover	
16.	Radar repeater	AN/APS-33A
17.	Radio compass	AN/ARN-7
18.	Radio compass control	AN/ARN-7
19.	MAD recorder	AN/ASQ-8
20.	Range and bearing indicator	
21.	Hinged plexiglass table-top	
22.	Instrument panel	
23.	Loran receiver-indicator	AN/APN-9
24.	Ground stablization computer-indicator	AN/APA-57
25.	Ground stablization control unit	AN/APA-57
26.	CW key	
27.	Sound absorbing head shield	
28.	Sonobuoy receiver	AN/ARR-26
29.	Bathythermograph recorder	RD-53/ARH
30.	Sonar sweep and timing unit	AN/AQS-2
31.	Sonar indicator-control	AN/AQS-2
32.	Sonobuoy recorder	VRW-7
33.	RCM detector remote control	AN/APR-9
34.	RCM detector indicator	AN/APR-9
35.	RCM direction finder indicator	AN/APA-69
36.	RCM direction finder control	AN/APA-69
37.	RCM pulse analyzer	AN/APA-64A
38.	RCM pulse analyzer indicator-control	AN/APA-64A
39.	Infra-red detector	AN/AAR-3
40.	Infra-red detector control	AN/AAR-3
41.	Radar indicator	AN/APS-33A
42.	Radar control	AN/APS-33A
43.	IFF transponder frequency control unit	AN/APX-6
44.	IFF transponder tuning unit	AN/APX-6
45.	IFF transponder code control unit	AN/APX-6
46.	IFF interrogator responder control unit	AN/APX-17
47.	Antenna reel control box	AS-401/A
48.	Low frequency radio transmitter	AN/ART-13
49.	Low frequency radio receivers	AN/ARR-15
50.	VHF radio transceiver	AN/ARC-19
51.	LF radio receivers	ARC-5
52.	Curtain	
53.	Shelf	
54.	Head rest	
55.	Frozen food locker	
56.	Storage cabinet	
57.	Warming oven	
58.	Sink	
59.	Coffee urn or thermos	
60.	Sliding door	
61.	Instrument rack	

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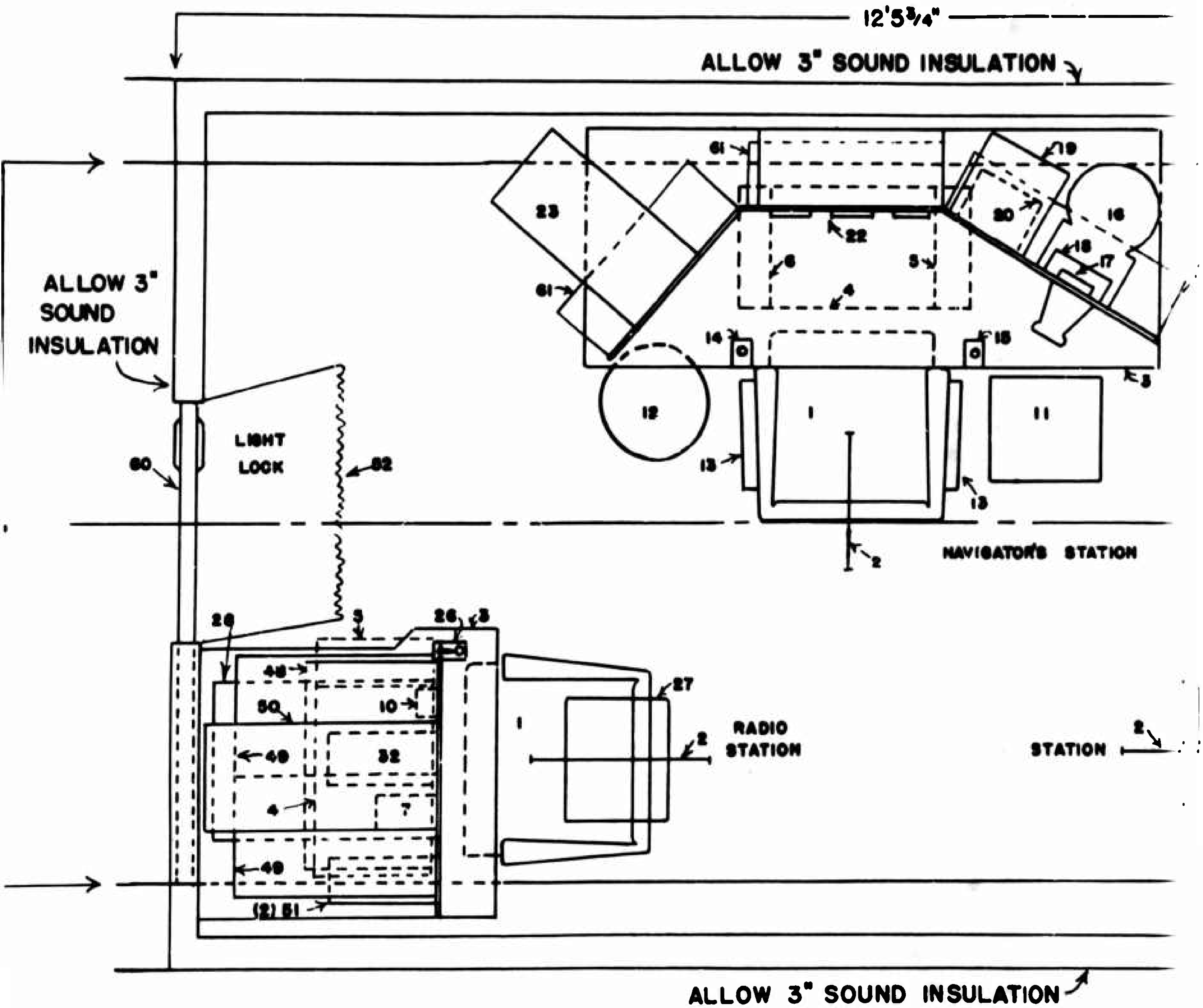

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Figure 13. Proposal for the layout of equipment in the ASW Plot of t... key to equipment numbering is given on p.58).

A

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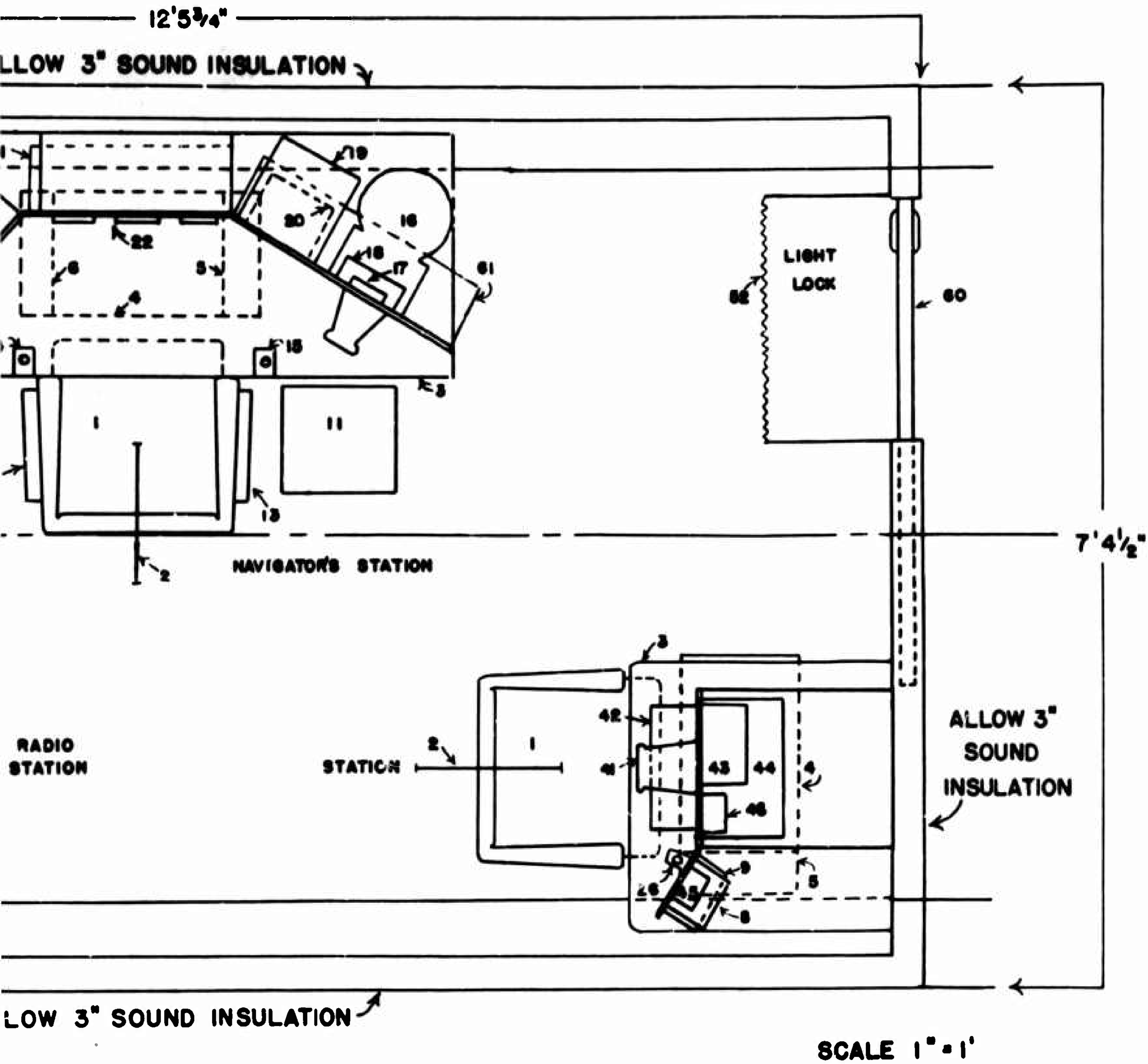


yout of equipment in the ASW Plot of the ZK-type airship. (The
imbering is given on p.58).

The general recommendations are to locate the navigator in the center of, and as close as possible to, all other operators within the ASW Plot. Locate the sonar station where the sound intensity is least. (This position is believed to lie on the center line of the ship at the most forward position. This should be verified by experimentally determining airship sound contours.) Locate the radar station immediately adjacent to the navigator's station.

4. Design of Work Stations

a. General Recommendations

Locate all equipment components, which do not require operation or attention, outside the ASW Plot, overhead, or in secondary positions. To reduce noise and vibration, locate all inverters, dynamotors, generators, etc. outside the sound-treated compartment.

Provide two ICS circuits for communications, one to connect only the pilots and the navigator, the other to connect all stations. Mount microphones on adjustable arms and have them actuated by foot switches. Make it possible for the navigator and pilots to select either circuit. Provide earphone switch boxes at each station so that any operator can pick up radio messages, ICS communications, and/or equipment auditory signals on his earphones. Locate controls for the operation of LF radio equipment at each electronic station, and provide CW keys at each station so that any operator can transmit or receive radio messages.

Mount equipment at work stations in panels or consoles, and mount all equipment units for quick and easy removal. Give the more important and more frequently used controls the preferred positions on the panel.

Make work tables 29 inches high and shock mount them from the wall and floor. Locate all primary equipment controls no farther than 20 inches from the edge of the operator's table and not more than 14 inches above the table. Locate all secondary controls no farther than 35 inches from the edge of the operator's table and not more than 35 inches above the table. Place primary detection scopes so that the center of the display is 21 inches above the work table. Have tube face directly above the table's edge. Make it adjustable in height, angle, and horizontal position. (A visor is not necessary, but if used, it should be 6 to 8 inches in length.)

For units of detection equipment which contain scope displays, make primary equipment controls identifiable by touch. Use range and bearing cursors or traces for determining target range and bearing. Have cursors present information on range and bearing counter-type indicators at the work station and connect them to a master repeater at the navigator's station. Build an artificial signal generator into (or locate one with) the equipment at each station. Design generator so that it produces a small signal of controllable intensity on the face of the scope, thus permitting each operator to determine optimum screen brightness for particular conditions of screen "noise", video gain, ambient illumination, and cathode ray tube characteristics.

For units of detection equipment which possess auditory displays, reproduce echo signals or target noises at frequencies which are least subject to masking. (A research program should be undertaken to determine these optimum frequencies.) Provide efficient sound-absorbing head shields for sound operators. Develop earphones or earphone shields which can insulate the wearer against ambient noise.

Provide illumination at all electronic stations by means of shielded red/white lamps on adjustable arms. Have a brightness level of approximately 1.0 footlambert at work stations.

Provide each electronic station with small table surfaces on each side of the operator for recording messages, operating CW key, etc. Give only the navigator a seat which swivels. Make all seats movable on tracks with locking devices. Make all seats contoured, provide them with elbow rests, pad them with fiberglass batts, and shock mount them to minimize vibration. Provide foot rests with rubber pad vibration absorbers at each station. Design seats according to the dimensions presented in Table 11.

Table 11. Seat Dimensions

	Dimension	Adjustment Required
Heat of seat above floor	19 inches	± 2 inches
Seat length	19 "	
Seat width	21 "	
Back height	24 "	
Height of arm rests	9.5 "	
Shoulder breadth	20 "	

b. Specific Work Station Designs

(1) Navigator's Station

Recommended designs for the navigator's station on the 3K-, N-, and 2K-type airships are illustrated in Figures 14 and 16. These designs are intended to incorporate the following recommendations:

Make the chart table at least 24 inches deep, 60 inches long, and exactly 29 inches above the deck. Make the table top of plexiglass construction and have it hinged (or removable) so that correction charts, tactical memoranda, and miscellaneous information can be located for ready reference. Shock mount the table from the wall and deck to minimize vibration.

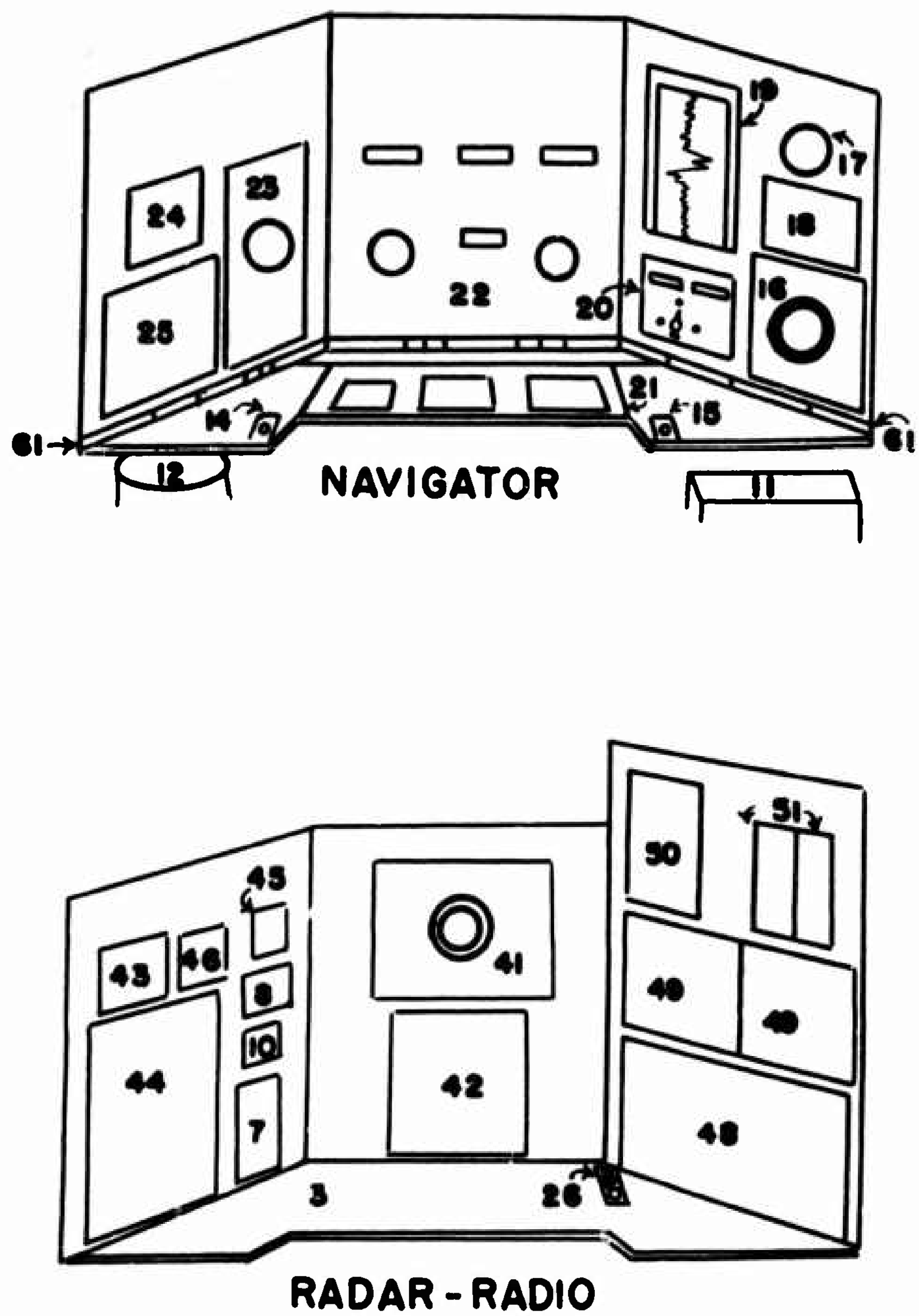
Locate the instrument panel just above the table, directly before the navigator. Shock mount instrument panel. On all instruments, use white figures on a black background. Illuminate instruments by means of edge-lighting--white during daylight, red at night. Have an instrument dial brightness of 0.5 foot-lambert. Include the following instruments: clock, timer, airspeed indicator, course indicator, temperature meter, pressure altitude meter, and target range and bearing indicator.

Make the clock, timer, airspeed indicator, and course indicator of countertype design with numerals one-half inch high. Have the clock read only hours and minutes; the timer, only minutes and seconds. For the timer, position a starting, stopping, and reset switch on the work table for convenient hand operation. Do not locate timer near clock on the panel. Have the temperature meter present temperature of outside air in centigrade degrees. Have the pressure altitude meter give barometric pressure in terms of equivalent altitude. The design and location of these last two instruments are not critical.

Design the target range and bearing indicator so that it repeats target range and bearing data from indicators at electronics stations. Include selector buttons on the indicator so that the navigator can obtain information from any station.

Mount the airspeed correction chart and gyro compass correction chart beneath plexiglass on the table top. Have both these charts designed so that interpolation is not necessary. Design and location of magnetic compass deviation chart are not critical.

Provide most accurate drift sight available. Have it gyro-stabilized and internally illuminated. Mount it on the floor immediately adjacent to the navigator for use with minimum body movement. Do not provide any other drift sight.



<u>Figure</u> 14. Schematic diagrams of the navigation and radar-radio stations on the 3K- and N-type airships showing recommended equipment positioning. (The key to equipment numbering is given on p.58.)

Provide a switch which will simultaneously release a sonobuoy from the sonobuoy dispenser or chute, release a smoke flare, and sound a special signal on the ICS. Use this release switch to supplement, not replace, a similar release switch at the pilots' station.

Provide a marker release switch which will simultaneously release a dye-marker and a flare,and sound a characteristic contact alarm over the ICS. Locate the switch adjacent to the MAD indicator.

Locate MAD indicator directly before the navigator and perpendicular to his line of sight. Use a black ink trace and include an auditory alarm to call attention to possible contacts. Eliminate one detector unit and the comparator.

Position loran and the radar repeater at eye level. Arrange the following instruments so that they can be used without gross body movements: ground stabilization control, directional sonobuoy indicator-plotter, radio compass indicator, radio compass control.

Provide permanent positions for tools, instruments, and computors on a specially designed rack holding a Mark II plotter, A. N. plotter, Mark VIII computor, Mark III plotting board, maneuvering board, dividers, and pencils. Place the rack within 20 inches of the navigator. Index chart rack for convenient usage.

(2) Radar Station

The design for the 3K- and N-type airships is represented in Figure 14. This design is intended to incorporate the following recommendations:

Locate the radar indicator at eye level (21 inches above table). Make it adjustable in height, vertical angle, and distance from operator. Make the visor six inches long and have controls touch-coded.

Locate the following instruments in primary panel positions: radar controls, IFF interrogator, frequency and code controls, remote controls for LF radio receivers and transmitter, optimum bias tester.

Locate the LF receivers and LF transmitter in secondary panel positions.

The recommended design for the 2K-type airship is shown in Figure 16. It is the same as the stations on the 3K- and N-type airships except that it lacks radio equipment.

(3) Radio Station

The recommended design for the 2K-type airship is shown in Figure 16.

Have push button tuning controls for sonobuoy receiver. Reproduce cavitation noises at frequencies which are least subject to masking by ambient airship noise. Provide an efficient sound-absorbing head shield for the station. Provide the operator with insulated earphones. Have each push button on the sonobuoy receiver illuminate a colored bulb on a small sonobuoy chart at the pilots' station. Make the color of each bulb correspond to the code color of a particular sonobuoy. Investigate the possibility of presenting sonobuoy signals on a visual display.

Locate sonobuoy wire recorder and directional sonobuoy receiver in primary panel positions.

Locate the following in secondary panel positions: LF receivers, LF transmitter, VHF transceiver, antenna reel control.

(4) Sonar Station

The recommended design for 3K- and N-type airships is illustrated in Figure 15.

Mount the sonar indicator control 21 inches above table. Present target noises and echo signals at frequencies which are least subject to masking by airship noise.

Provide the operator with a sound-absorbing shield and insulated earphones. Make controls identifiable by touch. Have the bearing and/or range displays repeat at the navigator's station.

Have push button tuning controls for the sonobuoy receiver. Reproduce cavitation noises at frequencies which are least subject to masking by ambient airship noise. Link tuning buttons to a remote indicator at the pilots' station.

Locate sonobuoy wire recorder, bathy-thermograph recorder, directional sonobuoy receiver, optimum bias tester, and radio remote control in primary panel positions.

(5) Countermeasures Station

The recommended design for the 3K- and N-type airships is given in Figure 15.

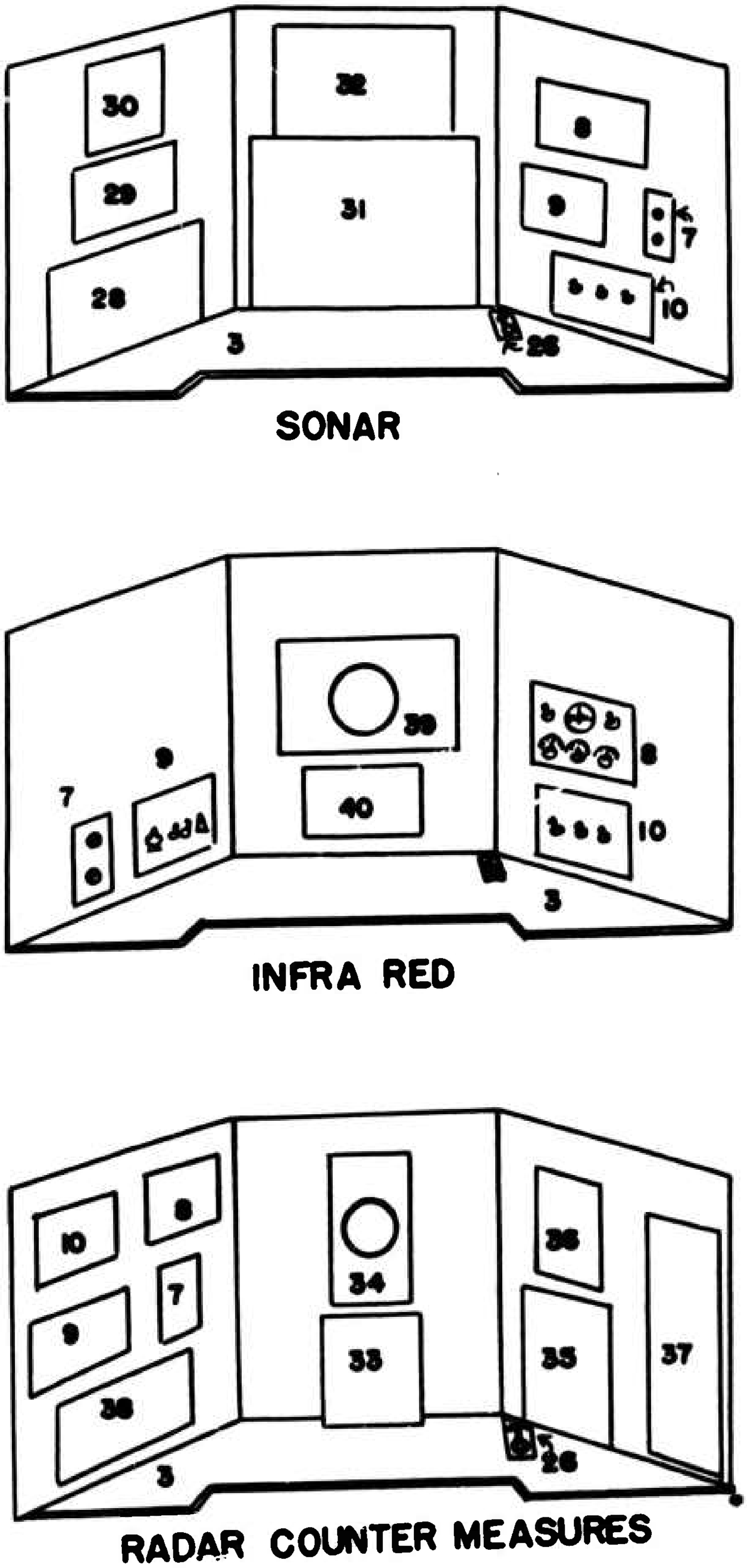


Figure 15. Schematic diagrams of the sonar, infra-red, and radar countermeasures stations on the 3K- and N-type airships showing recommended equipment positioning. (The key to equipment numbering is given on p.58 .)

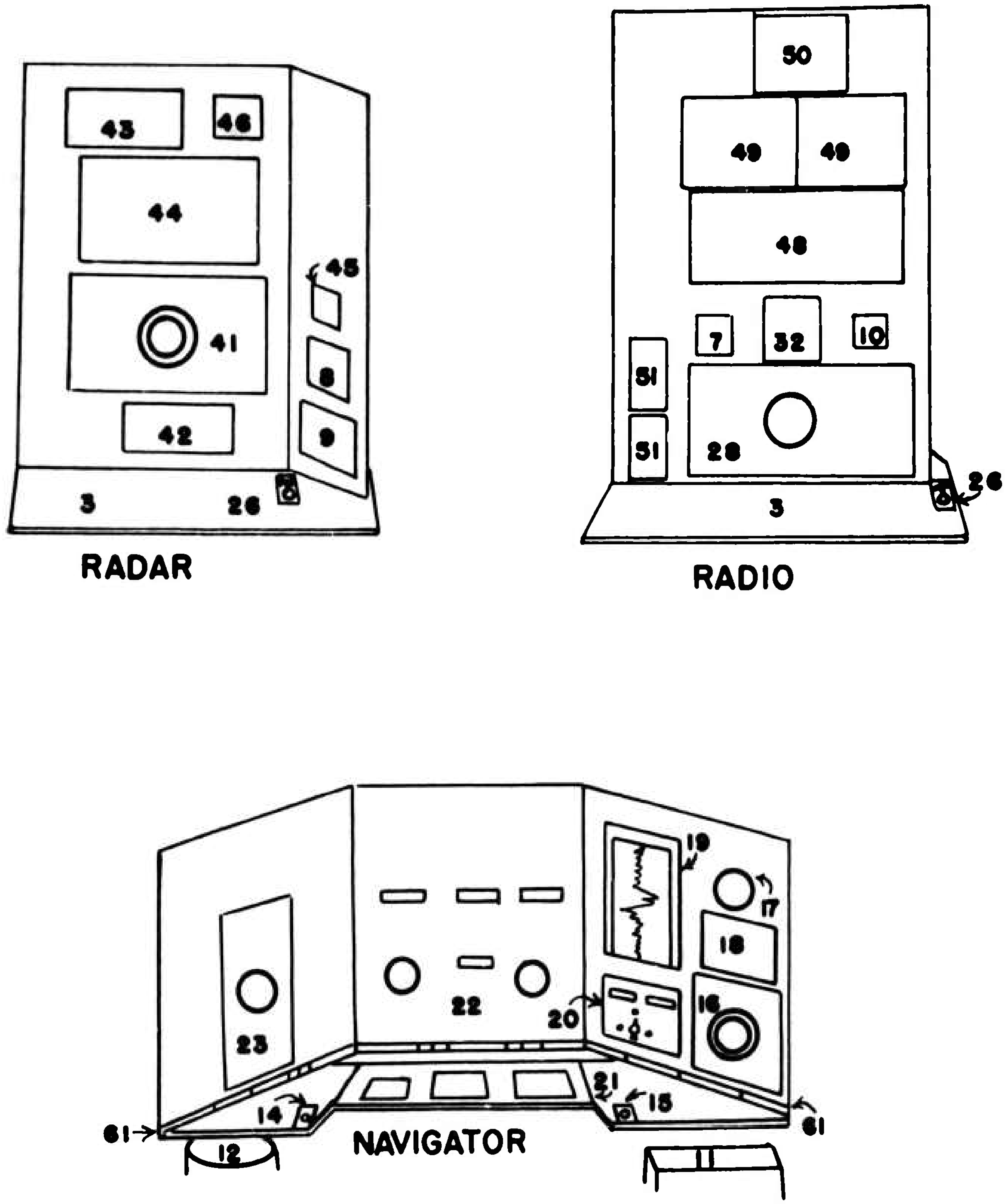


Figure 16. Schematic diagrams of work stations on the 2K-type airship showing recommended equipment positioning. (The key to equipment numbering is given on p.58 .)

Locate display center of radar detector indicator 21 inches above table. Make the display adjustable in height, angle, and distance from operator. Make controls identifiable by touch. Present auditory signals at frequencies which are least subject to masking by ambient airship noise.

Locate the radar detector remote control unit in a primary panel position. Have controls touch-coded. Have the azimuth indicator repeat at the navigator's station. Locate it in a primary panel position.

Locate pulse analyzer indicator-control, radio remote control, and optimum bias tester in primary panel positions.

(6) <u>Infra-red Station</u>

The recommended design for the 3K- and N-type airships is illustrated in Figure 15.

Locate the infra-red indicator display 21 inches above table. Make the display adjustable in height, angle, and distance from operator. Locate infra-red control unit, radio remote controls, and optimum bias tester in primary panel positions.

(7) <u>Relief Operator Station</u>

On the 3K- and N-type airships, provide radio remote controls. Also provide reclining chair with head and foot rest.

(8) <u>Service Station</u>

On the 3K-type airship, provide the following material and equipment: insulated cabinet for storing frozen pre-cooked meal trays, food and silver cabinets, warming oven capable of heating meal trays rapidly, a sink, and a coffee thermos or urn.

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APPENDIX

APPENDIX

The original data collected during this study formed the basis from which design recommendations were developed. These consisted essentially of observations of personnel activities, inter-communications, and performance times obtained during anti-submarine training exercises. The amount of material collected was so great as to prohibit its inclusion either in the body of this report or in the appendix. Some of the basic findings appear in the main part of the study. The remainder of the data are summarized here in order to afford an opportunity to evaluate properly the recommendations.

A. Collection of Data

1. Motion Picture Activity Samples

Photographic activity samples were taken continuously of all phases of combat activity during a six hour period on a simulated anti-submarine mission. The operation was conducted by two 2K-type airships flying out of Weeksville, N. C., on 16 February 1950.

A 16 mm. motion picture camera was mounted just aft of the ASW Plot facing forward. An operator stationed at the camera tripped the shutter to expose a single frame at regular intervals, spaced, on the average, five seconds apart. A timer was mounted in the field of view so that elapsed time could be recorded on the film. Almost 3600 separate photographs were obtained and subsequently analyzed. Each photograph was studied to identify crew activities. The data were then summarized to show how each man spent his time during the several combat phases (Figures A, B, and C).

2. Observer Activity Samples

Observers, stationed in the airship car recorded activity samples of individual flight mechanics and riggers at 30 second intervals during normal patrol and at 15 second intervals during hunting and tracking maneuvers. These data were collected during anti-submarine exercises on 4 and 5 January 1950 aboard 2K-type airships based at Weeksville, N. C. The distribution of activity and work loads for each of the auxiliary crewmen are presented in Figures D and E.

3. Communications Recordings

In order to determine patterns of personnel inter-communications, communication loads, and performance times, all messages transmitted over the ICS and the voice radio were recorded during simulated anti-submarine flights on 3K-type airships. It was possible to coordinate these data with

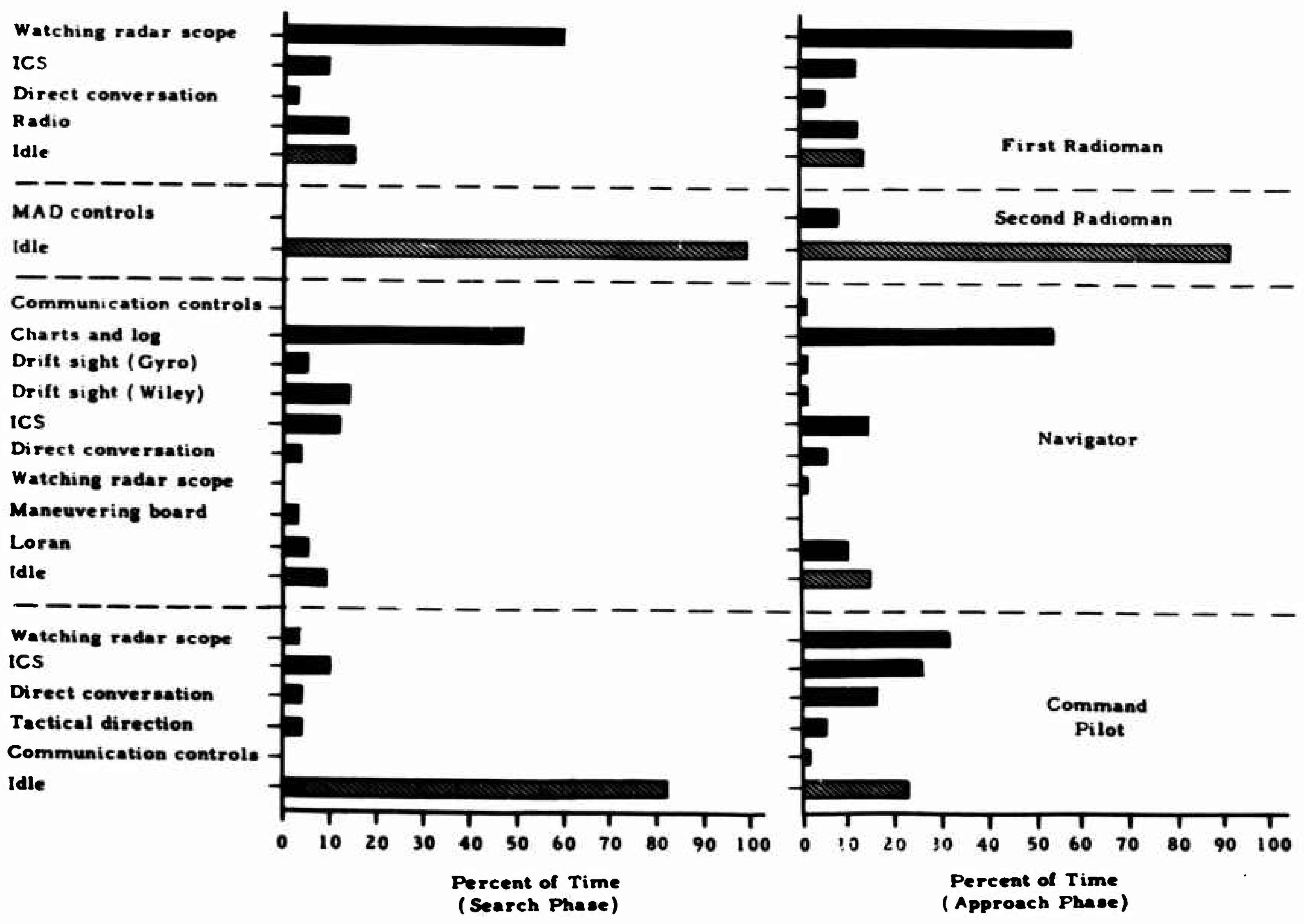

Figure A. Distribution of activities for personnel in the ASW Plot during search and approach phases.

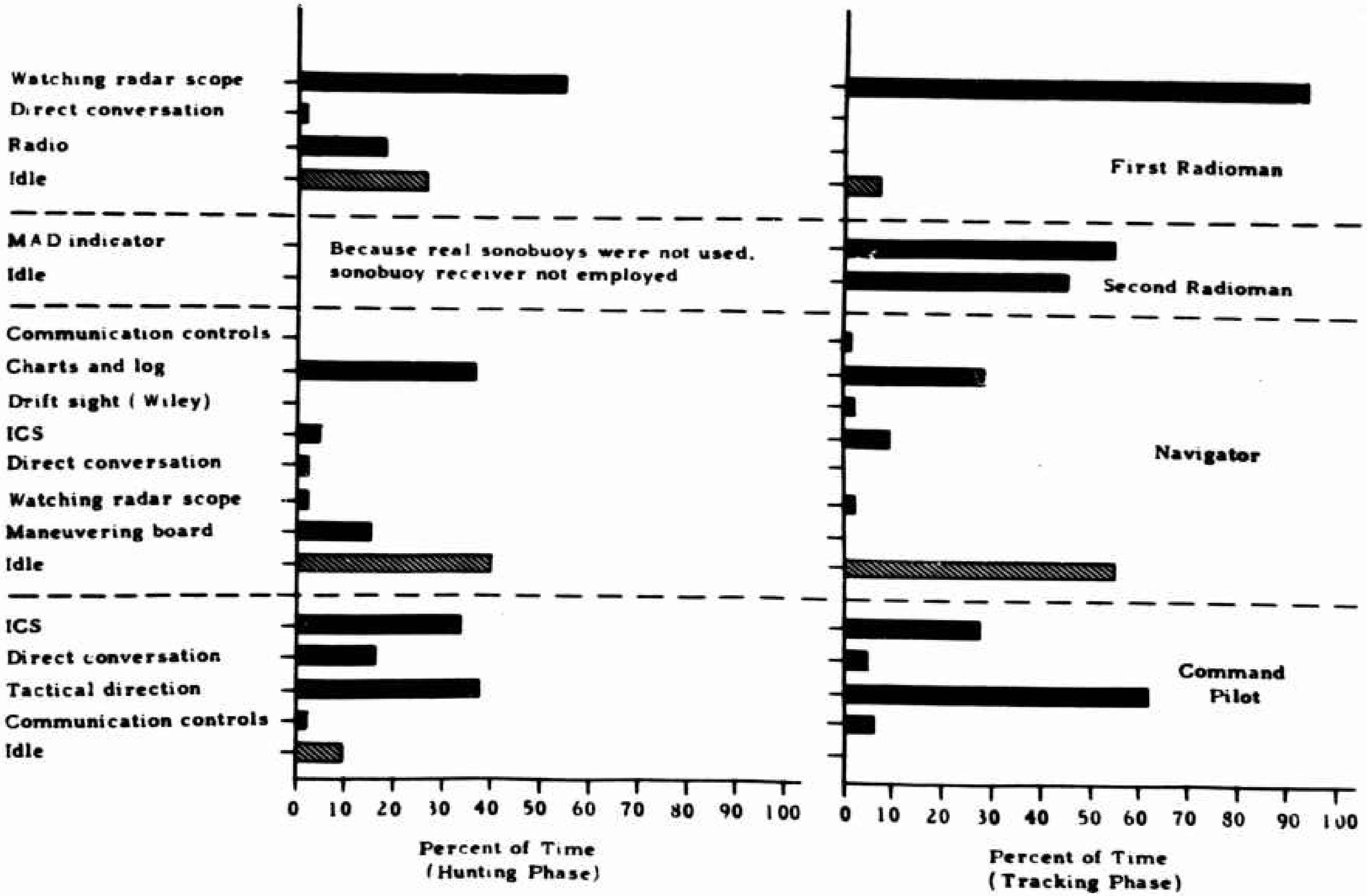

Figure B. Distribution of activities for personnel in the ASW Plot during hunting and tracking phases.

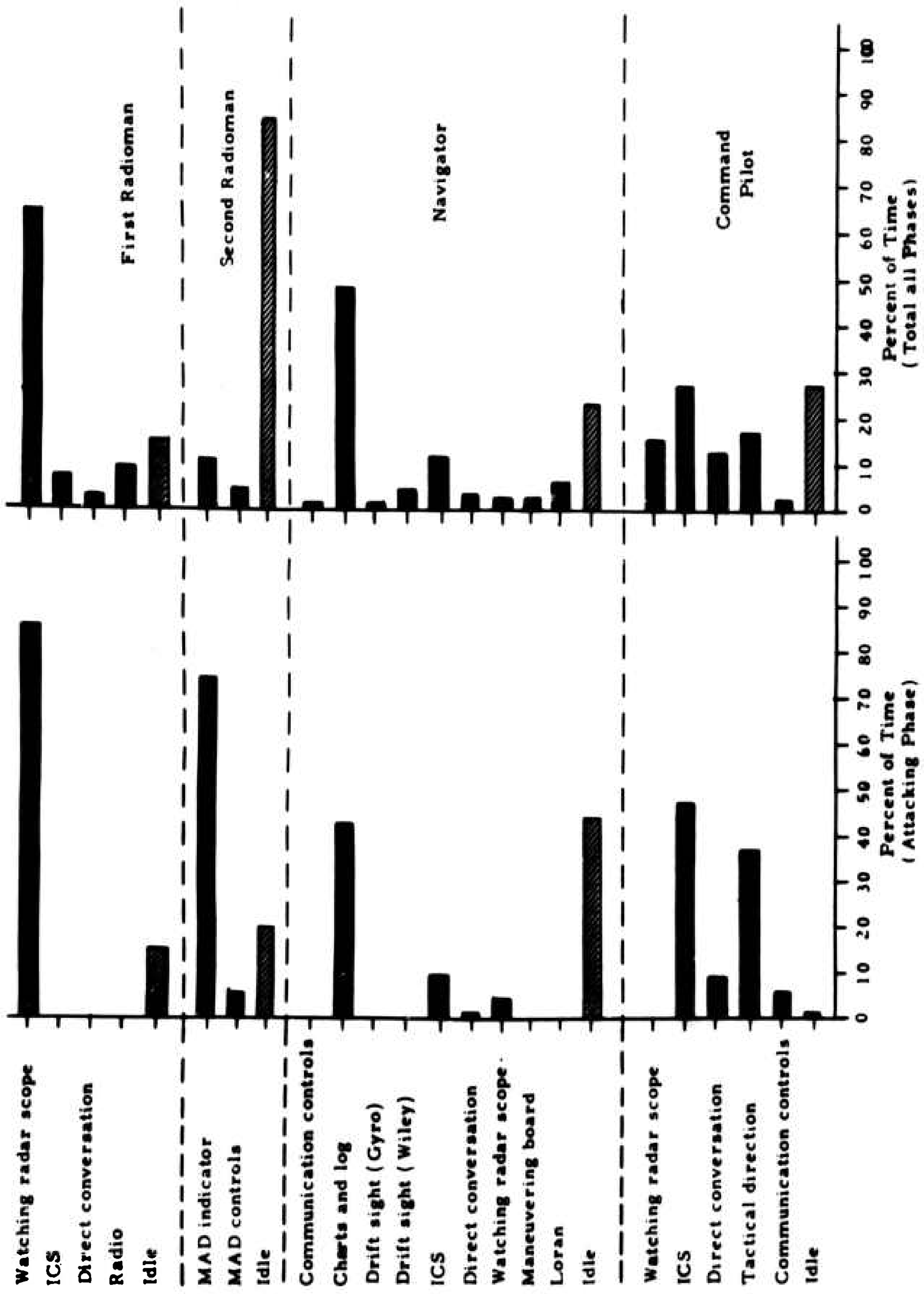

Figure C. Distribution of activities for personnel in the ASW Plot during attack phase and total of all phases.

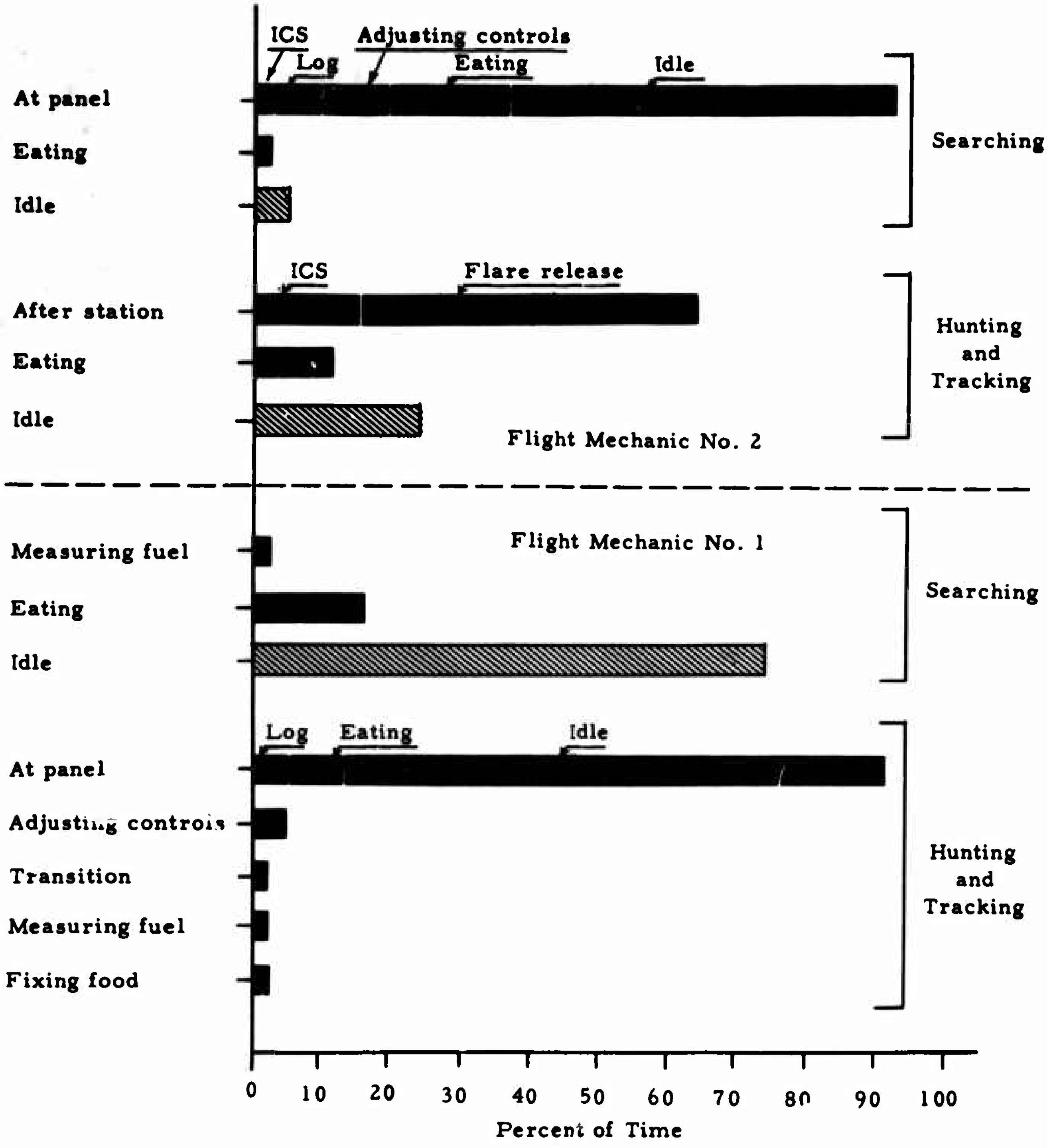

Figure D. Distribution of flight mechanics' activities during searching and hunting and tracking operations.

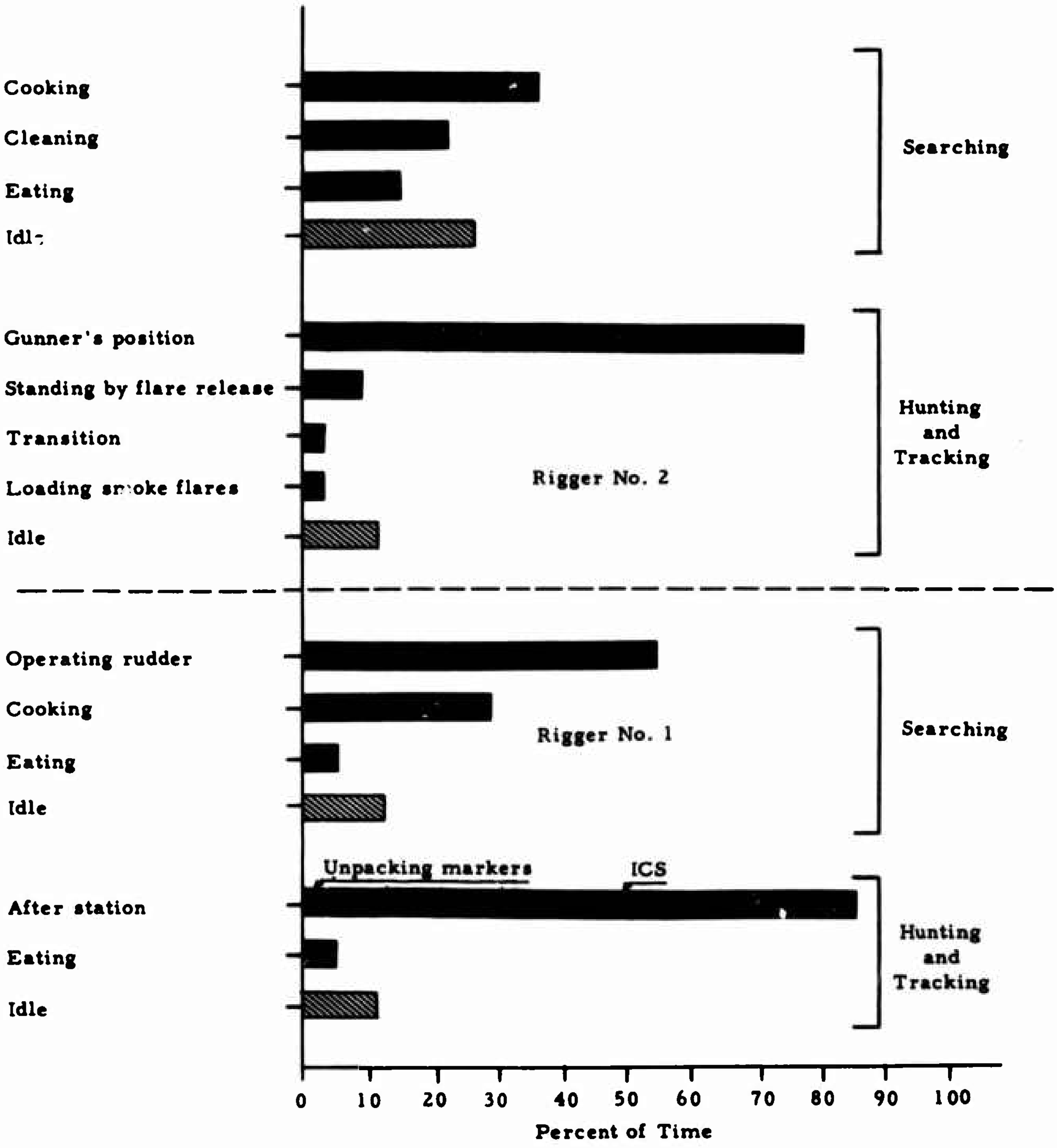

Figure E. Distribution of riggers' activities during searching and hunting and tracking operations.

activity observations by recording film footage and time readings at periodic intervals. The recordings were analyzed to determine origin and destination, frequency, and duration of all messages. These facts are summarized in Figures F and G.

B. Results

1. Command Pilot's Activity

During the search phase, the command pilot spent almost 80% of his time in idleness. He became more active, once the contact had been announced, devoting himself almost entirely to observation and combat direction. During these latter phases he spent about 30% of his time communicating over the ICS or voice radio.

2. Navigator's Activity

The navigator was idle only about 5% of the time during the search phase, which constitutes the bulk of airship operation. His major activities were plotting (40%), drift reading (18%) and intercommunication (11%). It is interesting to note that the navigator employed the Wiley drift sight much more often than the gyro-stabilized sight, despite the fact that it is less conveniently located and less accurate. Peak activity was reached during homing operations, but he was idle about one-third of the time during hunting, tracking, and attacking.

3. Radiomen's Activity

One radioman was on duty during searching and patrol operations. Watches were rotated every four hours with a relief operator. The duty operator was required to watch the radar display, monitor CW on the low frequency radio, and transmit radio messages. Because of these other demands on his time, his eyes were on the radar scope only 55% of the time. Lack of attentiveness is revealed by the fact that the operator looked out of the window or gazed into space 11% of the time.

4. Flight Mechanics' Activity

The primary task of the flight mechanic is to stand watch at the instrument panel. This watch during patrol is rotated every four hours between two mechanics. The off-duty mechanic during patrol is mostly idle. He was observed to spend less than a total of 5% of his time reading fuel gauges, filling out log, and similar chores. The mechanic on watch spent 80% of his time in apparent idleness (although he undoubtedly made occasional check readings on his instruments). He operated controls about 10% of the time (mostly to synchronize propellers) and performed miscellaneous duties at other times. During hunting and tracking maneuvers (at general quarters),

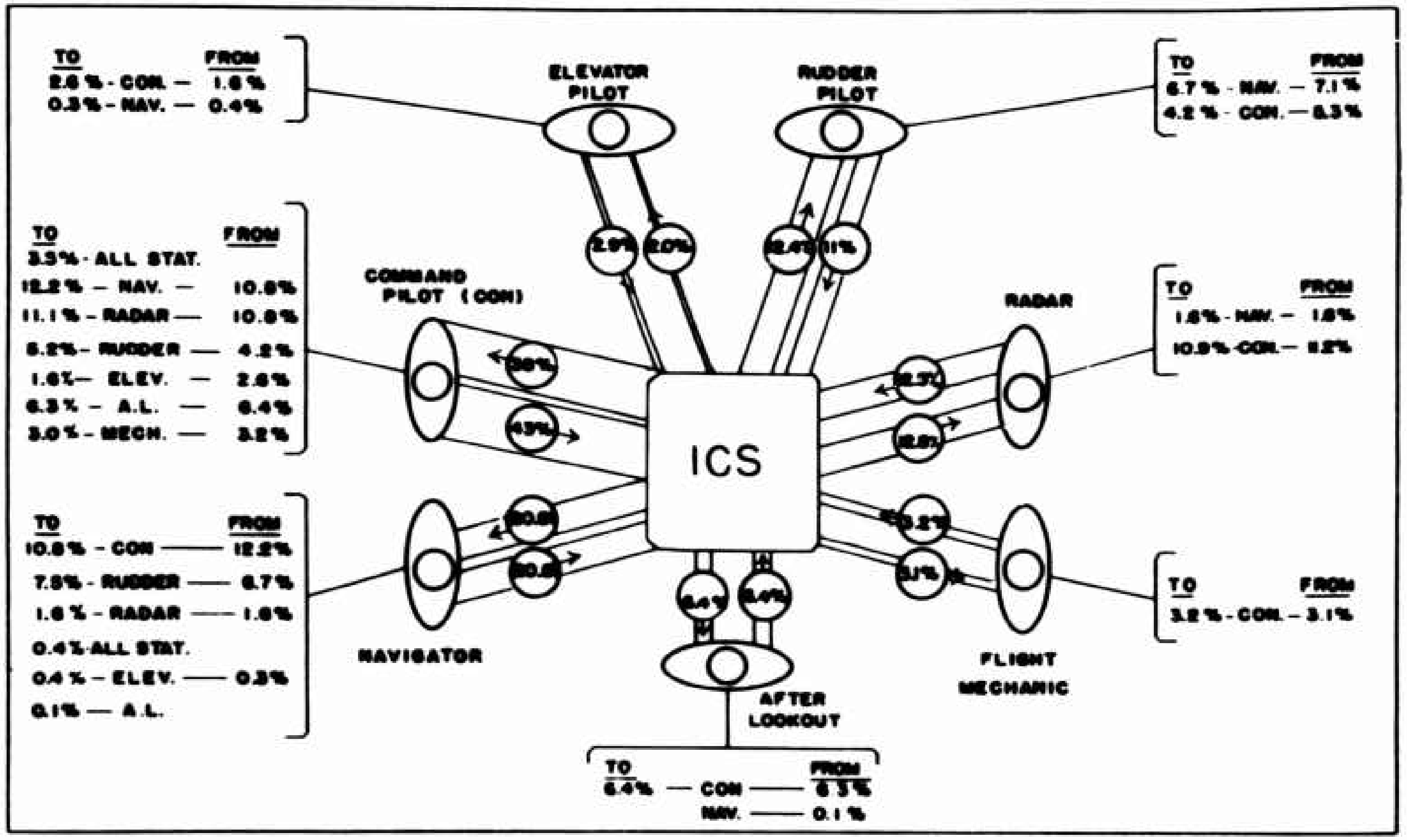

Figure F. Distribution of interpersonal communication.

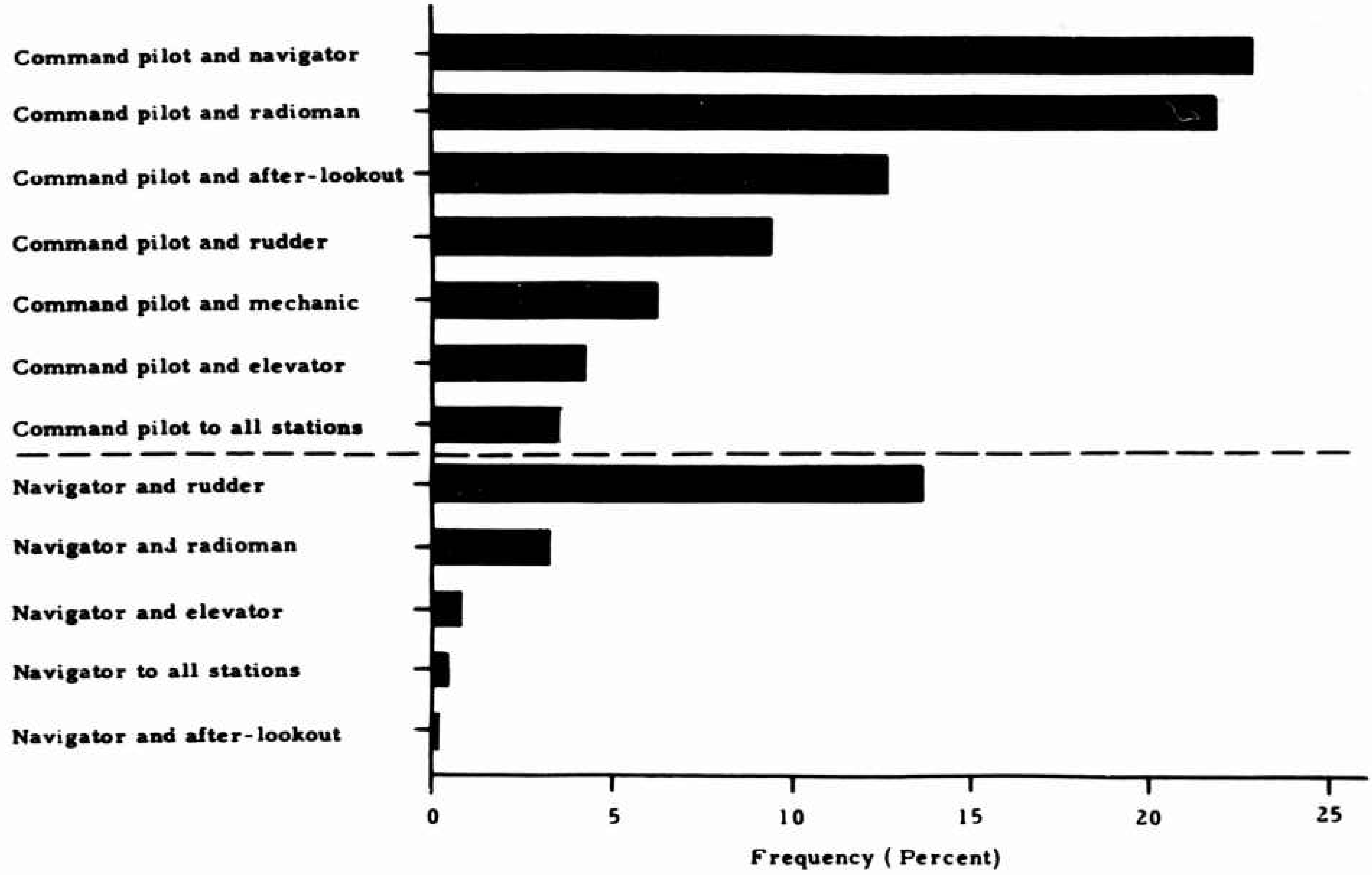

Figure G. Frequency of communications between airship crewmen.

the mechanic at the panel followed substantially the same routine. The off-watch mechanic, however, helped man the after-station about 65% of the time, standing by the flare chutes or serving as visual lookout.

5. Riggers' Activity

During patrol operations, two riggers acted chiefly as cooks. Although there were four trained pilots aboard (rudder pilot, elevator pilot, command pilot, and navigator), one rigger spent more than half the time as rudder pilot. Cooking, cleaning, and idleness accounted for the remaining activity of the riggers. During general quarters, one rigger manned the after-station (visual lookout, ICS, flares and dye markers) and the other rigger manned the forward gun post.

6. Performance Times

Certain performance times obtained from the photographic activity records and the sound recordings are summarized in Table A.

7. Communications

The data on communications between personnel show that messages were being transmitted 18% of the time. The command pilot participated in 82% of these messages (as originator or addressee), navigator (41%), radar operator (25%), after-lookout (13%), mechanic (6%), and elevator pilot (5%). For 48% of all messages, both the originator and recipient were in the ASW plot.

Table A. Performance times for selected activities

Activity	Personnel	Time Required (Seconds)
Obtaining wind stars	Navigator	304
Drift reading (Wiley Sight)	Navigator	18
Loran reading	Navigator	50
Reporting new radar target (reporting time only)	Radar Operator-Command Pilot	11
Reporting range and bearing of radar target	Radar Operator-Navigator	9
Acknowledging radar report	Navigator-Radar-Operator	6
Computing course to steer after target submerges	Navigator	69
Reporting arrival at EPS	Navigator-Command Pilot	14
Noticing and reporting MAD contact	Radio-Command Pilot	14