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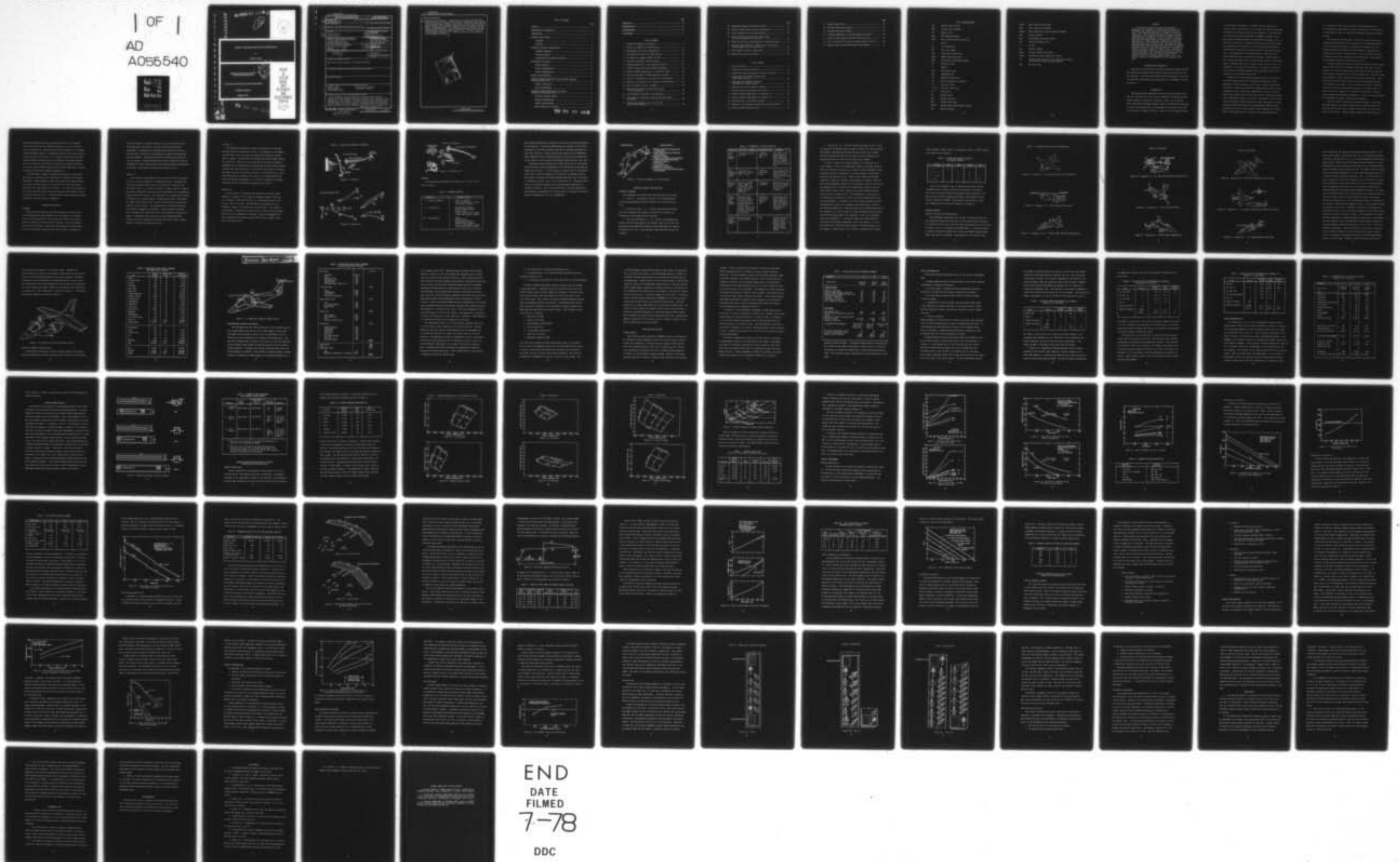

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DEPARTMENT OF THE NAVY
DTNSRDC

AIRCRAFT CONFIGURATIONS FOR HIGH-SPEED SHIPS

by

Thomas H. Boyd

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AVIATION AND SURFACE EFFECTS DEPARTMENT

DTNSRDC ASED-397

December 1977

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An analytical study was conducted to establish high-speed ship compatible aircraft configurations and to determine their capabilities and limitations in Navy missions. The study was restricted to subsonic aircraft configurations. The interface problems and design constraints associated with the application of Navy aircraft to high-speed ships were identified. Current aircraft in the Navy inventory and proposed advanced concepts were

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reviewed for applicability. Three open-ocean scenarios using the high-speed potential of the surface effect ship were postulated, and associated airborne missions were identified and defined. Findings confirm that the high-speed ship offers a number of benefits relative to small air capable ships. Conventional takeoff and landing aircraft can operate from deck lengths less than 600 feet. Short takeoff and landing aircraft can operate efficiently from deck lengths below 200 feet. Vertical takeoff and landing aircraft acquire up to a 50-percent increase in load capability at deck lengths of 400 feet.

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LIST OF ABBREVIATIONS

ABC	Advance blade concept
AEW	Airborne early warning
AR	Aspect ratio
ASW	Antisubmarine warfare
BCAV	Best cruise altitude and velocity
C	Cruise
C_L	Lift coefficient
CAS	Close air support
CCW	Circulation control wing
CSAR	Combat search and rescue
CTOL	Conventional takeoff and landing
CVA	Aircraft carrier
F	Fighter
FPR	Fan pressure ratio
HSS	High-speed ship
L/B	Length-over-beam ratio
IOC	Initial operational capability
L + C	Lift plus cruise
L + L/C	Lift plus lift/cruise
L/C	Lift/cruise
SA	Surface attack
SAR	Search and rescue
SES	Surface effect ship
SES-CV	Surface effect ship aircraft carrier
SOA	Speed of advance

STOGW	Short takeoff gross weight
STOL	Short takeoff and landing
STOVAL	Short takeoff and vertical attitude landing
TOS	Time on station
TRAC	Telescoping rotor blade concept
T/W	Thrust-over-weight ratio
U	Utility
VTO	Vertical takeoff
VTOL	Vertical takeoff and landing
VSTOL	Vertical and short takeoff and landing
V_e	Aircraft speed relative to the ship's deck attained at the end of a deck run during takeoff
WOD	Wind over deck

ABSTRACT

An analytical study was conducted to establish high-speed ship compatible aircraft configurations and to determine their capabilities and limitations in Navy missions. The study was restricted to subsonic aircraft configurations. The interface problems and design constraints associated with the application of Navy aircraft to high-speed ships were identified. Current aircraft in the Navy inventory and proposed advanced concepts were reviewed for applicability. Three open-ocean scenarios using the high-speed potential of the surface effect ship were postulated, and associated airborne missions were identified and defined. Findings confirm that the high-speed ship offers a number of benefits relative to small air capable ships. Conventional takeoff and landing aircraft can operate from deck lengths less than 600 feet. Short takeoff and landing aircraft can operate efficiently from deck lengths below 200 feet. Vertical takeoff and landing aircraft acquire up to a 50-percent increase in load capability at deck lengths of 400 feet.

ADMINISTRATIVE INFORMATION

The project was sponsored by the Naval Air Systems Command (AIR-320) and funded under Program Element 62241N, Task Area WF 41.421.206, Work Unit 1660-A10. The Aviation and Surface Effects Department of the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) conducted the study.

INTRODUCTION

The high-speed ship development now being actively pursued by the Navy will introduce a new era in naval operations by providing new ship classes capable of speeds up to 100 knots. Phase I of the Surface Effect Ship (SES) Development Program, aimed at expanding SES technology to ships of ocean-going size, has culminated in the trials of two 100-ton test craft to speeds of 80 knots. Phase II of this program focused on the advanced development of a 3000-ton SES and resulted in a contract award to Rohr Marine, Inc. to design the 3000-ton SES capable of speeds up to 90 knots with open-ocean capability. The broad technical base that has been established at DTNSRDC in support of the SES program, including hardware and sub-system development, is not restricted to small ships. Extensive testing of the two 100-ton craft has demonstrated the validity of the SES concept and has supplied verification of the design data base needed for proceeding to larger ships. The application of the SES principle to ship sizes of at least 20,000 long tons is confidently predicted. These ships will have revolutionary application in Navy missions and will offer advantages of reduced transit time to forward areas, quicker reaction in engagements, and increased survivability. If pursued as vigorously as the present development program, these high-speed ships will be available in the post-1990 time period.

In addition to the advantages summarized above, the wind over deck (WOD) associated with these high-speed ships should lead to operation of high performance aircraft from relatively small decks. Potentially, conventional takeoff and landing (CTOL) aircraft become candidates for short takeoff and landing (STOL) aircraft, and short takeoff and landing aircraft acquire the vertical takeoff and landing (VTOL) capability, relative to the deck. Furthermore, vertical short takeoff and landing (VSTOL) aircraft now under development in support of the Navy VSTOL plan and other proposed advanced VSTOL aircraft concepts will benefit in gross weight takeoff capability if the high WOD of the high-speed ship is utilized to provide increased lift.

It is appropriate that these two rapidly developing and diverse technologies (the high-speed ship and the VSTOL aircraft) be examined in a matrimonial sense as a potential high-speed ship/aircraft system concept.

The purpose of this study was to identify the opportunities and problems associated with aircraft operations from high-speed ships and to evolve preliminary designs of advanced ship compatible aircraft. Supporting objectives included the establishment of high-speed ship scenarios and missions, the determination of ship compatible aircraft configurations and their capabilities and limitations in Navy missions, and the design synthesis of SES aircraft carriers.

Interface problems and design constraints associated with the application of Navy aircraft to high-speed ships were identified. Current aircraft in the Navy inventory and proposed advanced aircraft concepts were reviewed for applicability to the high-speed ship. Selected aircraft were analyzed in mission applications and shipboard operations. Three realistic open-ocean scenarios which utilize the high-speed potential of the SES were postulated to counter anticipated threats. Associated airborne missions were identified and defined. For each scenario, an SES-CV with cruise capability of 60 knots was synthesized to satisfy range, payload, and endurance requirements. The ship aircraft complement was established and support requirements determined.

Selected aircraft configurations analyzed included a lift/cruise fan VSTOL concept, the Harrier AV-8B lift/cruise VSTOL aircraft, the Navy S-3A CTOL aircraft, and an S-3CCW STOL aircraft (S-3 with circulation control wing). The Navy X-Wing stopped rotor VSTOL aircraft is potentially compatible with the high-speed ship due to its foldable rigid rotor system and short takeoff capability; it was not included in this study since its capabilities are being documented in an advanced X-Wing development program. Two advanced aircraft concepts were evolved during the course of the study: (1) a canard lift/cruise fan offering reduced complexity and greater ease in performing the takeoff maneuver, and (2) a rotary-wing configuration utilizing the Sikorsky telescoping rotor blade concept (TRAC) offering twice the speed capability of current helicopters and improved shipboard compatibility.

High WOD offers a number of benefits when operating aircraft from small decks, including potential improvements in VSTOL aircraft mission performance. High-performance conventional takeoff and landing aircraft can operate from deck lengths less than 600 feet. STOL's can operate efficiently from deck lengths below 200 feet. The ship's speed capability will enhance the ship/aircraft system operational effectiveness in terms of aircraft radius of action. Increased takeoff weight capability provides flexibility in aircraft mission assignments.

SCENARIOS AND MISSIONS

SCENARIOS

Three open ocean scenarios have been developed to portray the use of the high-speed SES speed capability and the benefits to be derived from the resulting high WOD. The scenarios are seminal, but reflect a degree of realism as to future threat situations. They are consistent with the Navy's missions of sea control and projection of power ashore. An initial operational capability (IOC) date of 1990 is estimated for the system concept. Historical review of the use of aircraft by the Navy going back to World War II, current trends in Navy aircraft development, and dialogue with cognizant Navy offices and activities have provided a rationale in establishing the scenarios and applicable aircraft missions. Unclassified data and information were sufficient for this purpose. Platform characteristics were reviewed from data and information in Jane's Fighting Ships, and other unclassified publications and studies. The scenarios are depicted in Figures 1a to 1c.

Scenario I

This scenario is envisioned as a quick reaction with little advance notice to a threat situation at a land-based facility. High-speed SES aviation platforms at ready status are stationed at a stand-off base and respond quickly to a request for close air support (CAS) in a rapidly developing low-intensity conflict which is threatening a P-3 antisubmarine warfare (ASW) shore facility. The ships dash to the target area at speeds of 60 knots over an ocean distance of 2000 nautical miles. When within air range of 200 nautical miles, surface attack aircraft are launched to deter or limit the threat. The operating area of the SES's during the air strikes is assumed to be sanitized. Thirty-six hours on-station time is assumed, with twenty-four hours of CAS provided to the base commander. Conventional forces then arrive, and the high-speed SES's withdraw with their complement of aircraft and return to base. Replenishment is conducted during return to base.

Scenario II

The high-speed ship/aircraft concept is envisioned as a multiple platform system in a convoy escort role. As illustrated in the diagram, the SES's lead, flank, and trail the convoy which maintains a steady speed of advance. Airborne ASW and airborne early warning (AEW) missions are carried out. The SES's also conduct ASW activities with advanced equipment; each is equipped with an advanced point defense missile system. Surface attack (SA) and utility (U) aircraft are also based on the SES's. The primary mission of the utility aircraft is search and rescue. Seven high-speed ships are assigned to the convoy, one proceeding within the convoy for underway replenishment. The escort is provided for an eight-day period with the ships being replenished every two days.

Scenario III

In this scenario, high-speed ships loitering in friendly waters respond to a request for air support by dashing at speeds of 60 knots for a distance of 1000 nautical miles to a midintensity conflict area at sea. A mix of aircraft, including ASW, SA, and fighter (F), are provided in support of friendly action for three days. The situation is stabilized. Conventional aircraft carriers arrive and the high-speed ships retire for maintenance and resupply. During the engagement the SES's, equipped with an advanced point defense missile system, remain aloof of the battle area.

Figure 1 - Operational Diagram of Scenarios

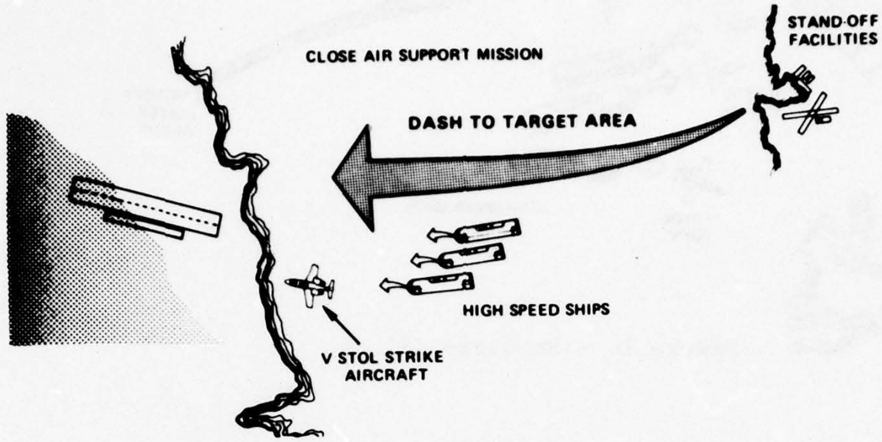

Figure 1a - Scenario I

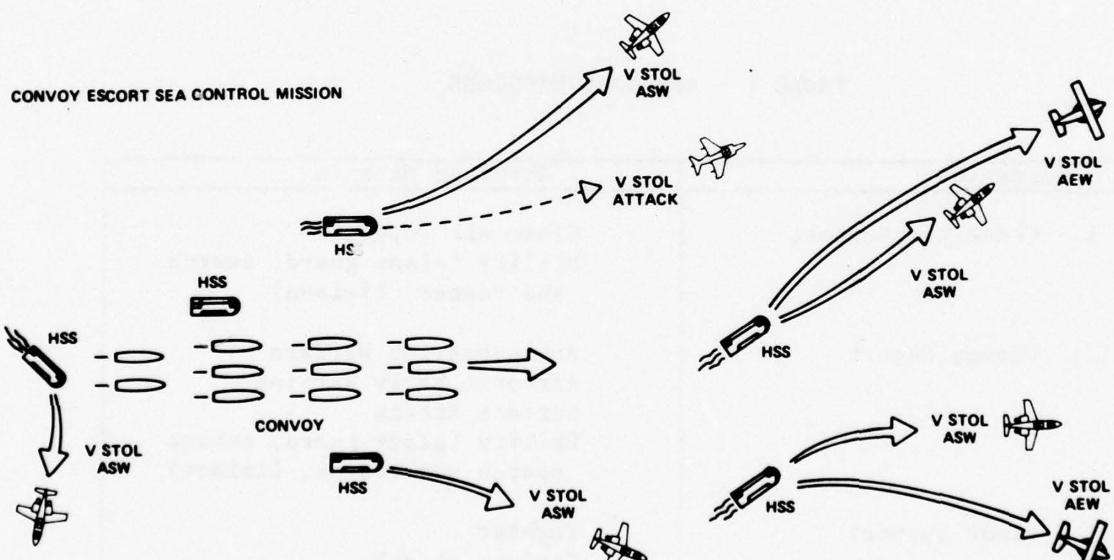

Figure 1b - Scenario II

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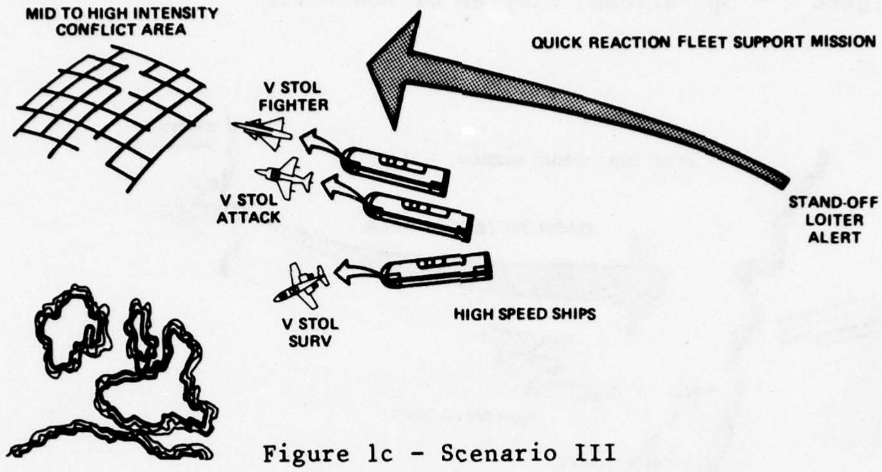


Figure 1c - Scenario III

MISSIONS

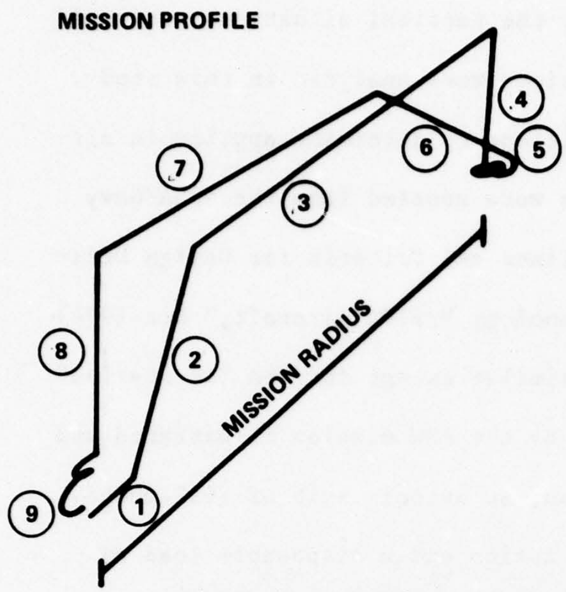
Airborne missions associated with Scenarios I, II, and III are given in Table 1.

TABLE 1 - AIRBORNE MISSIONS

Scenario	Airborne Mission
I. Close Air Support	Close Air Support Utility (plane guard, search and rescue, liaison)
II. Convoy Escort	Antisubmarine Warfare Airborne Early Warning Surface Attack Utility (plane guard, combat search and rescue, liaison)
III. Fleet Support	Fighter Surface Attack Antisubmarine Warfare Airborne Early Warning Utility (plane guard, combat search and rescue, liaison)

These airborne missions are required by the tactical situations portrayed by the scenarios. The CAS and ASW missions were analyzed in this study. Evaluations of the other missions sufficient to determine applicable aircraft were conducted. Mission profiles were adopted from the NASA/Navy VSTOL competitive study ("Design Guidelines and Criteria for Design Definitions Study of a Lift Cruise Fan Technology V/STOL Aircraft," Oct 1974).

In general, mission profiles are similar except for the "on-station" leg of the mission and are exemplified by the ASW mission illustrated and summarized in Figure 2. In this mission, an avionic suit of 7632 pounds useful load is carried throughout the mission and a disposable load of 2852 pounds consisting of two MK46 torpedoes and mixed types of sonobuoys is expended on station. Leg 5 is the "on-station" leg. The major differences in the mission profiles of the various missions considered are presented in Table 2. Due to these differences, aircraft configuration and propulsion requirements will differ and must be reflected in aircraft design if performance is not to be compromised.



MISSION SUMMARY

1. WARMUP, TAKEOFF, AND ACCELERATE TO CLIMB SPEED
2. CLIMB TO BEST CRUISE ALTITUDE AND VELOCITY (BCAV)
3. CRUISE OUT AT BCAV
4. DESCENT TO 10,000 FEET, NO ALLOWANCES
5. LOITER AT BEST ENDURENCE SPEED, 10,000 FEET, 4 HOURS
6. CLIMB TO BCAV
7. CRUISE BACK AT BCAV
8. DESCENT, NO ALLOWANCES
9. 10 MINUTES LOITER AND 5 PERCENT INITIAL FUEL, RESERVES

Figure 2 - Profile and Summary of the ASW Mission

CANDIDATE AIRCRAFT CONFIGURATIONS

AIRCRAFT CATEGORIES

Four categories of aircraft types were defined for this study.

1. Cruise, C. Conventional aircraft of the fixed-wing type incorporating propulsion units not utilized in any direct form for lift.

2. Lift plus Cruise, L + C. Aircraft incorporating propulsion units and independent lift engines utilized only to produce lift. Fixed-wing or rotary-wing types are included.

3. Lift plus Lift/Cruise, L + L/C. Aircraft incorporating propulsion units utilized primarily for forward flight and also for lift assistance during takeoff and landing, having independent lift engines utilized only for lift. Fixed-wing and rotary-wing type aircraft are included.

TABLE 2 - DIFFERENCES IN MISSION PROFILES

Mission	"On-Station" Segment	Disposable Load	Comments
Close Air Support (CAS)	5 minutes attack at sea level	2 AIM-9's, 1000 round ammo	200 nautical miles radius desired; empty weight contains 600 pounds armor; 10 minutes sea level loiter reserve plus 5 percent
Anti-submarine Warfare (ASW)	Loiter at best endurance, 10,000 feet, 4 hours	2 MK-46's Mixed sonobuoys	150 nautical miles radius desired; 10 minutes sea level loiter reserve plus 5 percent
Surface Attack (SA)	Loiter at 20,000 feet, combat at 20,000 feet and V_{max}; 50 nautical miles dash at 5000 feet	2 Harpoons, 2 AIM-9's	300 nautical miles radius; 10 minutes sea level loiter reserve plus 5 percent
Combat Search and Rescue (CSAR)	Loiter at BAV; 20 minutes dash 50 nautical miles at V_{max} and sea level; 10 minutes hover at sea level; pick up 200 pounds; dash back 50 nautical miles at sea level	2 AIM-9's 1000 round mini-gun ammo	300 nautical miles radius desired; empty weight contains 600 pounds armor; 10 minutes sea level loiter reserve plus 5 percent
Airborne Early Warning (AEW)	Loiter 4 hours at 25,000 feet	None	200 nautical miles radius desired against cruise missile threat; 75 nautical miles radius desired against surface threat

4. Lift/Cruise, L/C. Aircraft incorporating power plants utilized for propulsion in forward flight and also to produce lift during takeoff and landing. Fixed-wing and rotary-wing type aircraft are included. Aircraft incorporating separate lift devices but which depend on the propulsion unit(s) for power are included in this category.

In Table 3, takeoff and landing capability is identified by aircraft category. CTOL is the conventional takeoff and landing pattern in which the aircraft is accelerated to a speed at which aerodynamic forces created by the free airstream on the lifting surfaces is sufficient to raise the aircraft into the air. STOL is short takeoff and landing capability in which the aircraft is accelerated to a speed at which the free-stream aerodynamic forces are not sufficient to lift it into the air, and augmented lift is provided by the application of direct thrust or engine power. STOVL is short takeoff and vertical landing capability in which thrust or power used for lift augmentation in short takeoff is insufficient to provide lift forces at zero wind speed greater than the aircraft weight. In general, for viable aircraft systems, aircraft configurations in each of the categories are operationally limited to the indicated capabilities. CTOL operations are not considered practical for Categories 2, 3, and 4 because of flight performance penalties associated with providing direct lift capability. VTOL is not considered practical for Category L + C because of weight and volume penalties associated with providing independent direct lift engines; L + L/C is more attractive in VTOL applications because of reduced demands on the lift engines. Ninety percent of all subsonic configurations reviewed, either proposed, flight tested, or operational as VTOL or VSTOL concepts, fell within the L/C category.

TABLE 3 - TAKEOFF AND LANDING CAPABILITY
BY AIRCRAFT CATEGORY

Category	CTOL	STOL	STOVAL	VTOL
1. C	X			
2. L + C		X	X	
3. L + L/C		X	X	X
4. L/C		X	X	X

Sources for information used in identifying potential aircraft configurations were industry brochures and proposals, periodicals, Jane's All the World's Aircraft, development studies sponsored by the Navy and other services, ongoing developments, and advanced concepts studies conducted by DTNSRDC. Configurations representative of the four categories are illustrated in Figures 3a through 3i.

PROPOSED CONCEPTS

Canard Lift Cruise Fan VSTOL Aircraft

The predominant configuration for aircraft utilizing fans for lift and propulsion reviewed for this study is a three-fan concept consisting of a single nose-lift fan and two lift/cruise fans mounted aft of the center of gravity (c.g.) in a conventional airframe layout. A three-fan concept is needed to balance the moments due to the large offsets between engine thrust lines and c.g. locations. The necessity for the nose-lift fan

Figure 3 - Representative Aircraft Configurations

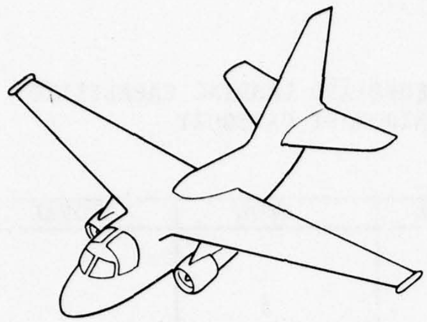


Figure 3a - Category C. U.S. Navy S-3A Aircraft Configuration

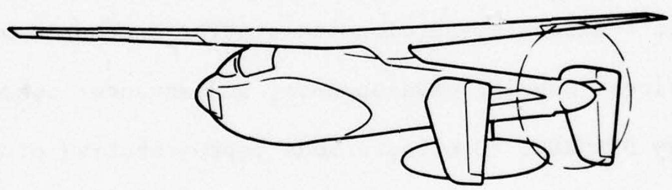


Figure 3b - Category L + C. VTOL Configuration Concept

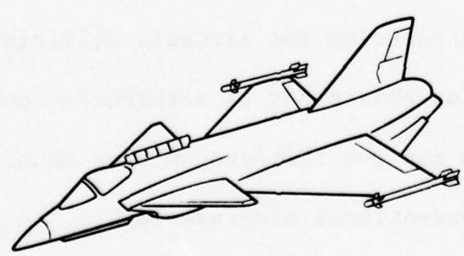


Figure 3c - Category L + L/C. Convair Model 200 VTOL Configuration

Figure 3 (Continued)

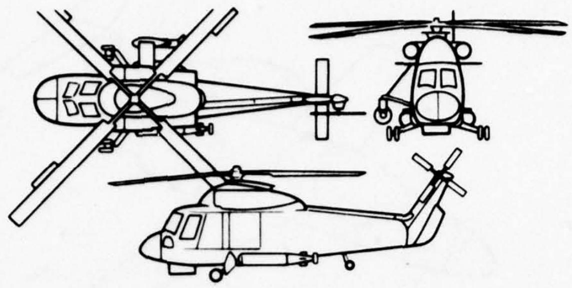


Figure 3d - Category L/C. U.S. Navy SH-2F Helicopter Configuration

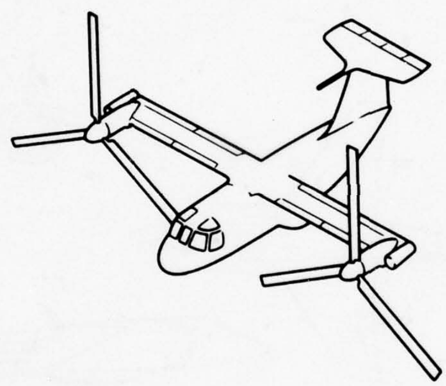


Figure 3e - Category L/C. Tilt Rotor VTOL Design

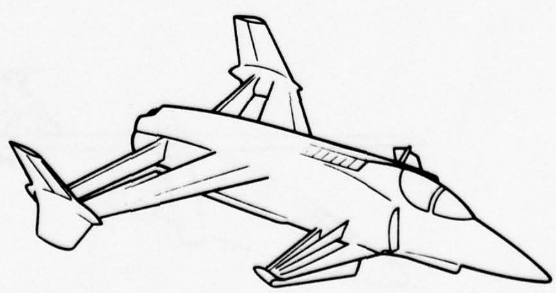


Figure 3f - Category L/C. XFV-12A VSTOL Configuration

Figure 3 (Continued)

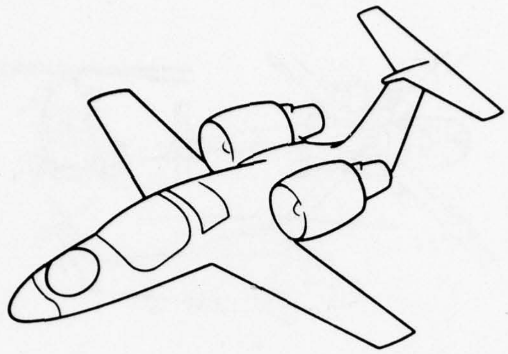


Figure 3g - Category L/C. Lift/Cruise Fan VSTOL Design Concept

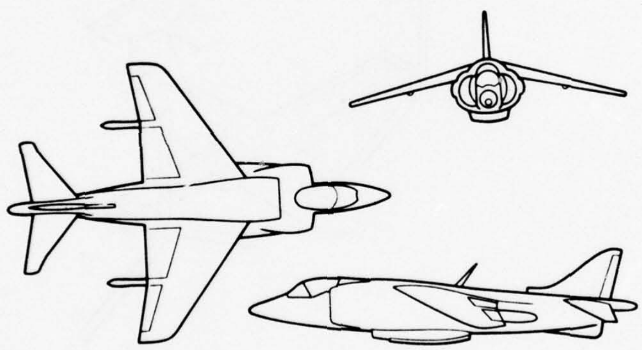


Figure 3h - Category L/C. U.S. Marine Corps Harrier AV-8B Configuration

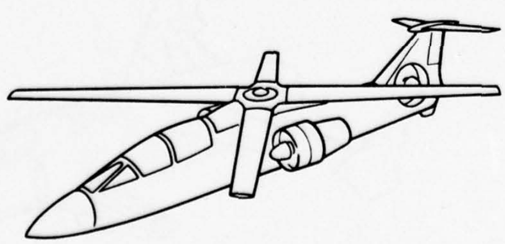


Figure 3i - Category L/C. U.S. Navy-Designed X-Wing VSTOL can be eliminated, and significant performance gains can result if the thrust line is made to coincide with the c.g. On conventional aircraft utilizing a horizontal tail, the c.g. is located generally near the wing quarter chord. VSTOL aircraft with engines located forward of the wing and balanced so that the thrust coincides with the c.g. become extremely stable and large trim drag penalties occur. Aft engine location requires either an unstable configuration or a very long fuselage and large tail in order to provide aerodynamic stability. Thus, for conventional aircraft, locating the thrust line through the c.g. is difficult to achieve. This difficulty can be overcome, however, by use of the nonconventional canard configuration which utilizes a canard surface forward and conventional wing aft with engines mounted forward of the wing. The canard allows the neutral point of the configuration to be located such that the vehicle is stable yet does not have large trim drag at cruise speed. The distance between the c.g. and the wing neutral point is determined by the clearance required for the engines to pivot. In the proposed concept, this distance is 62 inches. Assuming a 10-percent static margin and a wing neutral point at 0.25c, the distance between c.g. and canard quarter chord can be shown to be about 21.4 feet. The configuration is trimmed through a combination of canard elevator and wing elevons at high speeds. For short takeoffs, trim is accomplished by deflecting the canard flap and simultaneously deflecting the elevons to act as flaps. On vertical takeoffs and landings, a small bow thruster is used for fine trim, and fuel is shifted to keep the c.g. at the engine pivot point. Lateral control is achieved by conventional elevons in cruise and differential thrust in vertical mode. Heading is controlled by the vertical fins and by differential engine tilt in vertical flight. Benefits will accrue from this L/C concept in takeoff and landing since the total thrust vector can be rotated during ground roll and final approach. Preliminary evaluation of this configuration in an ASW mission with a 4-hour loiter and a 150-nautical mile radius indicates that the mission can be satisfied at a short takeoff gross weight (STOGW) of 34,500 pounds and 11,000 pounds of internal fuel. The configuration is depicted in Figure 4. A preliminary group weight statement is presented in Table 4.

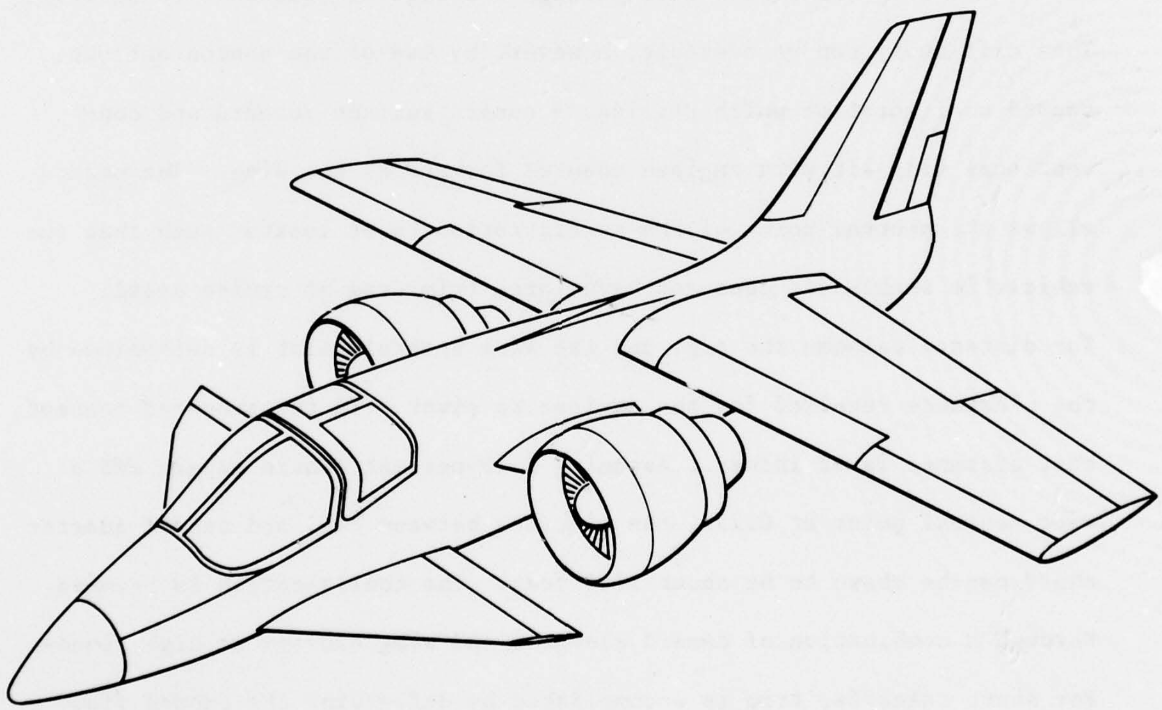


Figure 4 - The Canard Lift/Cruise Fan VSTOL Aircraft

TRAC Rotor Composite VSTOL Aircraft

Conventional helicopters are limited in speed capability and present shipboard compatibility problems associated with stowing and rotor starting

TABLE 4 - PRELIMINARY GROUP WEIGHT STATEMENT
ASW CANARD VSTOL AIRCRAFT

Item	Weight pounds	Moment Arm feet	Moment foot-pounds
Wing	1,100	34	37,400
Vertical Tail	180	43	7,740
Canard	180	20	3,600
Fuselage	2,800	28	78,400
Nose Gear	240	18	4,330
Main Gear	465	28	13,000
Flight Controls	680	30	20,400
Engine Section	5,892	27	159,000
Transmission	525	27	12,000
Instruments	234	12	2,820
Hydraulics	320	28	8,950
Electrical	469	27	12,650
Electronics	2,680	25	67,000
Armament	313	16	5,000
Furnishings	734	16	11,750
Air Conditioning	440	16	7,050
Anti-ice	150	30	4,500
Weight Empty	17,402	26.2	455,590
Contingency	1,716		
Crew	720	16	11,500
Trapped Fuel	100	27	2,700
Oil	90	27	2,430
O_2	280	16	4,480
Hardware	300	35	10,500
OWE	20,648	23.6	487,200
Fuel	11,000	27	297,000
Payload	2,852	35	100,000
STOGW	34,500	25.6	884,200

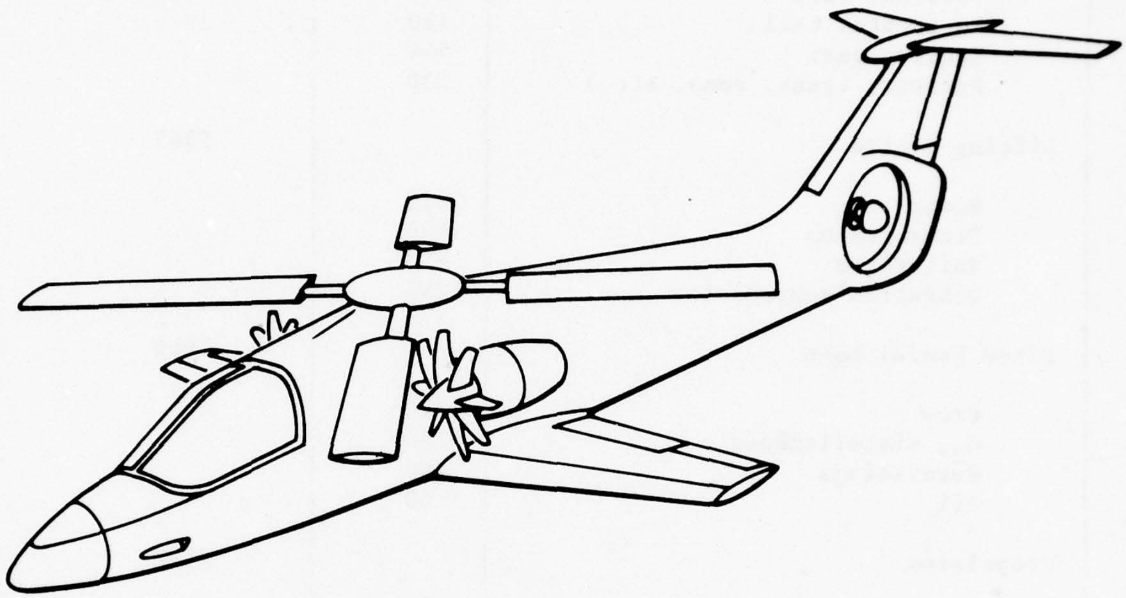


Figure 5 - The TRAC Rotor Composite VSTOL Aircraft

CONFIGURATIONS SELECTED FOR ANALYSIS

The requirement that the lifting efficiency of the aircraft increase with forward speed at the low end of the flight regime to ensure STOL performance was the primary criterion used in establishing a list of potential aircraft configurations for basing on high-speed ships. Wind over deck, although high in relation to the ship, is in the low speed end of Navy aircraft flight regimes and high wing aspect ratio will enhance lifting capability. Therefore, many current fixed-wing CTOL's were considered potential candidates. Wing folding for stowing purposes, yielding a degree of complexity and added weight, was considered desirable due to

TABLE 5 - PRELIMINARY GROUP WEIGHT STATEMENT
CSAR TRAC ROTOR VSTOL AIRCRAFT

Structure		3776 lb
Fuselage	1630 lb	
Wing	924	
Vertical tail	160	
Horizontal tail	180	
Landing gear	644	
Hardware (guns, ammo, etc.)	238	
Lifting System		5383
Rotor	2010	
Transmission	2490	
Tail rotor	690	
Vibration suppression	193	
Fixed Useful Load		1460
Crew	720	
O_2, miscellaneous	280	
Furnishings	400	
Oil	60	
Propulsion		2990
Fuel system	580	
Gas generators	1100	
Fans	1160	
Controls and Starting	150	
Subsystems		2035
Flight controls	800	
Instruments	190	
Hydraulics	100	
Electrical	300	
Avionics	325	
Air conditioning	30	
Anti-ice	100	
Auxiliary power	190	
		15644
Contingency		1560
Fuel		3000
Disposable load		4852
Ammo	221	
Missiles, sonobuoys or torpedoes	4632	
		25056

the increased aspect ratio. Helicopters have low aspect ratio lifting surfaces of about 1.27, but they provide STOL capability due to reduced rotor inflow with forward speed and therefore reduced induced drag. They have excellent hover and low-speed controllability. Navy CTOL aircraft that will be carried in future Navy inventories beyond 1990 were considered candidates for high-speed ship application since they will be available and development costs associated with advanced concepts may be avoided. Also, they offer higher performance capability than VSTOL's and, with their STOL potential when utilizing high WOD, present alternatives to VSTOL aircraft. Current and proposed VSTOL aircraft configurations are considered strong candidates because of recent Navy leanings toward considering an all VTOL capability in the Navy of the future. The current emphasis on VSTOL aircraft displayed in Navy circles reflects long range goals of dispersion of assets and flexibility of fleet operations. Therefore, a VTOL capability was considered desirable but not mandatory in this study.

The compatibility aspects of the ship/aircraft interface (discussed in a later section) were considered in the selection process. Aircraft weight and size were important considerations since the high-speed SES is confidently predicted to be weight and volume limited in realistic scenarios. Consideration was given to maintenance in that it was assumed that aircraft design simplicity may be desirable in order to reduce on-board maintenance requirements to a minimum. The selection objective was to eliminate from further consideration configurations considered unsuitable for SES-CV application. Other considerations in the selection of candidate aircraft for analysis were:

1. the availability of design and performance data,

2. the applicability to the airborne missions associated with the postulated scenarios, and

3. the projected life beyond the 1990 time frame in existing airframes.

The Navy designed X-Wing VSTOL aircraft is highly suited for basing on high-speed ships. Attributes include low spotting factors due to the foldable X-Wing blades, good STOL capability afforded by the unique circulation control X-Wing, and rigid blades that allow rotor start up and stop in high winds. This concept is presently undergoing advanced development and performance potential evaluations. The advancing blade concept (ABC) developed by Sikorsky is also considered a potential candidate for high-speed ship applications for similar reasons. The following aircraft were selected for analysis:

1. Three-Fan L/C VSTOL
2. Harrier AV-8A VSTOL
3. Advanced Harrier AV-8B VSTOL
4. S-3A Turbofan CTOL
5. S-3 CCW STOL, Modified S-3A
6. Canard L/C Fan VSTOL
7. TRAC Rotor Composite VSTOL

Lift cruise fan configurations have taken several forms, the prevalent being a three-fan arrangement using a nose fan (discussed earlier) driven by remotely situated main gas generators to provide about 30 percent of total VTOL lift and to provide trim in VSTOL operations. The three-fan L/C VSTOL will hereinafter be referred to as the L/C fan concept. The

L/C Fan performance capabilities presented in this report are representative of the three-fan layouts. The AV-8B Advanced Harrier is similar to the AV-8A; the major modifications are increased span and wing area and increased thrust. Modifications to the S-3A CTOL aircraft to provide STOL capability consist of incorporating a Coanda surface at the wing trailing edge to permit Coanda blowing for circulation control and circulation control hardware and sub-system within the airframe to provide air at needed pressure and flow rate. No visible changes are easily noted. Circulation control has been studied extensively at DTNSRDC and the S-3 CCW aircraft concept has been the subject of an advanced system concept. This CCW system will be flight demonstrated on an A-6 aircraft during FY 1979. The canard L/C Fan and TRAC rotor composite VSTOL concepts were developed to overcome recognized shortcomings in current and proposed VSTOL concepts when considered for operations from high-speed ships; these configurations maximize compatibility with the ship in their respective primary roles of ASW and combat search and rescue (CSAR).

HIGH-SPEED SHIP DESIGNS

DESIGN APPROACH

Past in-house studies conducted at DTNSRDC provided a starting point for estimates of ship performance sufficient to define seminal scenarios. An SES cruise capability of 60 knots and ocean ranges of 3000 nautical miles were assumed possible in ship sizes to 20,000 long tons. The tactical operational requirements were used to quantify design parameters for inputs to a ship synthesis computer program. Results of the design synthesis permitted refining the scenarios, and the design cycle was then repeated. Several iterations were required to develop the high-speed SES-CV configurations and to finalize the three scenarios described previously. The ship synthesis program, which had been developed at Mare Island Naval Shipyard, was refined during the course of this study. The program is structured to yield minimum weight ships; the optimization technique used ship design variables such as air cushion length and beam, air cushion pressure, and fuel weight. The remainder of the SES dimensions and weights were defined in terms of these variables. Ship design was not constrained to high length-over-beam (L/B) ratios. Ship aviation payload requirements determined by airborne mission analyses in the operational environment were used to establish minimum desired hangar deck widths. The ship design data are summarized in Table 6.

In Scenario I, ship performance requirements of 2000 nautical miles at 60 knots, 36 hours of operations on station, and a 700-mile return before refueling were the controlling factors in sizing the ship. In Scenario II, the aviation support requirements and aircraft complement were the controlling factors in sizing the ship. Ship performance was the controlling factor in Scenario III, in which a 1000-nautical mile dash at 60 knots, 72 hours of operations on station, and a return of 700 miles before refueling were requirements.

The SES CV configurations reflect the current trends in structural and hydrodynamic design of the rigid sidewall SES concept. Performance and propulsion technology associated with these designs are well understood, but no statistical base exists to confidently predict structural weight fraction. A weight breakdown of primary and secondary structural elements was necessary, as in preliminary design work, in order to

TABLE 6 - DESIGN DATA FOR SHIP SYNTHESIS PROGRAM

Scenario	I	II	III
Short Title	Close Air Support	Convoy Escort	Fleet Support
Aviation Items			
Number of Aircraft	10	18	32
Aircraft Empty Weight, long tons	63	150	274
Hangar Width, Minimum Desired, feet	64	84	85
Personnel Complement	135	233	516
Ordnance, long tons	72	27	494
Fresh Water, long tons	26	46	117
Fuel & Reserve, long tons	314	234	2381
Ship Items			
Dash Speed, knots	60	60	60
Dash Distance to Station, nautical miles	2000	1250	1000
Distance to Loiter, nautical miles	--	--	2500
Time on Station	36 hours	8 days	72 hours
Ordnance, long tons	50	100	200
Consumables Replenishment	700 nautical miles into return leg	Every two days on station	700 nautical miles
On-station High Speed, hours	6	24	24
On-station Low Speed, hours	30	24	48
Engine, Propulsion/Lift	FT9A/ LM2500	FT9A/ LM2500	FT9A/ LM2500

estimate structural weight. A structural weight penalty of 100 long tons was included in the support requirements of Ships I and II to allow for "beefing up" the flight and hangar decks to accept anticipated aircraft loads. Ship structural weight considerations are discussed later in this report.

DESIGN CONSIDERATIONS

The primary design considerations based on the tactical requirements were:

- hangar dimensions based on spotting factors and aircraft handling requirements in turnaround operations;
- aviation support, including flight and maintenance personnel, fresh water, aircraft fuel and ordnance, maintenance containers;
- aircraft landing loads and their impact on flight and hangar structural design;
- minimization of ships turbulence that may affect flight operations, impacting on locations and shape of ship superstructure, flight deck bow, powerplant exhaust locations and orientation, and fan intake locations;
- elevator locations.

Hangar dimensions of each ship were verified by spotting scaled planforms of the aircraft configurations to obtain the minimum spotting factor. A clear-through aisle was maintained to assure quick turnaround during tactical operations. Ordnance and fuel depots were considered as well as adequate space for routine maintenance procedures.

In developing the aircraft and aviation support requirements in each of the three scenarios, a sortie rate and air plan were developed. In Scenario I, it was assumed that (1) the strike aircraft are launched 200 nautical miles from the target area, (2) the average time over the target area for each aircraft is 10 minutes, and (3) the target area is under continuous attack with at least one aircraft over the target area at all times in any 12-hour period. The basic CAS mission profile was assumed, including aircraft fuel reserve, hot day, sea level takeoff conditions with 60-knots WOD and a 400-foot deck run. Two utility-type aircraft were included in the aircraft complement of each SES-CV to perform plane guard, CSAR, and liaison activities with the ground commander. Total strike aircraft requirement was computed to be 24, based on an 80-percent availability rate. Three SES-CV's, each having a complement of eight strike aircraft and two helos, met the requirements. The aircraft and support requirements for each of the SES-CV's are summarized in Table 7.

TABLE 7 - AVIATION SUPPORT REQUIREMENTS FOR SCENARIO I
(Weight is in long tons.)

Item	Quantity	Aircraft Weight	Fuel Weight	Ordnance Weight
AV-8B, CAS	8	45	303	72
Helo, U	2	18	13	
Flight Personnel	66			
Support Personnel	103	—	—	—
	10/169	63	316	72

The weight in long tons for the aircraft and aviation support is 613, including 23 for personnel, 26 for fresh water, 12 for maintenance and supply containers, and 100 for ship structural reinforcement. Fuel weight includes a 50-percent reserve above mission estimates.

In Scenario II, assumptions included advancing fields of passive sonobuoys at the aircraft range capability, 24-hour coverage of each field, AEW capability, surface attack capability, and utility aircraft on board to provide plane guard and CSAR. Aircraft and support requirements are summarized in Table 8 for each of seven SES-CV's required for the escort duty.

TABLE 8 - AVIATION SUPPORT REQUIREMENTS FOR SCENARIO II
(Weight is in long tons.)

Item	Quantity	Aircraft Weight	Fuel Weight	Ordnance Weight
L/C Fan, ASW	8	72.0	69.1	21
L/C Fan, SA	5	44.9	31.7	6
L/C Fan, AEW	3	26.8	31.7	
Helo, U	2	6.3	15.5	
Flight Personnel	49			
Support Personnel	184			
	18/233	150.0	237.0	27

The weight in long tons for the aircraft and aviation support of Scenario II is 611, including 39 for personnel, 26 for fresh water, 12 for maintenance and supply containers, and 100 for ship structural reinforcement. Fuel weight includes a 50-percent reserve.

In Scenario III, a mix of aircraft is provided including fighter, attack, ASW, surveillance, and utility. Aircraft and aviation support requirements for each SES-CV are summarized in Table 9. Three SES-CV's are utilized to carry out the mission. The weight in long tons for the aircraft and aviation support of Scenario III is 3353, including 87 for personnel, 117 for fresh water, and 29 for maintenance and supply containers. Again, aviation reserve fuel of 50 percent of mission requirements has been assumed.

TABLE 9 - AVIATION SUPPORT REQUIREMENTS FOR SCENARIO III
(Weight is in long tons.)

Item	Quantity	Aircraft Weight	Fuel Weight	Ordnance Weight
AV-8B, F	7	39.0	526	179
L/C Fan, A	16	143.0	1504	288
L/C Fan, ASW	3	26.8	141	27
L/C Fan Surveillance	3	26.8	141	
Helo, U	3	9.5	69	
Flight Personnel	188			
Support Personnel	328			
	32/516	245.1	2381	494

DESIGN CHARACTERISTICS

The characteristics of the ship configuration resulting from the design approach taken in this study are presented in Table 10. Referring to the itemized components, Auxiliary Systems includes electrical power, air conditioning, power units, etc. Outfit includes nonstructural bulkheads, insulation, fire protection system, and handling machinery. Ship Armament is an estimate to account for advanced point defense systems and other defensive armament. Other Variables includes unusable fuel, lube and oil, fresh water reserve for ship personnel, ship crew and stores, and ship ordnance. The L/B Ratio is the length-to-beam (L/B) ratio of the air cushion. Ship III cannot transit the Panama Canal. If an increase in displacement of about 110 long tons can be tolerated, Ship III can be reduced in width to below 106 feet, permitting it to transit the canal

TABLE 10 - CHARACTERISTICS OF THE SES-CV CONCEPTS
(Weight is in long tons.)

Scenario	I	II	III
Short Title	Close Air Support	Convoy Escort	Fleet Support
Ship	I	II	III
Structure	1408	2027	3894
Propulsion	318	318	531
Electrical	96	117	331
Command and Surveillance	56	56	56
Lift System	127	127	143
Auxiliary Systems	217	260	688
Outfit	215	258	686
Ship Armament	15	15	15
Margin	270	339	660
Light Ship Weight	(2722)	(3522)	(7004)
Ships Fuel off Station	900	473	1575
Other Variables	110	160	287
Variable Load Weight	(1790)	(1851)	(6932)
TOTAL SHIP DISPLACEMENT	(4512)	(5373)	(13936)
L/B Ratio, Cushion	8.2	6.1	8.9
Length OA, feet	559.2	574.0	815.8
Breadth OA, feet			
Horsepower	240K	240K	400K
L/B Cushion, feet/feet	526.5/64	541.3/89	783.1/88/3

(width 106 feet). Figure 6 presents three views of the ship designs and overall dimensions.

DERIVED SYSTEM CONCEPTS

The study efforts discussed in the preceding sections of this report culminated in three high-speed ship/aircraft system concepts. In review, design was initiated by postulating operational scenarios and defining associated airborne mission requirements. Ship sizing parameters used in the ship synthesis program were ship performance requirements and aircraft complement and support. In Scenarios I and III, ship performance requirements were instrumental in sizing the ships; in Scenario II, the quantity and type of aircraft and support needs were instrumental in sizing the ship. Thus, the establishment of the system operational capabilities was of major importance in the conceptual design process. The ship synthesis program used in this study yields minimum weight ships. This design approach was considered desirable because the performance of an SES, much like aircraft, is highly sensitive to weight. Furthermore, useful load is nearly a one-on-one relation with structural weight, a point elicited later in a discussion on the impact of aircraft landing loads on ship structural weight. Consistent with this design philosophy, minimum weight aircraft were considered desirable. The aircraft configurations selected for systems application reflect this criterion. Table 11 summarizes the three high-speed ship/aircraft system concepts derived in this study.

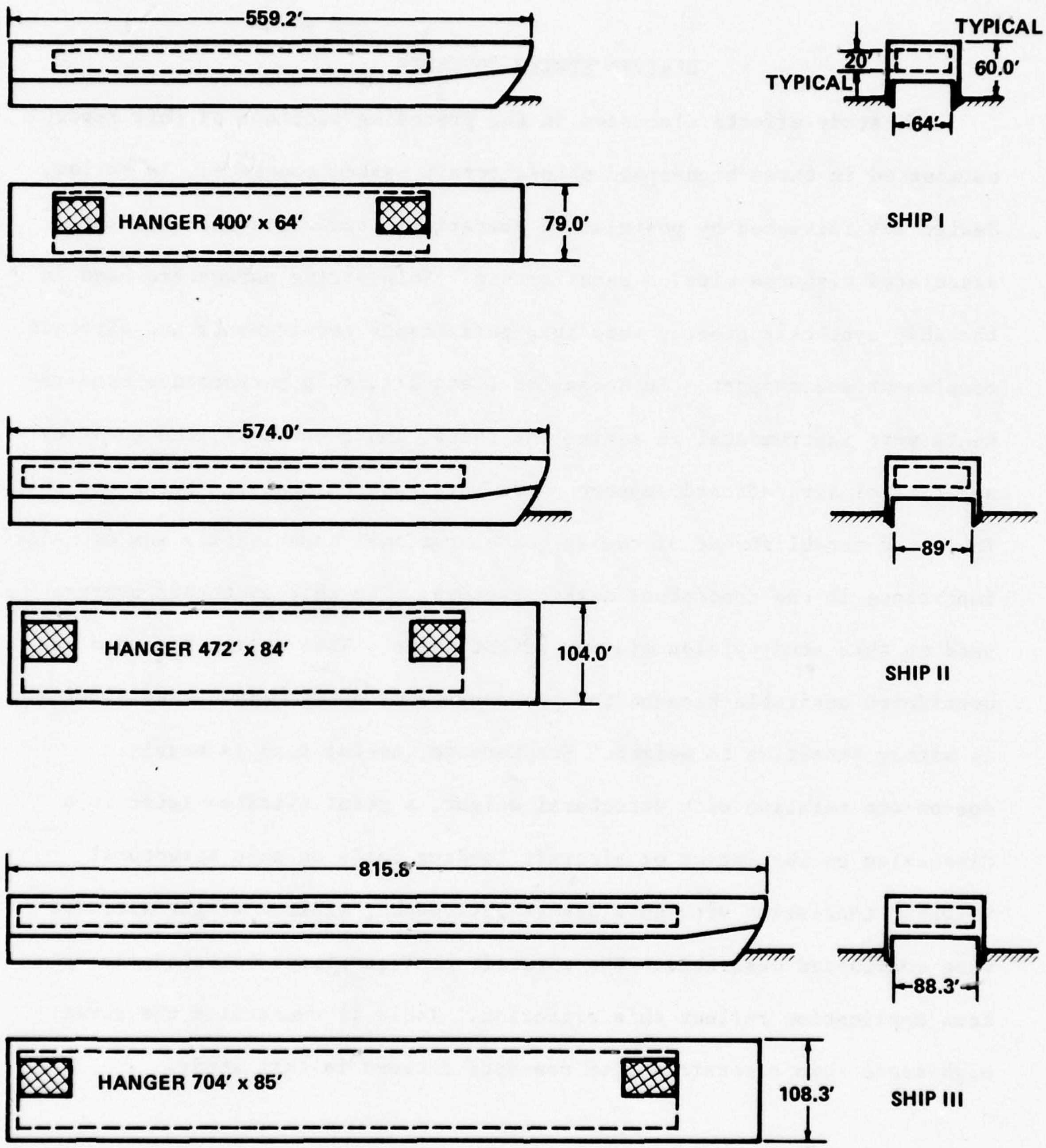


Figure 6 - Three-View Drawings of SES-CV Concepts

TABLE 11 - SUMMARY OF THE HIGH-SPEED SHIP/AIRCRAFT SYSTEM CONCEPTS

Scenario	SES-CV Class	Length/Width/ Deck Run feet	Airborne Missions	Quantity
1. Close Air Support	4500 long ton	559/79/425	CAS U	AV-8B/8 TRAC/2
2. Convoy Escort	5400 long ton	574/104/497	ASW(1) SA AEW(1) U	L/C Fan/8 L/C Fan/5 L/C Fan/3 TRAC/2
3. Fleet Support	14000 long ton	816/108/729	F SA(2) ASW(2) Surv(2) U	L/C Jet/7 L/C Fan/16 L/C Fan/3 L/C Fan/3 TRAC/3

(1)The S-3A can be utilized in the ASW and AEW missions of Scenario II at 44,000-pounds STOGW.

(2)The S-3A can be utilized in the ASW and surveillance missions of Scenario III at 53,000-pounds STOGW. The A-6 aircraft (CTOL) can be used in the SA role operating from this 14000 long ton class SES-CV.

POTENTIAL BENEFITS ASSOCIATED WITH AIRCRAFT OPERATING FROM HIGH-SPEED SHIPS

TAKEOFF CAPABILITIES

Takeoff capabilities were evaluated for WOD values of 0, 30, and 60 knots and for deck lengths of 200, 400, and 600 feet. The analysis consisted of the simultaneous solution of two equations, one defining the aircraft speed attained at the end of the deck run and the other defining the airspeed required for liftoff. The primary characteristics in takeoff of the aircraft evaluated are given in Table 12.

TABLE 12 - AIRCRAFT TAKEOFF CHARACTERISTICS

Aircraft	Installed Thrust pounds	Wing Area feet	Lift Coefficient
L/C Fan	31,500	370	1.00
AV-8A	15,500	201	1.20
AV-8B	16,000	230	1.20
S-3A	16,800	598	1.60
S-3CCW	16,800	598	3.50
Canard L/C Fan	25,000	320	1.00

Results are plotted in Figures 7a through 7f. Takeoff speed relative to the deck is presented as a function of gross weight, WOD, and deck run. This speed achieved at the end of the deck run is shown on the ordinate, and, added to WOD, is the speed necessary to achieve airborne flight. The high WOD provides potential benefits in terms of increased aircraft load capability, reduced power requirements, and reduced deck run. Although these benefits may be achieved simultaneously, to some degree, a tradeoff exists between thrust, deck run, and WOD, as shown in Figure 8. The significance of WOD is apparent. With increasing values of WOD, the tradeoff between thrust and deck run can be made at higher values of takeoff gross weight.

Figure 7 - Takeoff Capabilities of the Candidate Aircraft

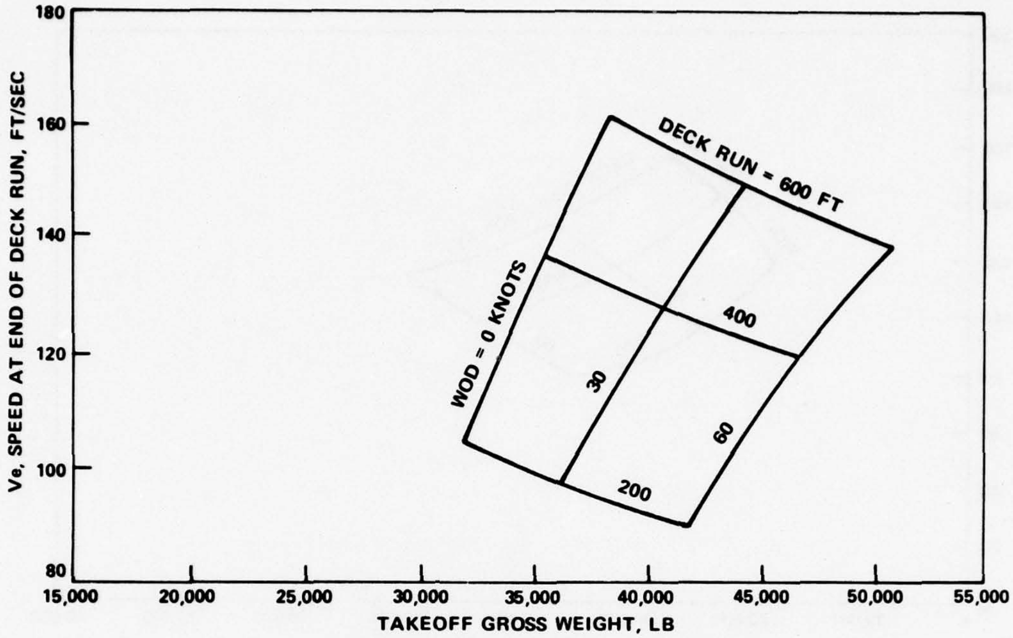


Figure 7a - L/C Fan VSTOL

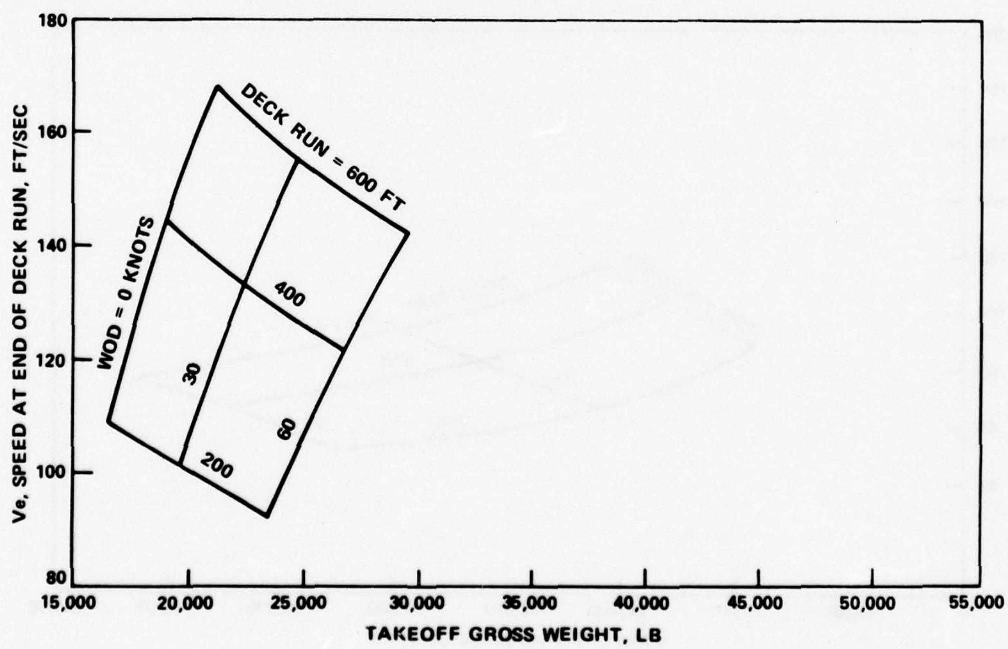


Figure 7b - Harrier AV-8A Jet VSTOL

Figure 7 (Continued)

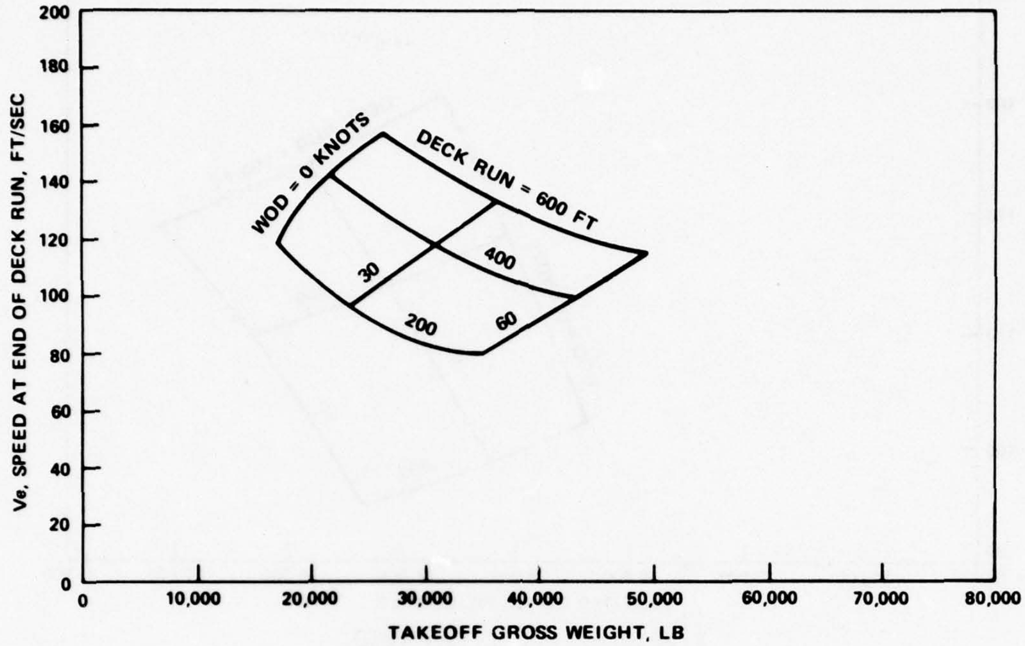


Figure 7c - S-3A CTOL

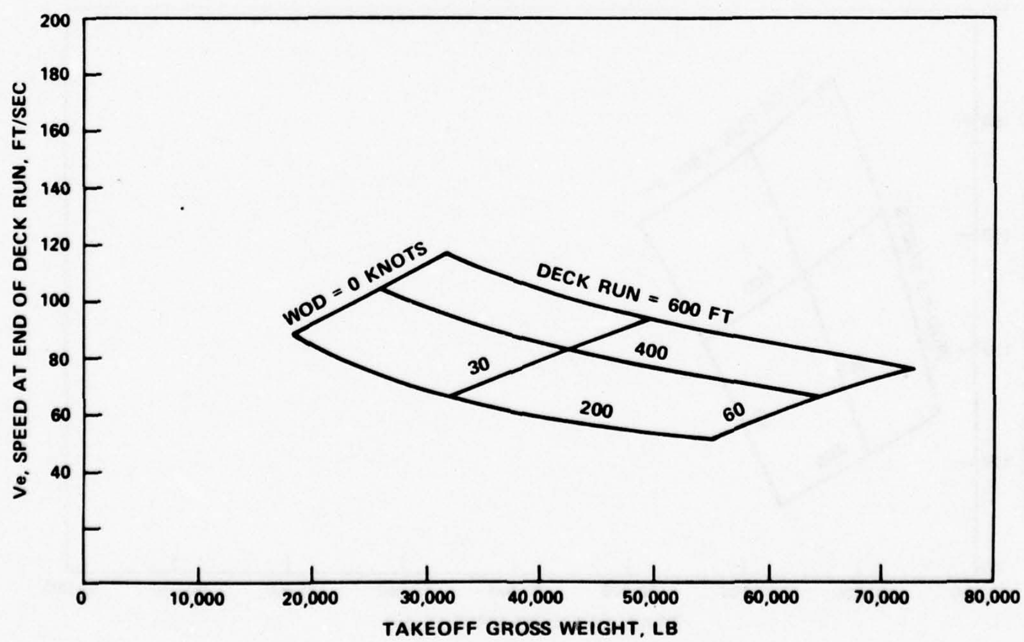


Figure 7d - S-3 CCW STOL

Figure 7 (Continued)

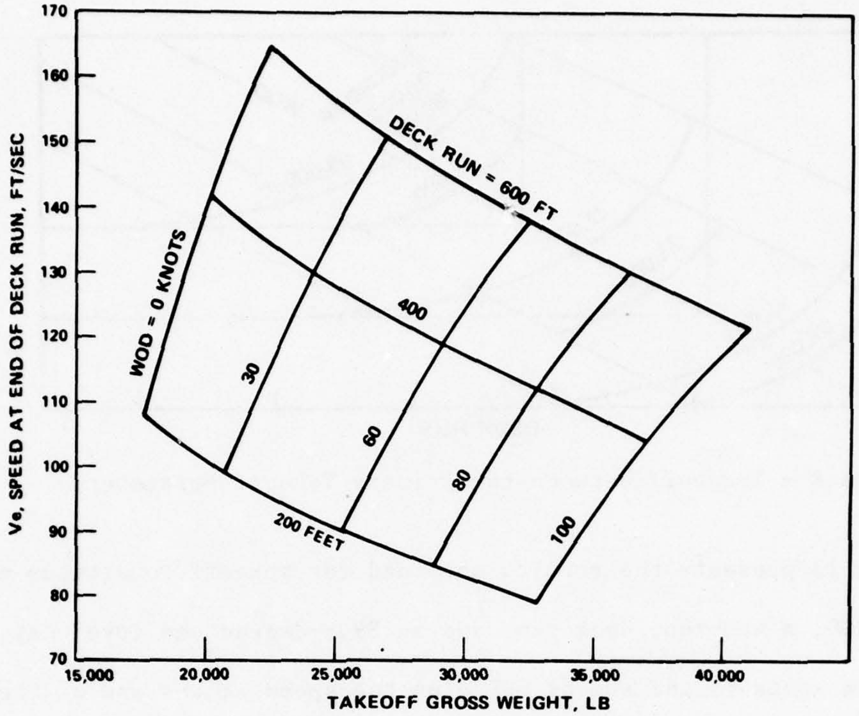


Figure 7e - AV-8B Jet VSTOL

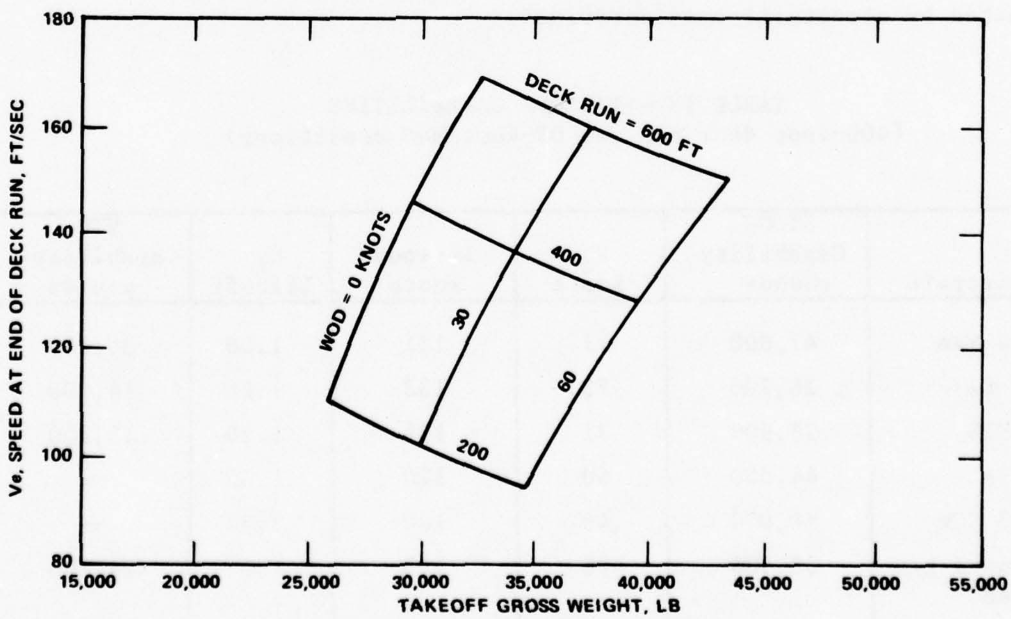


Figure 7f - Canard L/C Fan VSTOL

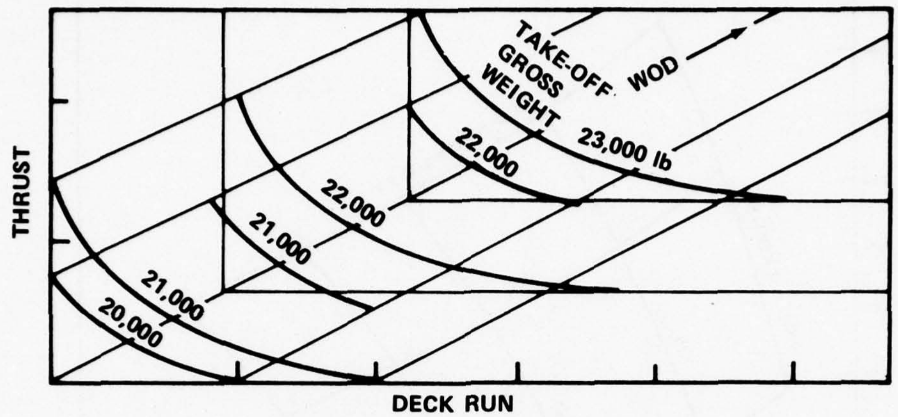


Figure 8 - Tradeoff between the Primary Takeoff Parameters

Table 13 presents the results obtained for takeoff conditions of 60-knots WOD, a 400-foot deck run, and an 89.8-degree sea level day. Airspeed in knots is the sum of WOD plus the speed at the end of the deck run V_e corrected to knots. The STOGW potential capability may be limited by structural considerations.

TABLE 13 - TAKEOFF CAPABILITIES
(400-foot deck run and 60-knot WOD conditions)

Aircraft	STOGW Capability pounds	V_e knots	Airspeed knots	C_L Liftoff	VTO Capability pounds
L/C Fan	47,000	71	131	1.00	30,000
AV-8A	26,700	73	133	1.20	14,800
AV-8B	28,900	71	131	1.20	15,300
S-3A	44,000	60	120	1.60	--
S-3 CCW	64,000	40	100	3.50	--
Canard L/C Fan	38,500	76	136	1.0	24,000

Structural limitation of the S-3A is currently 53,000 pounds. Figure 9 summarizes the potential improvement in aircraft takeoff capability with WOD for the 400-foot deck run condition. This improvement, expressed in percent of the takeoff gross weight capability achievable at zero WOD, is shown in Figure 10.

Deck run in takeoff and deck roll in landing as a function of WOD for the S-3A and S-3 CCW aircraft are presented in Figures 11 and 12. The three SES-CV's of this study are spotted on the graphs at their usable flight deck lengths to illustrate ship applicability. The S-3CCW can take off from all three ships, but the S-3A can take off only from ships II and III.

In Figure 13, the potential takeoff capability is presented as the ratio of takeoff gross weight to installed thrust as a function of the deck run for an 89.8-degree sea level day and a 60-knot WOD. Lift coefficient C_L is noted for each configuration. A gross weight limit of 53,000 pounds is illustrated for the S-3 aircraft by the horizontal dashed line. The maximum usable lift coefficient for the 600-foot deck run is about 2.0 for this gross weight limit.

MISSION PERFORMANCE

Mission Applications

Suitable missions for the selected aircraft are identified in Table 14. The aircraft cannot perform the missions with the same degree of effectiveness, but the missions can be performed at a sufficient level to justify the use of the aircraft in those missions indicated. The primary aircraft mission is listed first.

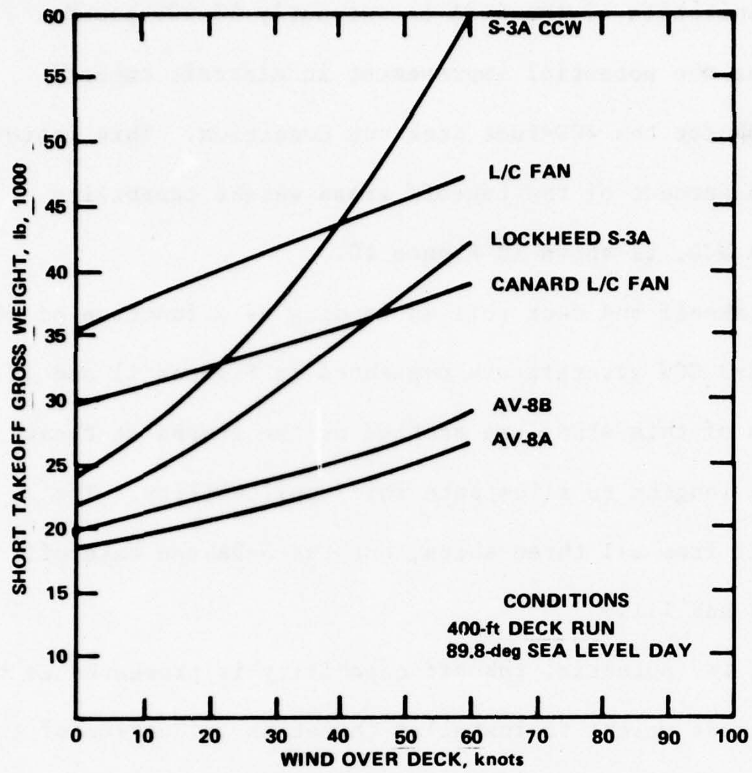


Figure 9 - Potential STOGW Capabilities
as a Function of WOD

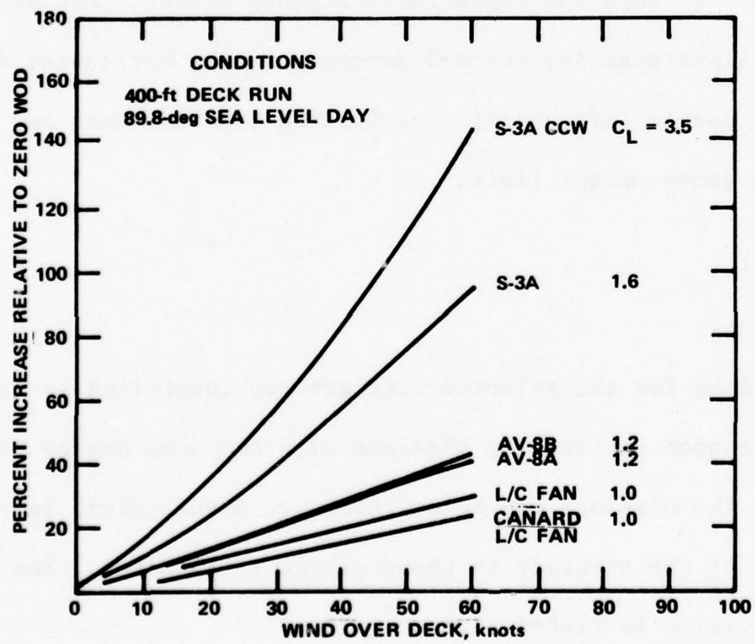


Figure 10 - Percent Improvement in STOGW
Capability with WOD

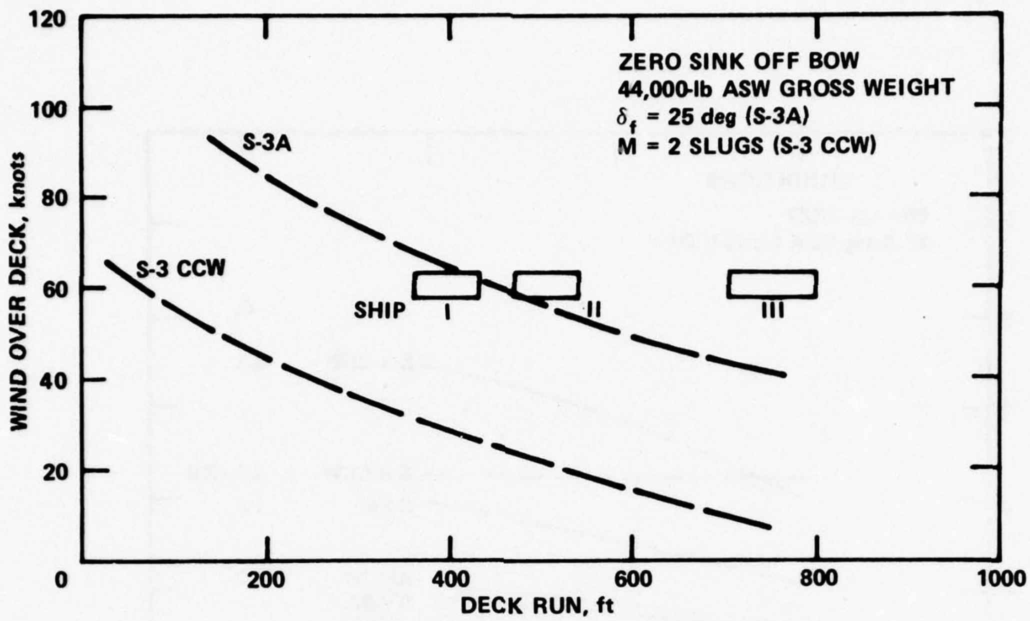


Figure 11 - Deck Run in Takeoff for the S-3A and S-3 CCW Aircraft

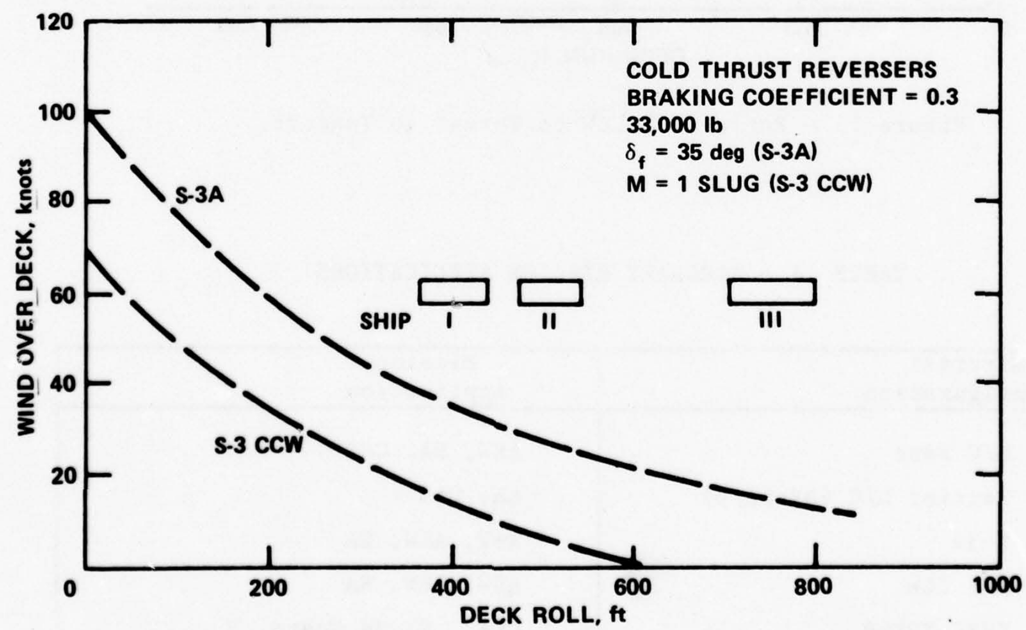


Figure 12 - Deck Roll in Landing for the S-3A and S-3 CCW Aircraft

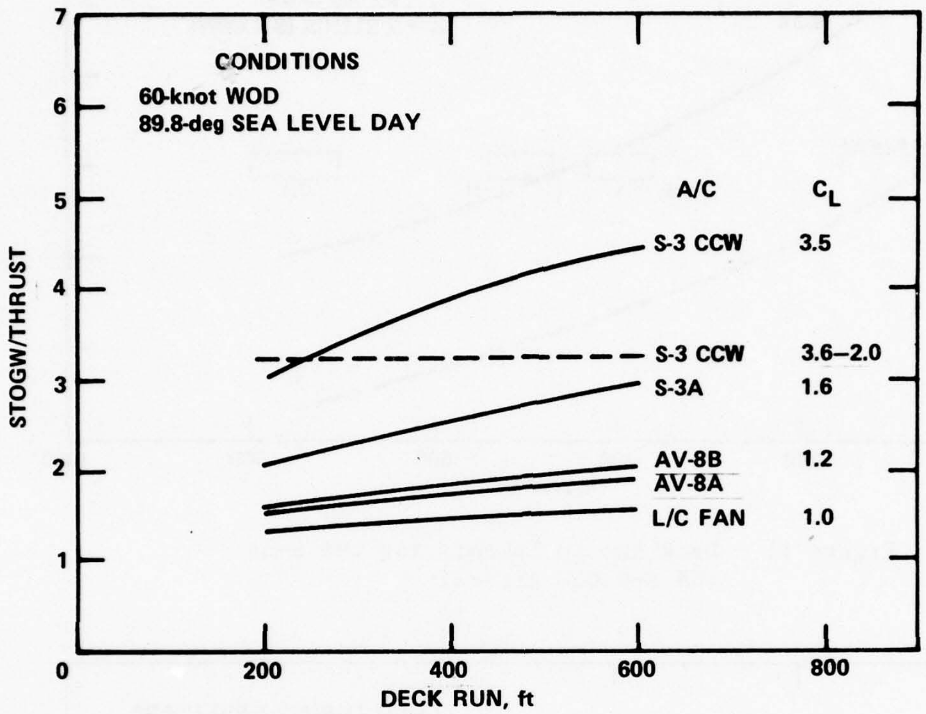


Figure 13 - Ratio of STOGW to Thrust in Takeoff

TABLE 14 - AIRCRAFT MISSION APPLICATIONS

Aircraft Configuration	Mission Application
L/C Fans	ASW, SA, CAS
Harrier L/C (AV-8A/B)	SA, CAS
S-3A	ASW, AEW, SA
S-3 CCW	ASW, AEW, SA
TRAC ROTOR	CSAR, Plane Guard, U

CAS Mission of Scenario I

The Harrier L/C AV-8B aircraft was analyzed in the CAS role of Scenario I. Payload capability as a function of radius of action is presented in Figure 14 for various values of WOD. A WOD of 40 knots will provide the STOGW capability to meet the air plan requirement of 1.5 long tons of aircraft ordnance per sortie. This capability is shown in Figure 15. Thus, the AV-8B VSTOL easily satisfies the CAS mission at a standoff distance of 200 nautical miles.

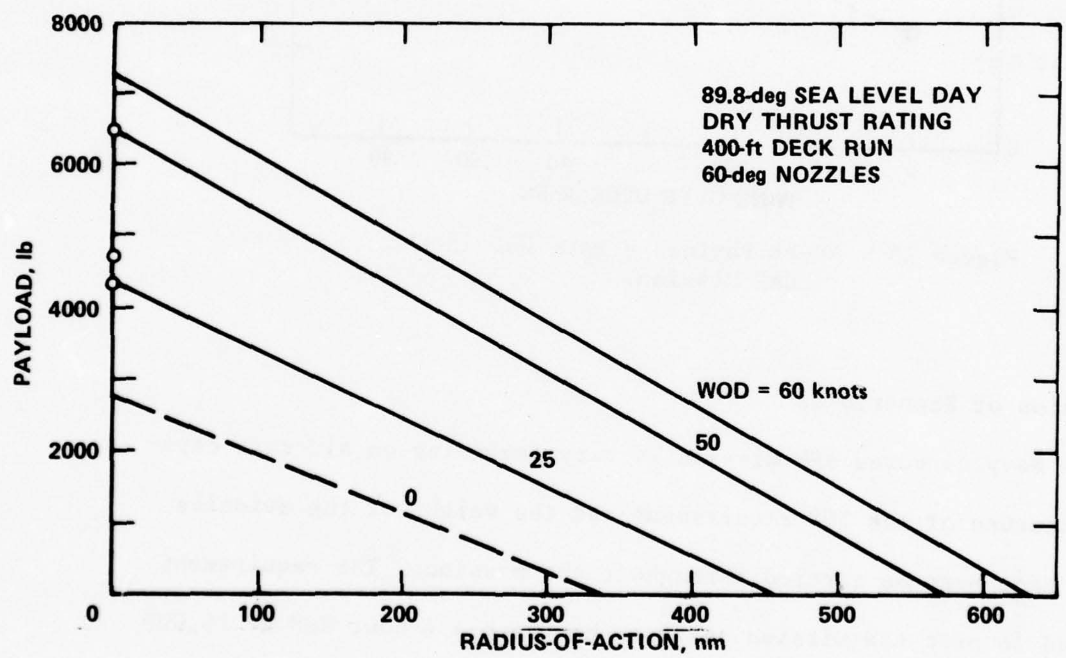


Figure 14 - Payload versus Radius for the AV-8B Aircraft in the CAS Mission

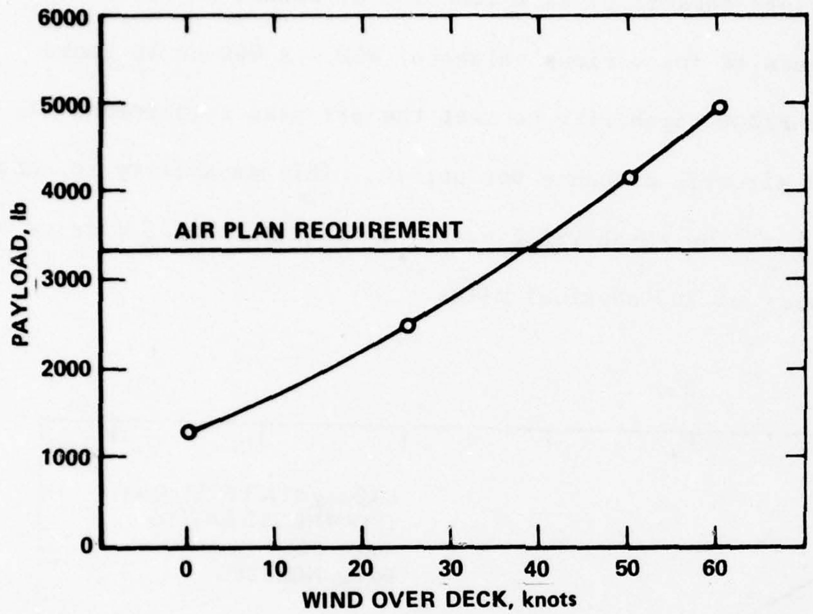


Figure 15 - AV-8B Payload versus WOD in the CAS Mission

ASW Mission of Scenario II

The Navy airborne ASW mission is very demanding on aircraft capability because of the TOS requirement and the weight of the avionics package that must be carried throughout the mission. The requirement most used in past ASW mission analyses has been a 4-hour TOS at 10,000 feet. If we assume a desired radius of action of 150 nautical miles, a mission analysis of the L/C fan VSTOL in this ASW role affords an opportunity to determine the potential benefits of high WOD, since these configurations cannot meet the requirement at zero WOD. Results of the analysis are presented in Table 15.

TABLE 15 - ASW MISSION ANALYSIS SUMMARY

Condition	(1)	(2)	(3)
WOD, knots	0.0	34.7	60.0
Deck Run, feet	400	400	400
Altitude/ Temperature	Sea level/ 89.8 deg	Sea level/ 89.8 deg	Sea level/ 89.8 deg
Radius, nautical miles	150	150	150
TOS, hours	2.40	4.00	5.30
Mission Time, hours	4.10	5.77	7.10
STOGW, pounds	35,600	41,350	47,900
STOGW/VTOGW	1.19	1.38	1.57

Column 1 represents a baseline computation. In Column 2, an incremental fuel was determined to achieve an additional 1.6-hour TOS. In Column 3, a 60-knot WOD was assumed, resulting in a TOS capability of 5.3 hours. Incremental increases in STOGW with WOD were apportioned to additional fuel and, when external fuel was required, allowances were included for increased structural weight and profile drag. Additional fuel for climb and cruise due to increased weight and drag was also accounted for. In each solution, several iterations were required to obtain a balanced radius of action. The 60-knot WOD provides a 32-percent increase in STOGW, relative to zero WOD, yielding an increase in TOS of 120 percent.

Total range was computed as an alternate means of measuring potential benefits. Range capability is presented in Figure 16. The slope of the curves represents fuel rate flow in pounds per nautical mile. External tanks are dropped when empty. The value of the aircraft weight at the maximum range point is the operating weight empty plus fuel reserves. Thus, an increase in WOD from 20 knots to 45 knots yields a potential improvement in range of about 400 nautical miles, or an average increase of 16 nautical miles of range per knot increase in WOD.

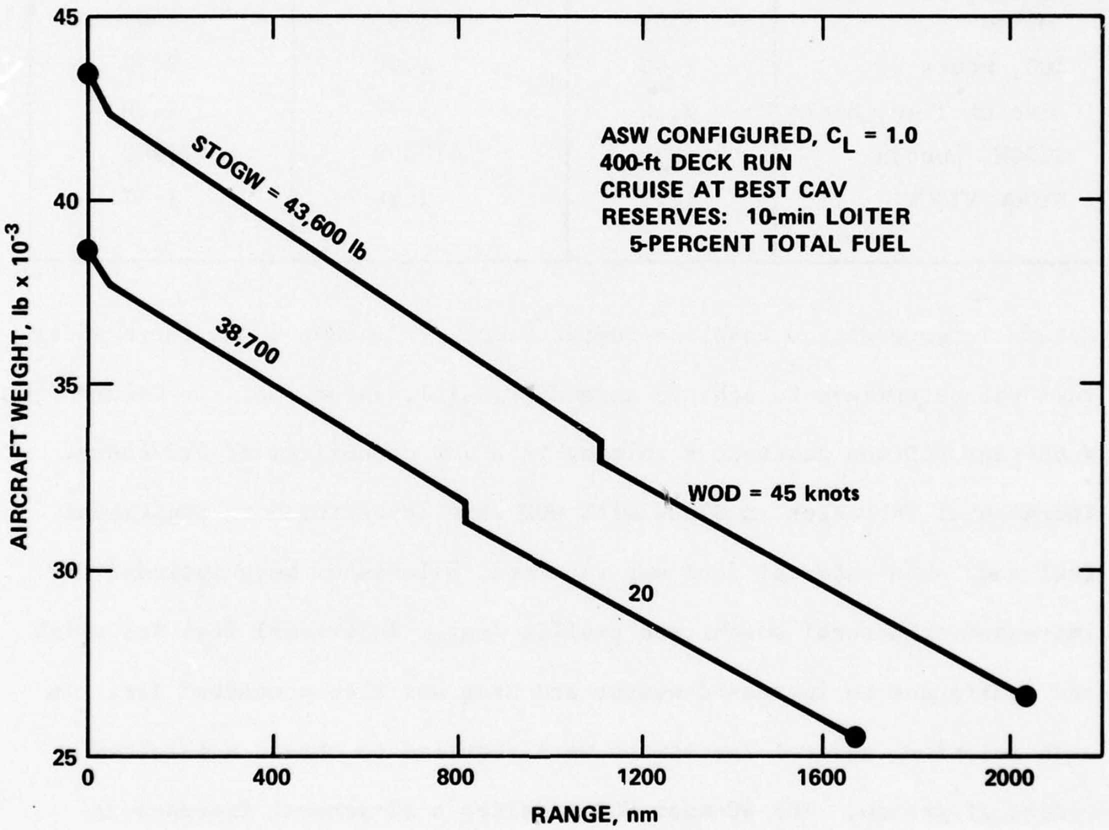


Figure 16 - Total Range as a Function of WOD for the Lift Cruise Fan VSTOL

ASW Screening Capabilities

A comparison of the ASW screening capabilities of the L/C Fan, the S-3A, and the Canard L/C Fan aircraft is presented in Table 16. Values of STOGW were selected to assure 4 hours of TOS in accordance with the sortie rate and air plan that was developed for Scenario II. The mission profile and requirements defined previously were assumed. Radius of action was corrected to accommodate the convoy speed of advance (SOA).

TABLE 16 - SCREENING CAPABILITY OF THE ASW-CONFIGURED AIRCRAFT

Aircraft	Canard L/C Fan	L/C Fan	S-3A
STOGW, pounds	34,500	43,600	44,000
WOD, knots	40	45	60
Deck Run, feet	400	400	450
TOS, hours	4.5	4.5	4.5
Search Speed, knots	240	242	370
Search Area, square nautical miles	7,000	7,120	10,000
Search, nautical miles	1,080	1,090	1,665

The ASW screening operation and the capabilities of the L/C Fan and the S-3A aircraft are depicted in Figures 17a and 17b. The SOA of the convoy, assumed to be 20 knots, and the 4 hours TOS determine the width of the fields of sonobuoys. Search area capability yields the span-wise dimensions of the fields. Thirty minutes in excess of the desired TOS was allowed in the mission analysis to provide for overlap of operations over the sonobuoy fields and for variations in the flight paths to and from station. A total mission time of 6.37 hours was computed for the L/C Fan and was used as the basis for comparison. The mission effectiveness of the S-3A measured in square miles of search area is seen to be about 40 percent more effective than the mission effectiveness of the L/C Fan. However, in the discussion on associated problem areas, it is

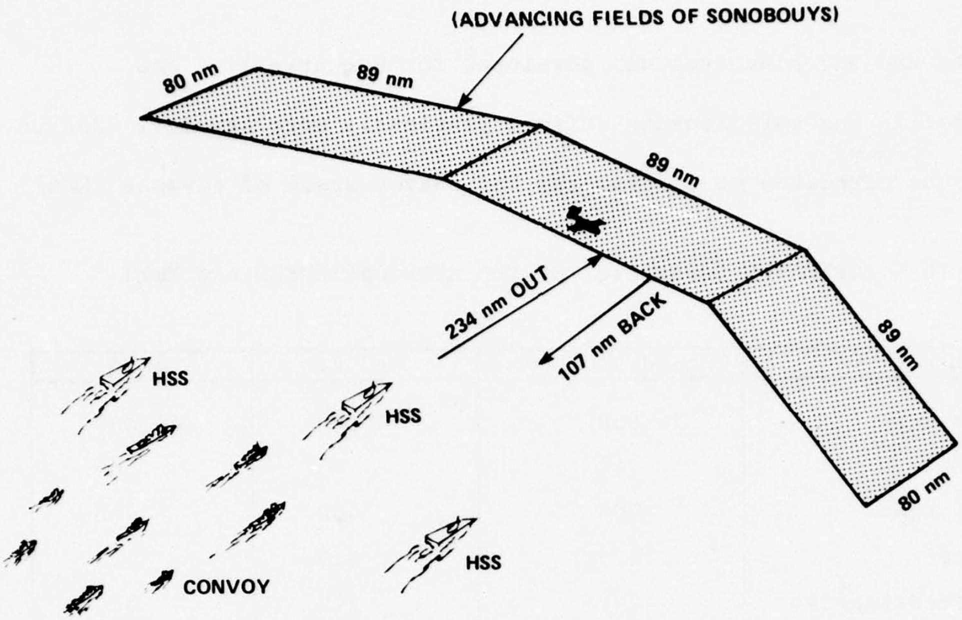


Figure 17a - L/C Fan Aircraft

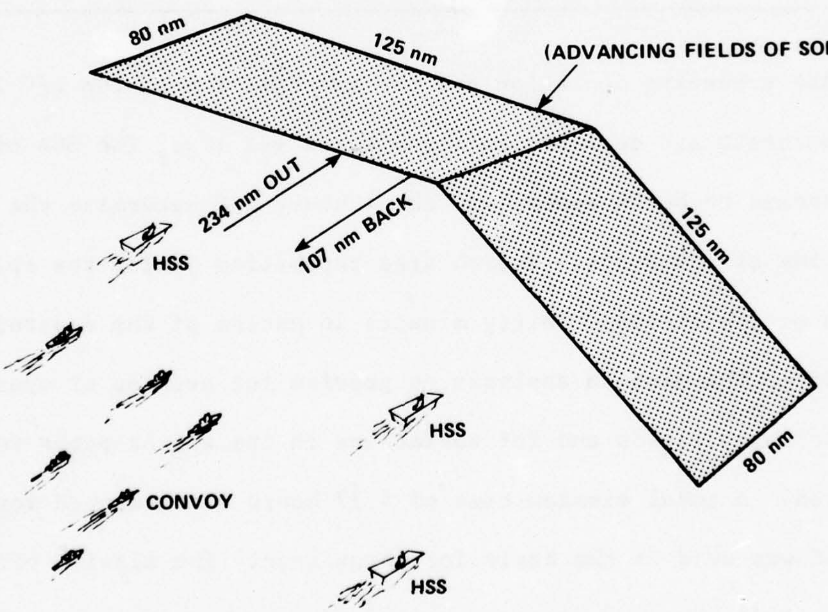


Figure 17b - S-3A Aircraft

Figure 17 - ASW Screening Capabilities of the L/C Fan and the S-3A Aircraft

shown that five S-3A's would replace eight L/C Fans in the high-speed ship of Scenario II (the relative spotting factors are 1.37 and 0.98 (referenced to the A-7 aircraft) so that operational effectiveness implications will necessarily include aviation support requirements and maintainability and reliability considerations. It can be shown that three of the 5400-ton class high-speed SES-CV of Scenario II would be needed on line to support a continuous screening operation having the dimensions shown above.

In the ASW screening mission analysis, the outbound leg of the aircraft was significantly increased as a result of the 20-knot SOA of the convoy. The L/C Fan aircraft, used as a baseline for comparison at the 43,600-pound STOGW and 4.5-hours TOS, yields a radius of action of approximately 150 nautical miles if the aircraft is to return to its point of origin, i.e., a zero-ship SOA. Therefore, the 20-knot SOA of the convoy in the above missions yielded an increase of about 84 nautical miles. This mission profile differs from that presented in Figure 2 by the addition of the distance covered by the SES-CV during the time the aircraft performs its mission. This revised profile is shown in Figure 18. An increase in radius of action over that of the basic mission results and is dependent on the speed of the high-speed SES-CV.

The L/C Fan VSTOL was further investigated in this modified mission profile. Three factors impact on the value of the mission radius. Ship distance covered during the airborne mission is the major contribution. Fuel saved on station due to operations at reduced gross weight is also significant. In addition, the aircraft will operate at a slightly higher average speed to station, but the effect is minor. The aircraft weight on station will decrease with increasing distance to the station area; therefore, fuel flow will decrease. In addition, a balanced mission profile requires the aircraft to rendezvous with the ship at the end of the total mission time. An iterative solution is required. Radius of action was determined as a function of the SOA of the high-speed SES-CV.

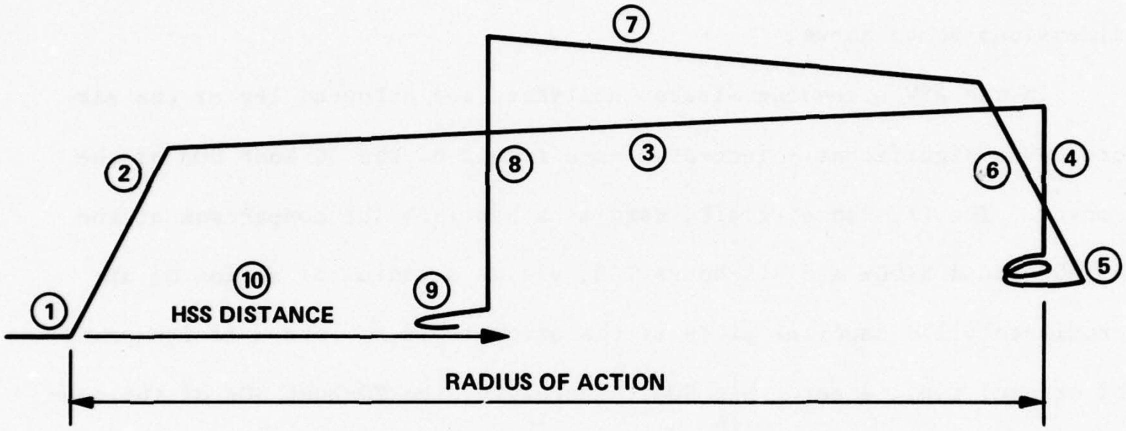


Figure 18 - Ship Speed Dependent ASW Mission Profile

In Figure 18, it was assumed that: (1) the ship SOA is equal to WOD, (2) the ship maintains heading and speed, and (3) the basic mission criteria apply. Results of the investigation are presented in Table 17.

TABLE 17 - EFFECT OF SHIP SPEED ON AIRCRAFT RADIUS OF ACTION

Ship Speed knots	Aircraft STOGW pounds	Mission Time hours	Ship Distance nautical miles	Radius of Action nautical miles	TOS hours
0.0	35,600	4.10	zero	150	2.40
34.7	41,350	5.84	203	275	4.00
45.0	43,600	6.47	291	328	4.55
60.0	47,700	7.40	444	390	5.30

Mission radius, STOGW, and TOS are plotted versus ship speed in Figure 19. At a ship speed of approximately 50 knots, the ship range places the ship directly under the aircraft at the end of the airborne mission (4.75-hours TOS). Therefore, there exists a ship speed above which aircraft TOS potential cannot be realized in order to rendezvous with the ship. Also, a tradeoff does not exist between TOS and mission radius as exists in the basic mission but between radius and ship speed, at ship speeds below 50 knots. Above 50-knot ship speed, the aircraft must abort its mission short of the total TOS capability to rendezvous with the ship. Alternately, the ship can reduce its speed after aircraft launch or vary its heading. Also, above 50 knots a tradeoff between TOS and aircraft radius can be made increasing aircraft radius to equal ship distance. For instance, at a ship speed of 60 knots, reducing TOS by about 0.12 hours increases aircraft radius by 54 nautical miles.

These tradeoffs are not intuitively evident, since they are obscured by the variables involved in the mission analysis. Therefore, they have been presented in terms of variations to the three ground rules established at the beginning of this discussion.

An estimate of ship fuel consumed during this modified mission can be made based on the data and results of the ship synthesis program, affording a measure of the cost to achieve the increased radius of action in the manner described above. Results are summarized in Table 18.

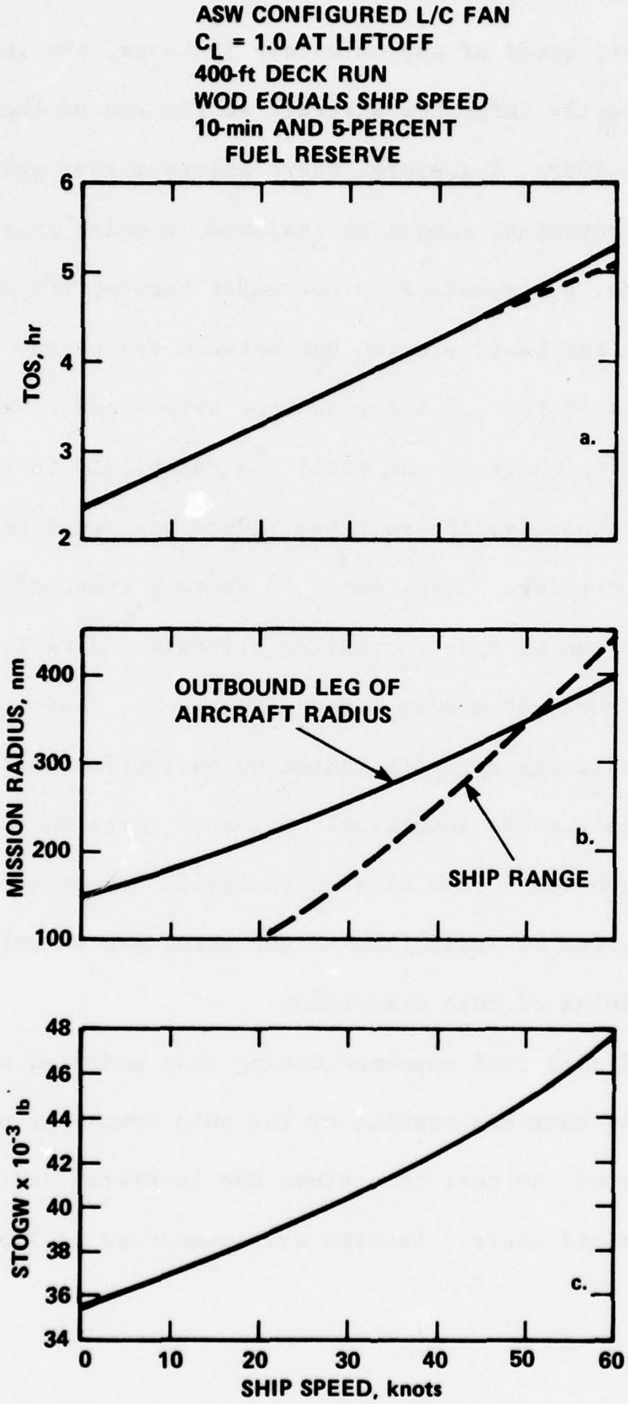


Figure 19 - Effect of Ship Speed on Aircraft Performance

TABLE 18 - COST IN SHIP FUEL TO ACHIEVE
INCREASED RADIUS OF ACTION

Ship Speed knots	Fuel Flow tons/hour	Fuel Consumed tons	Nautical Mile re: 150	Fuel Consumed Above Basic Mission tons	Increment in Fuel Cost tons/nautical mile
Loiter	6	25	0	0	0.00
34.7	15	88	125	63	0.50
45.0	22	142	178	117	0.66
60.0	38	281	240	255	1.06

Loiter Capability in the ASW Role

Loiter capability as a function of mission radius of action for the ASW-configured S-3A, the S-3 CCW, and the L/C Fan is presented in Figure 20. The S-3 CCW and the S-3A can perform the basic ASW mission (4.0-hours loiter) at radii of 820 and 580 nautical miles, respectively. Conversely, loiter time on station can be significantly increased at the basic mission radius of 150 nautical miles. The gross weights listed in Figure 20 are the maximum capabilities for the stated conditions. Two values of gross weight for the S-3 CCW are included to illustrate the significance of takeoff technique. The 48-knot WOD and the 49,000-pound gross weight conditions represent the capability if circulation control wing (CCW) blowing is on during the total length of the 400-foot deck run. The 53,000-pound gross weight at 48-knots WOD represents an increased capability obtainable if the CCW blowing is not turned on until near takeoff. The difference in gross weight is due to both higher values of aircraft aerodynamic drag associated with the high-lift concept when operating and also to reduced thrust available for acceleration. The current growth potential of the S-3A is 53,000 pounds.

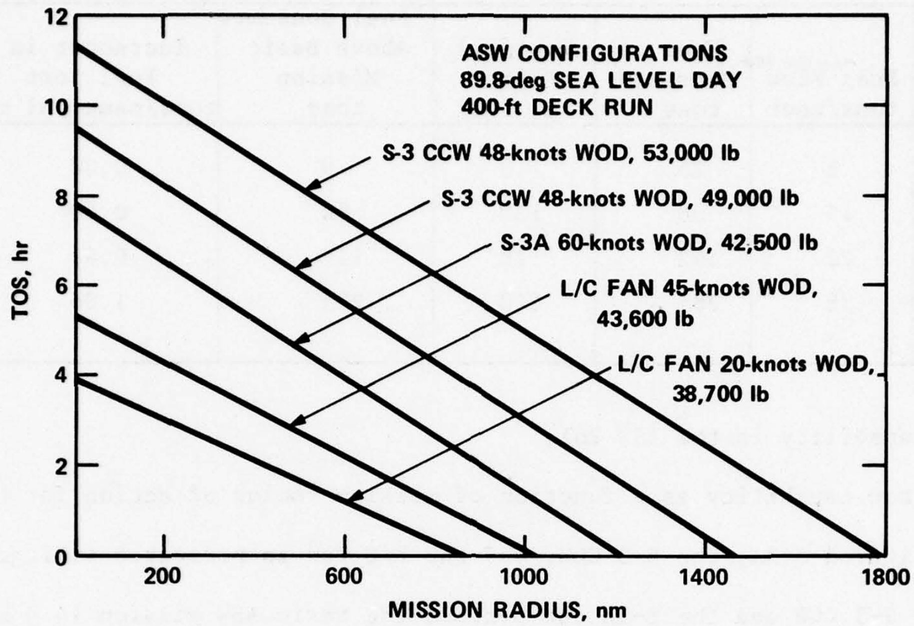


Figure 20 - Loiter Capability versus Mission Radius

Multimission Capability

Increased STOGW capability with high WOD suggests the possibility of achieving commonality in airframe configuration and design. Flexibility in mission applications of an aircraft would be achieved by designing an airframe to meet the needs of the various mission loads and by relying on the WOD to accommodate variations in mission gross weight requirements (overload capability). Conflicting requirements, however, exist in propulsion fan pressure ratio (FPR) and wing aspect ratio (AR) to achieve maximum performance in the critical leg of the mission, as shown in Table 19 by a range of representative values for these ratios. Therefore, whereas the utilization of WOD to increase STOGW capability affords greater flexibility in the aircraft mission assignment, multimission capability in a single airframe (airframe commonality) as a viable concept may still depend on the acceptability of the performance compromises in specific mission applications.

TABLE 19 - NOMINAL VALUES OF FPR AND AR MISSION REQUIREMENTS

Mission	FPR	AR
ASW	1.25	8
AEW	1.30	10
SA	1.40	7
CSAR	1.35	4
CAS	1.40	5

POTENTIAL PROBLEMS ASSOCIATED WITH BASING AIRCRAFT ON HIGH-SPEED SHIPS

SHIP/AIR INTERFACE ASPECTS

The unique Navy problem of operating aircraft from restricted take-off and landing areas will continue to be present with the high-speed ship/aircraft concept. Many of the ship/air interface aspects associated with today's Navy may become vital issues in achieving the high-speed Navy of tomorrow. This is particularly true because the SES-CV is confidently predicted to be weight limited and, perhaps, volume limited, making careful attention to operational requirements mandatory in designing a viable system.

Ship weight and volume constraints require new approaches to handling, traversing, and stowing aircraft and weaponry. Responsive, error free, and safe shipboard systems manned by a minimum of operating and maintenance personnel will be the basic guidelines in system design approach. Flight personnel and equipment will need protection from hazards associated with high WOD. Small, lightweight fire and damage control equipment will be necessary. New approaches must be developed to assure satisfactory performance of the functions associated with aviation support, preflight and postflight activities, emergency situations, and aircraft servicing during turnaround operations. Improved rearming rates will be desirable. New ship configurations and high WOD will create an environment not yet investigated. Interface aspects of shipboard operations on which continued development must focus include the following:

1. Aviation Support

   a. Deck crew mobility (personnel cannot perform satisfactorily in winds of 45 knots and higher).

   b. Activities associated with certain equipment and systems are sensitive to winds.

   c. Safety (dynamic pressure reducers, procedures).

   d. Personnel (complement, training).

   e. Servicing (refueling, turnaround time, emergencies).

   f. Weaponry handling and loading.

   g. Maintenance and supply (modular approach, simplicity, advanced technologies).

2. Preflight

a. Handling and maneuvering aircraft.

b. Engine start and warmup (exhaust temperature, velocity and footprint pressure, time).

c. Aircraft readying (unfolding wings, checkout).

d. Tie-down considerations (gear design and location, weather-cock stability, elevator turntable).

e. Communications, command and control.

3. Postflight

a. Retrieval and tie down (landing gear design, anchor mechanism).

b. Spotting (automatic, manual).

c. Footprint (engine exhaust down-wash characteristics, landing gear pressure, and impact forces).

d. Aircraft handling and maneuvering.

e. Communications, command and control.

4. Stowing

a. Spotting factor (aircraft size, variable geometry considerations, nesting capabilities).

b. Maintenance requirements (volume and weight).

c. Footprint pressure (aircraft weight, landing gear configuration).

d. Elevator size and location.

TAKEOFF CONSIDERATIONS

The aircraft takeoff capability will be directly dependent on the T/W ratio, wing loading, and usable lift coefficient. Two aspects of T/W ratio are important in the takeoff problem: T/W ratio available to produce acceleration during the ground run and T/W ratio required to conduct the transition maneuver immediately after takeoff from takeoff speed to climb speed. Also important is the aerodynamic drag associated with the aircraft takeoff configuration. High drag is detrimental both during ground run since it reduces the speed attainable and also during transition since acceleration to climb speed is reduced. The influence of drag and available thrust during the ground run on the S-3 CCW STOL aircraft is shown in Figure 20. A 4000-pound increase in takeoff weight is available if high wing lift is delayed to near the takeoff point. Also, aircraft configurations incorporating variable geometry and/or thrust vectoring offer control over the takeoff capability. In fact, the viability of STOL aircraft operating from restricted areas will be heavily dependent on the takeoff techniques offered by the configurations. To illustrate this point, the takeoff performance of both L/C and L + L/C configurations are compared in terms of incremental lift due to WOD. In Figure 21, a Harrier-type L/C jet VSTOL is compared with a VAK-191-type L + L/C VSTOL. The takeoff performance of the L/C configurations exceeds that of the L + L/C configurations. This additional capability increases with increased WOD; at 60-knots WOD, the increased capability exceeds 1000 pounds. The pertinent takeoff conditions are presented in the figure. The difference in performance is due to the rotatable nozzle of the L/C configuration providing higher values of longitudinal acceleration during the deck run than are available in the L + L/C configuration. In the latter concept, the lift engines (which provide approximately one-third of the lift required in vertical operations) cannot be rotated, and thus their contribution to the longitudinal acceleration

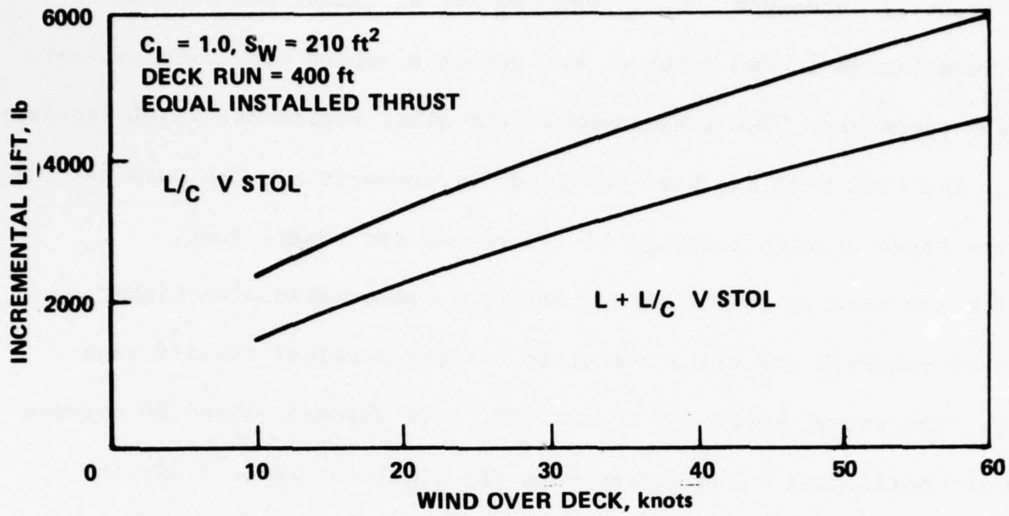


Figure 21 - Lift Cruise and Lift plus Lift Cruise VSTOL Aircraft Incremental Lift with WOD

is minimal. In general, L/C concepts have an increased performance potential because of total thrust vectoring. L/C fan concepts with nose-lift fans evaluated in this study can provide high values of longitudinal acceleration because the nose-lift fan blades can be set at zero thrust during ground runs which virtually directs all turbine power to the lift/cruise fans.

In transition flight, immediately after takeoff, the thrust requirements are heavily dependent on the spanwise distribution of lift. To achieve good performance in STOL aircraft, it has been necessary to distribute lift loads over a wide span to reduce induced drag. Induced drag is high at the low end of the flight speed regime and increases with reductions in wing span. Thurst-to-weight ratio requirements in transition can be conveniently represented by T/W values required to maintain minimum speed in level flight at the takeoff lift coefficients and gross weight. Somewhat higher T/W values (about 8 percent) are necessary for climb out.

Figure 22 shows the thrust requirements at transition for the aircraft investigated. Two bands of T/W versus airspeed are quite evident. One band represents STOL requirements; the other represents VSTOL requirements. The CTOL S-3A has been included for comparison. The pure jet flap data are based on wing loadings of 100 pounds per square foot.

A heavy penalty in volume and weight is associated with higher values of required installed thrust to achieve vertical takeoff capability. The thrust vector of these VSTOL's is assumed tilted 60 degrees above the horizontal. The approximate T/W limits of the S-3 CCW are indicated on the respective curve, based on the minimum operating weight (about 33,000 pounds) and the projected growth potential (about 53,000

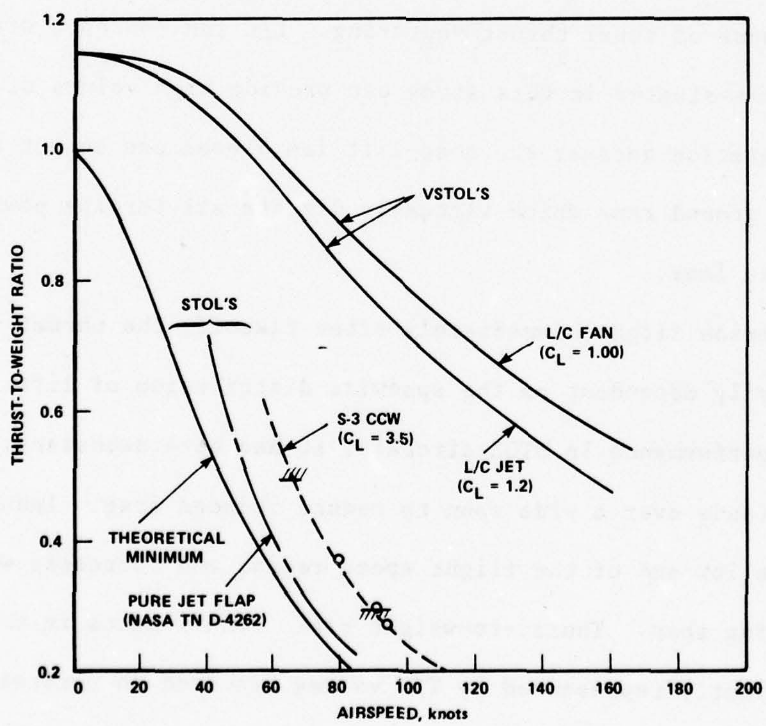


Figure 22 - VSTOL and STOL Thrust Requirements at Transition Airspeeds

pounds) of this aircraft. The STOL's should out perform the VSTOL's in those missions where range and/or endurance are critical capabilities because of much lower fuel consumption rates. It should also be noted that relatively high values of lift coefficient and good span loading distribution yield good STOL's. It appears that direct lift is required in STOL's to yield VTOL capability in WOD up to 50 knots.

LANDING CONSIDERATIONS

An assessment of the landing problem must consider:

1. Approach and descent paths through the wind shear and ship wake.
2. Aircraft flight characteristics which vary with aircraft configuration.
3. Wind shear (head winds across ocean).
4. Wind turbulence (meteorological and ship wakes).
5. Ship motions (dependent on ship characteristics and sea states).

In addition, the severity of the landing problem will impact on aircrew training requirements, command and control responsibilities, landing and approach aids, and guidance requirements.

To make maximum use of high WOD during landing operations, speed in final approach should be relatively low. Deck requirements in terms of aircraft retrieval will be minimized with reduction in relative speed. The general relationship between wing loading, lift coefficient, and approach speed is shown in Figure 23. A range of wing loadings associated with the aircraft types discussed in this report is identified. At these wing loadings, desired final approach speeds will require lift coefficients of 2.0 to 4.0. Wing loadings below 50 pounds per square foot in

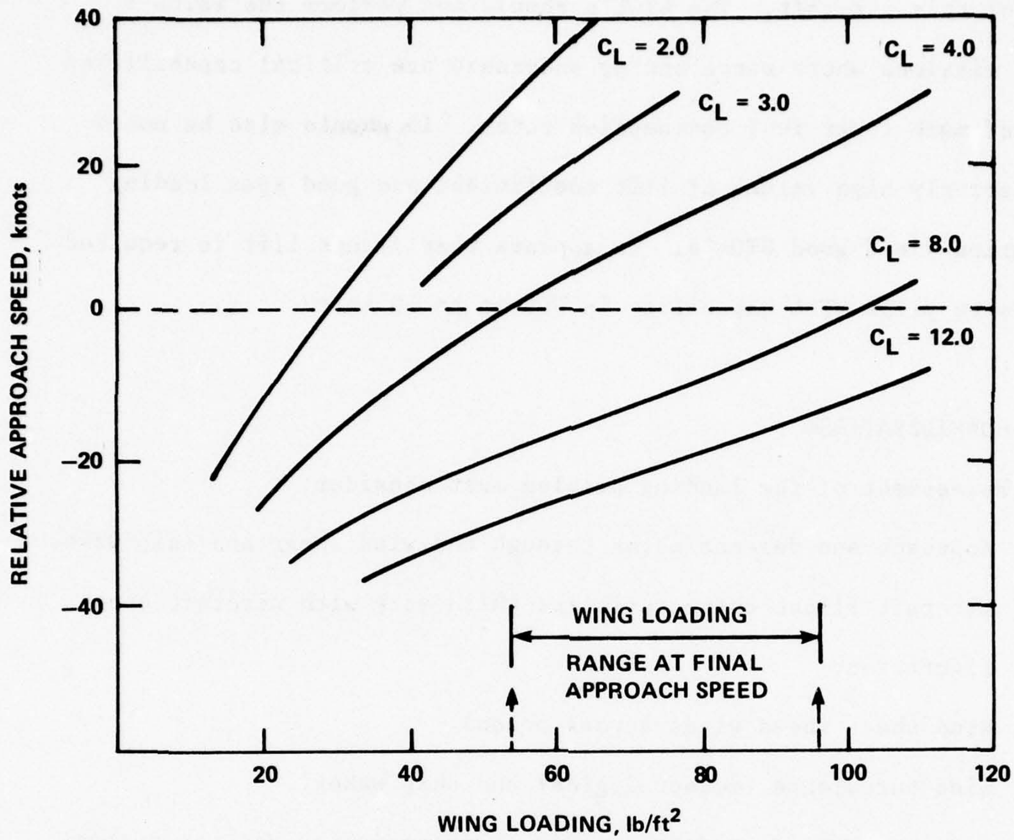


Figure 23 - Approach Speed Relative to 60-Knot Ship as a Function of Wing Loading and Lift Coefficient

the landing configuration will be difficult to achieve in practical designs that satisfy both shipboard compatibility and mission requirements.

MAJOR COMPATIBILITY FACTORS

The previous discussion on ship/air interface aspects highlights the potential problem areas associated with the high-speed ship/aircraft concept. No attempt has been made to prioritize these aspects as to their relative importance in achieving a viable system; however, to select aircraft concepts applicable to the high-speed ship, it was necessary to evaluate those compatibility factors considered of primary importance. The purpose of the study stated in the Introduction and the constraints and flexibilities which evolved in the synthesis of the high-speed ship configurations provided guidance in establishing critical areas. As development of the high-speed ship/system concept proceeds and as the future threat becomes more conclusive, the relative importance of the compatibility factors will be more easily defined.

Compatibility factors considered in the selection of aircraft as candidates for basing on high-speed ships are discussed below. In the review and analysis of the various aircraft types considered potentially suitable, interest focused on the impact which solutions to the problems associated with these factors might have on aircraft design and performance.

Aircraft Weight

Aircraft weight impacts on aircraft size (wing loadings), performance (power-to-weight ratio), and ship structural and volume requirements. It can therefore be assumed that minimizing aircraft weight should enhance compatibility with the high-speed ship; however, aircraft landing criteria will be the most influential factor impacting on aircraft size and weight, particularly in VSTOL configurations. Aircraft controllability, sink rate, and wave-off performance desired with critical engine out can result in serious weight increases. A landing criterion which resulted in no adverse aircraft growth was therefore borrowed from the joint Navy/NASA lift-cruise STOL competition studies. The aircraft shall be capable of maintaining a rate of sink of 15 feet per second at a gross weight not less than the operational weight empty plus 1000 pounds with one gas generator inoperative. A hover requirement would increase the design weight in excess of 25 percent.

Another aspect of aircraft weight considered was the possible aircraft design constraints imposed by ship structural requirements, perhaps limiting aircraft weight for conventional landing gear configured aircraft or requiring landing gear design changes.

The Structures Department (Code 1720) at DTNSRDC analyzed the effects of landing weight and tire configurations at assumed aircraft sink rates on the weights of deck structure. Results indicate that a weight penalty occurs in ship sizes below about 7000 long tons in order to accommodate aircraft with conventional landing gear arrangements and high pressure tires at sink rates of 15 feet per second. The penalty is illustrated in Figure 24.

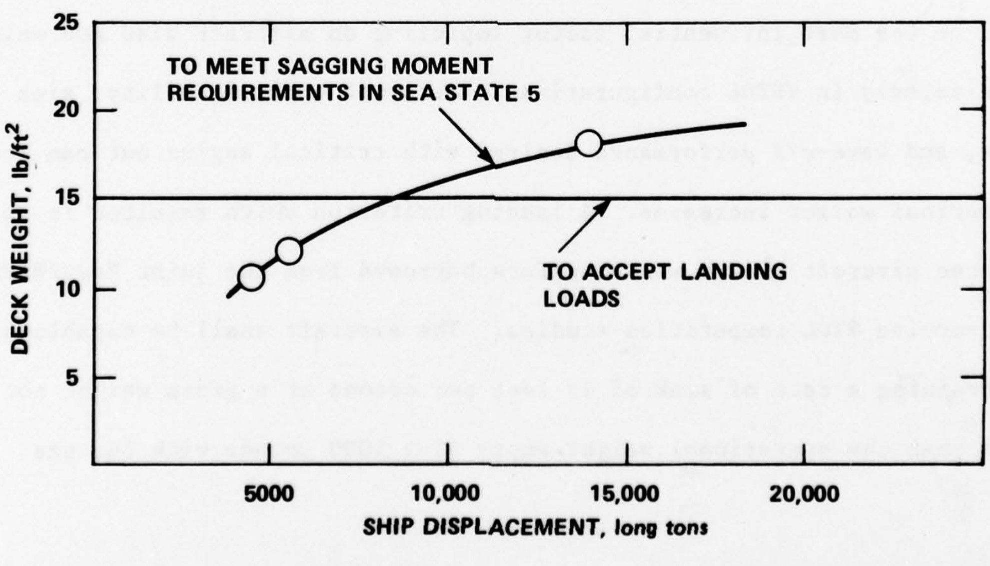


Figure 24 - Deck Weight versus Ship Displacement

The weight penalty would be nearly 2.6 percent of total displacement in Ship I and nearly 2.2 percent in Ship II. The penalty in terms of structural weight is 8.2 and 5.8 percent, respectively. More significantly, the cost in ship payload weight would be about 19 percent in Ships I and II and above 10 percent in ship fuel load. If the payload weights or range and endurance are critical to mission accomplishment and therefore could not be compromised, additional constraints in aircraft design would require careful tradeoffs between aircraft gross weight, sink rates in the landing configurations, and landing gear design and layout.

Aircraft Size

Minimizing aircraft planform dimensions is desirable to reduce spotting factors and to reduce stowing volume requirements. Overall height required in the hangar area is 19 feet and is consistent with current SES-CV propulsion plant requirements. Mechanical folding of components add little complexity and weight to the airframe and can be utilized in VSTOL aircraft as an effective way of reducing the spotting factor.

Figures 25a through 25c illustrate stowing concepts for each of the ship designs for this study. As described earlier, these ships are minimum weight designs that are consistent with the premise that the SES high-speed ship will be weight limited and can meet the scenario operational requirements, including ship performance, mission payload, and aviation support. The illustations are laid out to the same scale. Referring to Figure 25a, the aircraft complement includes eight AV-8B Harriers and two advanced TRAC aircraft chosen to perform the CAS and U airborne

Figure 25 - Hangar Deck Stowing Arrangements

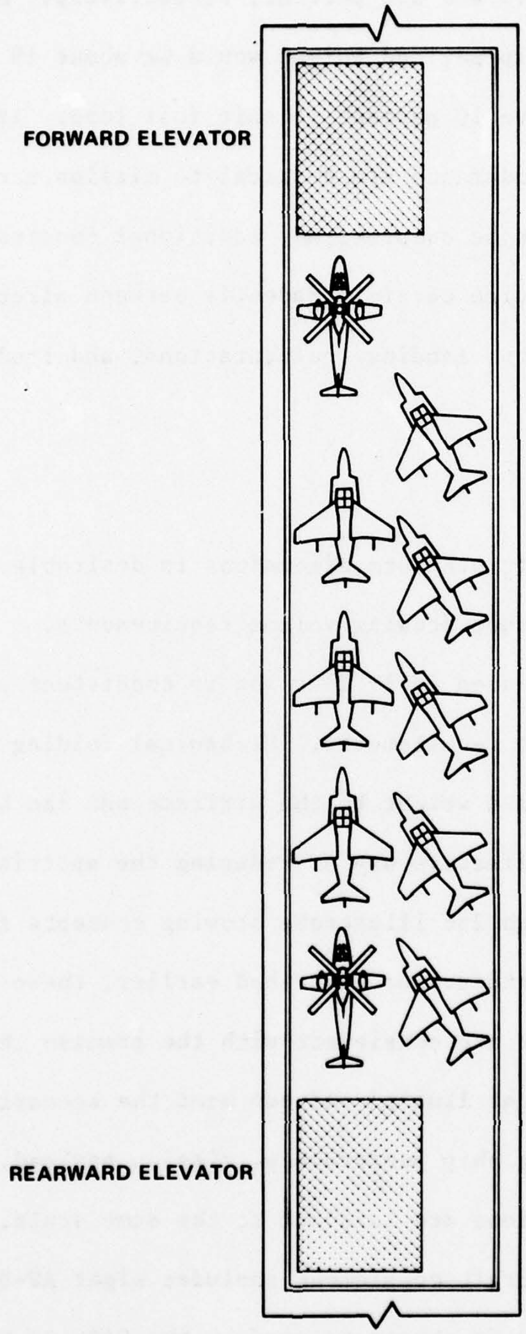


Figure 25a - Ship I

Figure 25 (Continued)

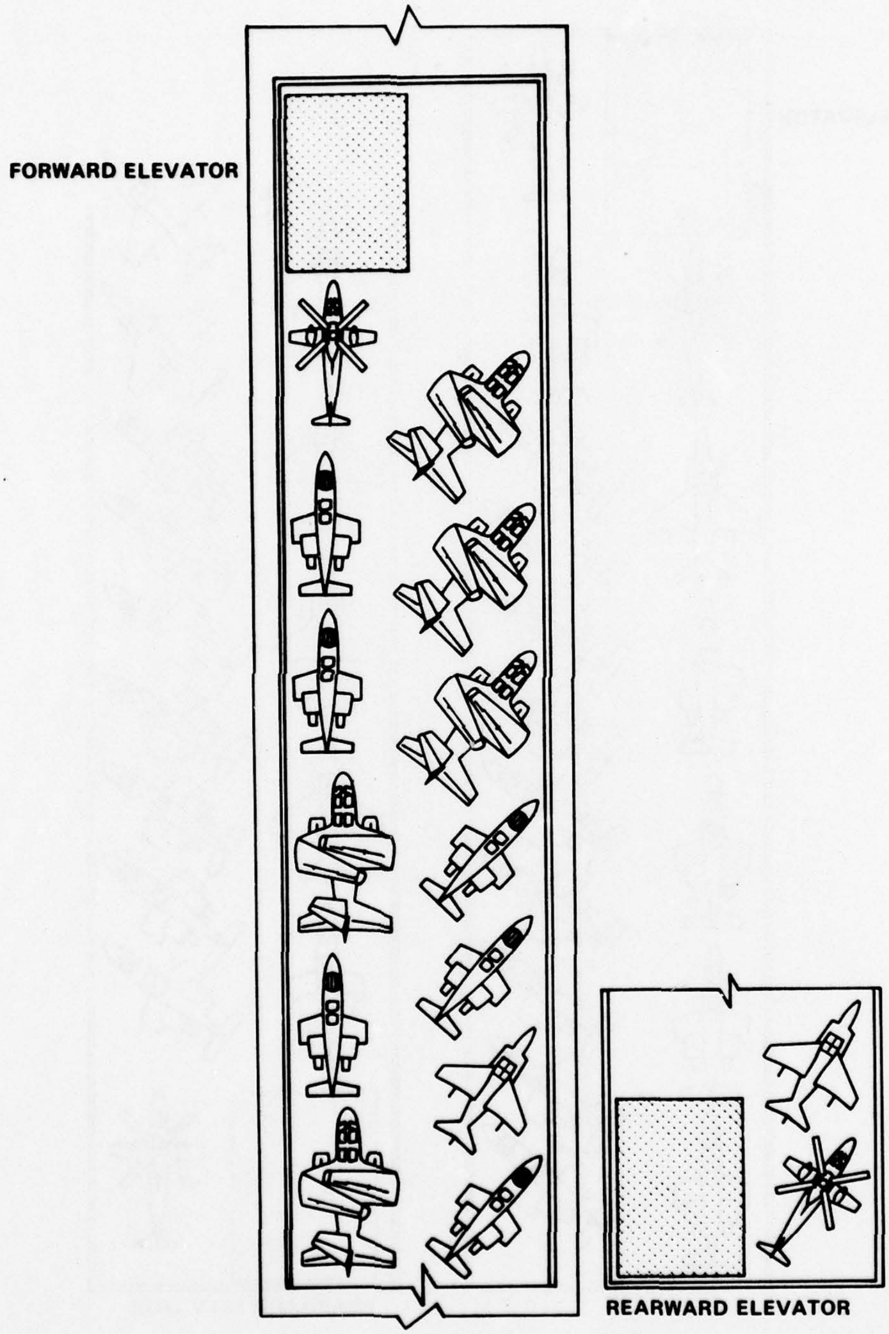


Figure 25b - Ship II

Figure 25 (Continued)

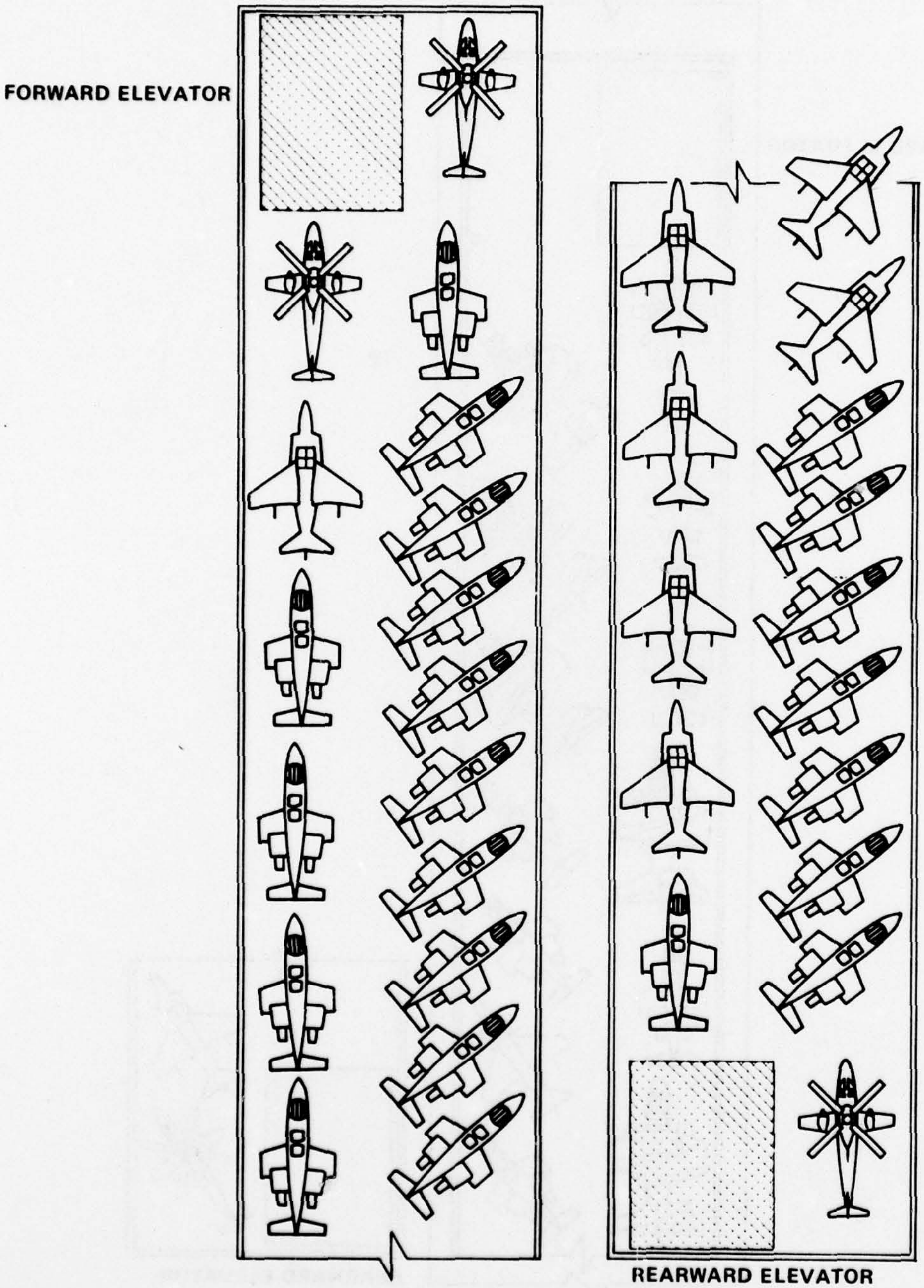


Figure 25c - Ship III

missions. The AV-8B has no folding capabilities. The TRAC rotor is shown reduced to minimum diameter. Quick turnaround of the combat aircraft for servicing and loading of weaponry was desirable. The stowing arrangement thus permits a through passage between elevators along one side of the hangar deck for these activities. The stowing arrangement of Ships II and III also reflect these considerations.

The aircraft complement of Ship II (illustrated in Figure 25b) consists of five ASW S-3A's, three SA L/C Fans, two SA AV-8B's, three AEW L/C Fans, and two utility TRAC helos. The foldability of the S-3A wings and vertical tail is illustrated. Stowed as shown, the five S-3A's require the space of eight L/C Fans. The wing tips of the SA L/C Fans are folded, which reduces the overall width of the aircraft to approximately 20 feet.

The aircraft complement of Ship III (illustrated in Figure 25c) consists of seven fighter AV-8B's, sixteen SA L/C Fans, three ASW L/C Fans, three surveillance L/C Fans, and three utility TRAC rotor aircraft. The wings of the SA L/C Fans are again folded.

Down-wash Characteristics

High values of down-wash velocities (100 knots) are potentially hazardous to personnel and to equipment. Temperatures associated with gas turbines may result in deterioration of landing pads and preflight areas. It was assumed that under high WOD operations:

1. The deck is clear of all personnel and equipment.
2. The high WOD will dissipate exhaust heat.

In addition, it was assumed that for conditions other than high WOD:

1. Adequate safety procedures are followed.
2. Dynamic pressure reducers are used to advantage.
3. Protective plates are provided under high temperature exhaust.

It should be noted that the AV-8A Harriers have accumulated thousands of takeoffs and landings at sea from a total of 21 different ships.

Down-wash characteristics may be more important in some mission applications than in shipboard operations. For example, low down-wash characteristics of the rotary wing, such as those characteristics offered by the TRAC rotor and the X-Wing VSTOL, are advantageous in search and rescue operations -- a consideration which could outweigh shipboard advantages.

Maintenance Requirements

The aircraft maintenance capability of the type of air-capable ships developed in this study may be limited because the ships are weight-limited designs. Therefore, only organizational maintenance is envisioned in the aviation maintenance system. Intermediate maintenance consisting of repair of aircraft components is not performed aboard ship. Aviation support associated with intermediate maintenance, including tools, special equipment, and trained personnel, is assumed to be maintained at the home base of the ships or to be available on other air-capable ships, for example, CVA's. This maintenance philosophy is consistent with the scenario profiles which require relatively low times at sea compared to present CVA endurance capabilities. Requirements, however, will still be influenced by the variety of aircraft types and quantities, and aircraft multimission capability may yield higher valued tradeoffs in terms of viable high-speed ship systems than are now anticipated in terms of aircraft life cycle costs. Aircraft availability will become more dependent on reliability and less dependent on maintenance and supply during sea going operations. Simplicity in aircraft design will become highly desirable, if not mandatory. Advanced VTOL or VSTOL aircraft are not expected to become as simple in design as their fixed-wing counterparts. Nevertheless, the relative complexity in configuration design may well decide the fate of candidate advanced aircraft concepts for high-speed ships. The anticipation of reduced on-board maintenance capability was one reason for eliminating the tilt-rotor VSTOL aircraft from consideration as a candidate for the high-speed ship concept at this time.

CONCLUSIONS

1. The high-speed SES-CV is a potentially feasible platform option offering increased flexibility in the Navy missions of sea control and projection of power ashore. Future operational scenarios foreseeing the use of the SES-CV must utilize ship speed capability and the resulting high WOD to enhance aircraft takeoff capability if viable systems are to be realized.

2. The ship/aircraft compatibility problems present in today's Navy are compounded in the weight- and volume-limited SES's of the high-speed ship/aircraft system concepts generated in this study. Primary concern is focused on the stowing and handling of aircraft and the aviation maintenance and supply requirements in order to maximize aircraft

complement. The number of ships utilized in the scenarios may be increased to significantly reduce ship aviation requirements, but the inclusion of procurement and life cycle costs as criterion in system design was beyond the scope of this study.

3. The potential benefits resulting from high WOD are the takeoff gross weight capabilities that would otherwise be lost due to reduced deck lengths of small air-capable ships relative to conventional carriers. Aircraft mission performance is directly related to takeoff gross weight capability.

4. The aerodynamic lift coefficient at takeoff has a significant influence on takeoff capability. Increasing the lift coefficient from 1.6 to 3.5 in the S-3A configuration (achieved by incorporating CCW) increased the takeoff gross weight potential by 20,000 pounds, or a 45-percent increase for the 400-foot run, 60-knot WOD condition. However, usable lift coefficients are constrained by aircraft attitude achievable at liftoff, minimum desired accelerations along the flight path after liftoff (induced drag is high), and airplane structural design limits.

5. Ship size is sensitive to operational requirements. In the scenarios postulated in this study, ship performance requirements sized the ships in which continued operations without replenishment exceeded three days; ship aviation requirements sized the ships in which continued operations without replenishment was two days. Thus, the system concepts operational requirements will become a design parameter in system design and must be carefully assessed.

6. The cost of vertical takeoff capability in aircraft configurations selected for their compatibility with the high-speed SES is reduced mission performance. The lift/cruise fan VSTOL aircraft types examined in this study were approximately 30 percent less effective in ASW screening operations than were the conventional S-3A aircraft at the same takeoff gross weight. The acceptability of this cost will depend on the firmness of the Navy's goals of flexibility of air operations at sea and dispersion of assets. Extended hover capability and down-wash requirements associated with specific missions such as plane guard and search and rescue outweigh other mission requirements; therefore, rotary wing-type VTOL aircraft remain strong candidates for these mission applications.

RECOMMENDATIONS

1. To ensure that the high-speed SES developing technology and the advanced aircraft configuration now proposed to satisfy future Navy needs are satisfactorily integrated in a viable high-speed ship/aircraft system concept, the aircraft technology should be developed along with the SES technology.

2. The investigation of aircraft landing and parking loads on flight and hangar deck structural design should continue. The sensitivity of ship size and displacement to deck structural weight should be examined, particularly in ship displacements below about 7000 long tons.

3. To improve the confidence in SES-CV structural weight fraction predictions, ongoing development of technology demonstrators and prototype

vehicles should be carefully monitored to establish trends in the weight distribution throughout the structural designs. With this information, improvements in the estimates of weight penalties due to aircraft loads should be made.

4. Efforts to reduce ship/aircraft compatibility problems should be continued. An ongoing assessment of the suitability of the aircraft in this study and other potential candidates, in air operations from proposed and developing SES-CV concepts, should be included in SES-CV development plans.

ACKNOWLEDGMENT

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