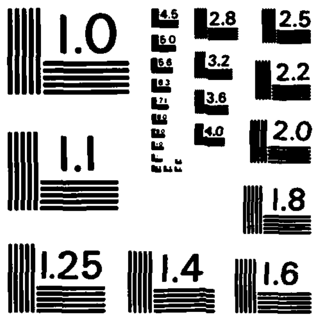
AD-A147 695 A STUDY OF SHIP BASED INFLIGHT REFUELING OF V/STOL AIRCRAFT(U) ROCKWELL INTERNATIONAL COLUMBUS OH NORTH AMERICAN AIRCRAFT OPERATIONS 07 APR 81 NR81H-18 1/2

UNCLASSIFIED N62269-81-C-0303 F/G 1/5 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

A STUDY OF

SHIP BASED INFLIGHT REFUELING

OF

V/STOL AIRCRAFT

FINAL REPORT

Rockwell International

Rockwell International

NR81H-18
7 April 1981

A STUDY OF SHIP BASED INFLIGHT REFUELING OF V/STOL AIRCRAFT

FINAL REPORT

Prepared for
Naval Air Development Center
Warminster, Pennsylvania

Contract No. N62269-81-C-0303

Rockwell International Corporation
North American Aviation Division
Columbus Plant
4300 East Fifth Avenue, PO Box 1259
Columbus, Ohio 43216

ABSTRACT

This report describes a study conducted by the North American Aircraft Division of the Rockwell International Corporation for the U.S. Navy under Contract N62269-81-C-0303. The objective of this study was to determine the feasibility of refueling V/STOL aircraft, including helicopters, by means of a ship-based refueling device which would circumvent the need for landing. Two alternative high fuel flow rate systems are projected through exploratory designs. Feasibility is indicated through analyses of solutions required to support and stablize the refueling device for engagement by V/STOL aircraft within the limits of available aircraft control power in a sea state 5 environment.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF TABLES

LIST OF DEFINITIONS

CAP	Combat Air Patrol
CIWS	Close-In Weapon System
DLI	Deck Launched Interceptor
DWL	Design Water Line
HIFR	Helicopter Inflight Refueling
H_Z	Hertz (Cycles per second)
IMA	Intermediate Maintenance Activity
MTBF	Mean Time Between Failure
NPRDC	Naval Personnel Research and Development Center
R/C	Rate of Climb
TACAN	Tactical Air Navigation
β	blade tip loss factor
C_t	thrust coefficient of rotor
$\Delta\Theta$	change in pitch
$\Delta\Theta_j$	change in thrust vector angle
$\dot{\Theta}$	pitch rate
ϕug	gust parameter (longitudinal)
ϕvg	gust parameter (lateral)
ϕwg	gust parameter (vertical)
ug	random gust velocity along the X body axis
vg	random gust velocity along the Y body axis
wg	random gust velocity along the Z body axis
σ_{u_g}	RMS intensity of random gust velocity - X axis
σ_{v_g}	RMS intensity of random gust velocity - Y axis

LIST OF DEFINITIONS (CONTINUED)

σ_{w_g}	RMS intensity of random gust velocity - Z axis
σ_{w_p}	RMS intensity of probe vertical velocity
$\ddot{h}$	Acceleration in Climb
$M_u\ 3\ u_g$	upsetting moment due to longitudinal gust velocity
$M_w\ 3\ W_g$	upsetting moment due to vertical gust velocity
L'_u	cross derivative scale for u_g
L'_w	cross derivative scale for w_g
L'_v	cross derivative scale for $3\sigma_{v_g}$
$L_\delta\ \delta_{A_{max}}$	total rolling moment available
M_v	pitching moment due to velocity along the Y axis
$M_{\delta_B}(\delta_B)_{AVG}$	average pitching moment available
N_u	normal force due to velocity along the X axis
N_w	normal force due to velocity along the Z axis
$N'_v\ 3\sigma_{v_g}$	control power required in yaw
$N_{\delta_p}\ \delta_p$	control power available in yaw
T_o	sea wave modal period
V_o	airspeed
ω	frequency (Radians per second)
u	velocity component along the X axis
w_p	vertical velocity of Refueling Probe
$Z_w\ 3\sigma_{wg}$	height control power required due to w_g
$Z_u\ 3\sigma_{u_g}$	height control power required due to u_g

1.0 INTRODUCTION, CONCLUSIONS AND SUMMARY

The ability of V/STOL aircraft to operate independently of large landing facilities is well recognized. Many of the new generation of Navy surface ships have facilities which will accommodate both V/STOL aircraft and helicopters. These auxiliary flight decks are generally small and the landing/takeoff operations can be hazardous, particularly under adverse sea and weather conditions.

The V/STOL aircraft's very low speed flight and hover capabilities provides good control for maneuvering in close proximity to surface ships and the potential for refueling from a hover. A device incorporating a drogue and fuel supply from the ship can provide a versatile refueling method if stabilized independently of ship and sea surface motion. This unique concept can provide a breakthrough in operational flexibility not possible with conventional (CTOL) aircraft. This ship to air fueling equipment (SAFE) concept eliminates the requirement to land for refueling and will make deck time available for priority functions, such as crew changes and reloading of expendables. The SAFE refueling system is not limited to air capable ships but can be installed on a variety of ships for dispersal throughout a task force.

1.1 STUDY PROGRAM

The study, described in this report, was conducted under the auspices of the Naval Air Development Center and monitored by NAVAIR 03 to determine:

a. The feasibility of maneuvering fixed wing V/STOL aircraft and helicopters into engagement with a stable refueling drogue at airspeeds ranging from 0 to 45 knots,

b. the feasibility of developing a ship based device designed to suspend a refueling drogue from a ship with the stability required to permit repeated engagements with safety, in sea conditions corresponding to sea state 5,

c. the tactical advantages of this ship based, inflight refueling equipment in support of fleet air missions, and

d. an implementation plan for further development of the concept and a suggested funding profile, should feasibility be indicated.

1.2 CONCLUSIONS FROM THE STUDY

The following conclusions are presented in the sequence in which they are supported by analyses described in subsequent sections of this report.

The feasibility of maneuvering contemporary and advanced fixed wing V/STOL aircraft, including the AV-8A and AV-8B, is supported by the comparison of the control power required to perform the drogue engagement in wind gusts accompanying sea state 5, and the control power available (Section 2.2.4). Preciseness of control or the ability of a naval aviator to engage a suspended drogue routinely has not been proved by this analysis and is considered to be beyond the scope of this study. Proof will require more extensive closed loop analysis and/or physical experiments which are recommended for further study.

The current visibility standards prescribed by MIL-STD-850B, Aircrew Station Vision Requirements for Military Aircraft, are adequate for safe engagement with a stable drogue suspended in close proximity to a surface ship (Section 2.2.2).

Feasibility is indicated for low risk development of a ship based inflight refueling device. Stabilization of a refueling drogue within limits required for V/STOL aircraft engagement is feasible in a sea state 5 environment. Limited design work was conducted only to the extent required to confirm feasibility. Two such exploratory designs are illustrated in Figures 1-1 and 1-2 as installed on the Spruance class (DD-963) destroyers. Figure 1-1 shows the option of mounting a refueling boom which is suspended and stabilized from the starboard side of the ship (described in Section 3.0). Figure 1-2 illustrates the installation of an alternative turbofan powered VTOL refueling module which suspends and stabilizes a refueling drogue from aloft (described in Section 4.0).

Tactical advantages have been described in which the effectiveness of Fleet Air Defense is extended, in a specific scenario, by means of ship based, inflight refueling capability (Appendix A, Confidential, under separate cover).

The ability to refuel airborne V/STOL aircraft deployed within a task force offers the following operational advantages.

a. Payload/range potentials of fixed wing V/STOL aircraft and helicopters including contemporary models can be increased.

b. Operations can be conducted with fewer aircraft assets available by extending time-on-station.

c. V/STOL aircraft can be refueled from ships which are not equipped with landing platforms, or where platform design would not accommodate the refueling aircraft.

d. Ship based refueling can be accomplished rapidly from ships which are fully occupied with their assigned helicopters.

e. Refueling from small ships can be safely accomplished in high sea states where landings would be hazardous.

f. V/STOL aircraft with low-fuel emergencies can refuel from small ships, independent of landing facilities.

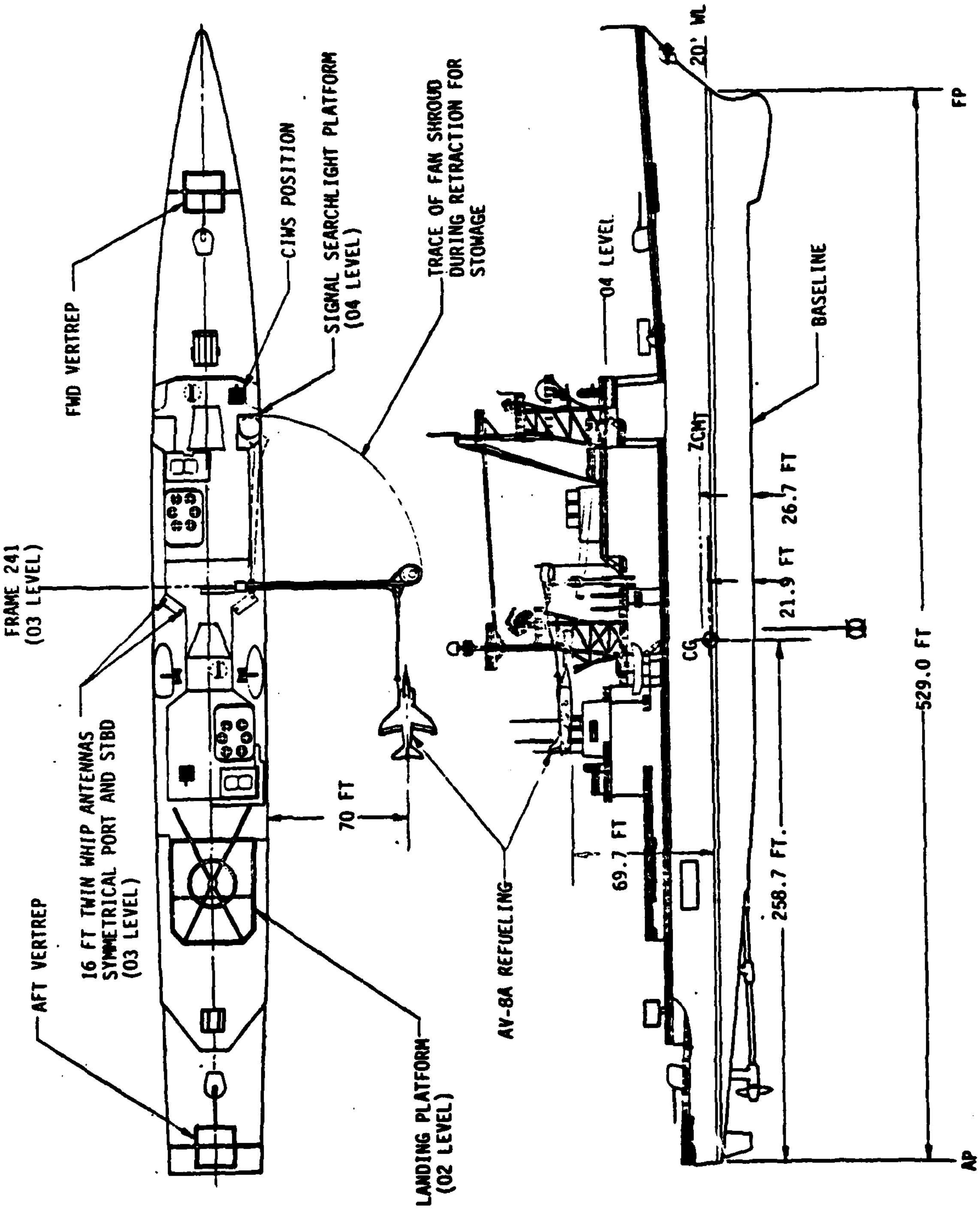


Figure 1-1 Suspended Refueling Boom System Installed on DD-963

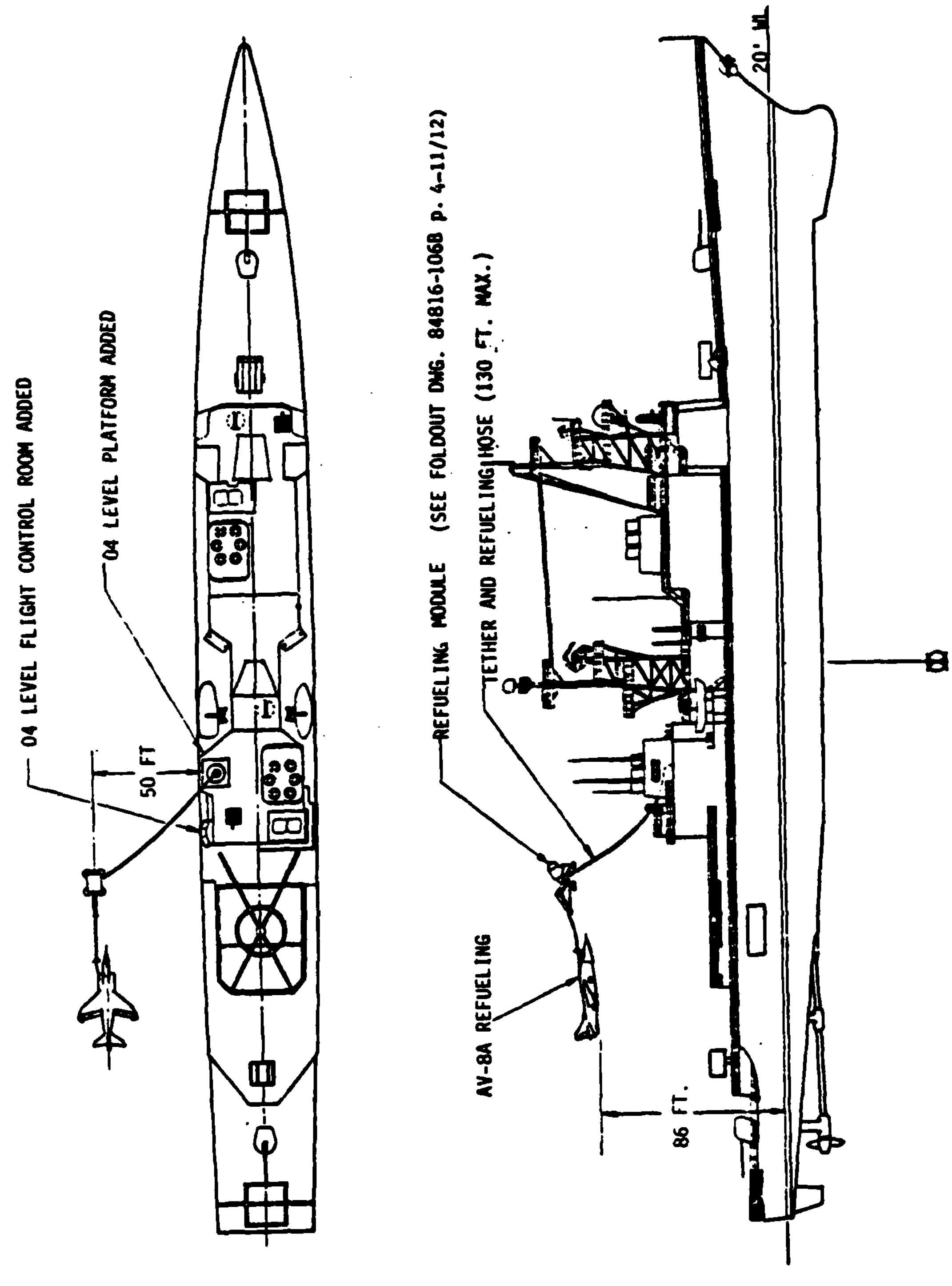


Figure 1-2 Airborne Refueling Module System Installed on DD-963

A comparison of the total life cycle (RDT&E, production, operations and support) costs to install 50 refueling systems and operate them for 20 years, at current money values, is described in Section 5.0. These estimated values are:

Suspended Refueling Boom System:	$129.6 M
Airborne Refueling Module System:	$279.2 M

The participants in this study believe that the suspended refueling boom system option offers a lower technical risk in achieving the desired sea state 5 refueling capability. Since the estimated total cost of the boom system is also less than half of the cost of the airborne module system, a development plan for the recommended boom system is contained in Section 5.0.

The report which follows this summary is arranged to initially describe the ship classes and aircraft sampled for the study. It then describes the analyses performed to determine feasibility of the aircraft to maneuver safely into engagement with a stationary refueling drogue, suspended over the sea surface. The details of suspension and stabilization of the drogue are thereafter described resulting in two technically viable options which were "filtered" from eleven candidate systems. The report concludes with comparative cost estimates of the two viable options and a development plan for the suspended refueling boom system.

THIS PAGE INTENTIONALLY LEFT BLANK

2.0 CANDIDATE SHIPS AND AIRCRAFT

2.1 CHARACTERISTICS OF CANDIDATE REFUELING SHIPS

Seven ship classes are selected as refueling base candidates for the study. These ship classes are illustrated in Figure 2-1 with selected characteristics. Each class is represented by the lead ship in the class with ship count shown in parentheses. For example, 26 Oliver Hazard Perry class frigates (FFG-7) have been ordered while construction of 33 more are projected by the Navy. Twelve of the Austin class ships (LPD-4) have been commissioned and construction has been completed. The LSD-41 class lead ship is now in contract negotiations with initial delivery to the Navy contemplated for late 1984. The contract design phase for LSD-41 was completed in 1979 and certain ship characteristics are now available.

Applications of the refueling devices studied in connection with these ships are not necessarily limited to the seven ship classes in Figure 2-1. The ship sample contains only air capable and amphibious aviation ships which are equipped with helicopter landing platforms and aircraft servicing facilities. The refueling devices described in this report would also be beneficial to fleet air V/STOL support if installed on ships other than those equipped for helicopters.

2.2 CHARACTERISTICS OF CANDIDATE V/STOL AIRCRAFT

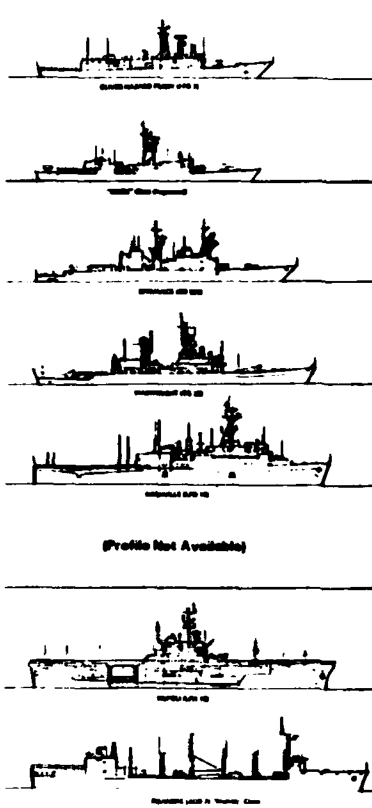
Six aircraft types were sampled for various phases of this study as shown in Figure 2-2. The contemporary AV-8A is of fundamental interest since characteristics of this aircraft are now well known and have been well documented. This forerunner fixed wing V/STOL aircraft displays certain low speed flying qualities which are considered to be in need of future refinement. Indeed the successor AV-8B is significantly improved in those undesirable aspects of the AV-8A which are compared subsequently in this section. Nevertheless the AV-8A was important to this study because if the feasibility of AV-8A refueling from a ship based device while in flight could be shown, then feasibility is also expected from the more advanced V/STOL aircraft to follow.

The SH-60B helicopter is now being readied for the LAMPS MK-III role as a successor to the SH-2 and is also of fundamental importance to this study since it is designed to operate from the candidate refueling ships. Aerodynamic characteristics of the SH-60B were not available for this study in sufficient detail to be included in the flying qualities analyses. The CH-53D, for which adequate data is available, was selected as a representative helicopter for analysis.

The NA-420 is a Rockwell exploratory design which is representative of a subsonic multimission V/STOL aircraft designed for the DD-963 class ships. In this study it is used as a dimension reference in sizing components of the suspended refueling boom concept.

The 141-005A is also a Rockwell exploratory V/STOL design which is representative of an advanced supersonic fighter intended for the DD-963

STUDY CANDIDATE SHIP CHARACTERISTICS



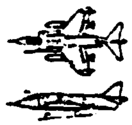
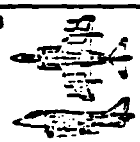
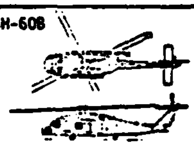
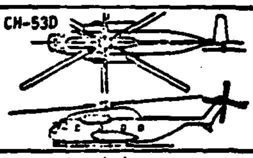
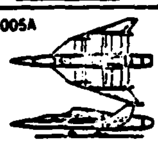
CLASS / LEAD SHIP	COMM.	DISPLACEMENT (LONG TONS) STD.	DISPLACEMENT (LONG TONS) FULL LOAD	LENGTH (FEET) OA	LENGTH (FEET) BP	BEAM (FEET)	DRAFT (NOMINAL) (FEET)	$\overline{GM}$ * (FEET)	ROLL PERIOD (SECS.)	BUILDER (LEAD SHIP)	MAX. SPD. (KNOTS)
FFG-7 PERRY (26 + 33)	17 Dec. '77	3521	3605	445	408	45.0	14.8/24.5 (Sonar Bulb)	4.1	8.97	BATH	29.0
FF-1052 KNOX (46)	12 Apr. '69	3011	3877	438	415	46.8	14.8/24.7	4.5	9.66	TODD	27.0
DD-963 SPRUANCE (31)	20 Sept. '75	5830	7810	563	529	55.1	18.4/29.0	4.8	11.41	INGALLS	33.0
CG-26 BELKNAP (9)	7 Nov. '64	6570	7900	547.6	524	54.8	18.8/28.8	5.6	9.65	BATH	32.5
LPD-4 AUSTIN (12)	6 Feb '65	10000	13900	570	548	84.0	23.0	9.1	13.1	N.Y.N.S.	21.0
LSD-41 (6?)	1984?	10876	15774	609		84.0	19.7	(N/A)	(N/A)	LOCKHEED	23.0
LPH-2 IWO JIMA (7)	26 Aug. '61	17000	18300	602	556	84.0	26.0	5.0	15.7	PUG. SND. N.S.	23.0
AOR-1 WICHITA (7)	7 June '69	12500 L.T.	37360	659	630	96.0	33.3	(N/A)	(N/A)	G.D. (QUINCY)	20.0

* TRANSVERSE METACENTRIC HEIGHT

Figure 2-1 Study Candidate Ship Characteristics

Rockwell International

STUDY CANDIDATE AIRCRAFT CHARACTERISTICS

AIRCRAFT	LENGTH (OVERALL) FT.	SPAN FT.	OWE LBS.	MAX. INTERNAL FUEL, LBS.	VTO WEIGHT LBS.
AV-8A 	45.55	25.27	12191	5161	17500
AV-8B 	46.33	30.33	12750	7500	19300
SH-60B 	64.80 ROTORS TURNING	53.70*	14720 (EST.)	4015	21884
CH-53D 	88.30 ROTORS TURNING	72.20*	24000 (EST.)	4270	42000
NA-420 	47.50	61.60	30272	15044	42230
141-005A 	54.70	33.00	19950	8433	29100

* ROTOR DIAMETER

Figure 2-2 Study Candidate Aircraft Characteristics

and superior class ships. Characteristics of this aircraft are used to represent advanced DLI and CAP aircraft for the fleet air defense analysis contained in Appendix A.

2.2.1 Refueling Probe Installation

The AV-8A is currently equipped with provisions for a flight refueling probe on the left hand upper inlet cowl (Figure 2-3). This installation was designed primarily for extending ferry mission range. The probe mast attachment to the fuselage structure is designed to breakaway if overloaded. In that event the probe remains latched to the refueling drogue and would be retrieved by the tanker aircraft. The breakaway fitting is equipped with a self-sealing check valve to prevent fuel loss if the probe mast separates. The probe is illuminated for night refueling from a source in the left wing leading edge.

Figure 2-4 tabulates the current USN and USAF design limit load requirements for aircraft refueling probe installations. A cursory analysis of external features of the existing AV-8A probe with assumed material properties indicates that the AV-8A design may not meet the radial force requirements of MIL-A-008865A. Suitability of the current design for refueling from the ship based concepts in this study has not been determined.

2.2.1.1 Proposed Refueling Probe for the SH-60B -- This helicopter has not yet entered service with the U.S. Navy and is not now equipped with a flight refueling probe. It is not known if a refueling probe is contemplated for this multimission helicopter. Figure 2-5 illustrates a refueling probe installation which is proposed as a result of this study. The probe location and size are guided by the following considerations:

1. The probe nozzle and drogue cone must always be visible to the pilot-in-command (RH seat) from the design normal eye position.

2. The probe mast must be of sufficient length to minimize air mass disturbances induced by the approaching main rotor stream tube upon the drogue cone (see discussion para. 3.6.2, page 36).

3. The mast length must be as short as possible, while satisfying the requirements of (1) and (2), resulting in a simple, lightweight installation with a minimum deck spotting penalty.

4. The mast must be co-located with radar and signal processing antennae to achieve minimum functional interference.

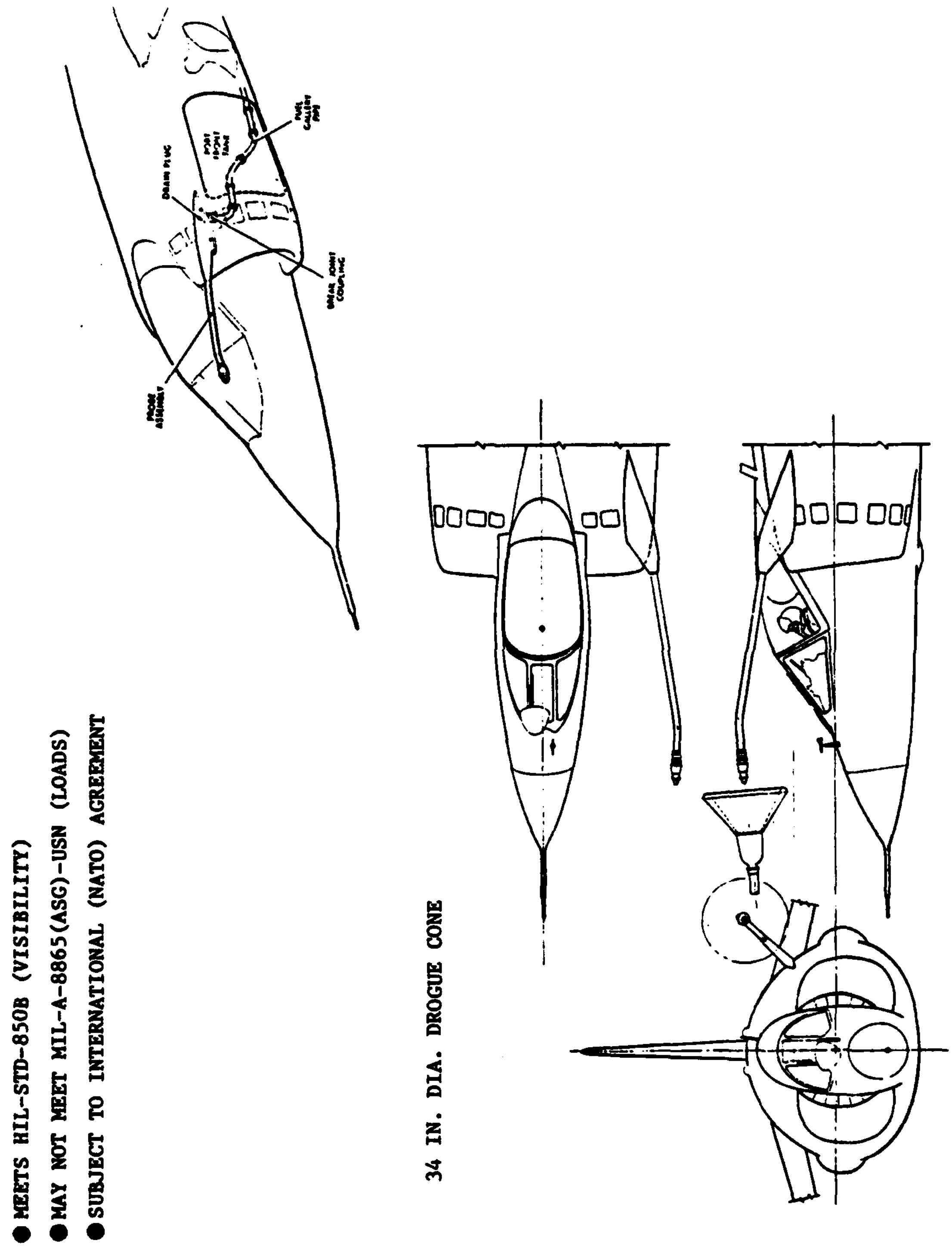


Figure 2-3 AV-8A Refueling Probe Installation

PROBE MAST LOADS LBS. - LIMIT / CONDITION	MIL-A-008865A (USAF): PROBE/DROGUE SYSTEM		MIL-A-008865A (USAF): BOOM ADAPTER SYSTEM		MIL-A-008865A (USAF) / MIL-A-8865 (ASG): DROGUE IMPACT	MIL-A-8865 (ASG): DISENGAGEMENT	
LONGITUDINAL FORCE - (F_L) COMPRESSION		-1330		-1330	-1130		
TENSION	670		670			800	800
RADIAL FORCE - (F_R) (ALL RADIAL DIRECTIONS)	670*	0	2000	0	0	0	500

* COVERS REQUIREMENT FOR 30 FPS GUST IN ANY RADIAL DIRECTION

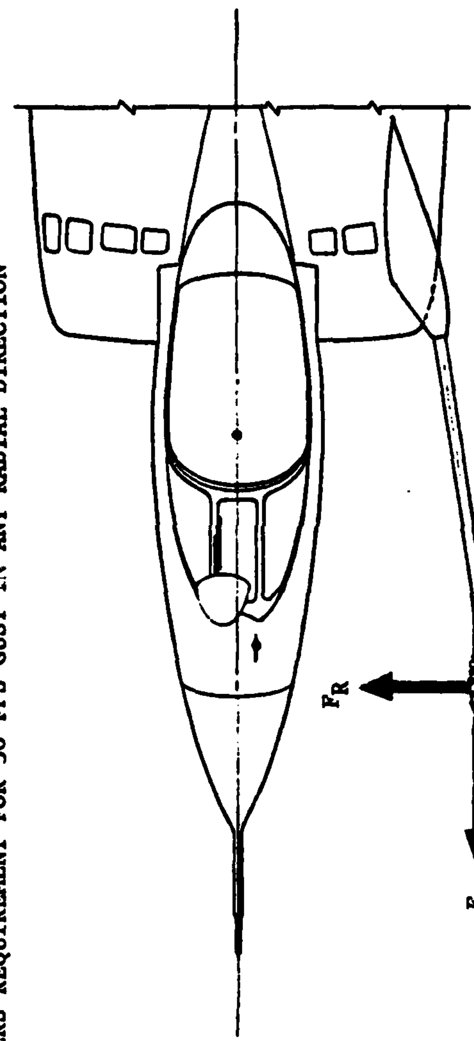


Figure 2-4 Probe Mast Design Load Requirements

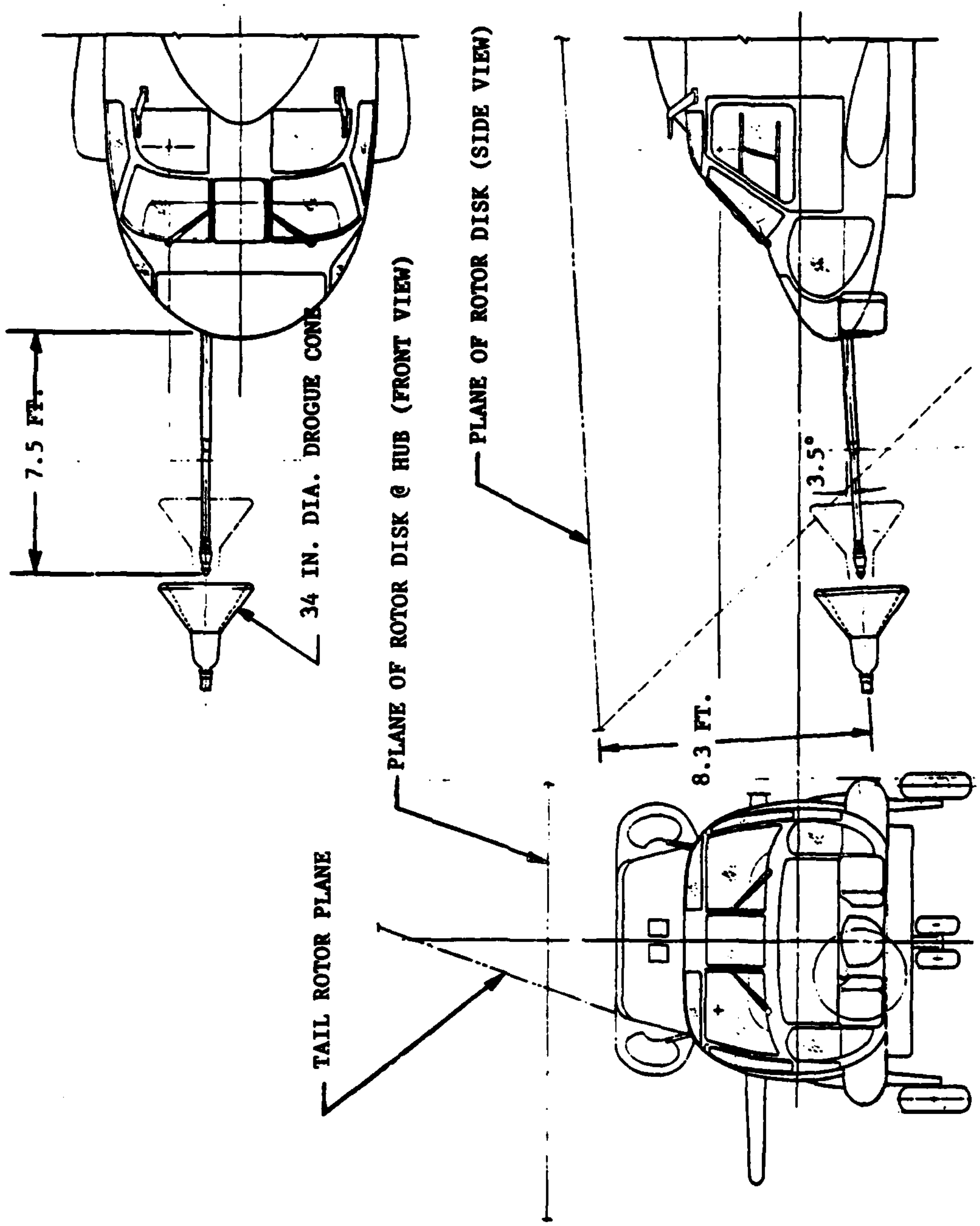


Figure 2-5 Proposed Refueling Probe Location for SH-60B

The probe layout recommended in Figure 2-5 will fulfill these four requirements in the shortest possible length (7.5 ft). It is attached to the cockpit floor structure and offset 1.0 feet to the right of the fuselage centerline. This structural attachment is between the ALQ-142 ESM and ARQ-44 Data Link antenna housings and their lower hemispheres including that of the APS-124 radar antenna.

2.2.2 SH-60B and AV-8A Visibility from the Cockpit

A rectangular visibility plot from the design eye position of the SH-60B is shown in Figure 2-6. The diagram is made in accordance with MIL-STD-850B for side-by-side helicopters. The drogue cone is shown as it would appear, two feet away from the probe, just prior to engagement.

Figure 2-7 illustrates the probe/drogue aspect from the design eye position of the AV-8A. The apparent obstruction of the view of the cone by the windshield frame is not, in reality, as obvious because of the benefits of binocular vision and head movements away from the design eye position which are not accounted for in the procedure.

2.2.2.1 AV-8B Visibility from the Cockpit - The geometry of the AV-8B production cockpit section was not available in sufficient detail to produce a visibility diagram. However, a comparison overlay of the AV-8B external contours with the AV-8A does indicate that visibility from the AV-8B cockpit may be improved over that of the AV-8A (Figure 2-8).

2.2.3 MIL-STD-850B Visibility Standards

A composite diagram of visibility standards for CTOL-single seat, helicopter side-side and helicopter tandem arrangements is illustrated in Figure 2-9. The current standards are adequate for safe engagement with a drogue suspended in close proximity to a surface ship.

2.2.4 V/STOL Aircraft Characteristics

The aircraft characteristics examined were those of the AV-8A, AV-8B and the Sikorsky CH-53D helicopter. Aircraft characteristics for the LAMPS III (SH-60B) were not available for analysis and by agreement with the Navy Program Manager, the CH-53D was chosen as a representative helicopter for analysis.

The AV-8A and AV-8B characteristics were obtained from References (k) through (m). Aerodynamic characteristics are similar for the AV-8A and AV-8B. Control power, however, is considerably improved about all axes for the AV-8B.

The CH-53D aerodynamic characteristics were obtained from Reference (o) in stability derivative form. Additional characteristics were obtained from Reference (p). It is noted that due to the unsymmetrical aerodynamic characteristics of the rotor disk, additional cross coupling derivatives occur due to perturbation translational velocity along each axis. This characteristic is typical of helicopters.

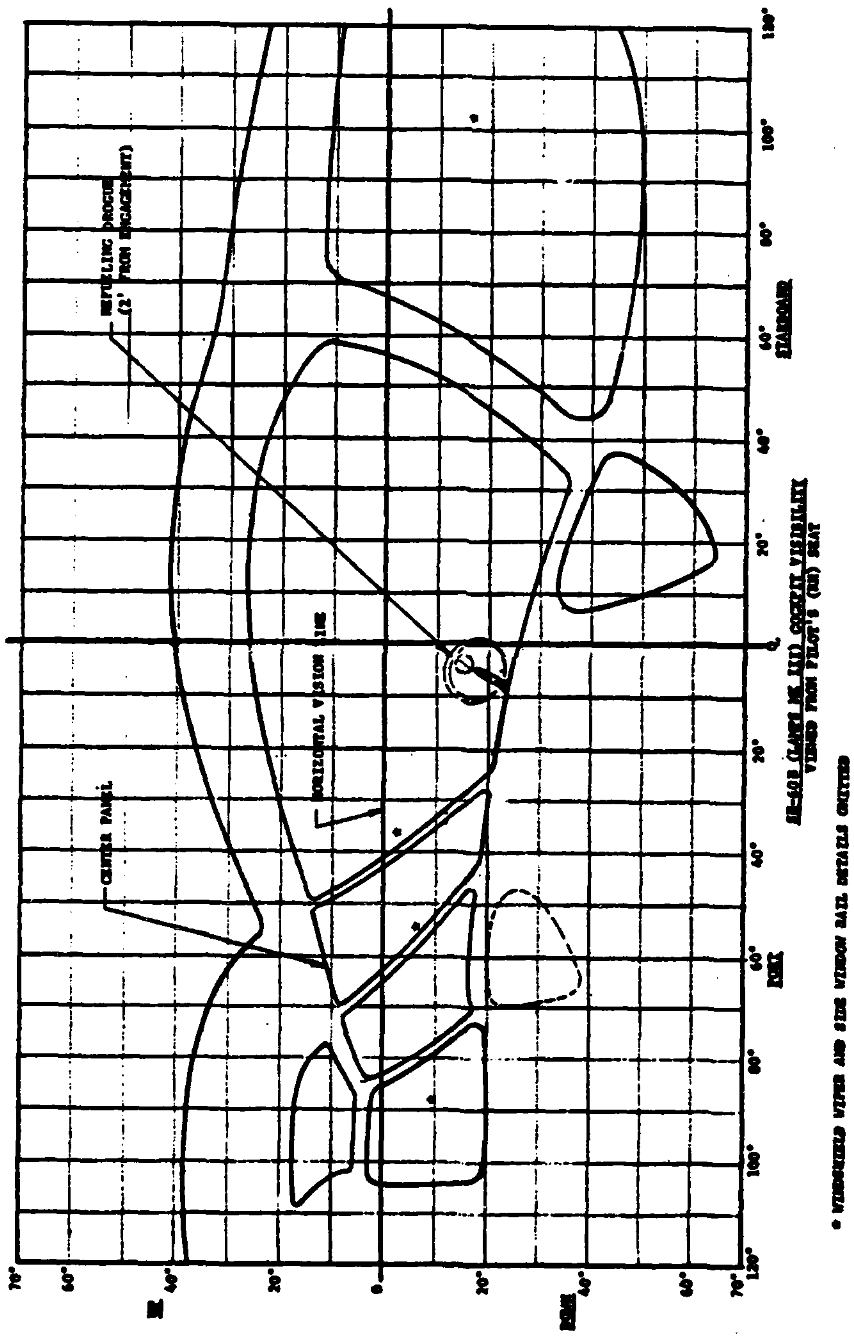


Figure 2-6 SH-60B Drogue Visibility

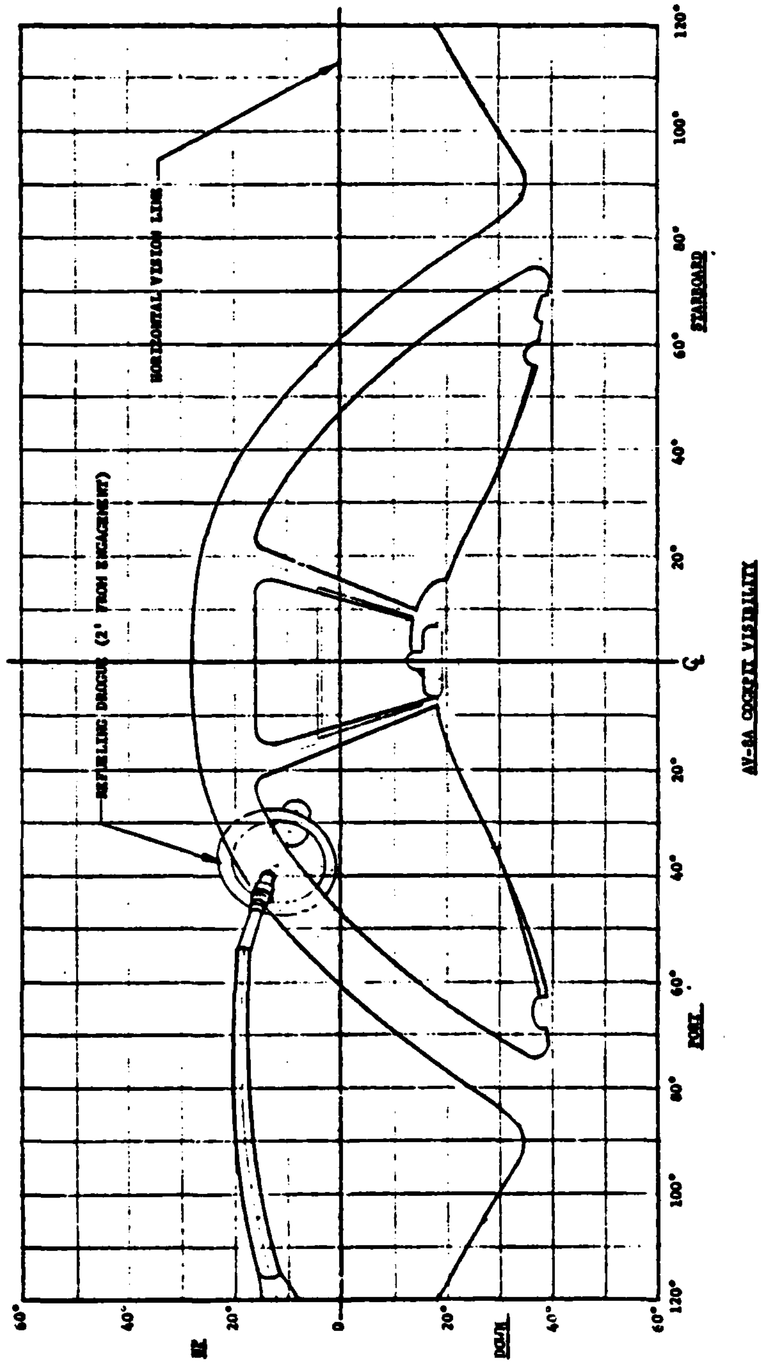


Figure 2-7 AV-8A Drogue Visibility

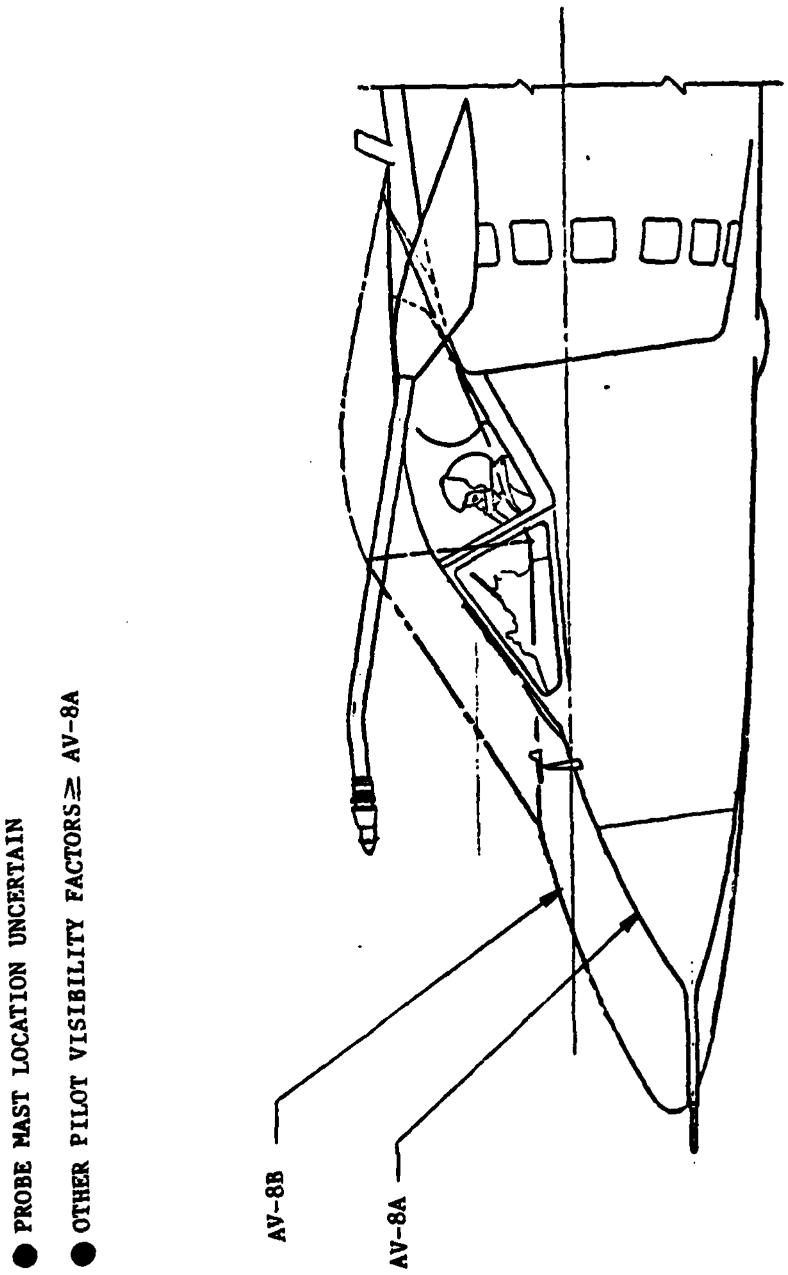


Figure 2-8 AV-8B Forward Fuselage Contours

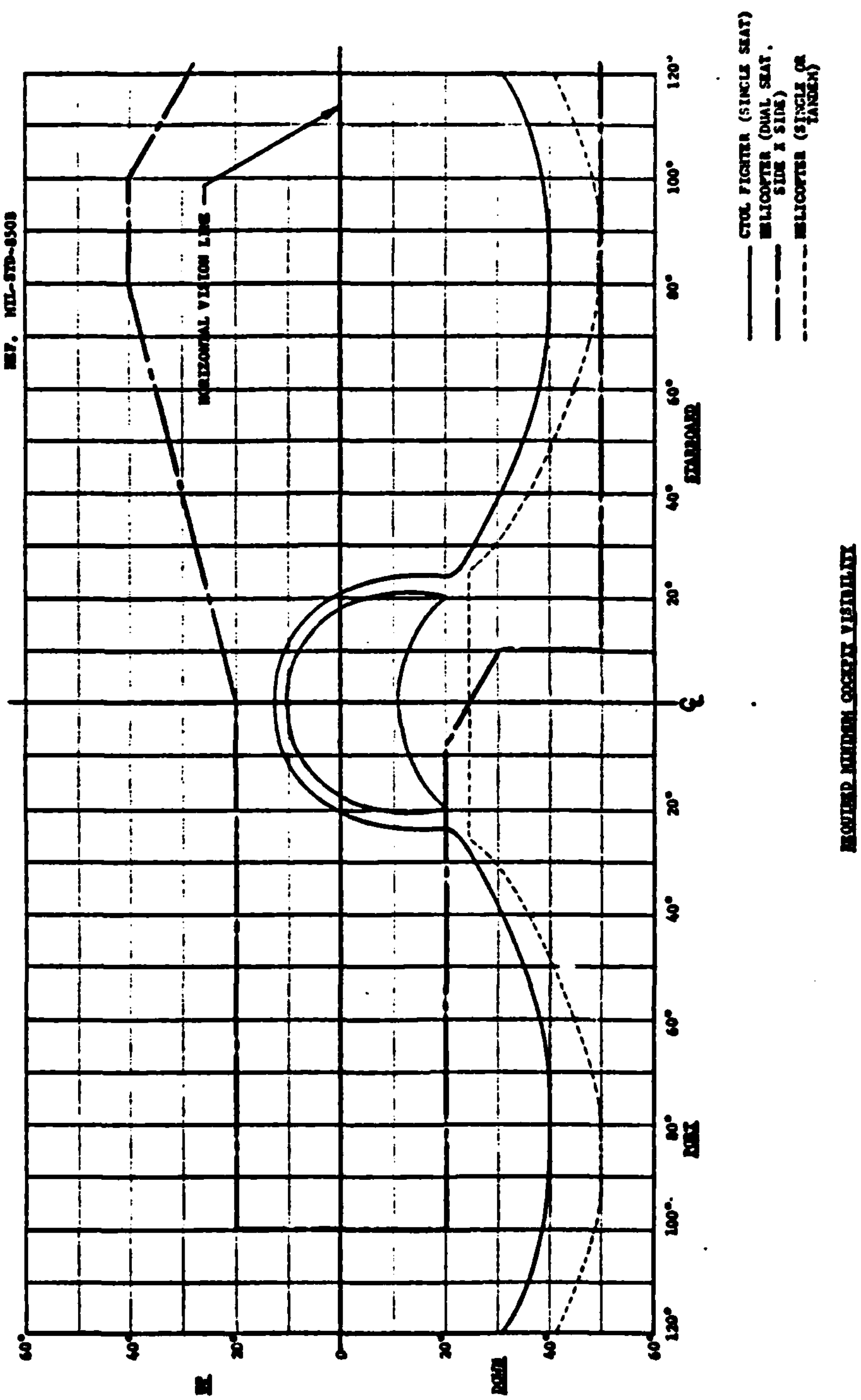


Figure 2-9 MIL-STD-850B Minimum Visibility Standards

The low speed flight environment was used with a maximum speed of approximately 52 knots set by a combination of wind and ship speed. Sea state 5 was assumed as the worst condition to operationally refuel at sea. An average steady wind of 22 knots was used for the sea state 5 condition. Maximum ship speed considered was 30 knots.

Location of the refueling drogue allows the aircraft to be essentially above the significant ship air wake for cross-wind (port) conditions. In addition, the aircraft were operating out of any significant ground (water) effects formed by the varying water surface. It was assumed that the free-air turbulence, i.e., independent of the ship, is the only disturbance encountered by the aircraft.

Avoidance of ship course changes required to accommodate refueling operations is a goal worthy of consideration. However, other constraints such as cockpit visibility for keeping the ship in view and minimum complexity of the refueling boom equipment are important. Therefore, it is assumed that ship heading change to maintain aircraft relative headings small, ± 20° (referenced to ship centerline) will be required (see Section 3.6 for further discussion). This permits zero aircraft sideslip since this simplifies the piloting task and is especially important in operation of the AV-8A aircraft due to control problems in sideslip conditions.

2.2.4.1 Proposed Procedure for Drogue Engagement and Maneuvering- It is assumed a normal approach to the ship can be made similar to carrier approaches using TACAN or other shipboard navigation equipment. When visual acquisition of the ship takes place, the pilot establishes station keeping at a point downwind of the drogue of approximately 90 feet horizontally and at the altitude of the drogue, as shown in Figure 2-10. The weather cocking feature of the drogue (see Section 3.4.3) can provide a sufficiently accurate cue for the pilot to set up his final line of approach to the drogue. When stabilized at the above point a pitch over or nozzle (AV-8A/B) vector change is made to produce approximately a 4-6 ft/sec (2.4 to 3.6 knots) closing velocity. As the drogue is approached, the pilot makes small corrections about all axes steering the aircraft by reference to the aircraft refueling probe and its relative position to the drogue. As contact with the drogue is made the aircraft is pitched up or nozzles vectored to resume the station keeping speed previously established. The last step described above must be briskly executed since a finite distance is required to decelerate and a limited fore and aft movement of the drogue permitted. After station keeping is established probe-drogue lock-on can be verified and if not achieved the aircraft must be backed off and the procedure repeated. The horizontal distance to decelerate back to the station keeping speed is shown in Figure 2-11 where the pitch angle or nozzle vector angle is assumed as a step. The amount of pitch angle to decelerate will, of course, be equal and opposite to the pitch angle used to produce the closing velocity which depends upon the aircraft.

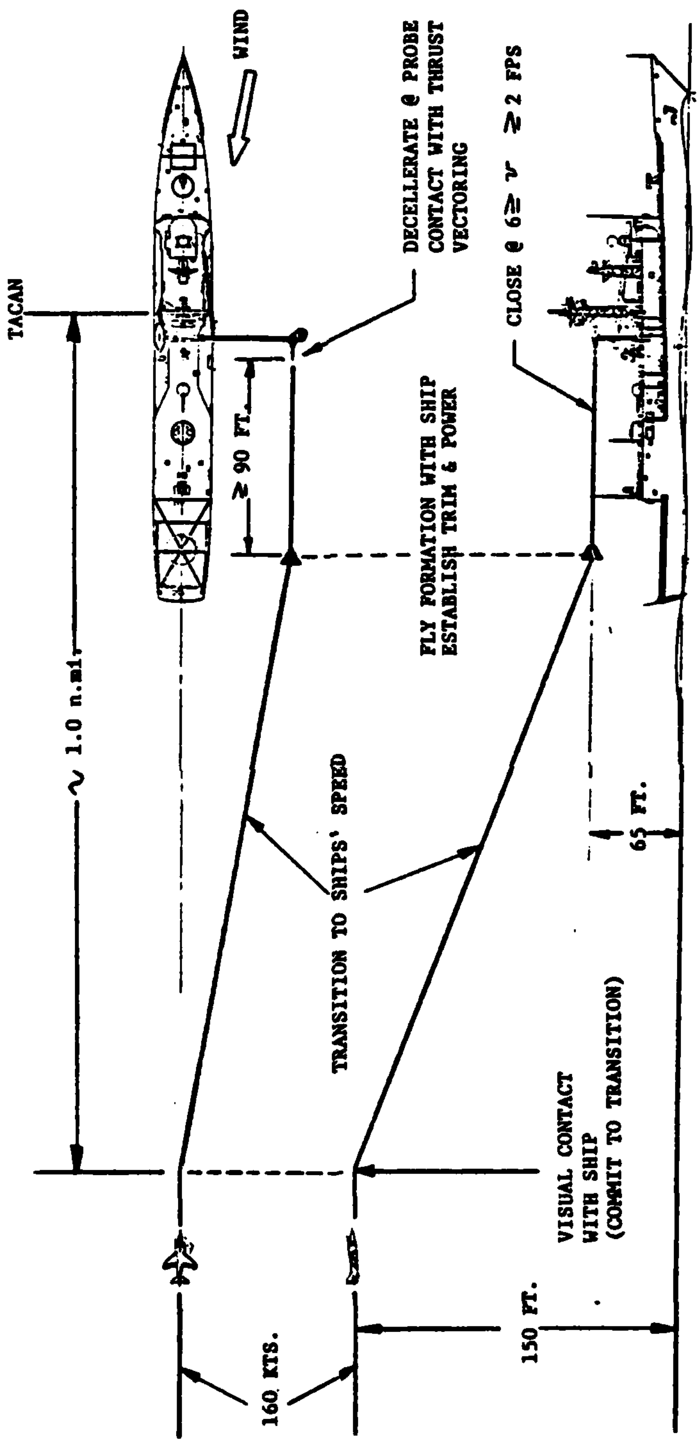


Figure 2-10 Drogue Approach Procedure

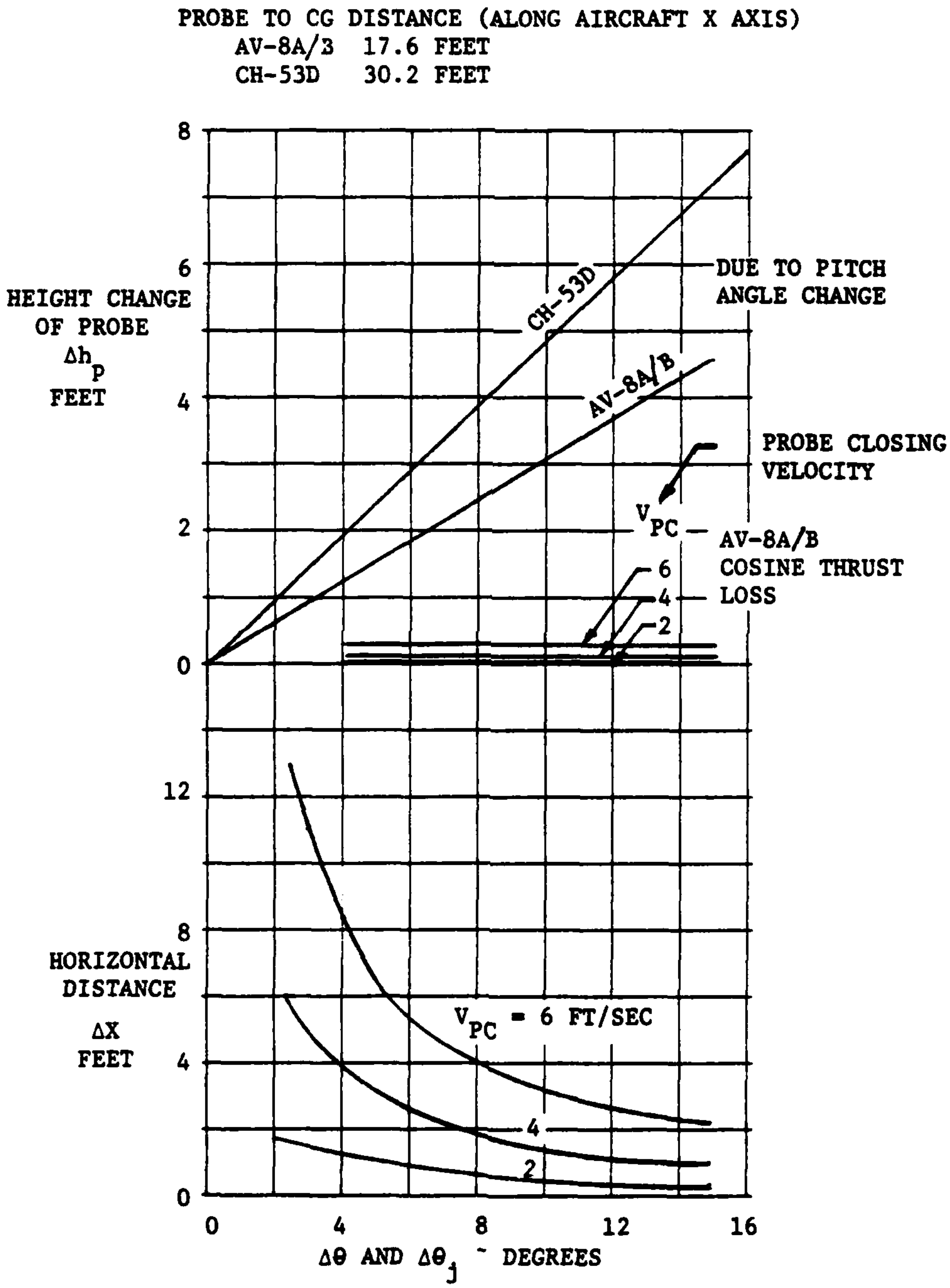


Figure 2-11 Deceleration Maneuver Characteristics

For V/STOL aircraft such as the AV-8A/B which are capable of vectoring thrust independent of aircraft attitude, a constant pitch angle can be maintained during the entire refueling procedure. However, for aircraft such as the CH-53D helicopter which must control forward speed by pitch angle, vertical movement of the probe tip will be substantial as shown in Figure 2-11 and is due to the long distance between the probe and the aircraft CG. For the helicopter case when forward speeds change the pitch angle and rotor lift also change (effective lift curve slope) and will require collective stick control corrections to reduce vertical excursions.

Figure 2-11 also shows the probe height change due to pitching of the AV-8A/B if that method of speed control were to be used. Since the thrust vector (lifting force) for the AV-8A/B is relatively uncoupled from the lifting surfaces, additional altitude change takes place due to rotation of the thrust vector given by

$$\Delta \text{Lift} = \text{Thrust } \text{Cos}\Delta\theta$$

where $\Delta\theta$ is due to pitch angle or nozzle change. As can be seen in Figure 2-11 the loss in altitude due to thrust component decrease is relatively small. Therefore, use of thrust nozzle vectoring for the AV-8A/B should produce minimum vertical displacement of the probe and simplify the refueling hook-up procedure.

It is noted that the most forward nozzle angle for the AV-8A and the AV-8B is 98.5°. Since low speed hovering utilizes nozzle angles of 81°, sufficient forward nozzle is available for deceleration of the AV-8A/B. Deceleration of the CH-53D helicopter will require a pitch-up and will therefore require vertical and horizontal deflection provisions in the drogue suspension.

Important considerations in location of the refueling drogue involve minimizing the effects of ship turbulence, ship stack gases and ground effect on the aircraft.

Ship turbulence includes wind-over-deck decrements and shedding of large vortices from bluff shapes on the ship superstructure. Relative winds beyond 30° off the ship centerline cause the turbulence to spread out and in addition, a down draft is created on the leeward side of the ship. Avoidance of stack gases from the ship are important since the aircraft engine performance decreases rapidly due to ingestion of higher temperature air. The stack gases can also be entrained by the downdrafts mentioned above. At the altitude of the refueling drogue the turbulence consists of smaller vortices since the superstructure elements are smaller.

For refueling operations it is assumed that ship headings will be chosen to produce wind vectors off the bow within limits set by ship wake avoidance and aircraft visibility from the cockpit as described in Section 3.6.1. The aircraft environment then consists of only free air turbulence. The random free air characteristics used are taken from MIL-F-8785C which is the flying qualities specification that is replacing MIL-F-8785B.

The MIL-F-8785C specification includes a description of random free air turbulence spectra that apply to low altitudes for carrier based aircraft. The u component is aligned with the wind-over-deck or in this case the aircraft velocity vector. The velocity components spectra which are independent of the aircraft relative position are shown below as a function of temporal frequency and aircraft velocity.

$$\Phi w_g(\omega) = \frac{71.6/Vo}{1 + (100 \frac{\omega}{Vo})^2}$$ Vertical velocity spectrum

$$\Phi U_g(\omega) = \frac{200/Vo}{1 + (100 \frac{\omega}{Vo})^2}$$ Horizontal velocity spectrum (aligned with aircraft velocity vector)

$$\Phi V_g(\omega) = \frac{5900\ [1 + (400 \frac{\omega}{Vo})^2]/Vo}{[1 + (1000)\frac{\omega}{Vo}^2][1 + (\frac{400}{3}\frac{\omega}{Vo})^2]}$$ lateral velocity spectrum

The spectra versus temporal frequency are plotted as shown in Figures 2-12 to 2-14. The corresponding root-mean-square gust velocity obtained by integrating the area under the curve of each of the above power spectra are also shown in Figures 2-12 to 2-14. Only lower frequencies (below approximately 3 rad/sec) produce any significant disturbance velocities. At the higher airspeeds the gust power is shifted slightly to the higher frequencies as indicated.

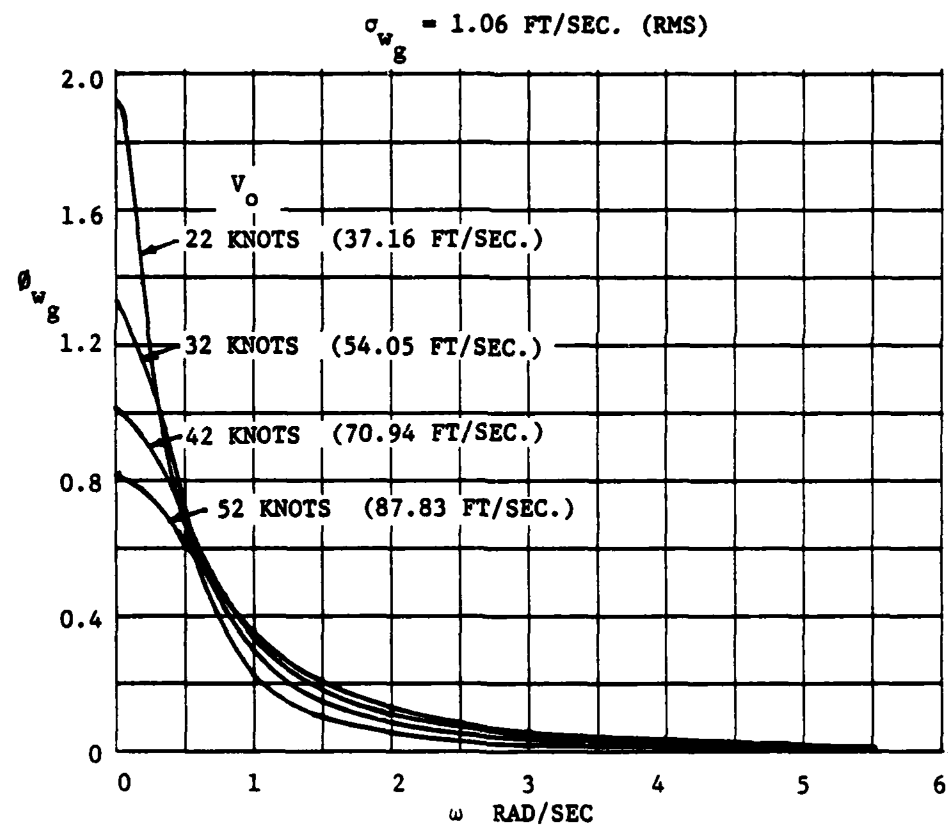


Figure 2-12 Random Free-Air Turbulence Vertical Gust Velocity Spectrum

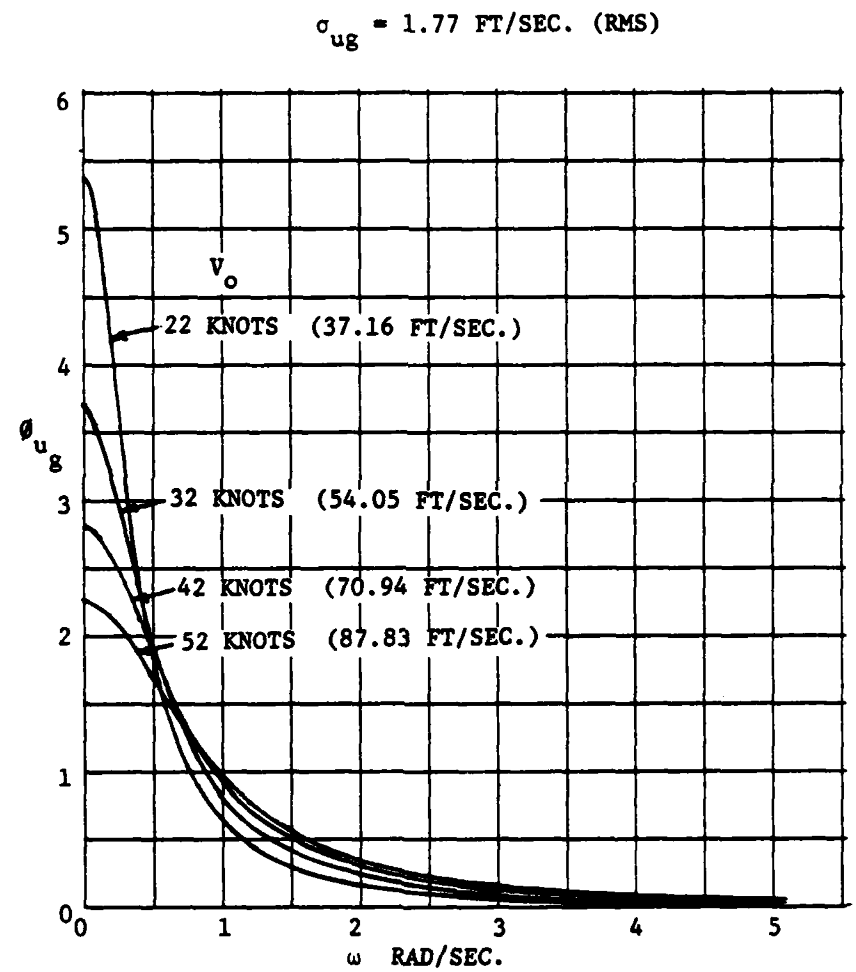


Figure 2-13 Random Free-Air Turbulence Horizontal Gust Velocity Spectrum

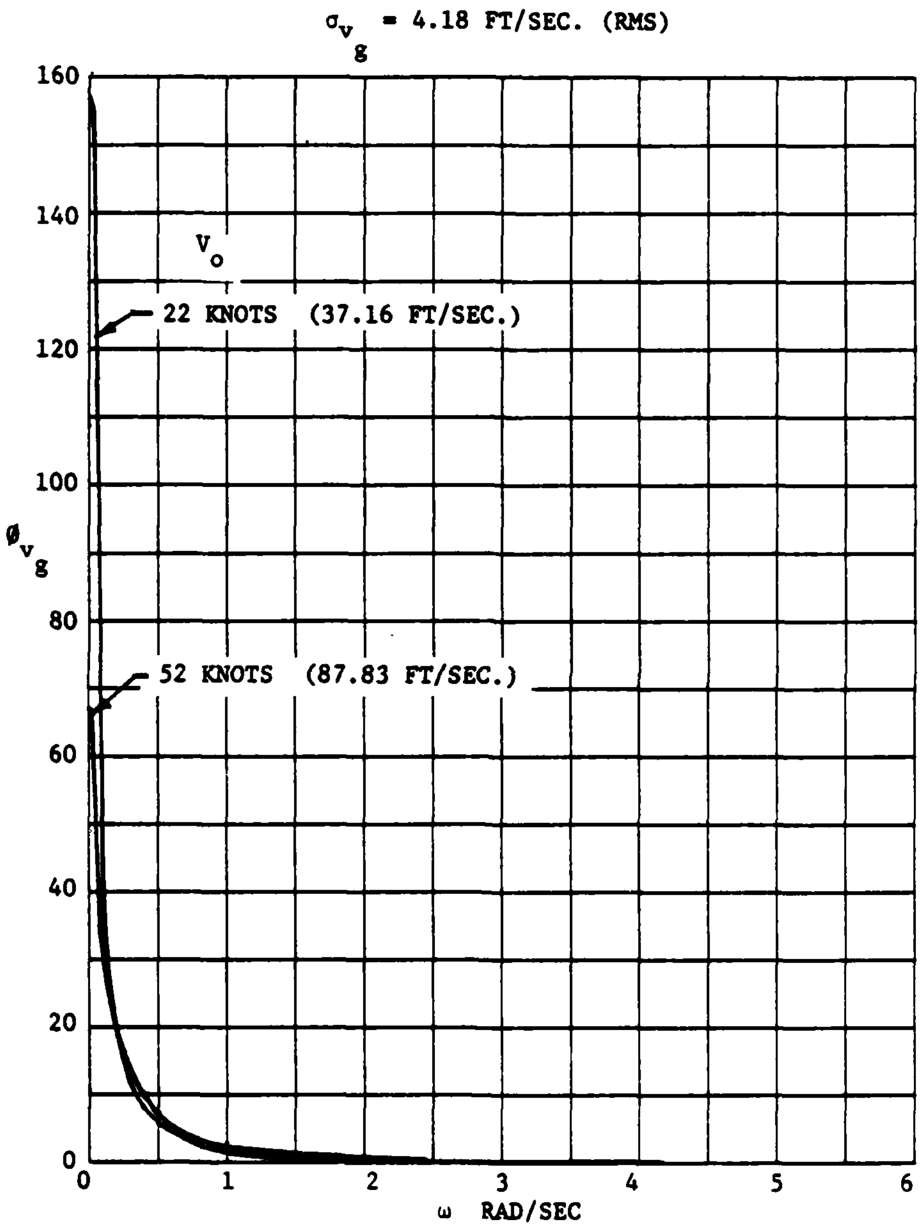


Figure 2-14 Random Free-Air Turbulence Lateral Gust Velocity Spectrum

Ground effects on V/STOL aircraft generally produce upsetting moments and forces as a function of aircraft height above the ground plane. For the case of V/STOL aircraft over water in a sea-state 5 condition, the shape of the sea surface is constantly changing and the local mean water boundary varies relative to the aircraft. In addition, propulsive flow effects from the aircraft can produce interactions on the sea surface which produces surface cavities and generation of water spray which in turn influences the ground effects on the aircraft. For the AV-8A/B aircraft jet velocities are high and concentrated in four jet plumes, and "ground effect" (favorable or unfavorable) would be expected to be pronounced. Much lower velocities occur for helicopters due to their relatively low disk loadings and a less pronounced ground effect occurs. It should be mentioned, however, that little is known of ground effect over water for V/STOL aircraft.

Since the undulating sea surface is expected to produce unwanted effects on V/STOL aircraft it is imperative that refueling operations be carried out above significant ground effects that disturb the aircraft flight path or attitude or reduce visibility. Ground effect on lift for the TAV-8B is shown in Figure 2-15 and was taken from Reference (l). The data in Figure 2-15 should be applicable to the AV-8B and indicates that strong variations in the ground effect begins at altitudes below approximately 15 feet. This is similar to flight experience for the AV-8A described in Reference (k) in which it is stated that ground effects are felt at 15 feet altitude. Therefore, at the planned altitude of the refueling drogue the AV-8A/B aircraft are expected to operate out of significant ground effects.

Using the method of Reference (q) the jet velocities at a distance of 44 feet (distance from AV-8A nozzles to sea surface) were computed for the front (cold) nozzles and rear (hot) nozzles. The jet velocities at the water are given below:

NOZZLE	VELOCITY AT NOZZLE FT/SEC.	VELOCITY AT 44 FT FT/SEC.
Front	1182	91
Rear	1773	163

The significant reduction in jet velocities, as shown in the above table, should reduce water spray effects at the refueling altitude in conjunction with the use of forward speed.

Ground effects for the CH-53D helicopter were not available. However, ground effects are less pronounced due to the low disk loading of rotors compared to high velocity jets. Therefore, at refueling height, ground effects are estimated to be negligible for helicopters.

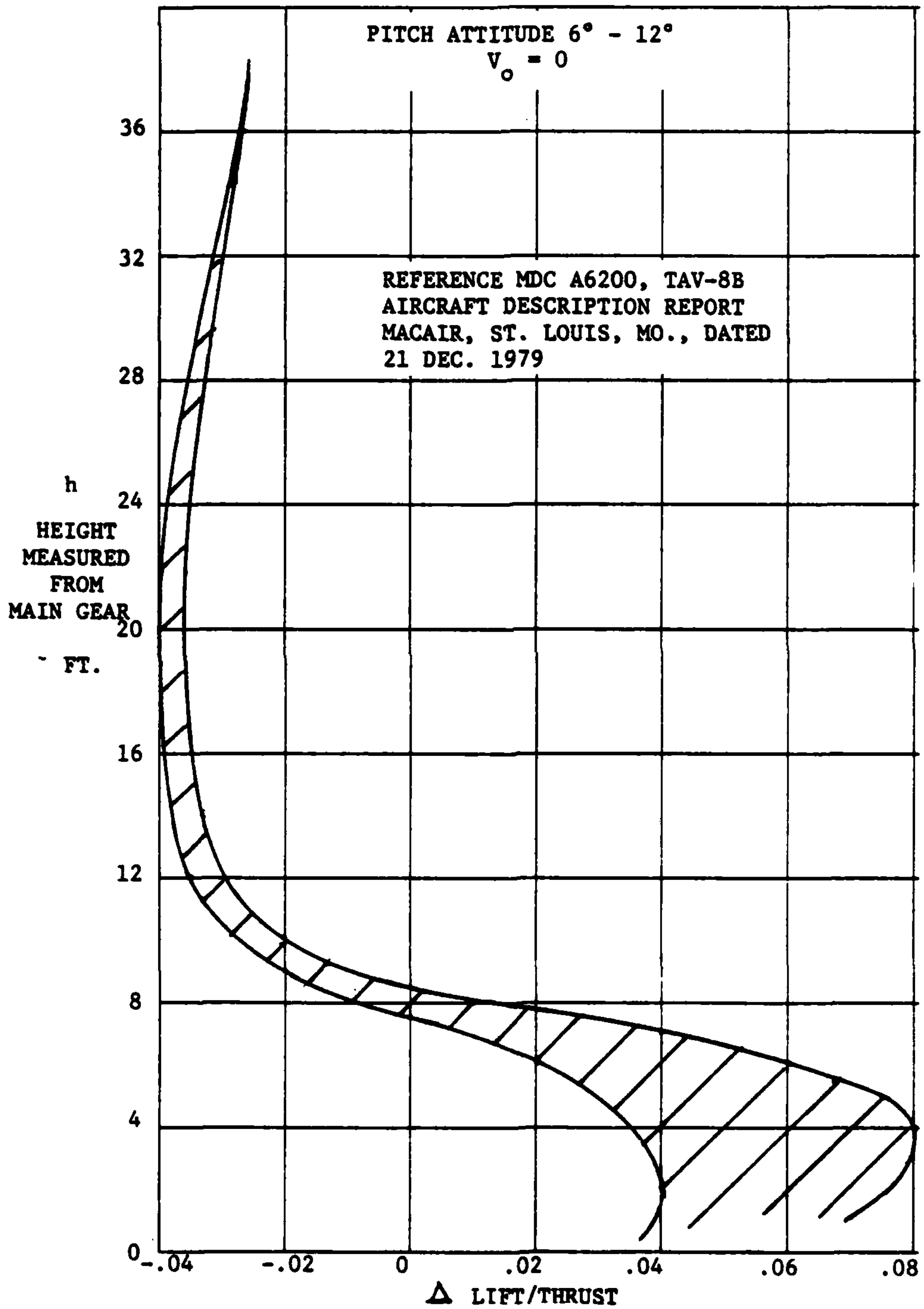


Figure 2-15 TAV-8B Ground Effect On Lift

2.2.4.2 Turbulence Effects On Aircraft and Low Speed Aircraft Response - Using the free air turbulence described earlier, the effects of a peak gust were compared to control power available for each of the three axes of each aircraft. The peak gust, in each direction, was determined from statistics of the turbulence to be approximately three times the root-mean-square value of the turbulence velocity, $3\sigma g$.

Aircraft angular acceleration due to the peak turbulence velocities were compared to the total control acceleration available for a particular axis and are shown in Figures 2-16 to 2-18 for the AV-8A and AV-8B. It is shown that the upsetting accelerations due to (M_w $3\sigma w_g$ and M_u $3\sigma u_g$ in Figure 2-16, for example) are generally small relative to the maximum control power available. Since the free air turbulence velocity components (W_g, U_g, u_g) occur randomly the most meaningful comparison for the AV-8A is with the simultaneous demand control (common bleed air source) shown in Figures 2-16 to 2-18. Similar values of simultaneous demand were not available for the AV-8B but it can be inferred that since control with single axis demand for the AV-8B is greater than the AV-8A, in each axis, control for simultaneous demand is also greater.

Figure 2-19 compares the peak turbulence velocity upsets on lift to the height control power available at several lift ratings for the AV-8A and B. It is not implied that the peak turbulence disturbance would require an immediate counteracting height control input. Actual height control input would depend upon the net altitude change due to the combined effects of random aircraft attitude changes and direct effects on lift (up and down) resulting from the turbulence. The comparison shown in Figure 2-19 is simply to put the relative magnitudes of turbulence effects on the aircraft in perspective.

The control power and peak turbulence effects for the CH-53 are shown in Figure 2-20 to 2-22. It is noted that the unsymmetrical nature of the rotor disk loadings causes a gust velocity in any given axis which will induce accelerations in all cross axes as well (i.e., cross derivatives such as M_v, L_u', L_w', N_u and N_w exist). The CH-53D helicopter data show, however, that the direct derivatives shown in Figures 2-20 to 2-22 are always larger than the cross-derivatives.

The vertical accelerations due to the peak gusts are shown in Figure 2-23. Height control power could not be shown since maximum values could not be determined from the available data. Height control sensitivity was available and is shown in Figure 2-24 along with the vertical rate of climb data. It can be inferred from these data that adequate height control for the CH-53D helicopter exists relative to vertical upsets from peak gusts.

The RMS (root-mean-squre) vertical velocities of the refueling probe due to continuous turbulence is shown in Figure 2-25 for the AV-8A/B and CH-53D. The RMS values were calculated by integrating the spectrums of Figure 2-28 which were obtained by combining the aircraft longitudinal transfer function (in terms of vertical velocity of the probe) with the

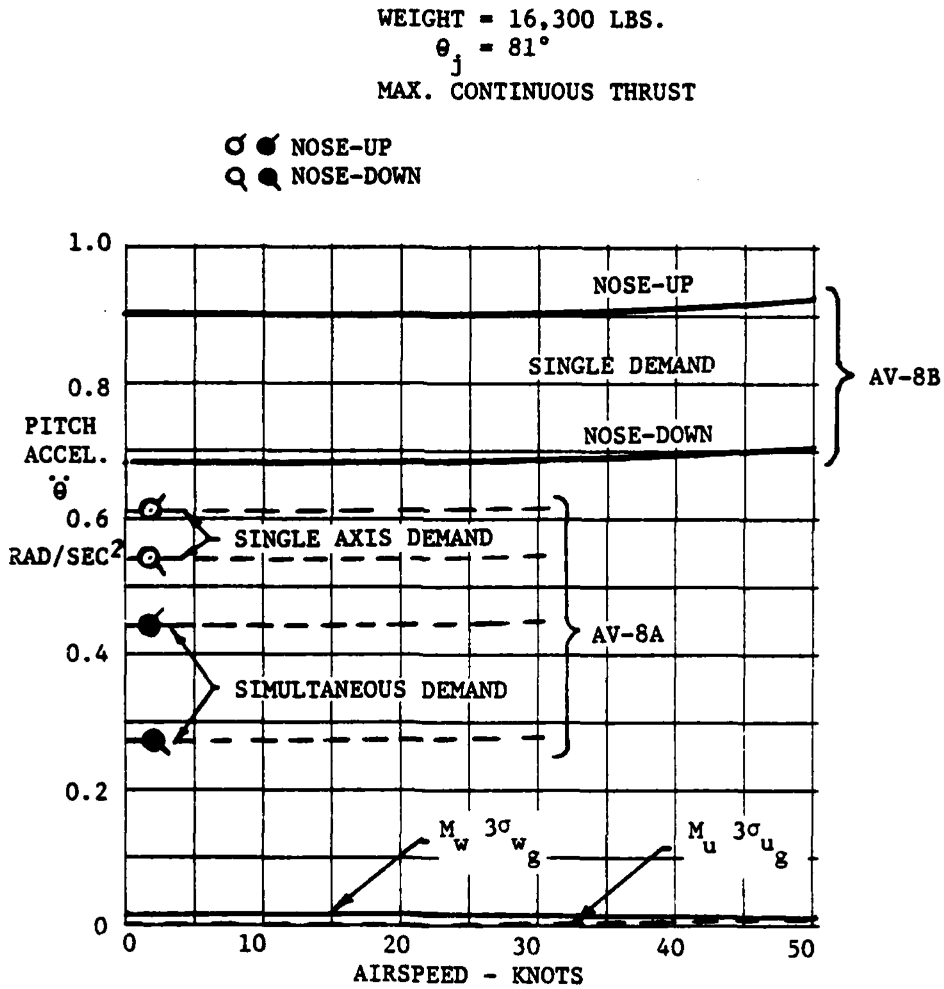


Figure 2-16 AV-8A and AV-8B Control Power in Pitch

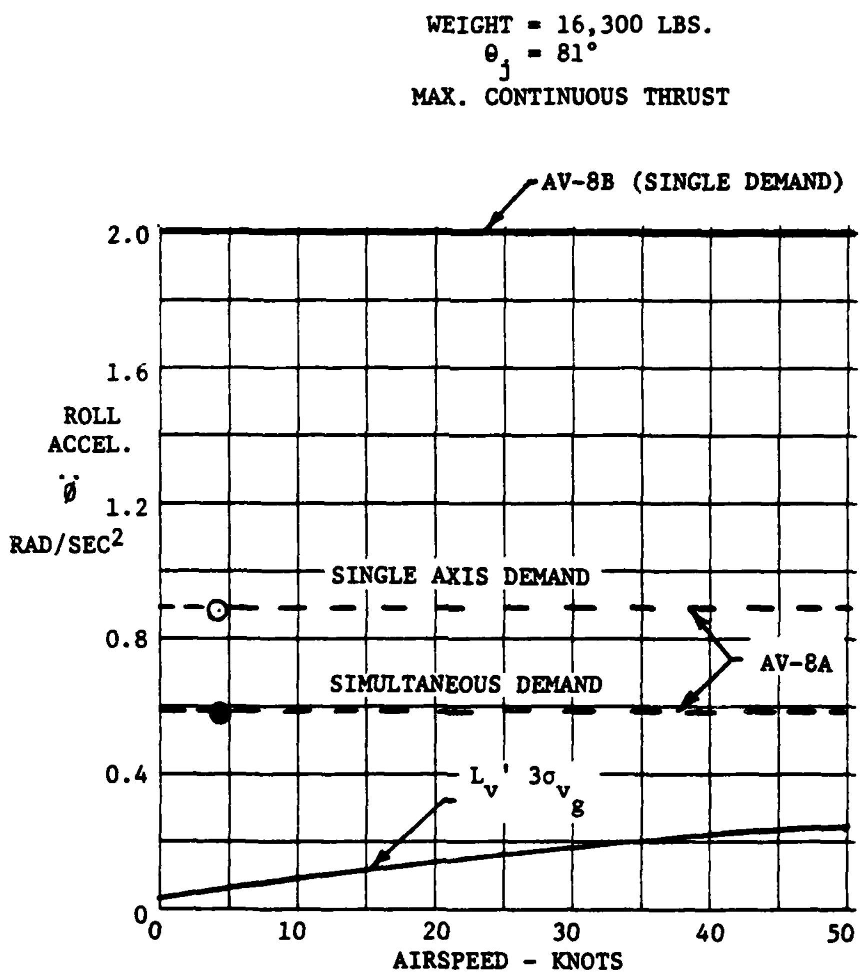


Figure 2-17 AV-8A and AV-8B Control Power In Roll

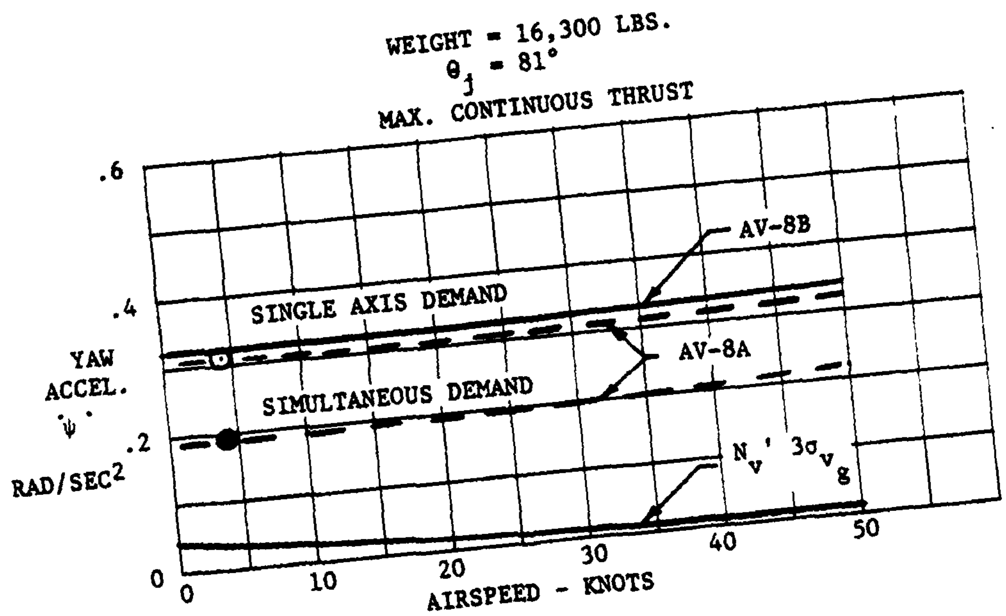


Figure 2-18 AV-8A and AV-8B Control Power In Yaw

WT = 16,300 LBS.
CG = .057 $\bar{c}$
θ_J = 81°

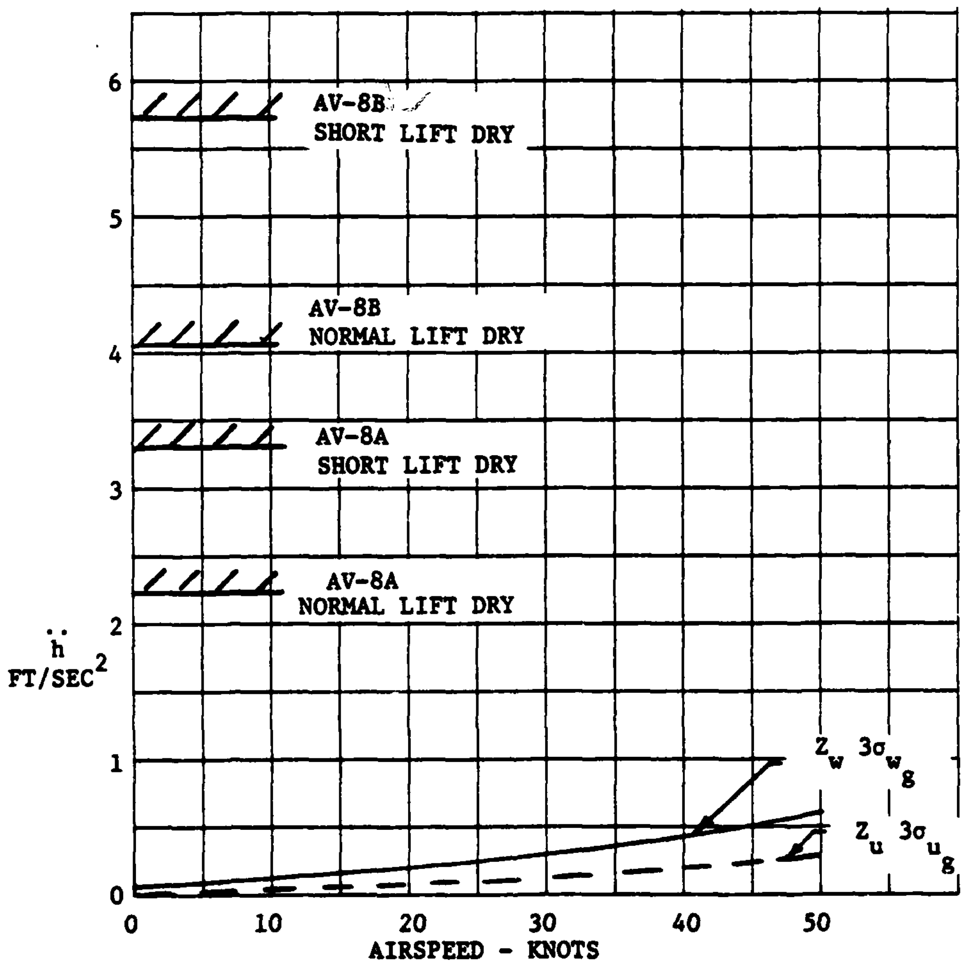


Figure 2-19 AV-8A and AV-8B Vertical Acceleration At Refuel Weight

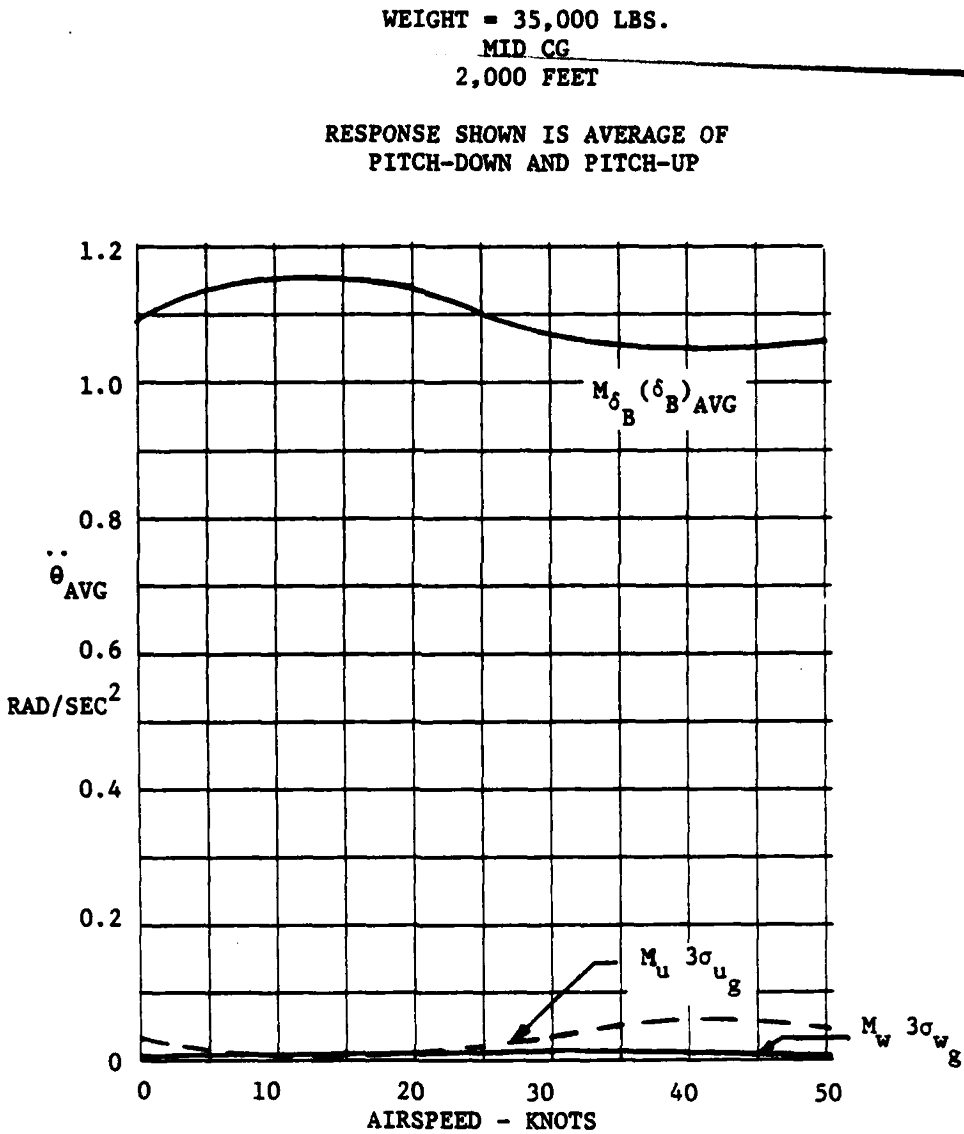


Figure 2-20 CH-53D Helicopter Control Power In Pitch

WEIGHT = 35,000 LBS.
MID CG
2,000 FEET

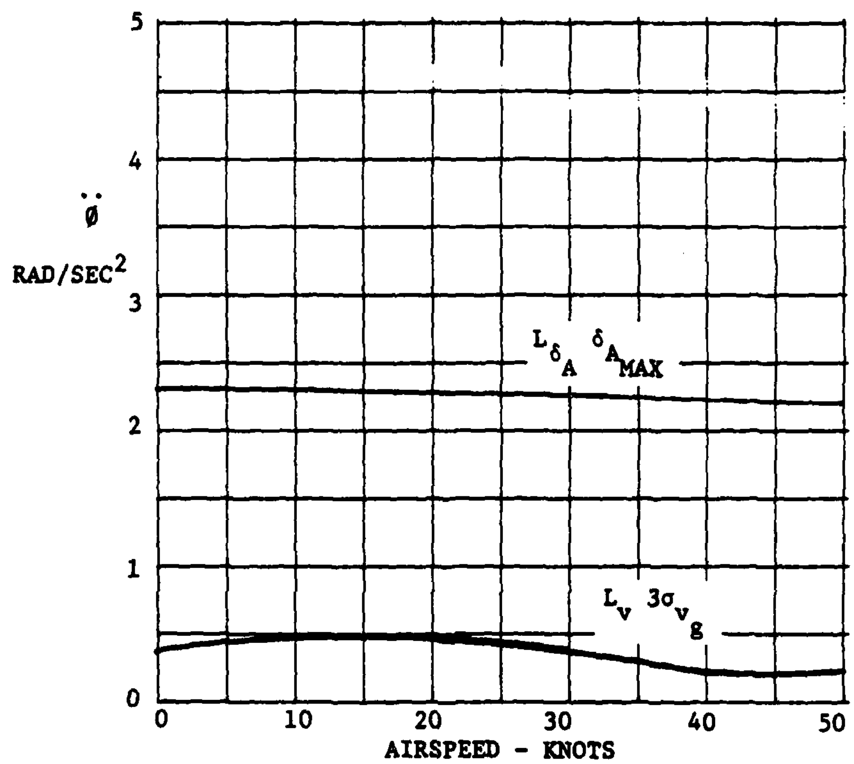


Figure 2-21 CH-53D Helicopter Control Power In Roll

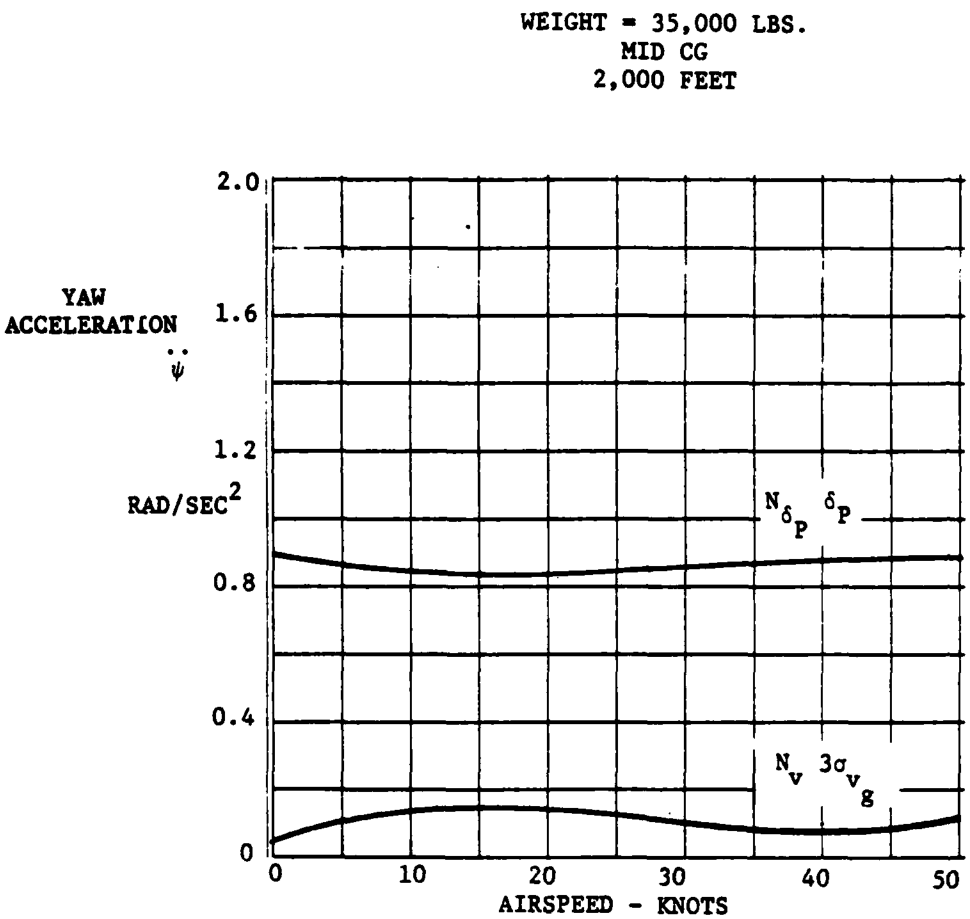


Figure 2-22 CH-53D Helicopter Control Power in Yaw

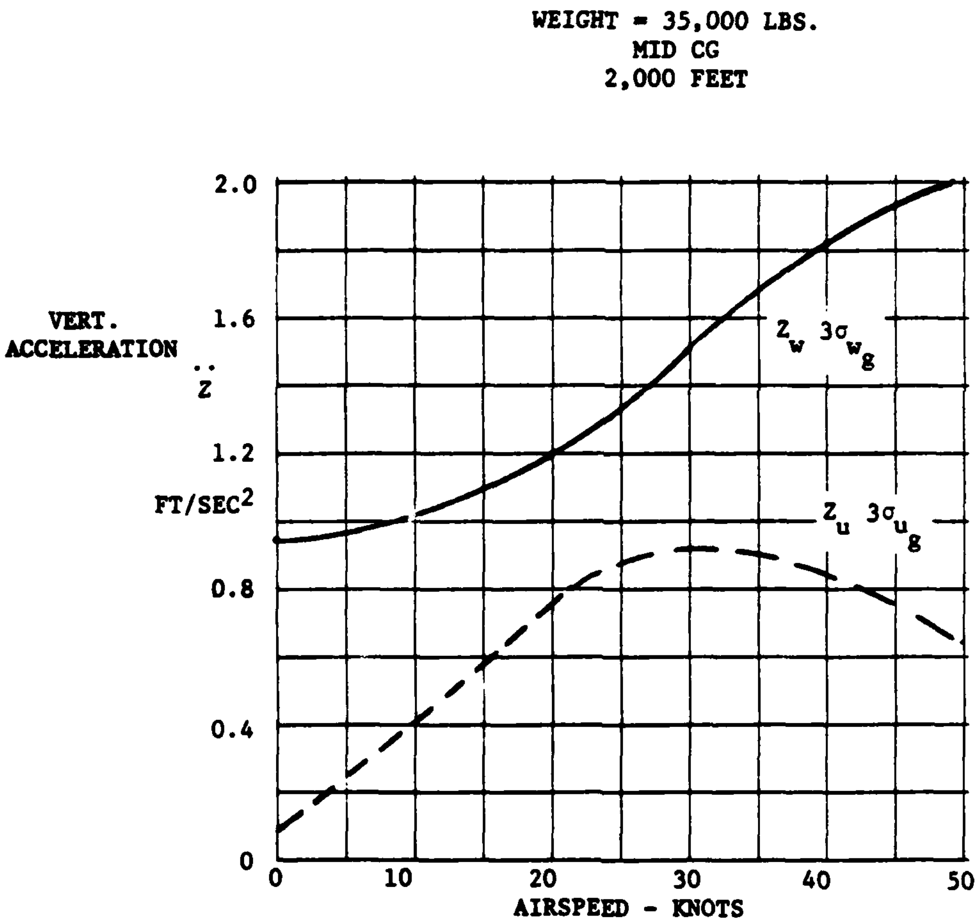
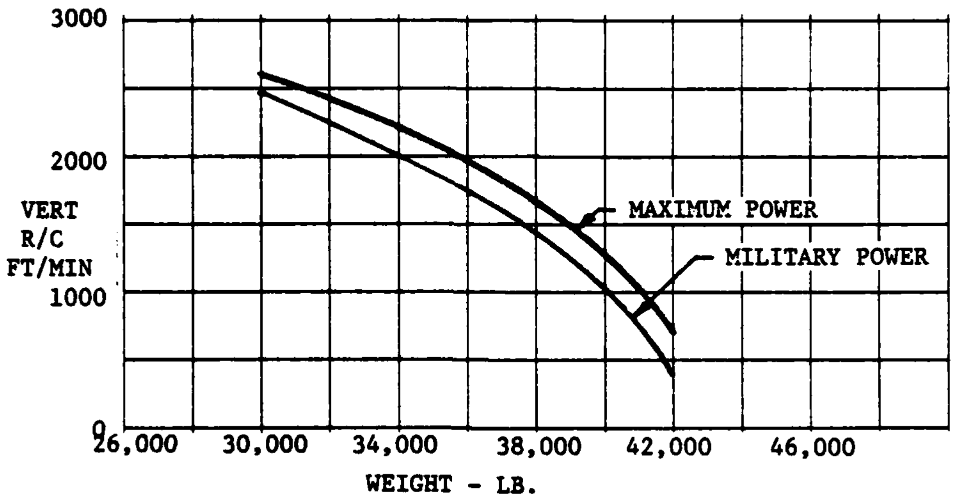


Figure 2-23 CH-53D Helicopter Vertical Acceleration Comparison

STANDARD DAY

VERTICAL RATE-OF-CLIMB CAPABILITY



VERTICAL ACCELERATION PER INCH
OF COLLECTIVE STICK
WEIGHT = 35,000 LBS. MID C.G.

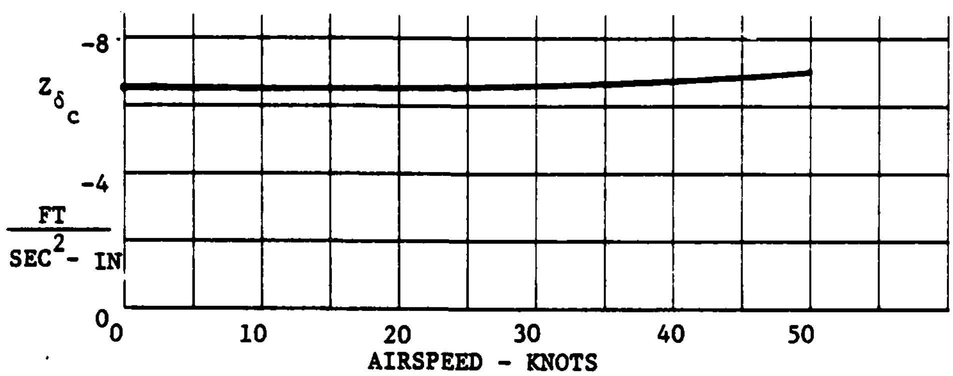


Figure 2-24 CH-53D Vertical Lift Capability

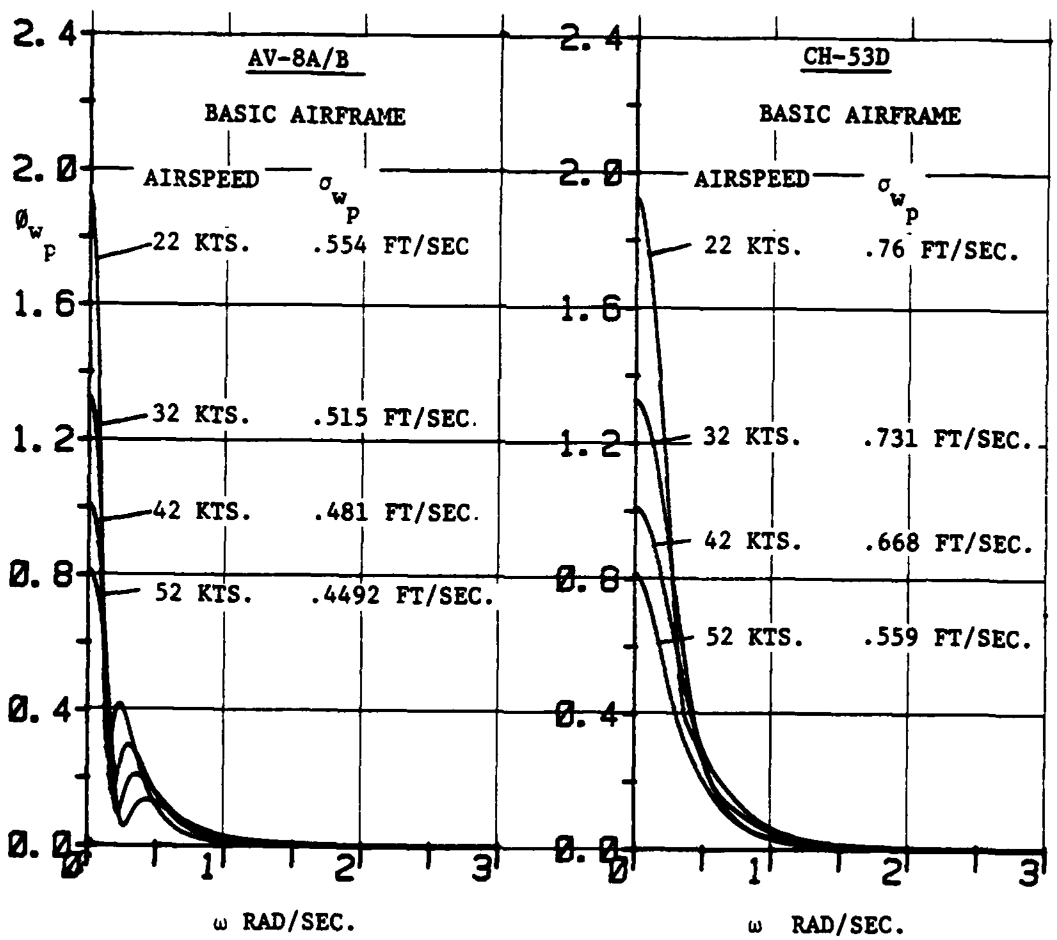


Figure 2-25 Vertical Velocity Spectrum of Refueling Probe Due to Random Vertical Turbulence

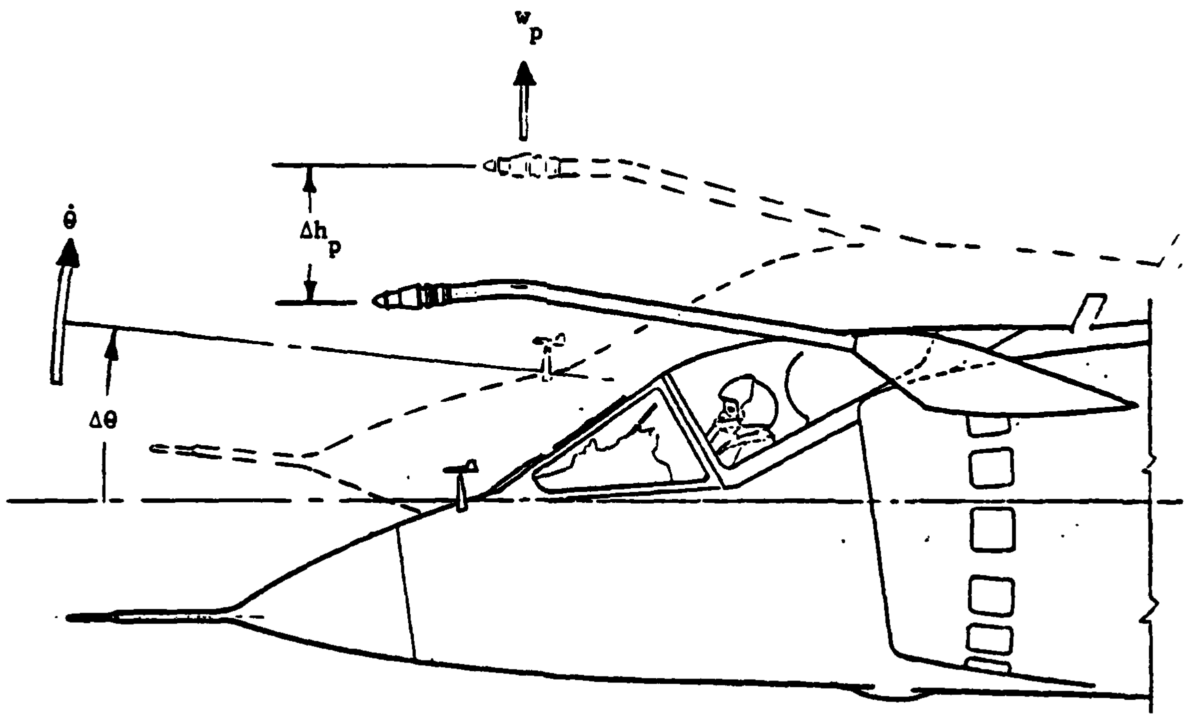


Figure 2-26 Refueling Probe Vertical Motion

turbulence power spectrums shown in Figure 2-12 for the vertical component of the turbulence. Vertical movement of the probe was chosen on the basis it would be the most disturbed direction and is due to both vertical translation and pitching of the aircraft as shown in Figure 2-26. The vertical velocities in Figure 2-25 are considered worst case since stability augmentation and pilot corrective inputs are not included. With pilot and stability augmentation inputs the vertical velocity of the probe tip would be further reduced.

The distance or amplitude of the probe vertical movement depends upon the frequency for a given value of probe velocity. For the case of the AV-8A/B aircraft a predominant frequency for the 22 knot case has a peak at a frequency of .25 rad/sec. The amplitude at that point would be 2.6 ft, again without stability augmentation or pilot corrective input. The frequency above is well within the pilot control response capability. As can be seen in Figure 2-25 the probe vertical velocity spectra do not have any peaks at the higher frequencies for either of the aircraft, therefore, pilot attenuation of refueling probe oscillations due to turbulence should be satisfactory.

It is concluded from this analysis that no limiting conditions are foreseen from turbulence.

2.2.4.3 Refueling Nozzle Engaging - Disengaging Effects On Control - Probe-drogue engaging and disengaging forces will induce transient forces and moments on the aircraft. Since the probe is offset vertically and laterally from the aircraft center-of-gravity the induced moments will be in the pitch and yaw axes. The engage/disengage probe force depends upon the level of hose pressure.

Table 2-1 compares the induced forces and moments to the available control power for the AV-8A and CH-53D aircraft. The induced forces and moments are transient in nature and control input to counteract them will also be transient. As shown in Table 2-1, for the pitch axis for the AV-8A, the induced pitching moment is opposite to the moment due to weight of the nozzle and hose and the engaging/disengaging transient effects on the aircraft response will be reduced. Results are opposite for the CH-53D helicopter since the probe is below the aircraft center- of-gravity.

The control shown in Table 2-1 was computed as if the induced transient effects were exactly controlled. The amount of control is considered nominal and well within the control power capability of the aircraft including the disengaging transient with a pressurized hose. For the AV-8B aircraft the induced forces and moments would be similar to those of the AV-8A but the percentage of maximum control power (simultaneous demand) would be reduced since the control power available is increased for the AV-8B aircraft.

The probe engaging force will assist the pilot in control of the horizontal flight path as this force will add to the deceleration effort required.

Table 2-1 Refuel Nozzle Engaging-Disengaging Effect on AV-8A and CH-53D

AV-8A

	AXIS	HOSE PRESSURE PSI	INDUCED FORCE LB.	INDUCED MOMENT FT-LB.	% CONTROL (SIMULTANEOUS DEMAND)
ENGAGING	PITCH	0	140	501 ① NOSE UP	6.8
	YAW	0	140	595 NOSE LT.	9.6
DISENGAGING	PITCH	0	320	1146 ① NOSE DN	9.5
	PITCH	50	520	1862 ① NOSE DN	15.5
	YAW	0	320	1362 NOSE RT.	21.9
	YAW	50	520	2210 NOSE RT.	35.6

① OPPOSITE TO WEIGHT MOMENT

CH-53D

	AXIS	HOSE PRESSURE PSI	INDUCED FORCE LB.	INDUCED MOMENT FT-LB.	% CONTROL (SINGLE DEMAND)
ENGAGING	PITCH	0	140	626 NOSE DN	.3
	YAW	0	140	328 NOSE RT.	.2
DISENGAGING	PITCH	0	320	1430 NOSE UP	.7
	PITCH	50	520	2324 NOSE UP	1.2
	YAW	0	320	758 NOSE LT.	.5
	YAW	50	520	1232 NOSE LT.	.7

2.2.4.4 Effect of Increased Weight Due to Refueling - As fuel is taken on during the refueling operation some control capabilities will change. Of most importance is the height control or lifting capability (out of ground effect). At the refueled weight adequate lift must be available to disengage by withdrawal from the drogue and lift away for transition to conventional flight.

Based on the data of References (k), (l) and (m), the lift/weight ratio for a dry (no water injection) short lift thrust rating is shown in Figure 2-27 for the AV-8A aircraft. It is noted that the short lift thrust rating is a time limited thrust (depending on ambient temperature), however, the thrust rating is only used during the lift-away maneuver. It is assumed that a maximum lift/weight value of 1.04 will provide satisfactory vertical acceleration capability since ground effect is not a factor. Corresponding data for the AV-8B aircraft is shown in Figure 2-28. Additional fuel can be taken on the AV-8B compared to the AV-8A due to the increased lift capability.

The axis most affected by the fuel taken on board during refueling will be the roll axis. The increased roll inertia will reduce roll acceleration. Figure 2-29 shows the effect on the roll acceleration as fuel is added to the AV-8A aircraft. For the three different external loadings shown in Figure 2-29, the reductions in roll response appear tolerable and should not limit controllability. Similar reductions would occur for the AV-8B aircraft but increased levels of control power are available in that aircraft. Increases in pitch and yaw inertia also occur due to the fuel taken aboard but are a much smaller proportion of the original inertia and are not expected to significantly affect the pitch or yaw response.

For the CH-53D helicopter the data presented in Figure 2-24 indicates fuel could be taken aboard up to approximately 42,500 pounds if an arbitrary lift-away vertical rate-of-climb of 500 ft/min. were assumed. Inertial changes due to fuel added on the CH-53D aircraft are small because of the relatively large inertias of the CH-53 basic airframe. Therefore, no consequential effects on controllability are expected as a result of refueling.

2.2.4.5 Summary of Aircraft Characteristics In V/STOL Refueling Operations -

1. The procedure described for approach, contact of the refueling drogue and resuming station keeping appears feasible. Altering of ship heading is required to allow refueling operations with zero aircraft sideslip angles, minimize ship wake effects on the aircraft and provide adequate clearance from the ship. The height at which refueling operations would be conducted will keep the aircraft free of aerodynamic ground effects and propulsive efflux induced spray.

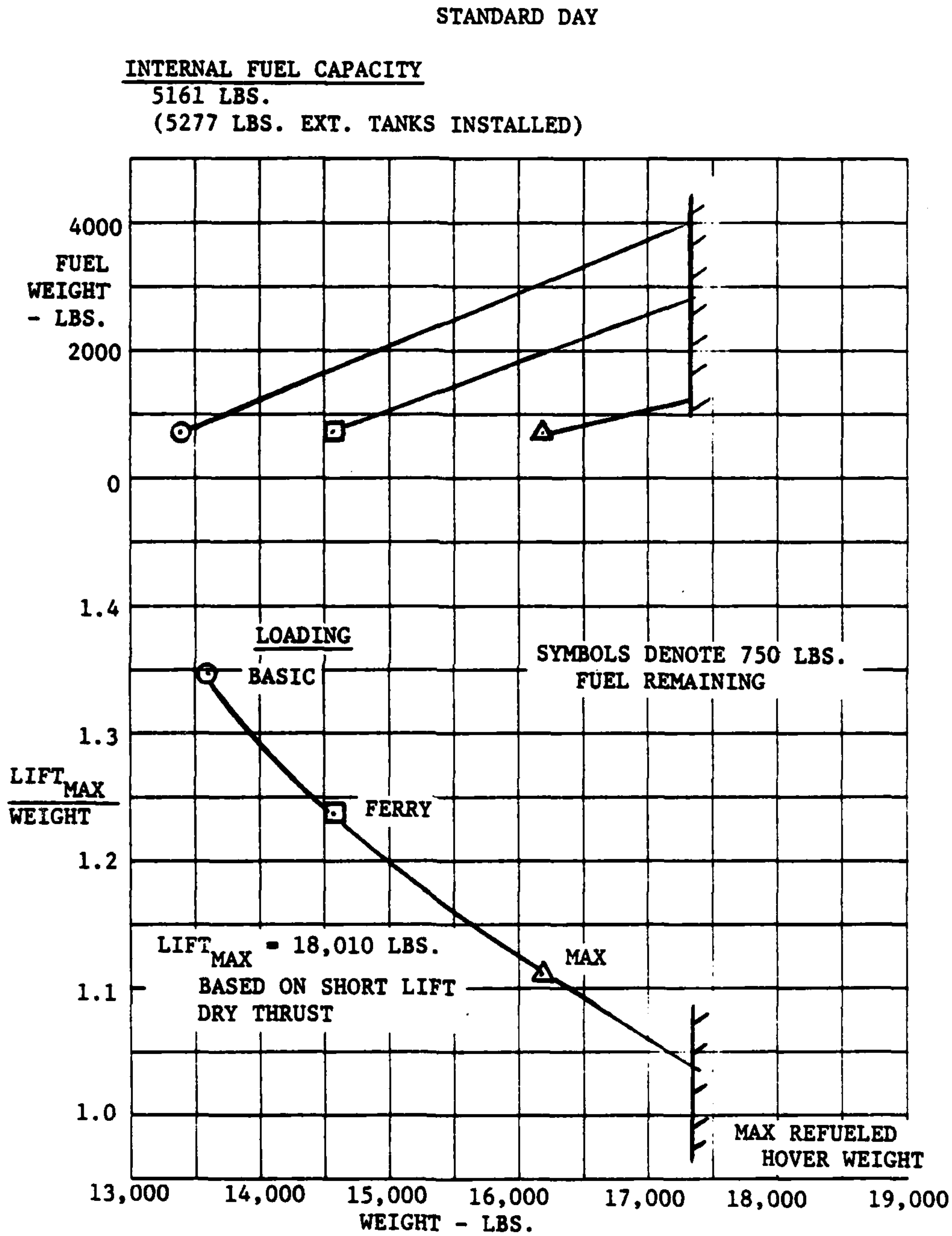


Figure 2-27 AV-8A Lifting Capability During Refueling

STANDARD DAY

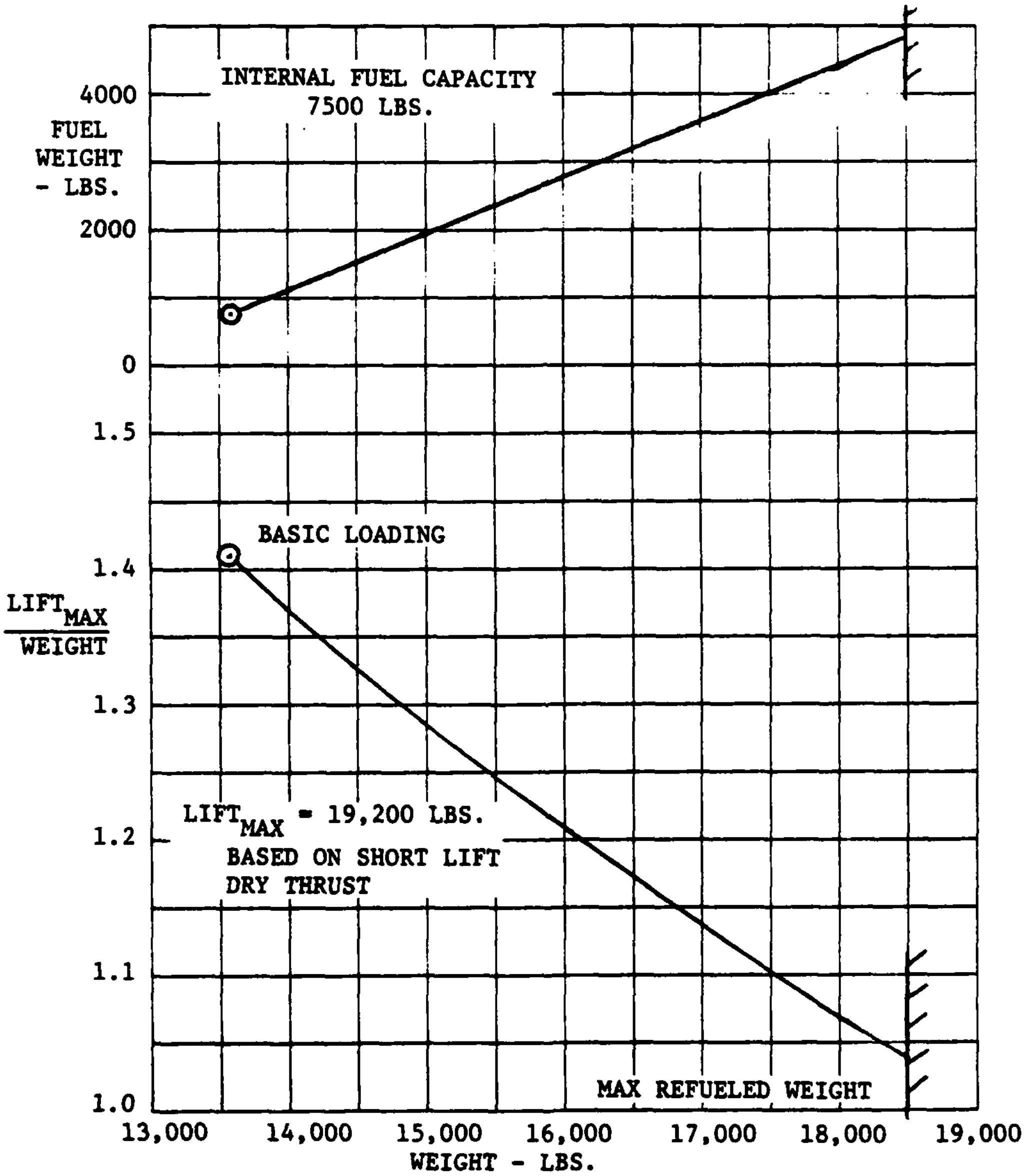


Figure 2-28 AV-8B Lifting Capability During Refueling

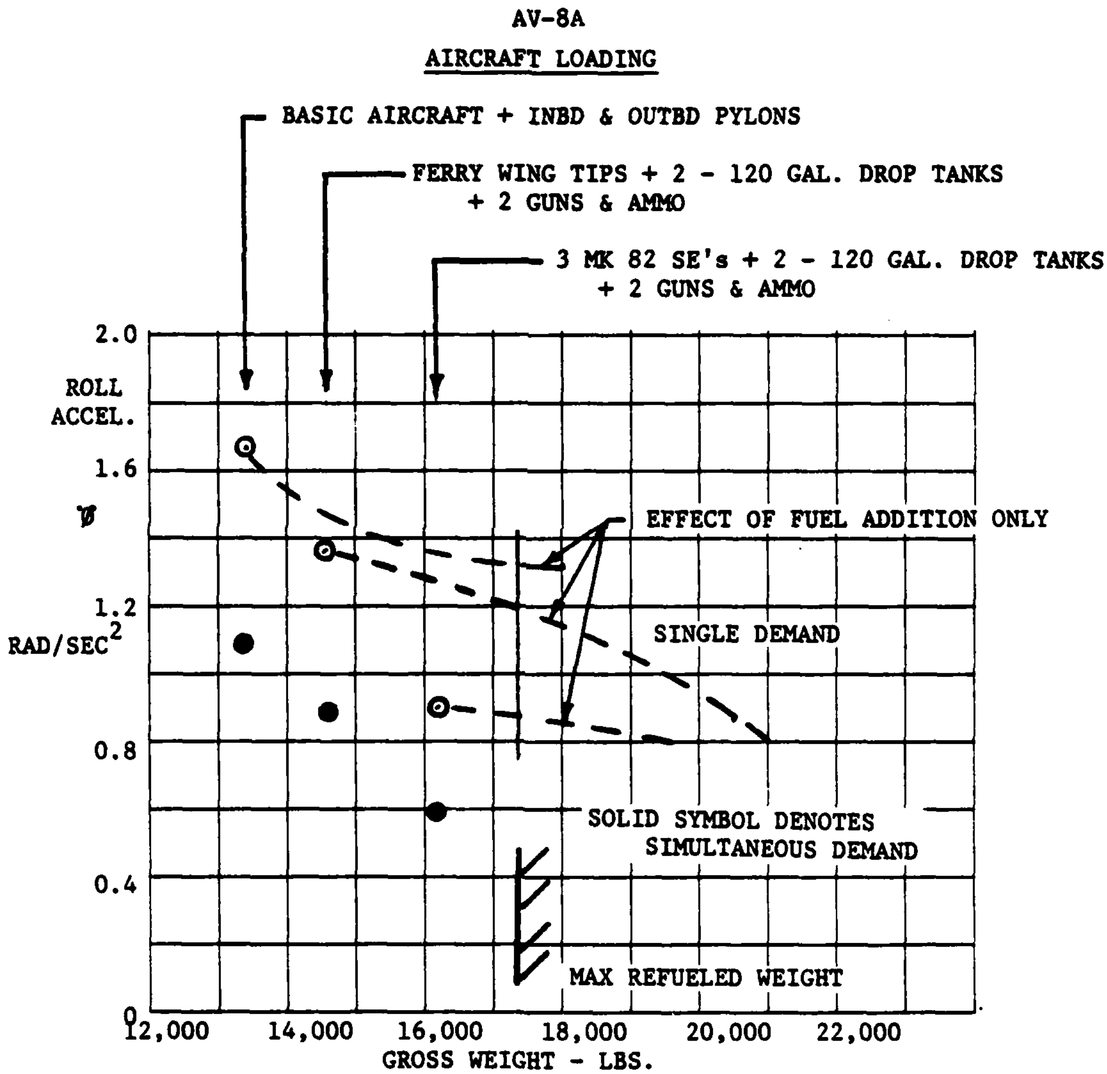


Figure 2-29 Effect of Aircraft Loadings on Roll Control Power

2. The examination of free air turbulence effects on the aircraft indicates they should be manageable relative to the control power available for each of the aircraft.

3. Pitch and roll control required to trim the weight effects of the drogue and hose (including fuel in hose) are adequate for each of the aircraft.

4. Pitch and yaw transient forces and moments are induced on the aircraft from engaging and disengaging of the drogue but should be controllable when evaluated relative to control power available for each aircraft.

5. Analysis of controllability with emphasis on height control as fuel is taken aboard set preliminary maximum weights for each aircraft based on the ability to lift away upon completing refueling.

6. Preciseness of control or the ability of the pilot to make repeated probe-drogue hook-up cannot be answered by the analysis performed and is considered outside the scope of this study. Confirmation requires a closed loop analysis with all elements appropriately represented and is recommended for future study.

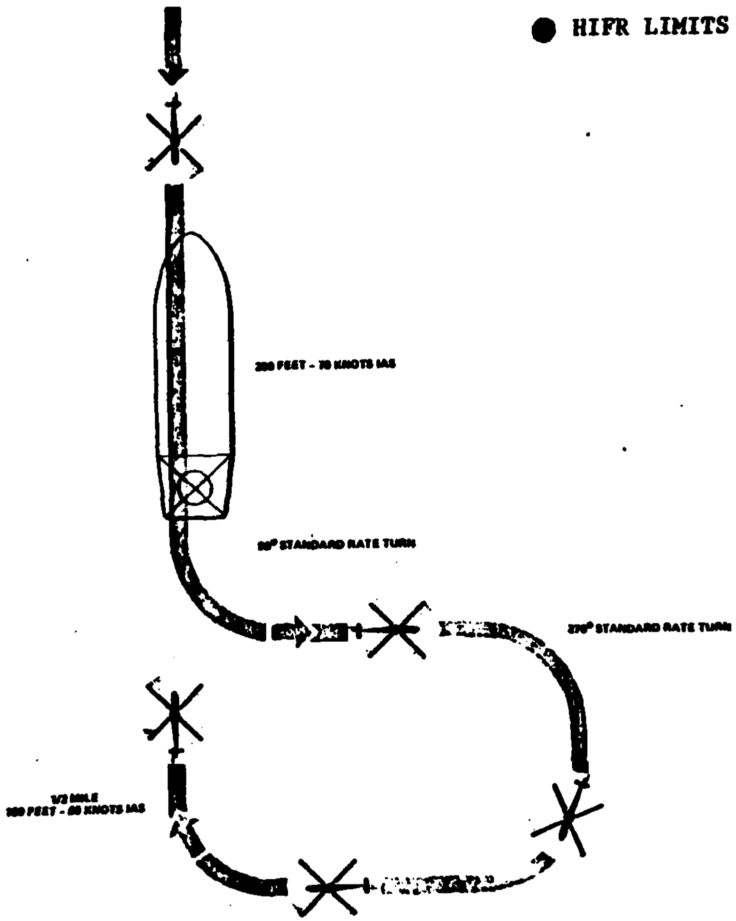
2.2.5 Approach and Transition for Refueling

Figure 2-30 depicts the current procedure for night and low visibility approach to the ship for helicopter inflight refueling (HIFR). This procedure was examined for application to fixed wing V/STOL aircraft such as the AV-8A and AV-8B with propulsive lift systems and is not recommended. To fly the helicopter procedure exactly as published, the fixed wing V/STOL aircraft must transition at the beginning of the approach from wing-borne to propulsive lift at a correspondingly large increase in fuel flow. Since the need to refuel coincides with a low fuel state any refueling approach should be designed to conserve fuel. Figure 2-31 illustrates a modification to the published helicopter approach wherein transition from wing borne flight is delayed until refueling contact is assured (Option 2). This approach is flown at 160 knots while maneuvering as prescribed for the HIFR approach. Much less fuel is consumed but the fixed wing aircraft has used a great deal more airspace and arrives at a position approximately four nautical miles astern of the ship. Even in marginal visual meterological conditions (VMC) of 1000 feet ceiling and three statute miles visibility (2.6 nautical miles) the ship may not yet be visible, which leads to the conclusion that the HIFR approach is simply unsuitable for fixed wing V/STOL aircraft. Option 3 prescribes a straight-in approach from astern using TACAN with transition from wing borne flight to propulsive lift beginning at 1.0 nm astern as shown in Figure 2-10, page 2-14.

However helicopters such as the SH-60B can perform the approach exactly as published for HIFR while benefiting from the combined closure speed of the ship and aircraft.

- LIMITED TO HELICOPTERS

- TACAN PRIMARY
- SUBJECT TO RADIO SILENCE (AIR SUPERIORITY)
- LO POWER Y/G CONCEPT STILL VIABLE
- HIFR LIMITS (NIGHT) 10° ROLL, 5° PITCH



FROM NATOPS AIR REFUELING MANUAL

Figure 2-30 Night/Low Visibility HIFR Approach

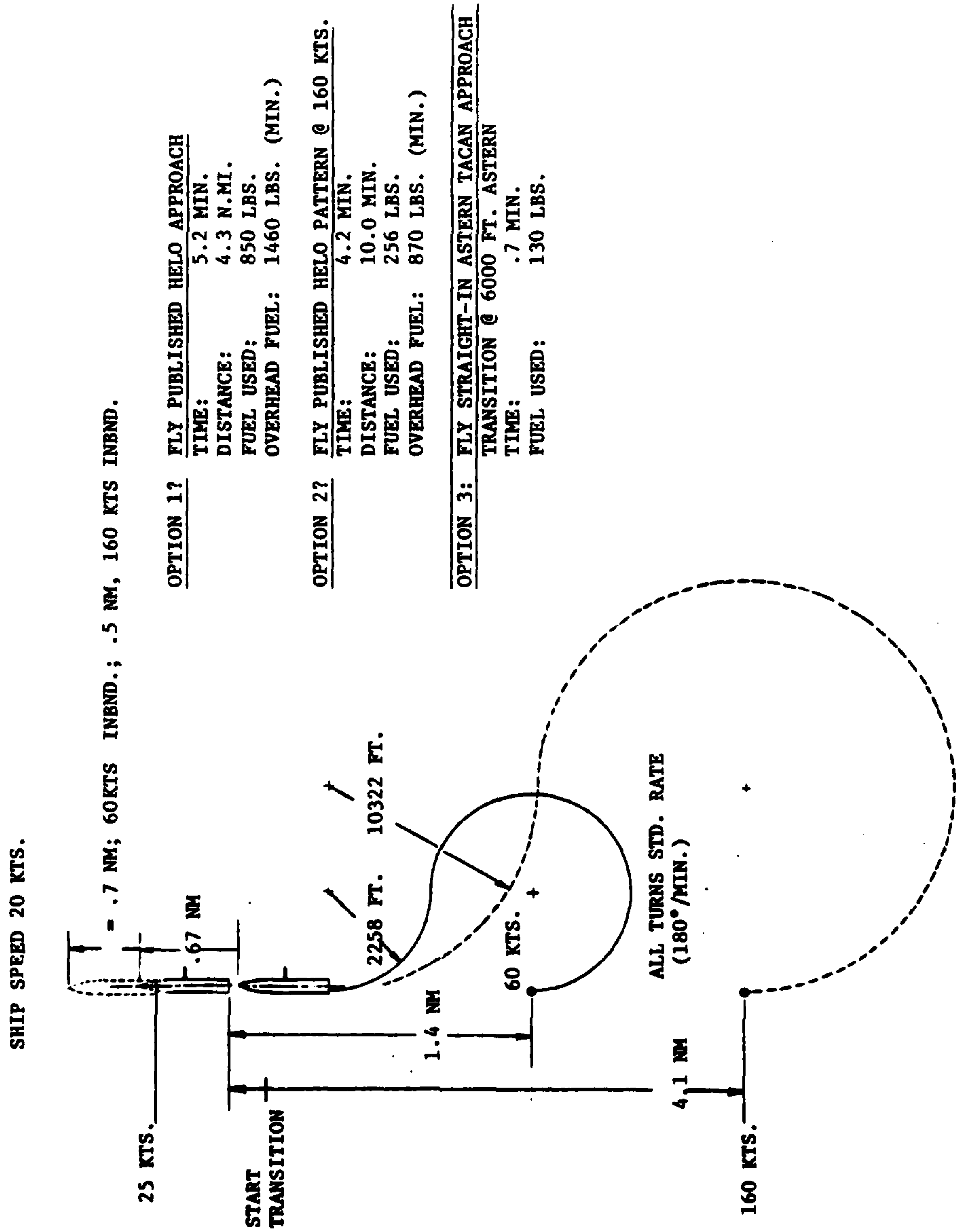


Figure 2-31 AV-8A Night/Low Visibility Approach Options

2.2.5.2 AV-8A Minimum Fuel State Requirements - While approaching a refueling ship at 160 knots airspeed an AV-8A aircraft will be consuming fuel at a rate of approximately 40 lbs/min. (gear up, full flaps, no external stores, speed brakes in). In transition to propulsive lift the fuel flow will increase to 172 lbs/min (at 1600 pounds fuel remaining) as the throttle is advanced and nozzles are positioned to support hover flight. From a formation position abeam of the ship and ninety feet astern of the refueling drogue, with trim and power established to match the ship's speed, the estimated time required to engage the drogue is 1.2 minutes. The refueling pilot should begin the drogue closure at approximately three knots above ship's speed from ninety feet astern with no less than 750 pounds of fuel remaining (Figure 2-32). This minimum amount provides a safety margin of three minutes. Aircraft fuel flow at drogue engagement would then be 160 lbs/min. (600 pounds of fuel remaining). Refueling flow will begin at the rate of 1200 lbs/min. (176 gal./min.)

2.3 SURVEY OF EXISTING REFUELING SYSTEMS

References (u) and (v) provide descriptions of all the conventional means of refueling aircraft from devices ranging from tank trucks through hydrants to air-to-air fuel transfer. Performance data for these devices is summarized in Figure 2-33 in terms of fuel nozzle flow rate and nozzle pressure. Aircraft carrier (CV) performance boundaries are shown with a nominal "design" characteristic. This range of performance is due primarily to the number of aircraft demanding fuel at a particular moment which can range from one aircraft to the multiple flights recovered from an "alpha" strike.

The USAF hydrant system is sized to rapidly refuel many large aircraft such as the B-52. This system can provide refueling rates of up to 1000 gallons per minute.

Air-to-air buddy tanker systems are designed to dispense fuel at the rate of at least 200 gallons per minute and large refueling aircraft such as the USAF KC-135 can supply over 600 gallons per minute with two refueling pumps operating.

Many existing USN aircraft are designed to accept refueling rates of 300 gallons per minute at a single nozzle pressure of 50 psig. The AV-8A will, however, accept fuel through the flight refueling probe at only 175 gallons per minute.

The maximum performance of the ship based inflight refueling devices described in this report is 400 gallons per minute at 40 psig. These values approach the upper limit of CV refueling capability.

2.3.1 AV-8A Elapsed Refueling Time

The AV-8A at a 13,800 pound hover weight (approximately 1600 pounds internal fuel remaining) consumes fuel at the rate of 25 gallons per

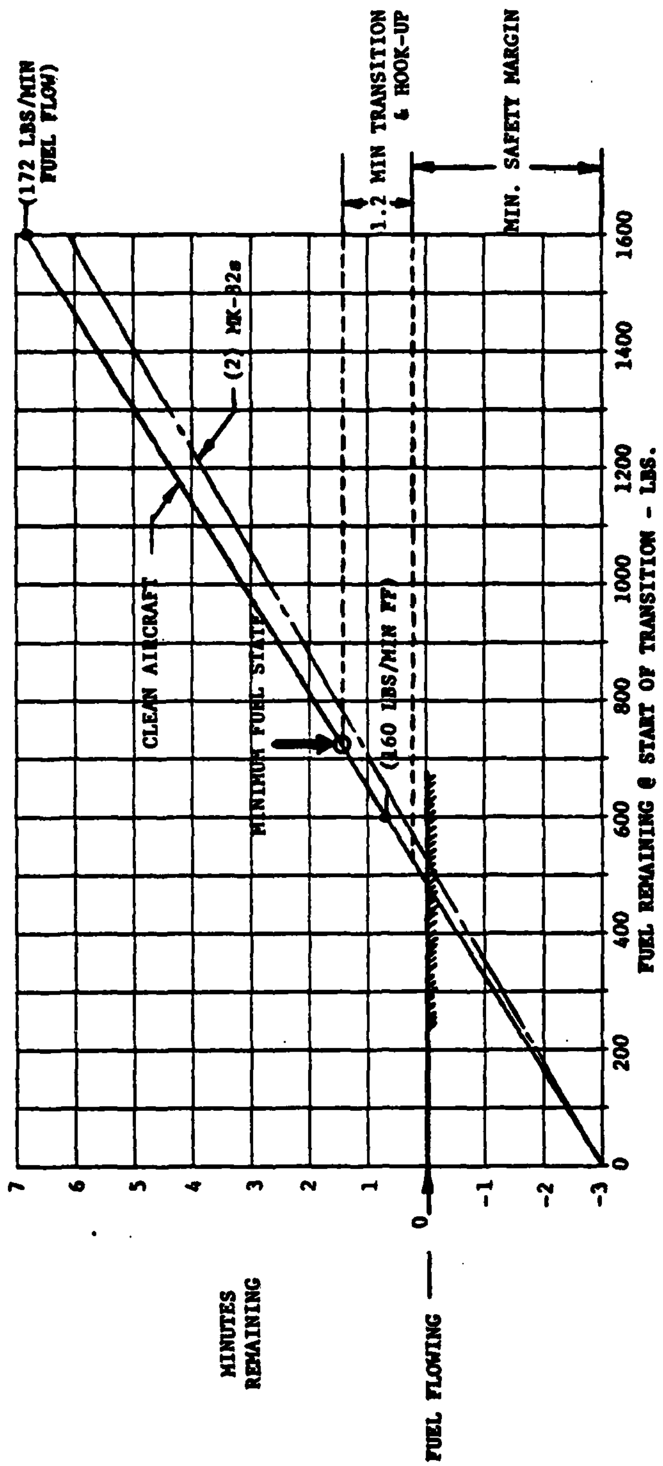


Figure 2-32 AV-8A Minimum Fuel State Requirements

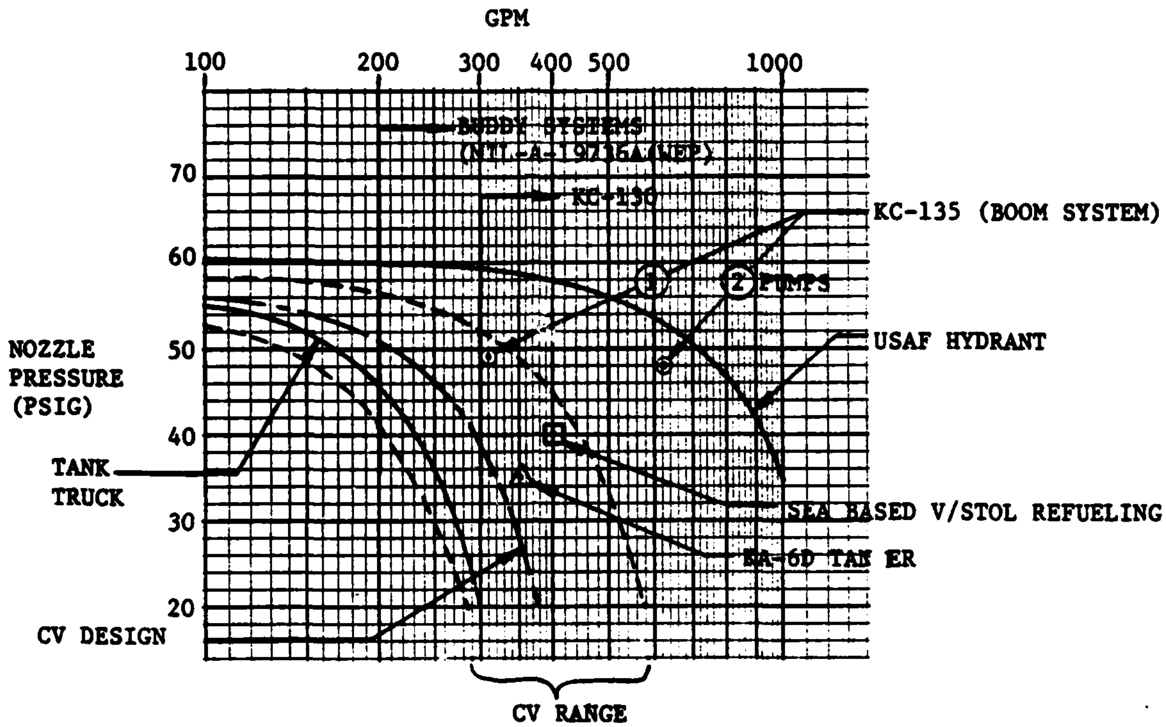


Figure 2-33 Tanker Performance Domain

minute (172 lbs/min.) to derive propulsive lift and control. Since the aircraft can be air refueled at 175 gallons per minute the resultant net refueling rate is 150 gallons per minute. As refueling continues up to the AV-8A maximum internal capacity, propulsive fuel flow must also increase to support the additional weight. Therefore the net refueling rate is slightly non-linear with quantity delivered but is never less than 145 gallons per minute.

The net time required to refuel an AV-8A in hover from a ship based, inflight refueling device would be 4.4 minutes, starting from 700 pounds remaining and refueling to full internal fuel, 5161 pounds.

2.3.2 HIFR

Most cruisers, destroyers, and frigates are required to be capable of refueling a helicopter in hover. Some Coast Guard cutters are also equipped with HIFR (Helicopter In-Flight Refueling) while naval auxiliaries (AD, AE, AFS, AG, AGF, AGFF, AO, AOE, AOR, AR, ARS, AS, ASR, ATF, ATS, AVM) are not required to have this capability. Amphibious ships (LCC, LKA, LPA, LPD, LSD, LST) and Military Sealift Command ships (T-AF, T-AGM, T-AGS, T-AO, T-ARC, T-ATF) are also exempt.

The HIFR system is a low pressure (40 psi), low flow rate (50 gpm) system that is not appropriate for jetborne V/STOL aircraft. To refuel with HIFR, the helicopter must come to a hover above the designated deck spot and lower its rescue hoist, to which deck personnel manually attach a segment of 1.5 inch I.D. fuel hose and a metal saddle section. A Wiggins quick disconnect is fitted to the delivery end of this segment. The opposite end is connected to the ship's fuel supply hose. The saddle is drawn up by the helicopter, through a hatch, and manually connected by the crew to the helicopter's refueling fitting mounted on an internal bulkhead. The helicopter hovers a 30 to 40 feet altitude while fuel is being pumped aboard, and the hose attachment sequence is then reversed. The process requires several deck hands, an LSO, and considerable coordination.

3.0 SHIP BASED REFUELING DEVICES

3.1 CANDIDATE REFUELING SYSTEMS

A preliminary set of ship to air refueling system design requirements was established to provide guidelines for system concept development. These system goals are as follows:

- Compatibility with on board aircraft refueling equipment and techniques, and with projected V/STOL fighter attack, helicopters and V/STOL multimission aircraft.
- Compatibility with installation on a wide range of Navy ships likely to constitute a typical convoy/task force.
- Provide safe operation in a sea state 5 environment.
- Provide a fuel transfer rate of 5000 pounds in three minutes or less.
- Assure high refueling system availability.
- Make use of current technology.
- Provide simple mechanization for high reliability, low risk, and ease of operation with existing Navy skill levels.
- Keep projected development and production cost low to permit extensive deployment of the ship based refueling system.

This section and section 4.0 describe two viable ship based V/STOL refueling systems which were selected from a variety of candidates listed in Table 3-1. The candidates considered in this study are listed by categories of physics applied to suspend and stabilize a drogue from a ship for refueling V/STOL aircraft. Adjacent columns identify the device and the method by which the device might be controlled. In the case of rejection of the device from further analysis, the most important reason for rejection is emphasized by a bold outline in the wind/sea state column accompanied by brief explanatory remarks. For example, tethered balloons are attractive candidates for initial consideration because of low relative cost and compact stowage potential. However, they are found to be sensitive to the gust environment in winds accompanying the higher sea states (4 to 6). V/STOL aircraft refueling requires that the refueling drogue target remain virtually stationary in space if engagement is to be successful and readily repeatable. Multiple tethers could be rigged to sufficiently stabilize a balloon but the rigging would be elaborate and necessarily symmetrical. This symmetry would require that the balloon be rigged directly over the ship which is considered to be unsafe and otherwise undesirable for refueling propulsive lift aircraft. An alternative to symmetrical rigging might be a reaction control system powered by a storable propellant system or balloon mounted gas generator. The low cost and compact stowage features which were initially attractive are now rapidly eroding, with further consideration of the logistics problems for storing and resupply of helium or hydrogen and possibly propellants.

Other devices such as tethered kites might be developed to work satisfactorily but without low windspeed capability and were therefore rejected.

The two candidates adopted for further analysis are (1) the turbofan powered VTOL platform or module, and (2) the ship mounted suspended boom system, as indicated by the arrows.

Table 3-1 Candidate Refueling Devices

TYPE	DEVICE/SYSTEM	CONTROL	WIND/SEA STATE POTENTIAL 0-2	2-4	>4	REMARKS
AIR MASS DISPLACEMENT	TETHERED BALOON	AERODYNAMIC	X			HIGHLY GUST SENSITIVE @ ELEVATED SEA STATES. INADEQUATE DYNAMIC PRESSURE AVAILABLE FOR CONTROL IN LOW WIND ENVIRONMENT. CANDIDATE REJECTED.
		REACTION CONTROL	X	X		GUST SENSITIVE (AS ABOVE). REACTION CONTROL SYSTEM HARDWARE AND POWER SOURCE DISSOLVES POTENTIAL SIMPLICITY AND COMPACTNESS FOR STORAGE OF BALCON. CANDIDATE REJECTED.
AERODYNAMIC	TETHERED KITE	AERODYNAMIC (OTHER)			X	GUST SENSITIVE. VERY LARGE LIFT SURFACE REQUIRED AT LOW DYNAMIC PRESSURES. NO ZERO WIND CAPABILITY. CANDIDATE REJECTED.
POWERED LIFT SYSTEMS	VTOL PLATFORMS					
	ROTARY WING	INDUCED AERO.	X	X		GUST SENSITIVE. COMPLEX CANDIDATE REJECTED.
	FAN(SHROUDED)	VECTORED THRUST/ REACTION	X	X	X	SATISFACTORY. (FAN DEVELOPMENT REQUIRED)
	(1) ⇨ TURBOFAN	VECTORED THRUST	X	X	X	SATISFACTORY. (USING OFF-SHELF HARDWARE)
	JET	VECTORED THRUST	X	X	X	LOW THRUST/HORSEPOWER. INEFFICIENT PROPULSION CYCLE FOR STATIC THRUST APPLICATION. CANDIDATE REJECTED.
AIRCRAFT INSTALLED DE-VICES (WINCH & FUEL COUPLING)	HIFR	AIRCRAFT	X	X		INADEQUATE FLOW RATE AND SEA STATE.
	V/STOL SUITABLE HIFR	AIRCRAFT	X	X		AIRCRAFT WEIGHT PENALTY. CANDIDATE REJECTED (DECK CREW REQUIRED WITH ATTENDANT HAZARDS)
SEABORNE DEVICES	TOWED PARAVANE	HYDRODYNAMIC	X	X		VERY LARGE PORTABLE DEVICE. ELABORATE DECK HANDLING REQUIRED. DROGUE POSITION CONTROL PRECISION INADEQUATE AT HIGH SEA STATES. CANDIDATE REJECTED
SHIP MOUNTED DEVICES	(2) ⇨ SUSPENDED BOOM	HYDRO-MECHANICAL	X	X	X	SATISFACTORY. (FAN DEVELOPMENT REQUIRED). LOW TECHNICAL RISK

3.2 DEFINITION OF SEA STATES AND ACCOMPANYING WINDS

The open ocean consists of waves which have been generated by winds or from swells generated by storms originating some distance away from the present position of a ship. In reality the sea surface is comprised of a combination of wind and swell generated waves. Wind generated waves are very irregular in shape and tend to be short crested when compared to the long crested and more regular condition of swells. Short crested irregular seas increase in amplitude (wave height) as a function of increasing duration and velocity of the winds which have provided the energy to generate them. Short crested seas are modified and intensified by swells.

Statistical models of the sea surface have been developed to approximate the open ocean for studies of ship responses to a given seaway. The study of seaway behaviour is an involved science and further discussion on this subject can be found in References (a), (b) and (c).

This ship based refueling study is more concerned with ship responses rather than the seaway itself and depended notably on the works of the most authorative source now available, NSRDC. Of particular importance in deriving ship motion characteristics, especially for the smaller ships in the study sample (FFG-7 and FF-1052), is the data published in Reference (a). A Ship Motion Computer Program is also made available by the Naval Air Engineering Center, Reference (b), whereby ship responses can be derived for any given heading in a seaway with the aid of a digital computer.

A definition of sea states is given here in tabular form (Table 3-2) which fits the two parameter, swell corrupted, wind generated seaway model attributed to Bretschneider (described in Reference (b)).

Table 3-2 Definition of Sea States

DEFINITION OF SEA STATES

STATE	RANGES OF SIGNIFICANT WAVE HEIGHTS $\bar{\zeta}_{1/3}$ FT	RANGES OF MODAL WAVE PERIODS T_0 SEC
1	0 - 1.92	0 - 3.08
2	1.92 - 4.13	3.08 - 4.52
3	4.13 - 5.66	4.52 - 5.29
4	5.66 - 7.35	5.29 - 6.03
5	7.35 - 13.04	6.03 - 8.03
6	13.04 - 20.80	8.03 - 10.15
7	20.80 - 40.33	10.15 - 14.13
8	40.33 - 61.58	14.13 - 17.45

ACCOMPANYING WINDS (APPROXIMATE)

WIND SPEED RANGE KTS	BEAUFORT NUMBER
CALM TO 7	1 - 3
7 - 12	3 - 4
12 - 16	4
16 - 19	5
19 - 24	5 - 6
24 - 31	6 - 7
31 - 47	7 - 9
>47	>9

REF. VINE & VELKMANN
WOODS HOLE OCEANOGRAPHIC INSTITUTE

3.3 SHIP MOTIONS AND COORDINATE SYSTEM

The six degrees of freedom under which a rigid body such as a ship can respond to seaway pertubations are diagrammed in Figure 3-1 . There are three translatory and three rotational motions as follows:

Translatory	Heave	Vertical motion of the CG along the Z axis
	Surge	Longitudinal motion of the CG along the X axis
	Sway	Horizontal motion of the CG along the Y axis
Rotational	Pitch	Motion of the X axis about the pitch axis Y
	Roll	Motion of the Y axis about the longitudinal axis X
	Yaw	Motion of the X axis about the vertical axis Z

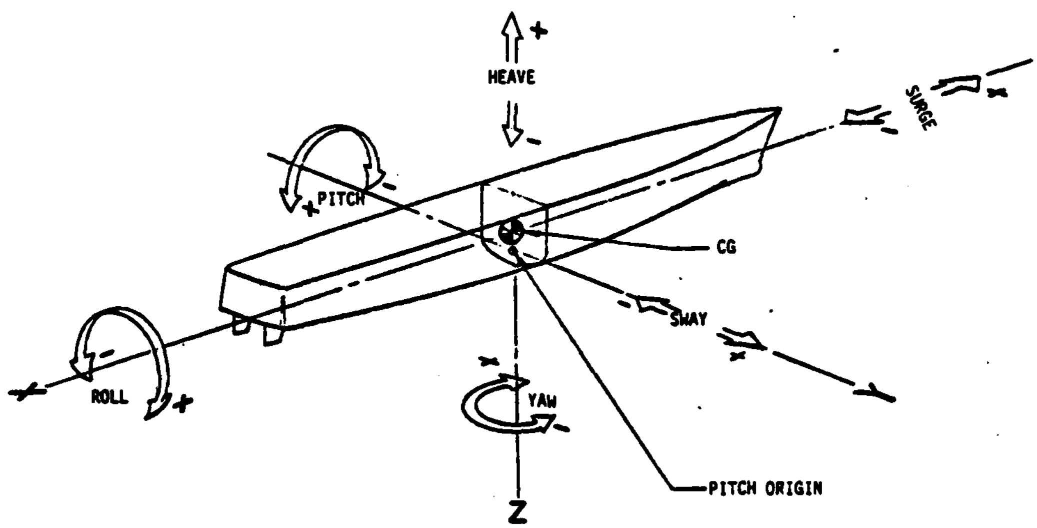


Figure 3-1 Ship Motions and Coordinate System

Pure single axis motion in a seaway is rare and momentary. Ship behaviour in the open sea is characterized by randomly distributed motions in combinations of all six types. The amplitude of a single motion such as pitch can be observed to predominate as a function of ship heading through the seaway.

3.4 THE SUSPENDED REFUELING BOOM SYSTEM *

3.4.1 Description

A standard type MA-2 (MS 24355 ASG) refueling drogue coupling with attached target cone is suspended from the starboard side of the ship, over the sea (Figure 3-2, and Foldout Drawing 84816-100, page 3-39/3-40), by a truss type boom. The inboard end of the boom is supported by a horizontal pivot which permits rotational motion of the boom about the pivot, in a vertical plane. The horizontal pivot is in turn supported at the upper end of a 24 ft vertical post which is attached to the ship's structure by means of a lower horizontal pivot.

* Patent applied for.

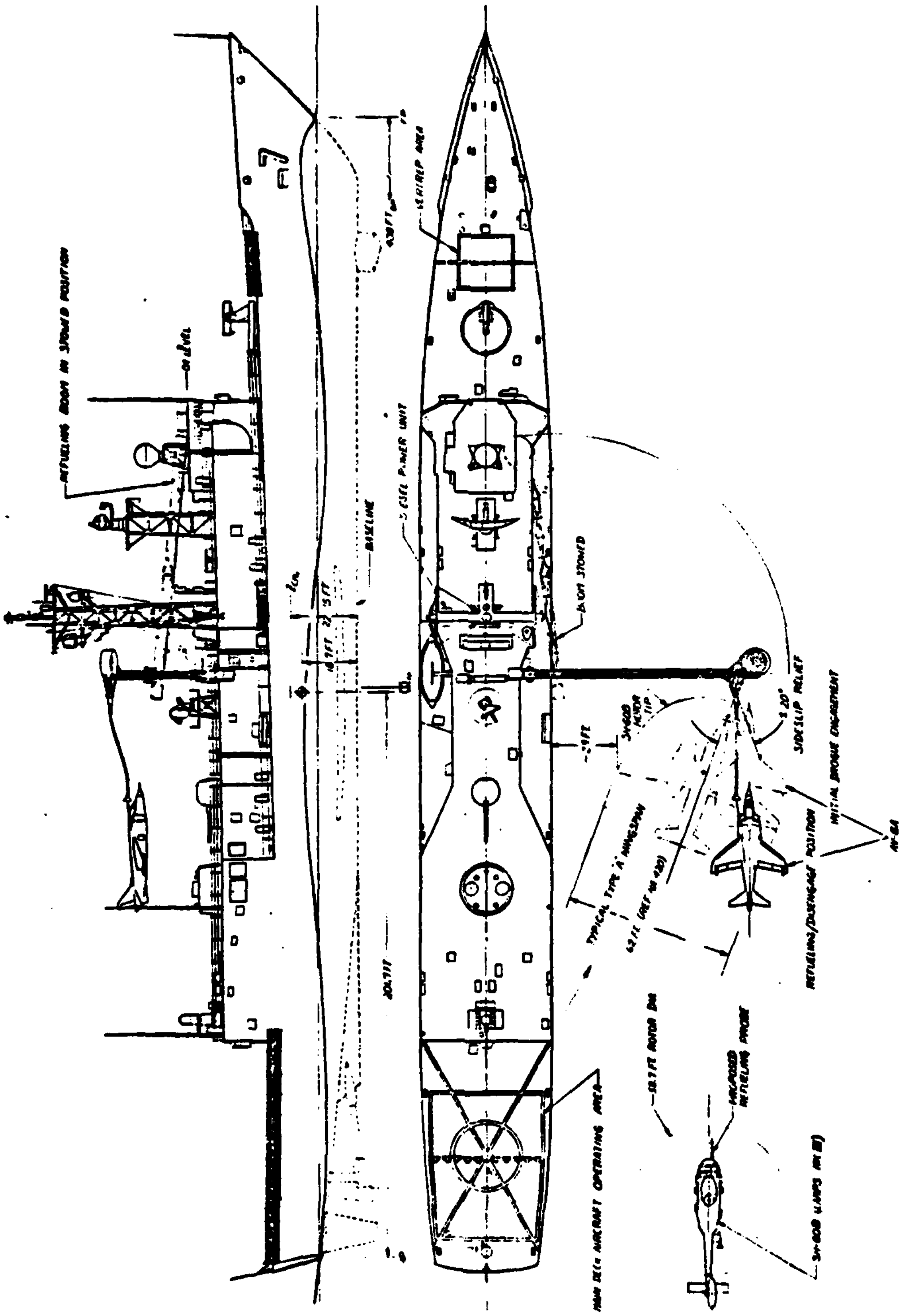


Figure 3-2 Suspended Refueling Boom System Installation on FFG-7

The position of the refueling drogue is controlled in the space over the sea by a boom control system which stabilizes the drogue in two degrees of freedom. Elevation from the sea surface is controlled by modulation of a lift fan located at the tip of the boom and lateral position is controlled by a hydraulic actuator connected between ship's structure and the vertical post. The boom mass is supported statically at its inboard end by a large pneumatic spring installed between the boom truss and the vertical post. The refueling drogue is thus stabilized against disturbances due to ship's roll, heave, sway and their encountered combinations (Figure 3-3). The proposed midship proximal location of the boom suspension is intended to minimize the effects of pitch and yaw motions such that additional control for these motions is not required through sea state 5. Uncompensated pitch, yaw and surge will be apparent to the refueling pilot in the form of low acceleration, mild translatory excursions in a "surge like" manner. While refueling, these excursions are attenuated by fuel hose slack.

3.4.2 Boom Retraction and Stowage

The ship mounted vertical post which supports the inboard end of the refueling boom is equipped to rotate about a vertical axis which is concentric with the post centerline. When unlocked for stowage the boom assembly is pivoted forward by the lateral position actuator which is offset from the vertical post axis by 1.2 ft. This offset permits a retraction moment to be developed whenever the vertical post is unlocked, of sufficient magnitude (approximately 38,000 ft. lbs) to retract the boom forward against a 40 knot wind. The vertical post design will not permit boom rotation rearward beyond a position which is normal to the ship centerline. On the Perry class frigate (FFG-7, Figure 3-4) the vertical post is first positioned against its outboard stops before the retraction moment is developed so that the boom will clear the main mast rigging when stowed. On the larger ships in the study sample such as the DD-963, the post is set in the vertical position for retraction and stowage. A platform is required in each case to support the outboard end of the stowed refueling boom and to provide a walkway for fuel system and fan maintenance.

3.4.3 Side-Slip Relief Feature

Aerodynamically derived control effectiveness and stability of fixed wing, direct propulsive lift aircraft diminish exponentially with decreasing airspeed. At airspeeds below that required for wing borne flight, propulsive lift must be generated with stability and control moments artificially provided by a reaction control system, propulsive lift vectoring or a combination of both. The contemporary AV-8A V/STOL aircraft exhibits yaw instability at airspeeds below that of wing borne flight to which the pilot must be very attentive (Reference (i)). Sideslip motions must be avoided such that any refueling device to which the AV-8A is approaching or in contact with must be aligned longitudinally into the relative wind.

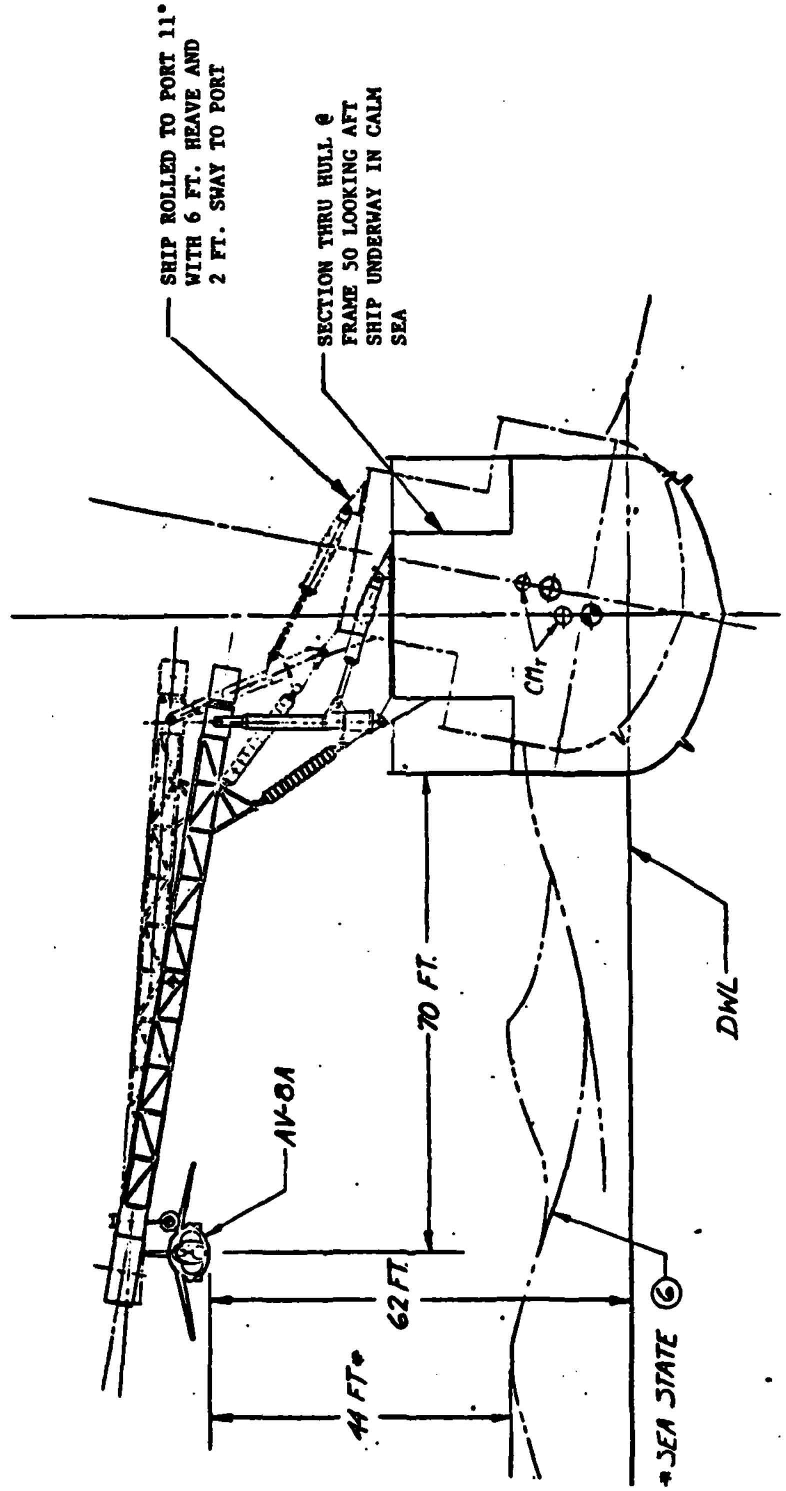


Figure 3-3 Section Through FFG-7 Hull

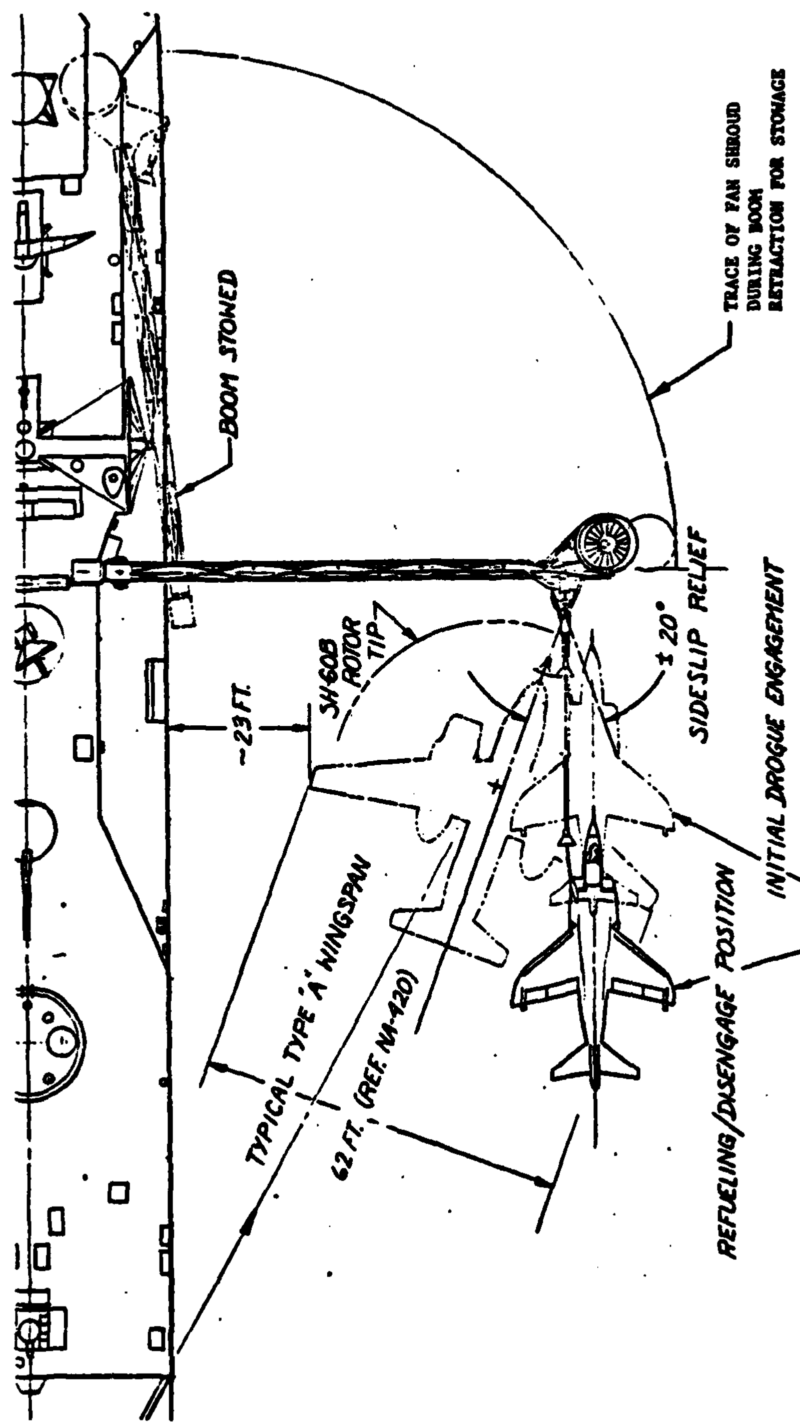


Figure 3-4 Plan View - FFG-7

The refueling drogue support mechanism is thus always servoed into alignment with the relative wind, within the ± 20° limits provided. The drogue support cannot be simply "weathervaned" with wind power at these low dynamic pressures. It is hydraulically servoed and damped, acting on commands from a small wind sensing vane mounted near the outboard tip of the refueling boom.

3.4.4 Port Or Starboard Suspension

The selection of a starboard side suspension on air capable ships is nearly arbitrary from a technical point of view, depending primarily on the ship's architecture and weapons/antenna interference criteria.

The LPH-2 class amphibious aviation ships require a starboard side suspension amidship to maintain unobstructed airspace for predominantly port side air operations.

The AV-8A currently has provisions for a flight refueling probe mounted on the LH inlet cowl (Figure 2-3, page 2-5). The probe tip is viewed 40° to the left of the airplane centerline. A starboard side suspension of the refueling boom enables the pilot to view the drogue target, the boom and the ship all in the same field which is preferable to the head and eye movement required with port side suspension.

It is also thought that installation of the refueling boom components from the customary starboard pier side is advantageous.

3.5 REFUELING BOOM SYSTEMS AND COMPONENTS

The purpose of the study described in this report was to determine feasibility of ship based inflight refueling devices. An exploratory design of the boom was undertaken only to the extent necessary to determine the approximate sizes and mass properties of the components in the system. Refinement of that exploratory design as a result of subsequent analyses was not undertaken but trends became apparent which will benefit future design work.

3.5.1 The Boom Truss Structure

Figure 3-5 illustrates the boom concept of a triangular cross section truss. The truss is weld fabricated of 6061-T6 circular aluminum tubing with three longerons, vertical members to stabilize longeron position, and alternating diagonals to accommodate bi-directional vertical loads on the boom. The main upper longeron is four inches in diameter, lined with a teflon sleeve and used as the fuel feed for the refueling equipment mounted near the tip of the boom. The teflon sleeve is provided as a durable and lightweight substitute for a length of standard fuel hose. It serves to protect the longeron from potential long term chemical reactions with the fuel and to discourage collection of fuel contaminants within the supply line. As a deicing/antiicing measure, fuel is recirculated through one of the three inch diameter lower longerons (also teflon lined) at a rate which is inversely proportional to the aircraft refueling demand.

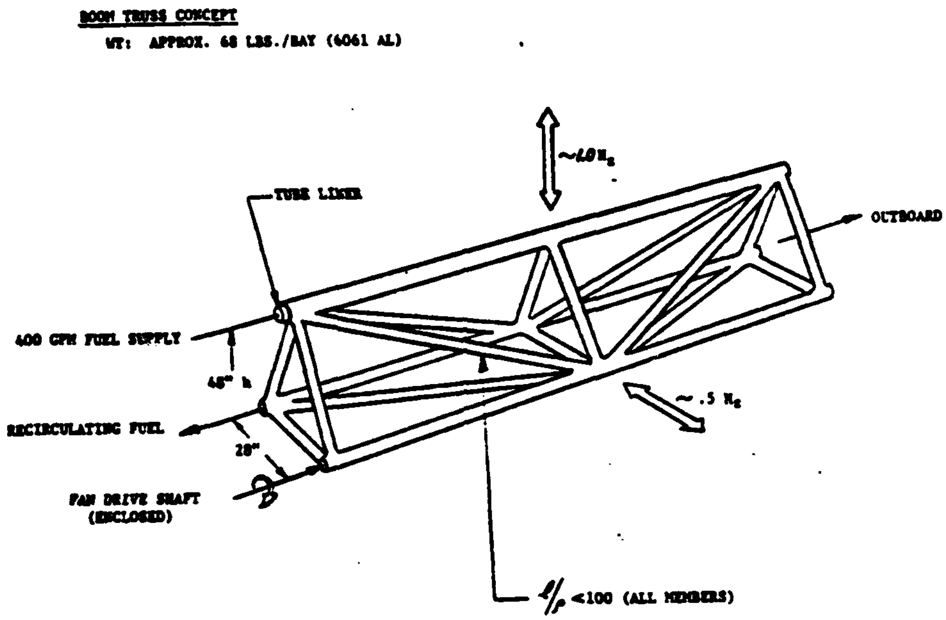


Figure 3-5 Boom Truss Concept

The process of adiabatic compression which results when the fuel pressure is raised for rapid circulation (400 gpm) in the boom also raises the thermal energy level of the fuel which can be used for structural deicing. The other three inch lower longeron is used to house a low torque high RPM fan drive shaft with appropriate bearings and flexible couplings incorporated at intervals along the span of the boom. These fittings permit torque shaft freedom while the boom is under deflection.

The isosceles arrangement of the boom cross-section provides greater stiffness in the plane of the major (vertical) axis than in the horizontal plane.

The exploratory design truss illustrated here revealed a resonant frequency (as if cantilevered) of approximately 1.0 H_z in the vertical plane and .5 H_z in the horizontal plane. Further dynamic analysis of the structure integrated with the stabilizing control system indicates that further stiffening in the vertical plane to approximately 1.5 H_z may be desirable. The .5 H_z value in the horizontal plane adequately provides for deflections from aircraft refueling probe-to-drogue contact loads.

3.5.2 Structural Corrosion

Design for corrosion resistance including materials selection must be carefully considered in any engineering of the complete ship based refueling boom assembly.

The aluminum alloy 5086 is nearly inert to clean seawater but is often difficult to procure (Reference (e)). The alloy 6061 from which the exploratory truss design is contemplated has excellent weld characteristics, good balance of strength and toughness, good resistance to marine corrosion and ready availability in a wide variety of forms. Its chemical compositon is akin to some casting alloys which are used in marine applications such as outboard motor housings and gear cases.

3.5.3 Refueling Equipment

The refueling equipment is mounted near the outboard tip of the boom aft of the shrouded lift fan assembly. This system consists of a hose reel containing 35 feet of 2 3/8 in. (ID) MIL-H-4495B fuel hose which is banded with fluorescent rings at intervals of ten feet. These rings indicate to the refueling pilot the amount of hose dispensed during withdrawal for refueling after the initial drogue capture is accomplished. The hose reel is connected concentrically with the boom upper longeron fuel feed line and is controlled by a hydraulic retraction motor. A fuel recirculation and surge damping valve is incorporated with the reel mechanism to supply the refueling aircraft proportional to demand, recirculate excess flow and to protect the aircraft from surge pressures. The hose and drogue assembly can supply fuel to the aircraft at a maximum rate of 360 gpm at 40 psig while the maximum feed flow in the boom is at the rate of 400 gpm.

Following each refueling, the dispensed hose is retracted into a "drogue presentation" position by the reel motor into a spring fairlead. The spring fairlead serves to mechanically stabilize the drogue cone from wind gusts and helicopter rotor downwash disturbances during drogue capture. The fairlead spring rate must be such that pitch and yaw excursions during capture are tolerated without overloading the aircraft mounted probe. Following drogue capture the pilot withdraws from the boom to a refueling position up to 30 feet aft of the capture position. The fuel hose is pressurized after a few feet of hose is withdrawn, thereafter permitting refueling with hose slack and more relaxed flight control manipulation.

Unlike air-air refueling there is an insignificant amount of aerodynamic drogue cone support due to the very low dynamic pressures available at ship based refueling speeds. Figure 3-6 illustrates the hose trail angle of approximately 4° which would be expected following disengagement of the drogue by the refueling aircraft. During refueling, therefore, one half of the dispensed hose and fuel weight plus the weight of the drogue (about 89 pounds for 30 feet of hose) will be supported by the refueling aircraft.

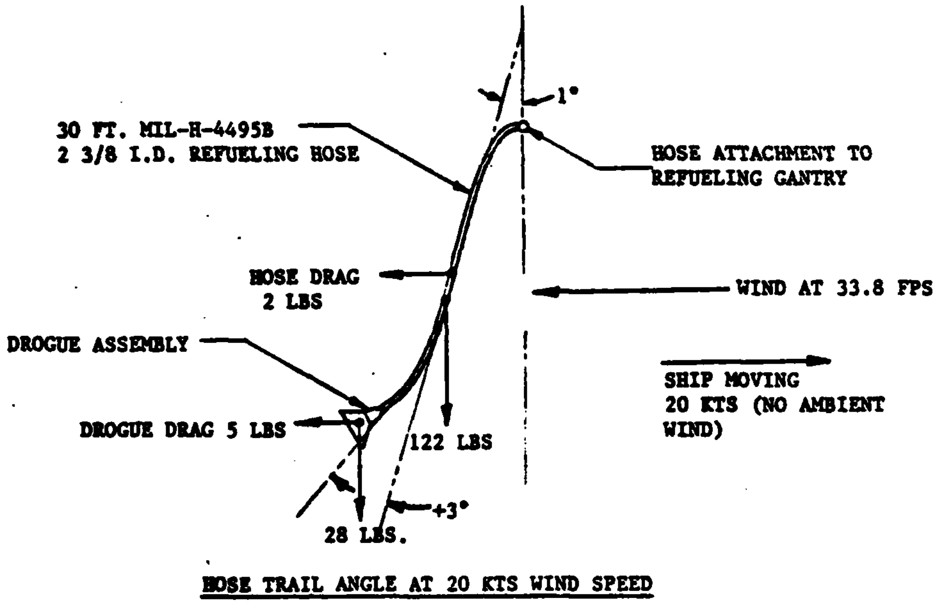


Figure 3-6 Refueling Hose Characteristics

3.5.4 Control to Counteract Drogue and Hose Weight

The aircraft control to trim the weight moment due to the drogue and one half of the hose and internal fuel weight is shown in Table 3-3. The pitch control and roll control are shown as a percentage of maximum control power and indicate that only nominal amounts of control are required leaving adequate control for turbulence or other transitory disturbances.

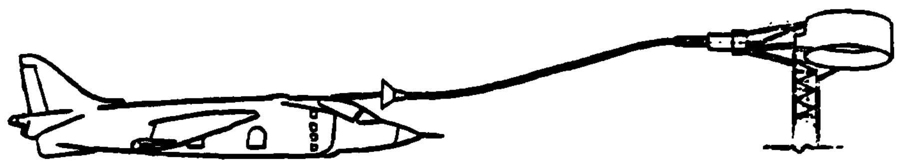
3.5.5 Drogue Disengagement

When refueling is completed the pilot of the refueling aircraft must reposition the nozzle or rotor thrust vector to withdraw from the refueling boom. The standard MS drogue will release the probe tip at a nominal tension force of 320 pounds (see Table 2-1 , page 2-36) when refueling pressure is extinguished automatically upon withdrawal of the last five feet of hose on the reel. A breakaway disengagement is also available to the pilot while fuel pressure is on, resulting in a nominal tension force of 520 pounds at 50 psi fuel pressure.

3.5.6 Shrouded Fan and Drive Motor

Control of the refueling boom and drogue height above the sea surface is provided by the tip mounted fan. The fan drive motor is mounted coincident with the boom axis in a counterweight position on the port side

Table 3-3 Control to Counteract Refueling Drogue and Hose Weight



ASSUMPTIONS

- 30 FEET MAXIMUM HOSE EXTENSION
- 0 TO 50 KNOTS
- NEGLIGIBLE AERODYNAMIC FORCES ON DROGUE AND HOSE
- DROGUE + ½ HOSE AND FUEL WEIGHT REACTED BY PROBE

PITCH

AIRCRAFT	FORCE AT PROBE	MOMENT ABOUT CG	% PITCH-UP CONTROL TO TRIM
AV-8A	89 LBS.	1558 FT-LB.	9.4/11.9% ①
AV-8B	89 LBS.	1558 FT-LB.	6.3 ②
CH-53D	89 LBS.	2688 FT-LB.	1.3 ②

ROLL

AIRCRAFT	FORCE AT PROBE	MOMENT ABOUT CG	% ROLL CONTROL TO TRIM
AV-8A	89 LBS.	378 FT-LB.	4.9/7.5% ①
AV-8B	89 LBS.	378 FT-LB.	2.2 ②
CH-53D	89 LBS.	208 FT-LB.	0.3 ②

① SINGLE AXIS DEMAND/SIMULTANEOUS AXIS DEMAND
② SINGLE AXIS DEMAND

of the vertical post upper pivot. The complete boom assembly is statically stablized by the combination of motor counterweight and the air spring support outboard of the boom pivot (Figure 3-7). Complete counterweighting for static balance is not desired since the boom would then be directly responsive to pure heave motions of the ship. The air spring is thus incorporated to assist counterweighting. Motor power is transmitted mechanically through a boom longeron, as previously described, to a right angle gearbox mounted on the fan shroud. The fan hub gearbox converts the high shaft speed input to a lower fan rotor speed and drives the fan. Since the boom assembly is statically stable the fan thrust is only employed for control and boom inertia damping by modulation of thrust amplitude and direction with blade pitch changes. Under calm conditions very little thrust is generated and, should the fan or drive system fail, the boom tip will not descend into the sea.

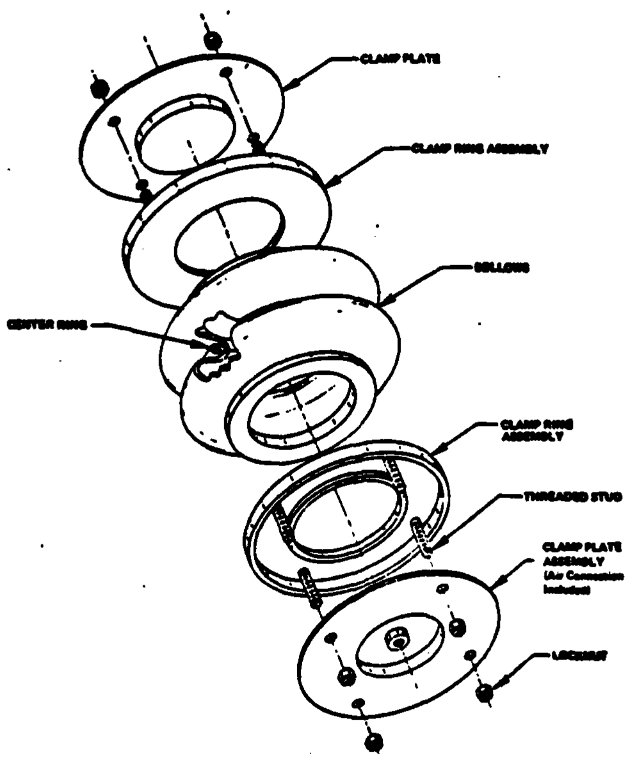


Figure 3-7 Segment of Air Spring Assembly

Extensive analysis is required to precisely size the fan and drive motor and has not been completed. The exploratory design illustrated in this report provides a fully reversible maximum fan thrust of 600 pounds while being driven by a constant speed electric motor of 60 BHP. Fan disk power loading is approximately 1.0, operating at a maximum fan pressure ratio of less than 1.1.

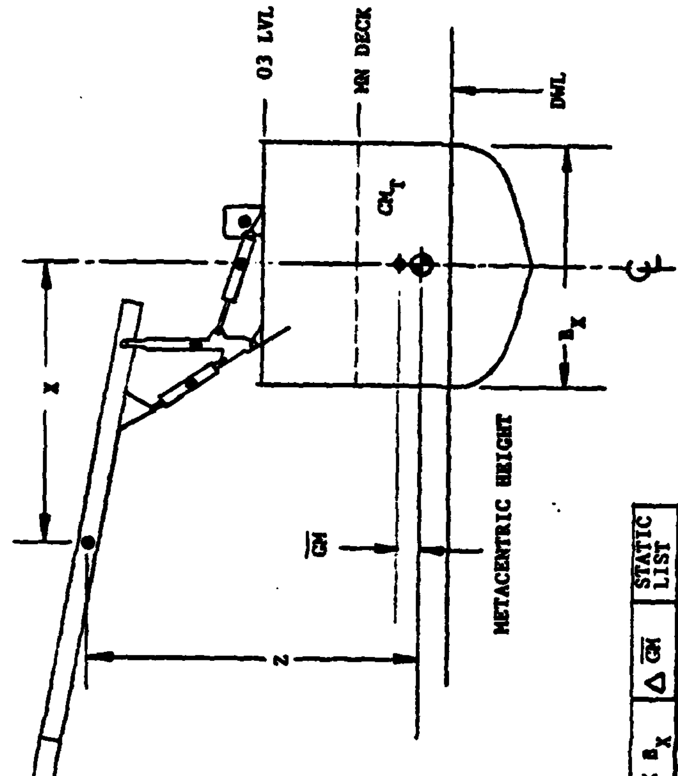
3.5.7 Boom System Power Supply

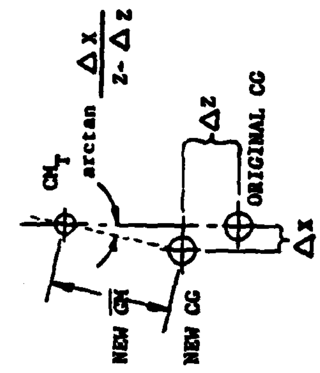
The maximum simultaneous power requirements for the fan, lateral control system, signal processing and lighting are estimated to be in the order of 100 kilowatts. An enclosed 450 BHP continuous duty diesel marine engine can be supplied complete with essential refueling boom system accessories, including the 400 gpm refueling supply pump, as a power source which would be independent of the ship's supply. Although ship's power might reasonably be tapped, the self contained unit would provide autonomous operation of the refueling system under combat conditions and greatly simplify ship alterations at the time of installation.

3.5.8 Effect On Metacentric Stability

The FFG-7 class frigate is the smallest of the ships in the study sample (Figure 2-1, page 2-2). An evaluation was made of the FFG-7 transverse metacentric stability change due to installation of the complete refueling boom system as shown in Figure 3-8. The value $\overline{GM}$ is the transverse metacentric height and represents the distance from the ship's center of gravity to the metacenter (see Reference (f)). If a deadload weight is added to the ship on a deck which is above the existing CG location, the net CG will rise in the hull thereby reducing the metacentric height. The waterline (Z plane) location of the metacenter will not change since that is determined primarily by the shape of the submerged hull cross-section. A righting moment is developed when a ship rolls if the CG remains inboard of a line connecting the metacenter with the hull center of bouyancy. Should the CG move outboard of this line, the ship will capsize.

Metacentric height is often used by naval architects as an indicator of the dynamic stability of a ship in roll as well as a static measure. Figure 3-8 shows the effects of the refueling boom moments added above the CG for both standard and full load displacements. Two options are considered which include boom installation with or without the independent power supply (diesel power unit). From standard displacement the installation of the boom and power supply will decrease the metacentric height by 3.0 percent and introduce a static list of 0.49° to starboard. From full load these values are 3.7 percent and 0.65° to starboard respectively. These metacentric height values are all greater than 6.4 percent of the ship's beam and are considered to be adequate for open ocean vessels (Reference (f)). It is also noteworthy that a portion of the full load weights are in the form of liquid consumables which, when partially depleted, will restore the metacentric height toward a value of 8.7 percent BX (beam dimension).





	WEIGHT LBS.	DIST. FROM CG-FT. X	DIST. FROM CG-FT. Z
BOOM ASSEMBLY	2330	53.4	63.0
AIR SPRING	1200	23.2	43.8
POST & FITTINGS	11220	15.6	42.3
ACTUATOR	3418	0	34.0
SUBTOTAL	18168		
DIESEL PWR. UNIT	4450	-14.0	32.0
TOTAL	22618		

FFG-7	DISPLACEMENT LONG TONS	$\overline{GM}$ FT.	% B_X	$\Delta \overline{GM}$	STATIC LIST
BASIC STD	3521*	4.05*	9.00	0	0
WITH BOOM	3529	3.95	8.78	-2.5%	.6°S
WITH BOOM & PWR. UNIT	3531	3.93	8.73	-3.0%	.49°S
BASIC FULL LOAD	3605	3.00	6.66	0	0
WITH BOOM	3613	2.90	6.44	-3.3%	.8° S
WITH BOOM & PWR. UNIT	3615	2.89	6.42	-3.7%	.65° S

*NSRDC SPD-738-01

Figure 3-8 Change in Transverse Metacentric Stability (FFG-7)

3.5.9 Boom Installations

Table 3-4 summarizes the recommended mounting locations for the suspended refueling boom system on the eight ship classes in the study sample. All installations are on the starboard side. Ship frame and deck level locations for the boom mount primary structure are given along with the resulting drogue height above the sea surface. Minimum drogue height is 67 feet on the FF-1052 class frigate. This drogue position provides more than adequate clearance to avoid the AV-8A stability and lift transients due to ground effects, even at the significant wave heights encountered in sea state 6. Helicopters such as the SH-60B are much less sensitive to ground effects than are propulsive lift V/STOL aircraft.

The architecture of six of the ship classes favor forward retraction of the boom whereas the CG-26 and AOR-1 classes require rearward retraction.

Location of the refueling boom on the AOR-1 class represents a departure from the desired midship proximal location. Since the suspended boom is not stabilized for excursion in pitch, it is desireable to locate the device as close to the ship's CG as possible. This location on the AOR-1 is occupied by prime replenishment and fueling stations at the main deck level. Numerous cargo booms, gantrys and masts are located near cargo holds which must remain clear. The presence of the suspended refueling boom in these areas would seriously interfere with replenishment operations conducted from the starboard side. Due to the large size (up to 37,000 L. tons) of these ships, however, it is thought that they are much less responsive in pitch to a given sea state than the smaller ships

Table 3-4 Mounting Locations - Suspended Boom Structure

		BOOM MOUNT		DROGUE HEIGHT (FT.)		
SHIP	SIDE	FRAME	DECK LEVEL	ABV. DWL	RETRACT	REFERENCE
FFG-7	STBD	100(*1)	03	68	FWD	84816-100 page 3-39/3-40
FF-1052	STBD	88	02	67	FWD	BUSHIPS DWG. NO. FF1052-845-2435989
DD-963	STBD	120	03	81	FWD	FIG. 1-1, p. 1-3 (INGALLS DS 145008)
CG-26	STBD	116 FWD	03	72	AFT	BUSHIPS DWG. NO. DLG26-845-1994792A
LPD-4	STBD	99	04	104	FWD	FIG. 3-9, p. 3-19(BUSHIPS LPD8-845-2166158)
LSD-41	STBD	187(*2)	37.5(*4)	113	FWD	NAVSEA DWG. NO. 5363758A
LPH-2	STBD	77	06	108	FWD	FIG. 3-10, p. 3-20
ADR-1	STBD	69(*3)	02	76(*5)	AFT	BUSHIPS DWG. NO. ADR-1-845-2522019

NOTES:
(1) 200 FT. AFT OF FP
(2) 187 FT. AFT OF FP
(3) 182 FT. FWD OF AP
(4) 37.5 FT. ABV MAIN DECK
(5) ABV 35 FT. W.L.

in the sample. Therefore, the boom mount structure is located well aft of amidship, just above the wardroom galley on the 02 level and clear of fueling station No. 9. Rearward retraction and stowage does not interfere with the replenishment spaces nor with the helicopter platform. When the boom is deployed for aircraft refueling, ship pitch changes will be interpreted by the boom mounted vertical accelerometer as a heave motion against which the boom is fan stabilized. Although motion data for the AOR-1 is not available for this study, it is expected that the sum of heave and interpreted heave due to pitch motions will be within the heave compensation limits of the boom control system in sea state 5.

There are inevitable but relatively minor interferences between existing ship installations and the refueling boom system during retraction for stowage. For example, Figure 3-9 illustrates the proposed boom mount location at frame 104 (04 level) on the LPD-8 (LPD-4 Class). The boom upper support pivot is located 24 feet above the 04 level mounting structure and, during retraction, the boom is inclined downward at a 16° angle to position the fan assembly between the 03 and 04 levels. The outboard components of the boom would sweep through existing whip antennae and signal searchlight hardware. Should installation of the refueling boom system be undertaken, engineering attention must be given during design to reposition these components and eliminate interferences. Mounting provisions for the lateral actuator on the 04 deck would impose an awkward passage to the ladder from 04 to 03 levels (frame 102), adjacent to the mount. The ladder could be repositioned to face inboard at frame 103 to illiminate this interference.

On all of the eight ships a stowage platform must be added for support of the boom outboard end and to facilitate routine maintenance of boom components. On the LPH-2 class, Figure 3-10, a structural platform must be added to the starboard side of the island between the 05 and 06 levels at frame 77 for boom mounting. The lateral actuator can then be accommodated athwartship in the existing passage to the radar dome (frame 82) aft of the island. Fan stowage is located just under the forward 3"/50 twin mount gun tub at flight deck level.

3.5.10 Stabilization/Control System

Stabilization of the refueling boom in the vertical plane can be accomplished by using signals from boom mounted accelerometers to drive a control system in a manner that keeps the ship induced accelerations zeroed. Isolation of ship's roll and sway results from the positioning of the boom laterally by the action of a hydraulic actuator. Vertical boom motions resulting from ship's heave and the components caused by roll are isolated by modulating the boom height with lift generated by a motor driven fan. Both the vertical and lateral control loops employ position feedback that keeps the boom centered prior to the engagement of the stabilization commands. Figure 3-11 shows a simplified block diagram of the stabilization loops.

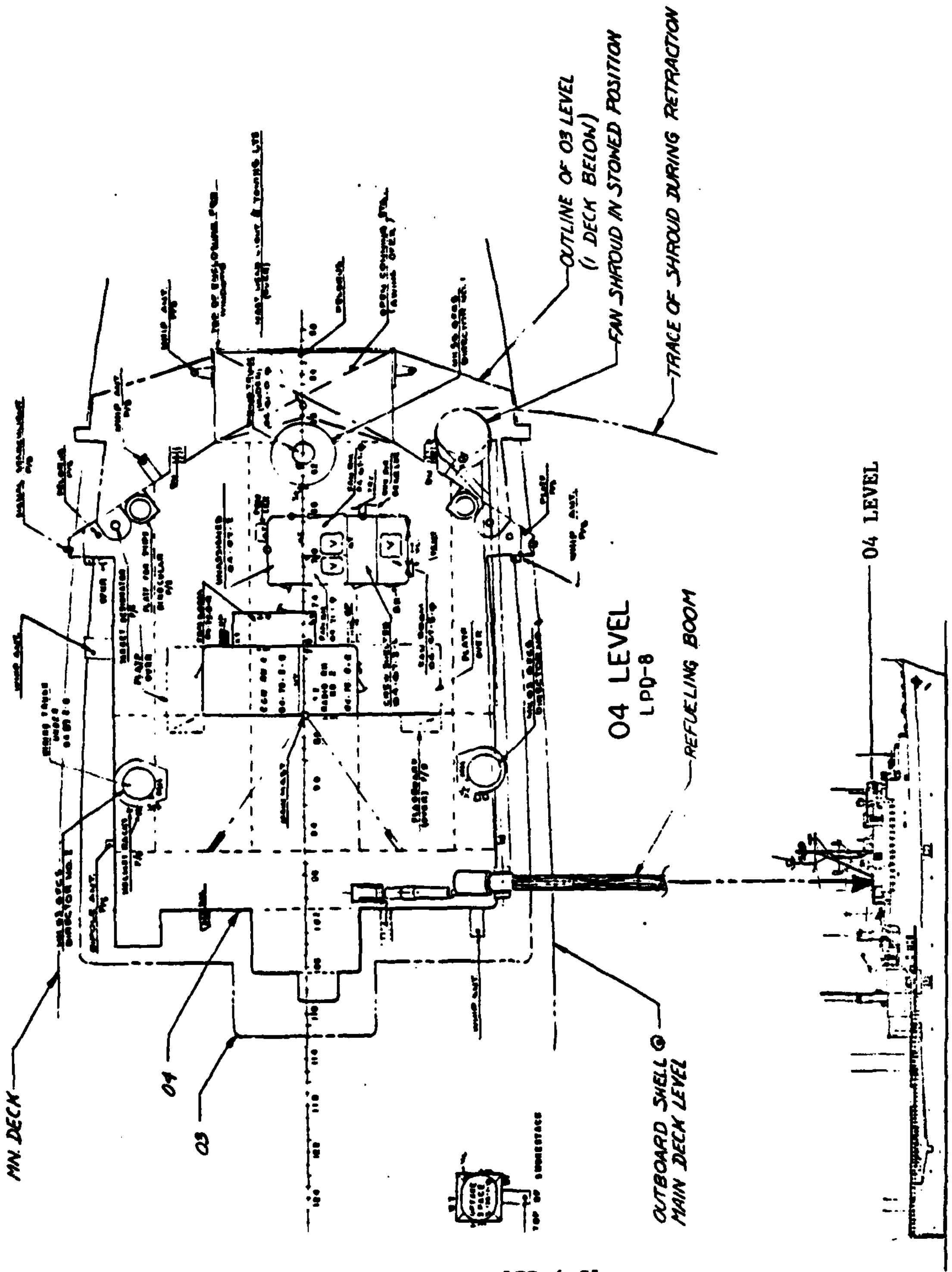


Figure 3-9 Proposed Boom Mounting - LPD-4 Class

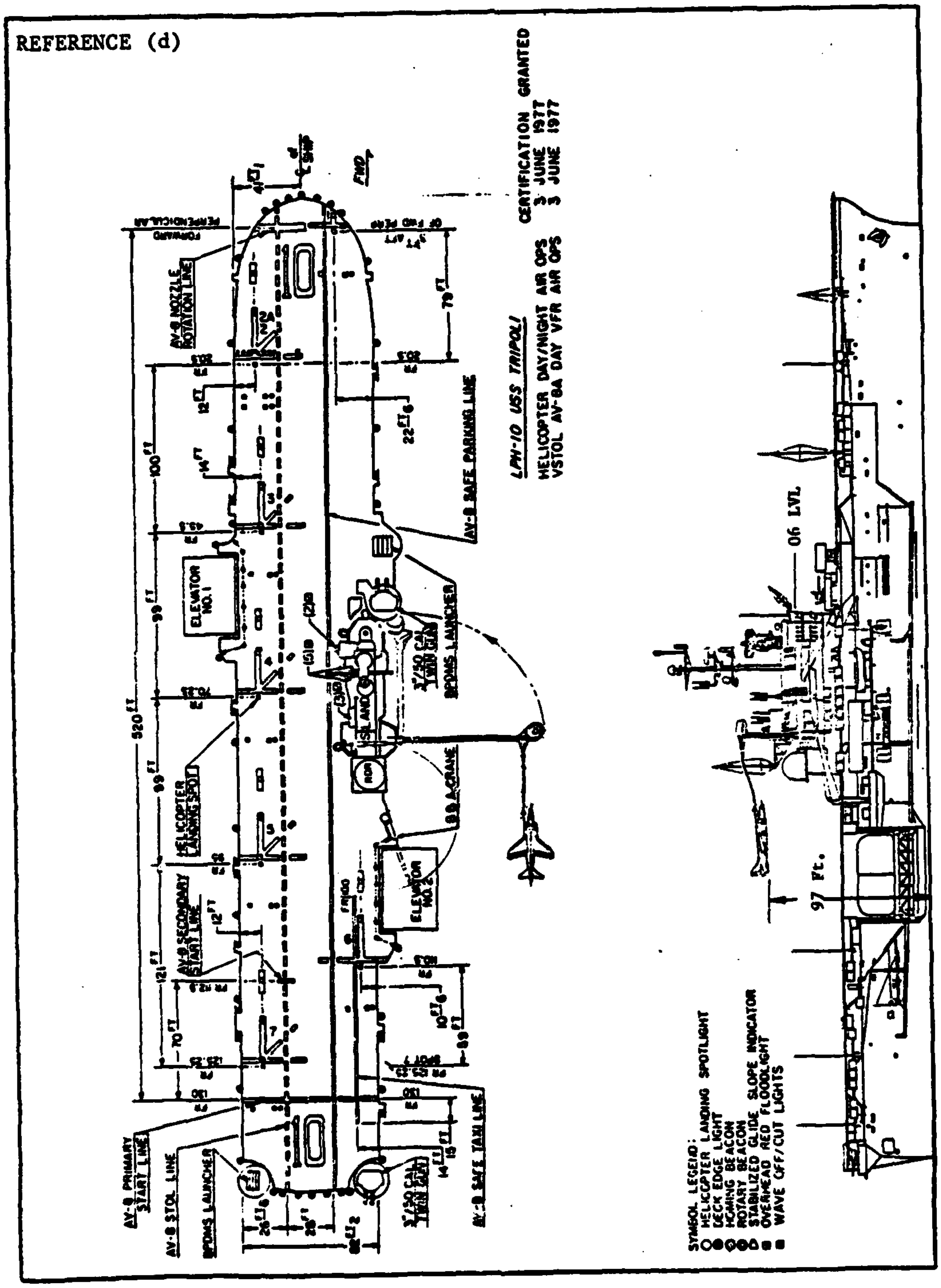


Figure 3-10 Proposed Boom Mounting - LPH-2 Class

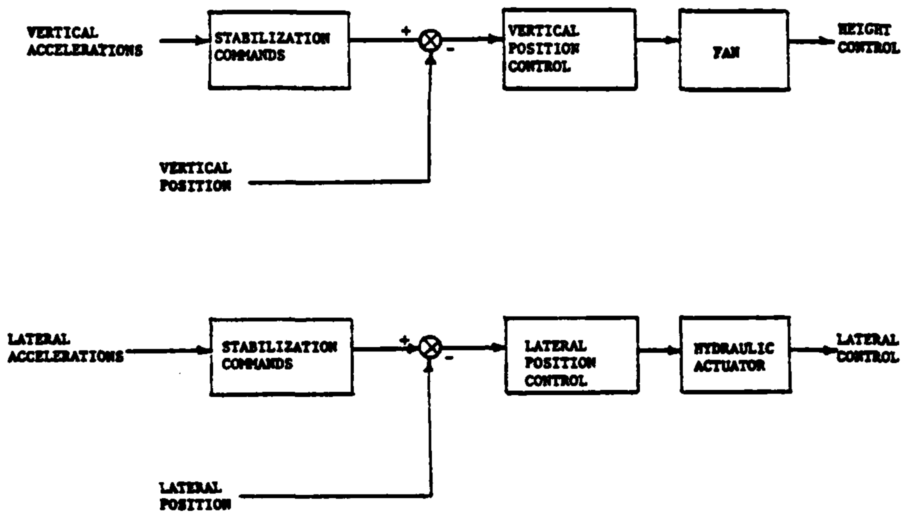


Figure 3-11 Simplified Stabilization/Control System

3.5.10.1 Design considerations - The dynamic requirements for stabilizing the boom evolve primarily from the amplitude and frequency of ship motion, and the wind/air wake turbulence encountered.

3.5.10.2 Ship Motion - The first steps in establishing a viable stabilization concept are to: (a) identify and scope the wide range of ship/seaway operating conditions where the airborne refueling procedure will be used and, (b) to determine the maximum (worst case) ship motion that could be expected. Analysis of ship motion is focused on the FFG-7 and the DD-963 classes of ships operating in sea state 5 conditions. The predicted responses of these class ships in various seaway environments are contained in the ship motion data base of Reference (a). The data of Table 3-5 has been extracted from this reference which shows the FFG-7 and DD-963 maximum expected motion amplitudes in 1000 consecutive cycles in a sea state 5 condition (i.e. wave modal periods of seven seconds and significant wave heights of ten feet). For these ships the 150° heading in a short crested sea represents the worst case conditions anticipated for the airborne refueling operation. Table 3-6 shows the worst heading ships responses of the FF-1052 in ten feet significant wave height seas.

Table 3-5 Maximum Expected Ship Responses In 1000 Cycles

(20 Knots, T_O = 7 Sec., 10 Ft. Wave Height (Sea State 5)

		FFG-7				DD-963			
PARAMETER	UNITS	180° LONG	180° SHORT	150° LONG	150° SHORT	180° LONG	180° SHORT	150° LONG	150° SHORT
VERTICAL ACC	FT/SEC^2	4.12	6.10	5.39	7.30	2.23	3.69	2.95	4.88
VERTICAL VEL	FT/SEC	3.08	4.72	4.13	5.76	1.75	3.16	2.41	4.35
VERTICAL DISP	FT	2.45	3.79	3.27	4.83	1.26	2.83	1.71	4.05
LATERAL ACC	FT/SEC^2	0	0.99	0.50	1.91	0	0.63	0.31	1.44
LATERAL VEL	FT/SEC	0	0.82	0.37	1.71	0	0.56	0.22	1.38
LATERAL DISP	FT	0	0.74	0.30	1.71	0	0.52	0.15	1.41
ROLL ANGLE	DEG	0	1.89	1.26	4.43	0	1.07	0.60	2.19
PITCH ANGLE	DEG	1.34	2.30	2.23	2.46	0.67	1.04	0.93	1.19

Table 3-6 Maximum Expected Ship Responses in 200 Cycles/For Worst Heading FF-1052

20 Knots, T_O = 7 Sec., 10 Ft. Wave Height (Sea State 5)

PARAMETER	UNITS	LONG	SHORT
VERTICAL ACC	FT/SEC^2	9.66/105	6.76/120
VERTICAL VEL	FT/SEC	7.70/105	5.40/105
LATERAL ACC	FT/SEC^2	7.08/105	4.83/105
LATERAL VEL	FT/SEC	6.30/75	4.50/90
ROLL ANGLE	DEG	20.5/75	10.4/75
PITCH ANGLE	DEG	.3/120	1.8/105

The responses are shown for comparison with the 150° and 180° ship's headings of the other two ships in Table 3-5. Based upon the foregoing data, design values for boom accelerations, velocities, and travels necessary to stabilize against ship's motion can be estimated.

3.5.10.3 Wind and Airwake Turbulence - Questions arise on how to best accommodate the effects of wind gusts and turbulence in the design of the stabilization system. During the final phases of flight just prior to hookup, the pilot is engaged in a precise tracking task to maneuver the aircraft's fuel probe into the drogue. Since the aircraft and the boom are in close proximity they are both subjected to the same disturbances. It would appear advantageous to design the boom with the same gust response characteristics as that of the aircraft in order to minimize their relative displacements. Gust detectors similar to angle of attack vanes used on aircraft could be installed on the boom to sense a disturbance and command a boom displacement to follow the aircraft's gust induced motion. Regardless of the approach, the solution of gust and airwake compensation, if needed at all, will require accurate models of the candidate ship's airwakes, models of a low altitude atmospheric turbulence, and the gust response characteristics of the aircraft involved. These models together with a detailed dynamic simulation of the boom and ship's motion should be employed in piloted simulations to identify and establish the levels of motion control needed for the refueling task.

3.5.10.4 Dynamic Requirements - Based upon the worst case ship motion and by allowing some additional margin for gust compensation, the dynamic requirements for the vertical and horizontal axes of control can be estimated. Table 3-7 shows the maximum expected ship motions in 1000 cycles for the FFG-7 and DD-963 during sea state 5 conditions (repeated from Table 3-5 and the corresponding boom dynamics needed for stabilization).

3.5.10.5 System Description - A pictorial view of the boom and its actuation components is shown in Figure 3-12. Both axes employ position feedbacks that maintain the lateral and vertical displacements centered within their respective limits in the absence of stabilization commands. The vertical position feedback consists of the angular displacement "A" between the boom and its support post while the lateral feedback is the measure of the roll actuator travel "B". Two accelerometers, one vertical and one lateral mounted on the fan end of the boom, supply stabilization signals that command boom position. The lateral and vertical control functions are mechanized in Figures 3-13 and 3-14, respectively. Initially, both position control loops are engaged with the stabilization commands deactivated. The boom will be driven to center in both axes by the signals from the position transducers. The rate networks shown in each of the feedback paths supply rate damping for the position loops. The stabilization functions consist of filtered accelerometer signals that are integrated twice to obtain position commands in each axis.

Table 3-7 Comparison of Worst Case Ship Motion and Stabilization Design Requirements

Sea State 5 - Maximum Expected in 1000 Cycles at CG

PARAMETER	UNITS	FFG-7 150° SHORT CRESTED	DD-963 150° SHORTCRESTED	REQUIREMENTS
Vertical Acc	Ft/Sec^2	7.3	4.9	$\pm$ 10
Vertical Vel	Ft/Sec	5.8	4.4	$\pm$ 15
Vertical Disp	Ft	4.8	4.0	$\pm$ 12
Lateral Acc	Ft/Sec^2	1.9	1.4	$\pm$ 10 (1)
Lateral Vel	Ft/Sec	1.7	1.4	$\pm$ 15
Lateral Disp	Ft	1.7	1.4	$\pm$ 12 (1)
Roll Angle	Degrees	4.4	2.2	(2)
Pitch Angle	Degrees	2.5	1.2	-

(1) Includes requirement for lateral acceleration induced by ship's roll

(2) Displacement will accommodate $\pm$ 11° roll angle

Having activated the position loops, the engagement of the stabilization inputs are accomplished automatically and sequentially. Zero crossing detectors are used in both axes to inhibit engagement until the accelerations pass through null. This logic presents unwanted initial position shifts that would unbalance the boom's operating limits. The automatic engagement logic is also mechanized to inhibit engagement of the vertical axis until after the lateral axis has been engaged. Initially, the vertical accelerometer sees significant acceleration components due to heave and to ship's roll as a result of the boom's cantilevered position. Since the major component of lateral acceleration is that due to ship's roll, operation of the lateral stabilization system removes both the lateral accelerations and the vertical accelerations caused by rolling. The predominant vertical accelerations are those resulting from only the ship's heave motions.

Some long term, slow drift rates can be expected with this system as a result of the ship's pitch motions and that due to the drift from the electronic integrators. Although it is expected to be quite small, this drift could result in an unacceptable unbalance of the boom's actuation limits if left uncorrected for an extended period of time. Automatic trim circuits could be implemented in the vertical and lateral control electronics as shown in Figures 3-3 and 3-4. These functions would periodically rezero the boom's position if a null shift exceeded a predetermined limit. The collection rate would have to be set low enough to avoid complicating the refueling pilot's tracking task.

3.5.10.6 <u>Actuation Requirements</u> - The actuation forces required in the vertical axis can be estimated from (a) the force or torque needed to accelerate the boom's inertia while operating against a spring, and (b) the force needed to statically balance the offset weight. Having the

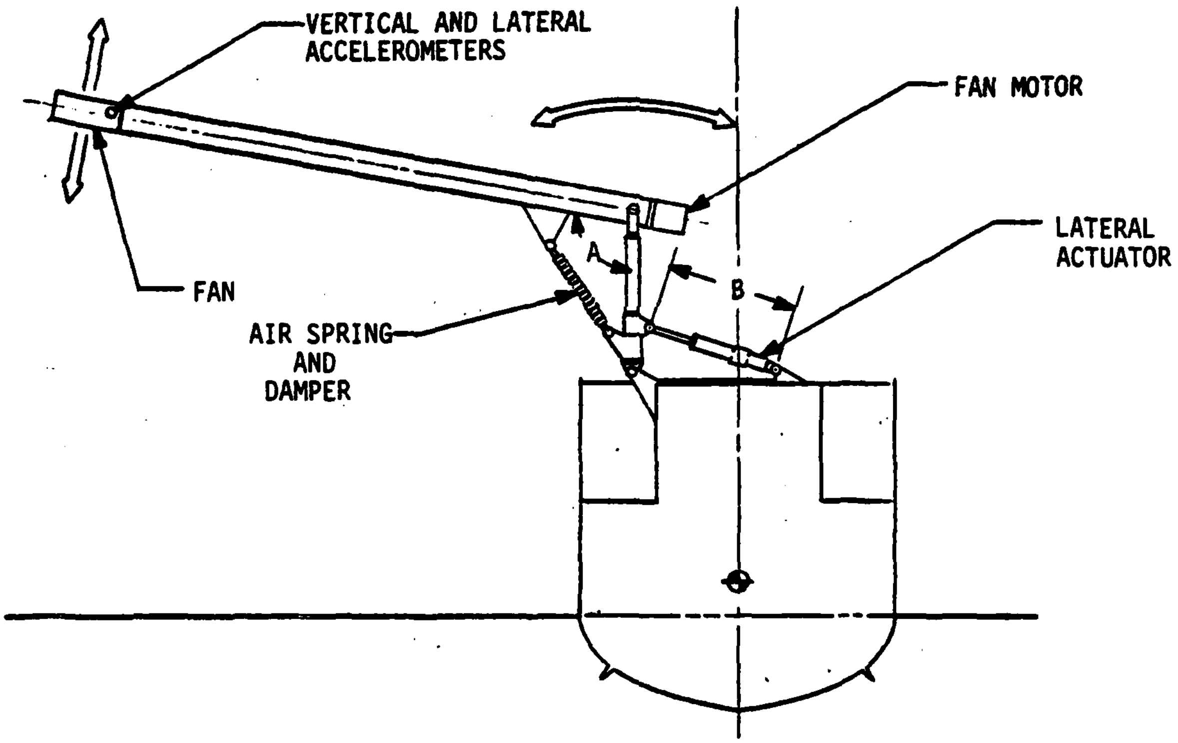


Figure 3-12 Refueling Boom Actuation Displacements

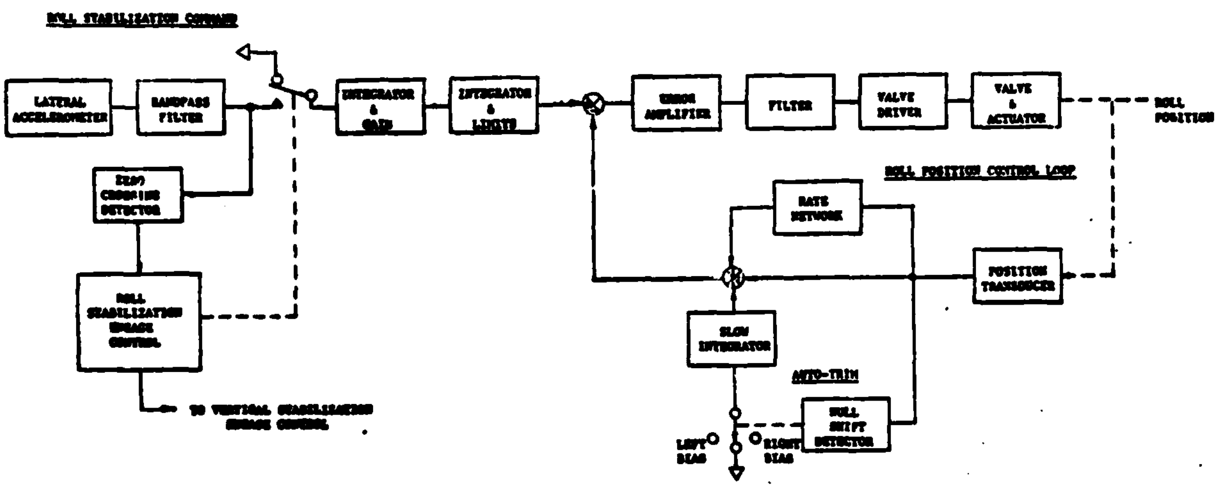


Figure 3-13 Roll Stabilization/Control Block Diagram

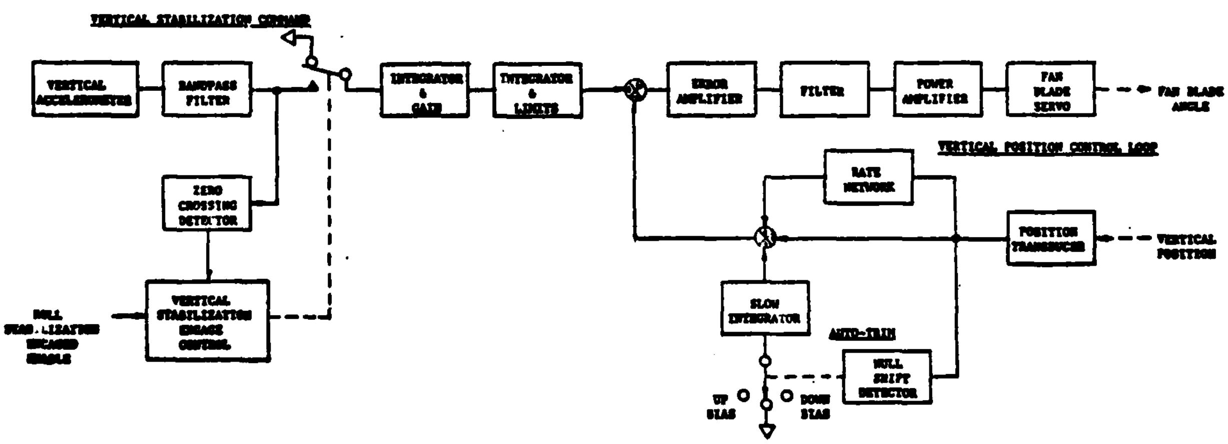
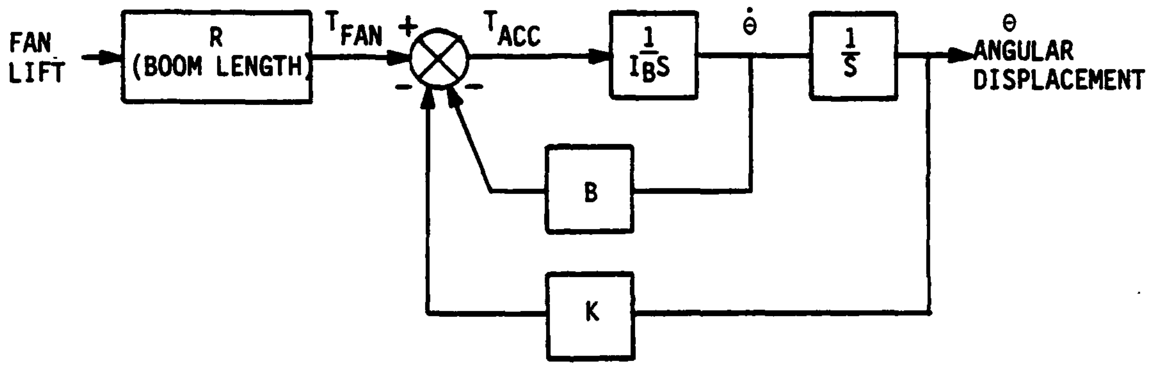


Figure 3-14 Vertical Stabilization/Control Block Diagram

spring travel sized to horizontally balance the boom reduces the fan lift requirements to that needed for movement. Figure 3-15 shows a simplified block diagram of the torque summation about the vertical pivot.



I_B - Boom Inertia
B - Viscous Damping Coefficient
K - Spring Constant
T_{FAN} - Fan Torque
T_{ACC} - Acceleration Torque
$\theta, \dot{\theta}$ - Angular Travel and Rate
S - Laplace Operator

Figure 3-15 Torque Summation, Vertical Axis

As shown, the acceleration torque equals the fan torque minus that required to overcome viscous damping and to displace the spring. Since the accleration and velocity parameters are 90° out of phase, the viscous damping torque can be ignored. Therefore, the maximum fan lift forces can be approximated from the sum of the acceleration requirement and the force needed to extend and compress the spring over its full range of travel. Figure 3-16 illustrates fan lift requirements versus vertical acceleration and various values of spring constants. These values are based upon an estimated boom moment of inertia of 178,000 ft-lb-sec^2 about its point of vertical rotation. Variations of this value would result in proportional changes to the slope of the curves. The lift intercept values at zero acceleration represent the amount of lift needed to compress or extend the spring to its maximum value. The selection of a

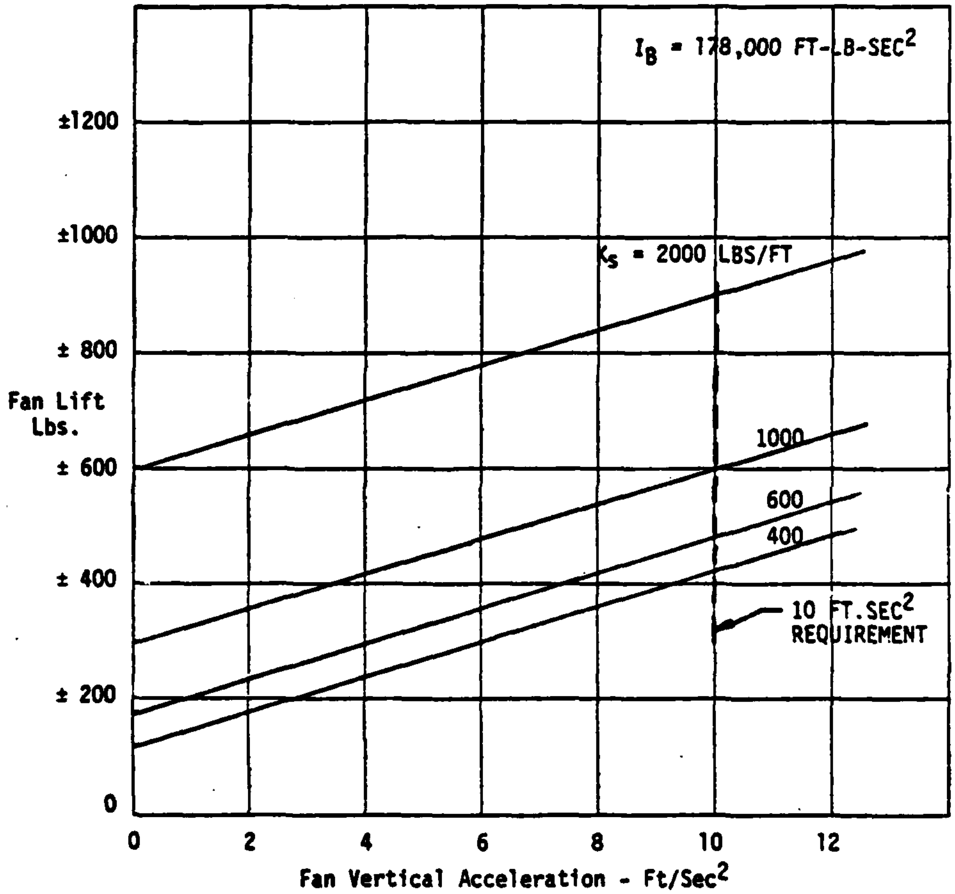


Figure 3-16 Fan Lift Versus Acceleration and Spring Constant

spring constant is subject to certain constraints as a result of its effect on the boom's natural frequency and its accompanied influence on closed loop stability. This subject is addressed in paragraph 3.5.10.7.

The lateral actuator forces can be sized in a similar manner by summing the torques about the support post pivot needed for static balance and for holding the boom/support assembly against a rolling ship. The boom's lateral acceleration requirement was shown in Table 3-7 to be $\pm$ 10 ft/sec^2. This actually represents the acceleration of the boom due to the ship's rolling motion with the boom laterally centered with respect to the ship (i.e. stabilization disengaged). The actuator force required to hold the boom centered against this acceleration in conjunction with that required for static balance represent the major factors in sizing the actuator. The actuation forces are actually at a minimum when the stabilization system is engaged in the presence of a rolling ship. Due to its inertia, the boom assembly tends to remain stationary in inertial space with the actuator force employed to overcome pivotal friction and to balance the offset weight. In general, the same reasoning can be applied to the vertical axis but the presence of the spring complicates the analogy. The methodology previously used to size the fan lift was valid by assuming the ship stationary and calculating the forces needed to move the boom. Table 3-8 shows the actuator forces needed to hold the assembly against the worst case lateral acceleration of 10 ft/sec^2. The figures are based upon an estimated moment of inertia of the boom and vertical support post of 300,000 ft-lb-sec^2 about the lateral pivot.

Table 3-8 Lateral Actuation Requirements

REQUIREMENT	ACTUATOR LOAD - LBS.
1. Acceleration	18,000
2. Static Balance	13,000
Total	31,000

The actuator travel requirements are ± 4 feet and its mechanical design must provide for a high level of stiffness. A high flow rate variable displacement hydraulic pump, driven by the boom power supply, will be needed to power the actuator at high flow response levels.

3.5.10.7 Control Stability - The control and stability of the boom must be addressed first separately and then collectively in the following phases of operation:

a. Initial positioning

b. Pre-stabilization engagement

c. Stabilization engagement

During the initial positioning phase, the boom is unstowed, the lateral hydraulic actuator and its position control loop are powered, and the air spring is inflated to elevate the boom to a horizontal position. At this time the fan will be off until the boom is positioned outboard in its normal operating mode. In the pre-stabilization phase, the fan and the vertical position loop are energized in conjunction with the previously engaged lateral position loop to keep the boom positioned vertically and horizontally with respect to the ship. During the third phase, the stabilization systems are engaged to inertially stabilize the boom with signals from the boom mounted accelerometers. The lateral control loop design with regard to closed loop stability is direct and uncomplicated. The approach would be to establish a position loop bandwidth sufficiently beyond the highest expected ship motion frequency (approximately one radian) and then proceed with closing the outer accelerometer loop.

Control of the vertical axis is less straightforward due to the necessity for the air spring both as a support device during the initial positioning phase and as a backup support in the event of a fin failure. During the stabilization phase it would be better to remove the spring entirely because of its undesirable coupling of ship's vertical motion directly to the boom. In this situation, however, approximately 1100 pounds of fan lift would be needed for static balance alone which would unacceptably increase the weight of the fan drive system. Having established the need for the spring, the next task is to select the optimum spring constant which would provide the best overall performance in the three operating phases. The selection of this constant is limited on the high end to about 2000 lbs/ft. Higher values would require excessive fan lift (> 1000 lbs), see Figure 3-16, during the stabilization phase. The lower limit is about 400 lbs/ft because of the excessive spring travel needed to absorb the weight of the boom in the event of a fan failure. With fan lift, the spring would compress to approximately 7500 pounds of force through 15 feet of travel. The range of spring constants between these limits coupled with the boom's inertia creates a mechanical oscillator having natural frequencies of 0.6 to 1.4 rad/sec that fall in the band of expected ship motion frequencies. This complicates the stability of the vertical position loop because its closed loop band width must extend beyond the highest ship motion frequency. However, with selective compensation the loop can be stabilized independent of the natural frequency location of the boom/spring combination. Therefore, the spring constant should be selected on the basis of its impact on minimizing fan lift while providing an acceptable boom stiffness in the initial positioning phase. An approximate figure would be 1000 lbs/ft which results in a natural frequency of about one rad/sec.

Figure 3-17 shows a hypothetical gain/frequency characteristic of the vertical acceleration loop. The open loop gain should be maintained as high as possible across this range of frequencies to achieve good stabilization. At frequencies beyond the highest ship motion, the gain must be rapidly attenuated, briefly slowed at crossover, and then again rapidly attenuated to avoid structural coupling with the boom's first bending mode.

3.6 SHIP'S SPEED MANAGEMENT

3.6.1 Engagement and Refueling Speeds

One of the goals for selection of ship based refueling devices from the candidate concepts shown in Table 3-1 specifies the capability of refueling V/STOL aircraft without imposing operational restrictions upon the ships. Operations which are detractive from each ship's primary mission would thus be minimized. The design of the system should permit aircraft refueling from any speed within the capability of the ship

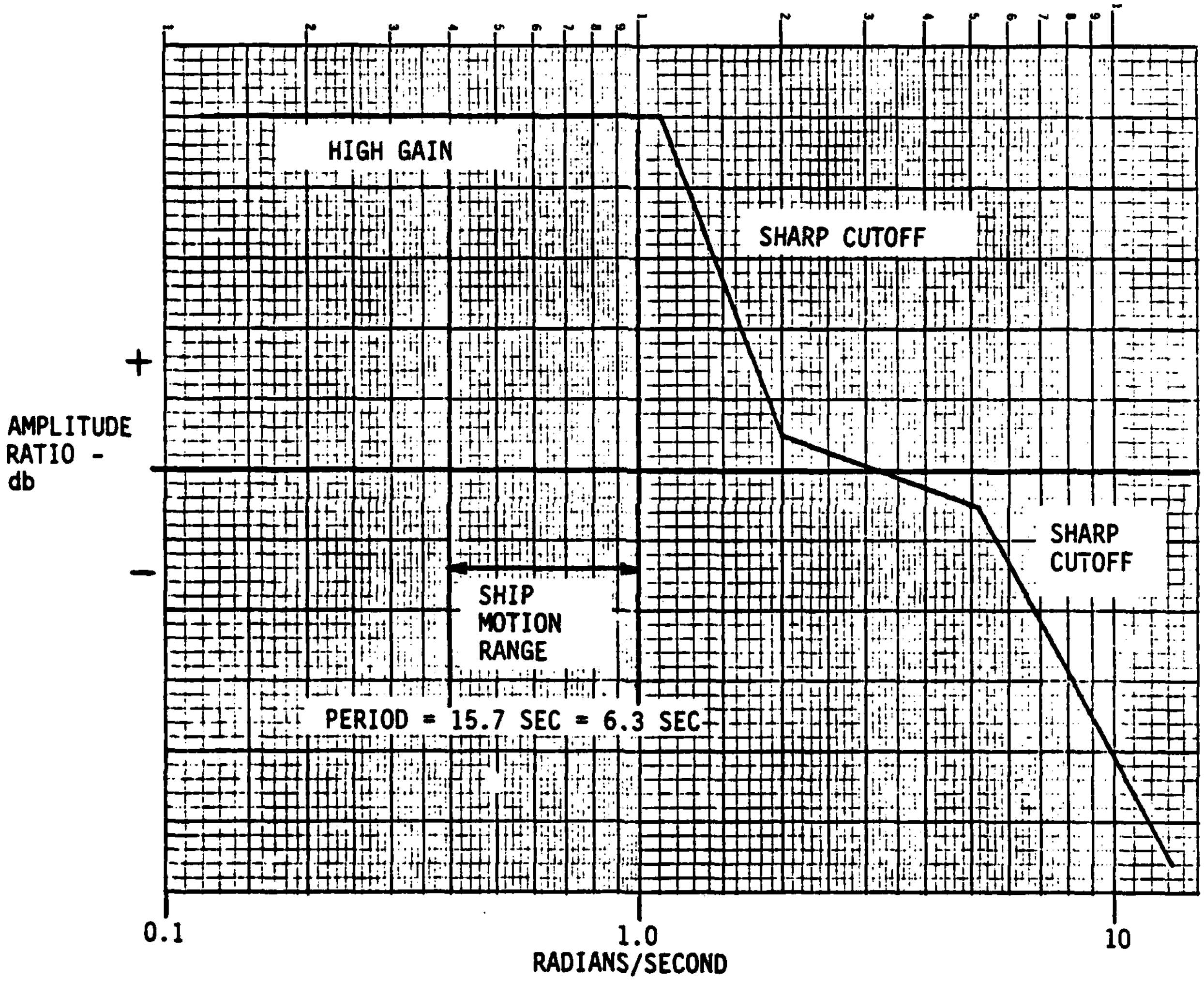


Figure 3-17 Vertical Stabilization - Open Loop Desired Gain Versus Frequency Characteristics

ranging from zero knots through the maximum speed of the ship and including the sum of maximum speed and the nominal windspeed accompanying sea state 5. Against head seas this would cover a range of:

WIND (KTS)	SS	SHIP SPEED RANGE (KTS) DD-963	AOR-1	WIND OVER DECK (KTS) DD-963	AOR-1
Calm	1	0-33	0-20	0-33	0-20
24	5	10-23	6-15	34-47	30-39

Within sea state 5 these ships will not achieve their maximum speed because of the combined effects of increased hydrodynamic resistance and additional Sea Kindliness considerations.

Figure 3-18 illustrates the reduction in ship's speed as a function of advancing sea state. It shows that DD-963 would be expected to maintain up to approximately 95 percent of its design maximum speed at significant wave heights of ten feet (mid sea state 5). Prudent ship speed management in deference to Sea Kindliness (galley and crew considerations), however, will otherwise limit speed to approximately 70 percent of her design maximum during low threat cruise operations, particularly against head seas.

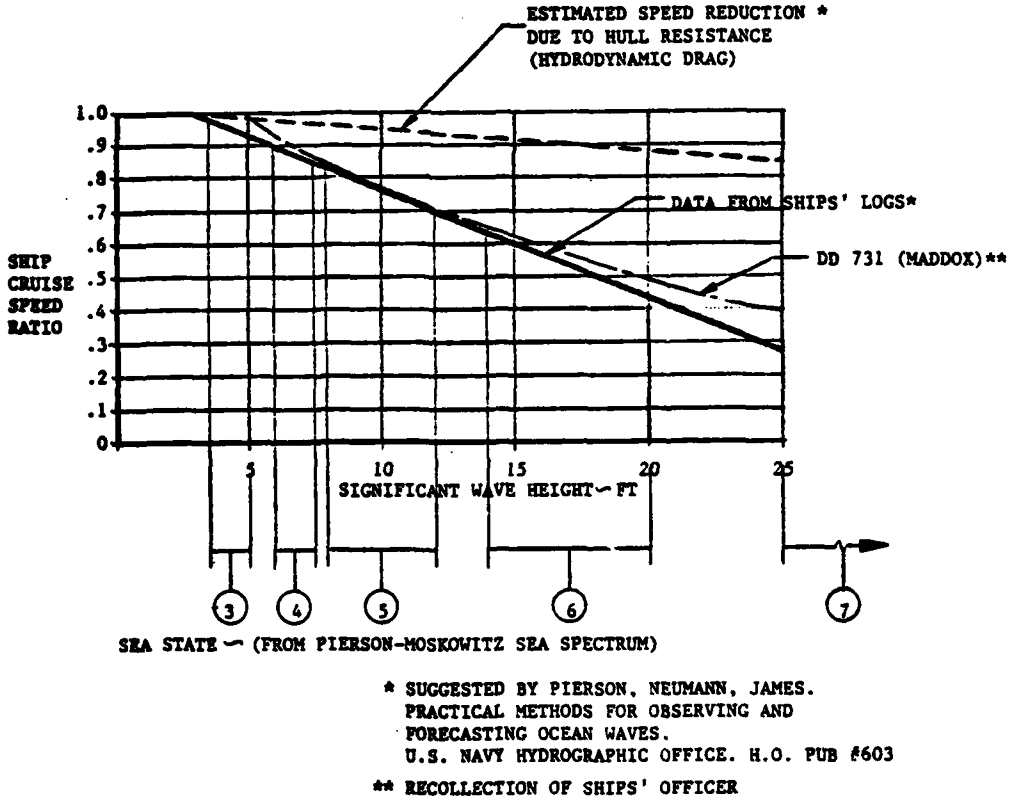


Figure 3-18 Ship Speed Reduction Data

AV-8A takeoff and landing operations aboard ships are currently limited to wind speeds below 45 knots (Reference (h)). The combination of ship speed and head wind previously tabulated (0-47 knots for DD-963 and 0-39 knots for AOR-1) reasonably match the requirements of the AV-8A in jetborne flight and with the refueling sideslip relief feature (± 20°) imposes no speed restriction on the ship during refueling. The ship must, however, turn into the relative wind within the limits shown in Figure 3-19. For example (from Figure 3-19 data point), an Austin class LPD equipped with the refueling boom, preparing to refuel a flight of AV-8As while cruising

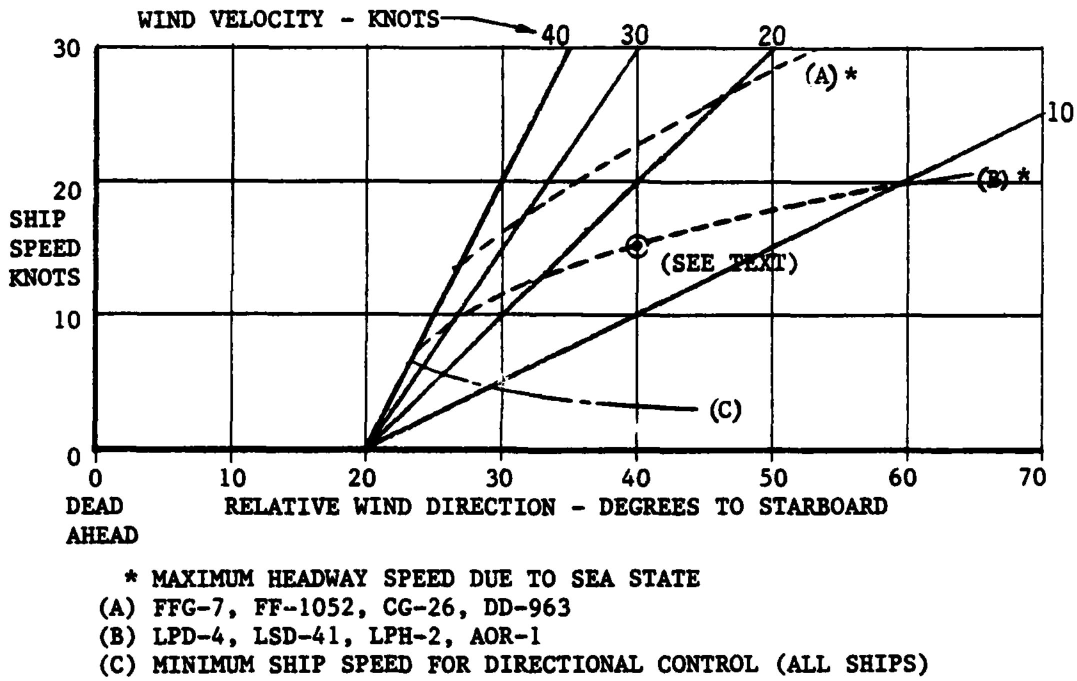


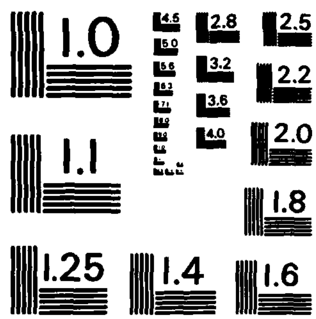
Figure 3-19 Ship Refueling Heading Requirements

in sea state 4 at 15 knots will turn to a heading which places th ambient wind vector within a range of 40° to starboard to 20° to port. High ambient winds from portside relative headings greater than 20° would position the ship's turbulent airwake directly over the starboard refueling station. Although this turbulent condition is within the control power limits of the aircraft to accommodate (Figure 3-20), it would increase cockpit workload and should probably be avoided. The reader is reminded at this point that the expected wind velocities accompanying given sea states (as presented in Table 3-2, page 3-3) apply to wind generated waves over at least 100 miles of seaway (long fetch) and over a 20 hour period. The seaway often contains waves generated by the effects of swell from storms orginating elsewhere. A swell confused sea need not always be accompanied by high winds and conversely high local winds can be experienced temporarily in a benign seaway.

AD-A147 695 A STUDY OF SHIP BASED INFLIGHT REFUELING OF V/STOL AIRCRAFT(U) ROCKWELL INTERNATIONAL COLUMBUS OH NORTH AMERICAN AIRCRAFT OPERATIONS 07 APR 81 NR81H-18 2/2

UNCLASSIFIED N62269-81-C-0303 F/G 1/5 NL

END
FILMED
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

REF: NADC REPORT 77123-30 VOL. 1
LPD-CLASS SHIP
50 FEET ALTITUDE
NOZZLE ANGLE FIXED
SEA STATE 5
INCLUDES SHIP AIRWAKE

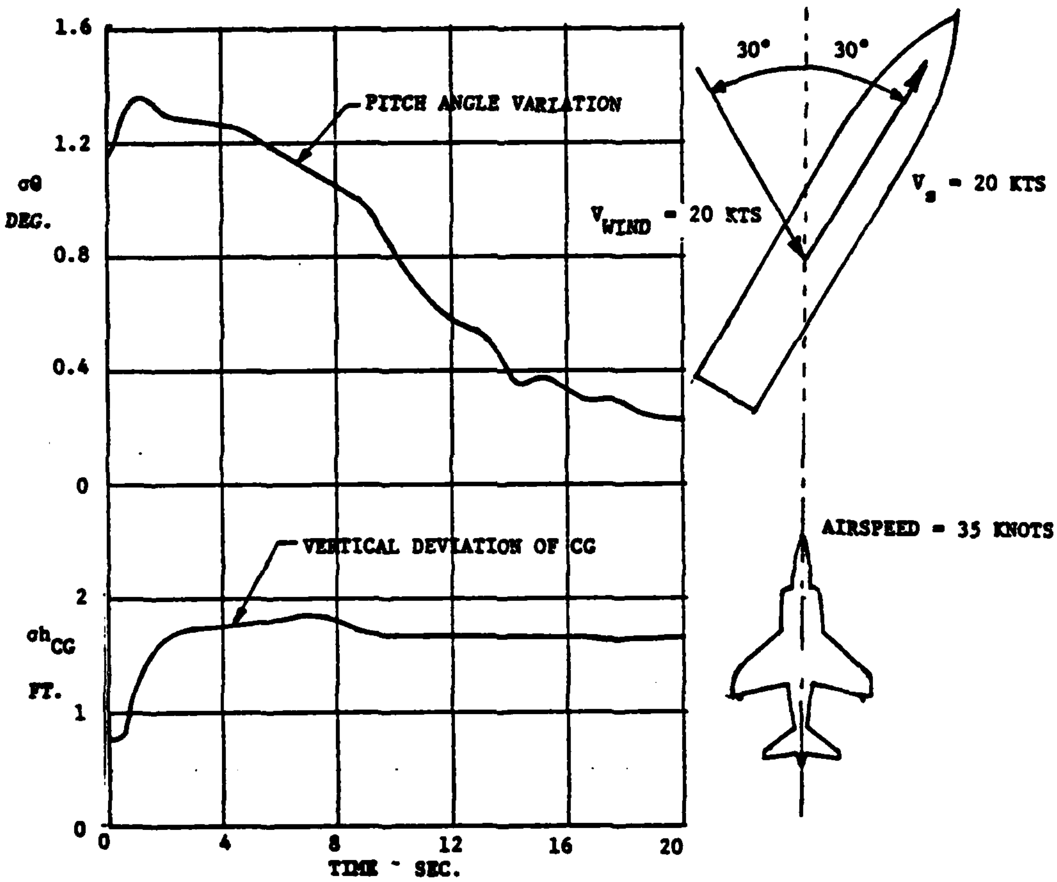


Figure 3-20 AV-8A Approach Through Ship Airwake

In actual practice no calculation would be required, whatever the wind velocity or direction. A relative wind direction sensing vane, mounted on the outboard end of the refueling boom, required to slew the drogue support directly down wind, can also command a repeater indicator mounted in the ship's wheelhouse. The helmsman need only steer to position the indicator within the sideslip limits of the refueling boom.

3.6.2 Helicopter Refueling

A helicopter main rotor operating in hover produces a stream tube which is downward flowing and normal to the plane of the rotor disk. The rotor is operating in what is defined as the normal working state if it is not descending through the surrounding air mass (Reference (w)). In the normal working state, as the helicopter is accelerated in forward flight, the rotor induced stream tube deflects rearward as a function of the ratio of the forward flight velocity and the rotor induced velocity (taken in the plane of the rotor disk) (Reference (x)). The magnitude of stream tube deflection is given as:

$$\chi = \tan^{-1} (V_F/v_o), \text{ degrees}$$

where:

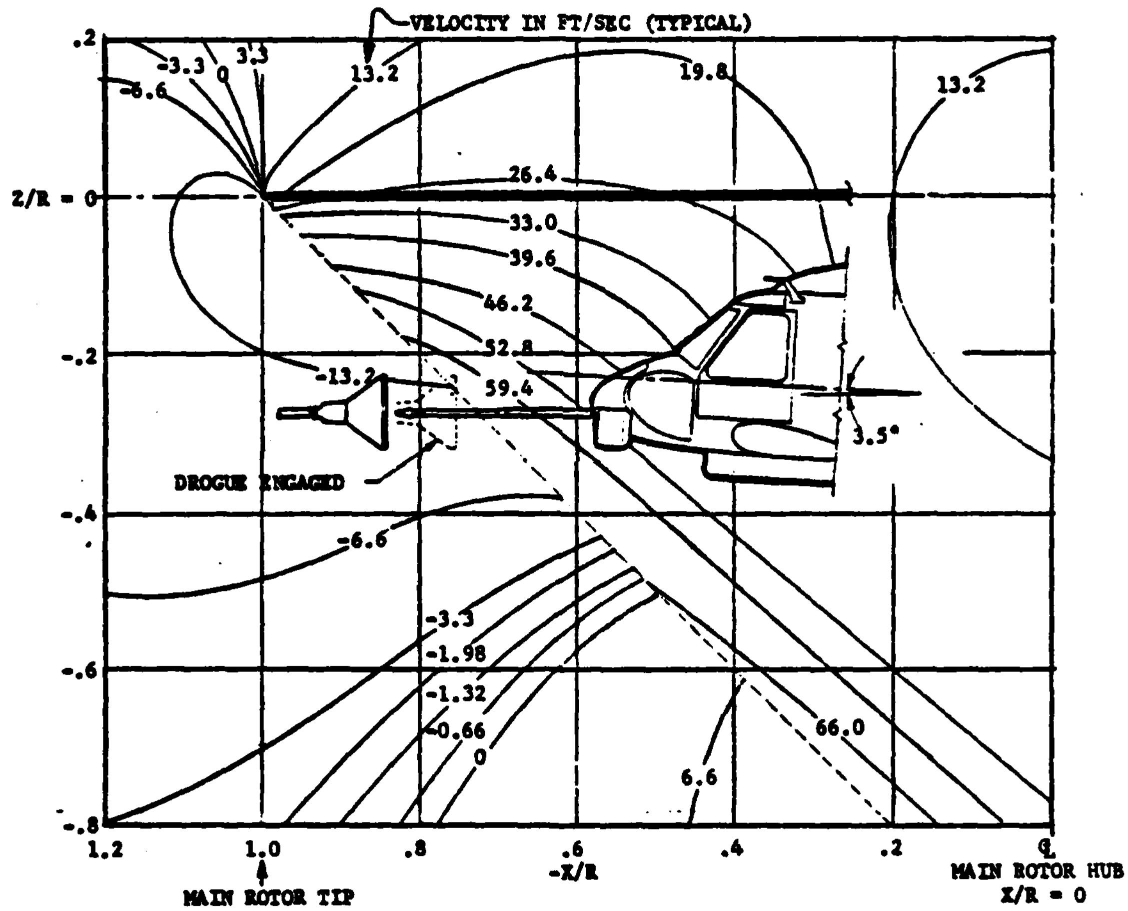
V_F = the forward flight velocity

v_o = rotor induced downwash velocity in the rotor plane

The rotor induced downwash velocity is a function of the rotor disk loading and rotor blade characteristics. Figure 3-21 illustrates rotor characteristics, induced field velocities and stream tube deflection estimated for the SH-60B (LAMPS MK 111) helicopter while in forward level flight where the forward velocity is equal to the rotor induced velocity and the stream tube is deflected 45°. In this case both velocities are equal to 33 ft/sec (approximately 20 knots). The inflight refueling probe minimum length, established in Section 2.2.1.1, page 2-4, falls just outside the region of high shearing stress between the forward edge of the stream tube and the approaching air mass at this forward speed. The boundary will include the turbulent effects of the rotor tip vortex which may induce drogue jitter and complicate probe and drogue engagement at lower speeds.

When the boom mounted refueling drogue is retracted into the "ready" position it is mechanically stablized but not rigidly, such that pitch and yaw variations of the refueling aircraft during engagement will not overload the probe in bending. Further study is needed to determine the optimum value of probe leng*h, rigidity of drogue stabilization and engagement speed. The obvious solution of extending the probe beyond the rotor tip to avoid any potential engagement problems is fraught with other penaltities such as hangar stowage, complexity and reliability of probe retraction mechanism and aircraft weight.

Rotor Tip Speed: 725 Ft/Sec., Rotor RPM: 258
Rotor Geom. Area: 2262 Sq. Ft., Equiv. Area (Se) - 2142 Sq. Ft.
W/Se = 15500 Lbs/2142 = 7.24 Lbs/Sq. Ft. (At Refueling Weight)
β = .973 (4 Blades)
C_t = .0055
v_o = 33 Ft/Sec. = V_f (19.54 knots)



ISOGRAM OF ROTOR INDUCED FIELD VELOCITIES
- SH-60B LAMPS MK III AT V_f ≅ 20 KTS

Figure 3-21 SH-60B Estimated Rotor Characteristics (V_F = 20 Knots)

Since the AOR-1 (slowest ship in the sample) can theoretically provide wind-over-deck velocities of at least 20 knots in head seas, the SH-60B probe length illustrated in Figure 2-5, page 2-7, is considered feasible.

3.6.3 Advanced V/STOL Aircraft Refueling

Refinement of existing V/STOL technologies in combination with emerging technologies will provide low speed flying qualities which are superior to those of the AV-8A. Indeed the AV-8B successor is a significant advancement over the AV-8A with more control power available in all axes in addition to stability augmentation. The result is a reduction in cockpit workload with a corresponding reduction in the task complexity of engaging the drogue and refueling.

Requirements which result in large multimission V/STOL aircraft with refueling weights greater than 25,000 pounds must consider the higher kinetic energy levels available in drogue engagement with a semi-rigid refueling boom. Lower and more precisely controlled drogue closure rates may be required along with revision of MIL-A-8865 (ASG) to provide higher probe limit load capability.

4.0 THE AIRBORNE REFUELING MODULE

Exploratory designs of several turbofan powered airborne refueling devices were outlined in search of a viable arrangement. Example 6B (Figure 4-1, 4-2, and Foldout Drawing 84816-106B, page 4-11/4-12) is powered by a militarized version of the widely used JT-15D commercial turbofan manufactured by Pratt and Whitney (Canada). The militarized version is designated JT-15-5M and is now being proposed for the VTX (new "all-through" jet trainer) program. The uninstalled sea level static thrust of this engine is 3300 pounds. Should this engine not be selected as the VTX power plant, P&W plans to certify an uprated commercial version of the JT-15-4 at 3000 pounds static thrust.

4.1 REQUIREMENTS OF THE OVERALL SYSTEM

1. Refueling capability must be compatible with the eight ships in the study sample. For purposes of this study the DD-963 installation with the airborne refueling module is considered to be typical.

2. Operational refueling capability will be provided at sea conditions through sea state 5.

3. Fuel transfer rates equivalent to existing air-to-air systems will be made available.

4. The refueling operation shall be monitored by a systems operator with control of the module by direct observation of the flight as well as instrumentation that displays information critical to the module and the refueling operation.

5. The operator shall be able, at any phase of the operation, to respond to conditions which indicate malfunction and manually control the module such that the safety of the aircraft or the ship are not impaired.

6. The installations on the ship will be configured such that the primary function of the ship is not degraded and installation may be accomplished without major modifications.

7. The aircraft installed fuel system provision shall be identical to/or compatible with Navy in-flight refueling systems.

8. The design shall be selected for making use of in-hand technology and available materials and equipment. Marginal levels of performance shall be avoided to assure low risk in achieving the overall capability.

9. Costs of the total system for development, ship installation and O&S will be considered in selecting the approach from the options available.

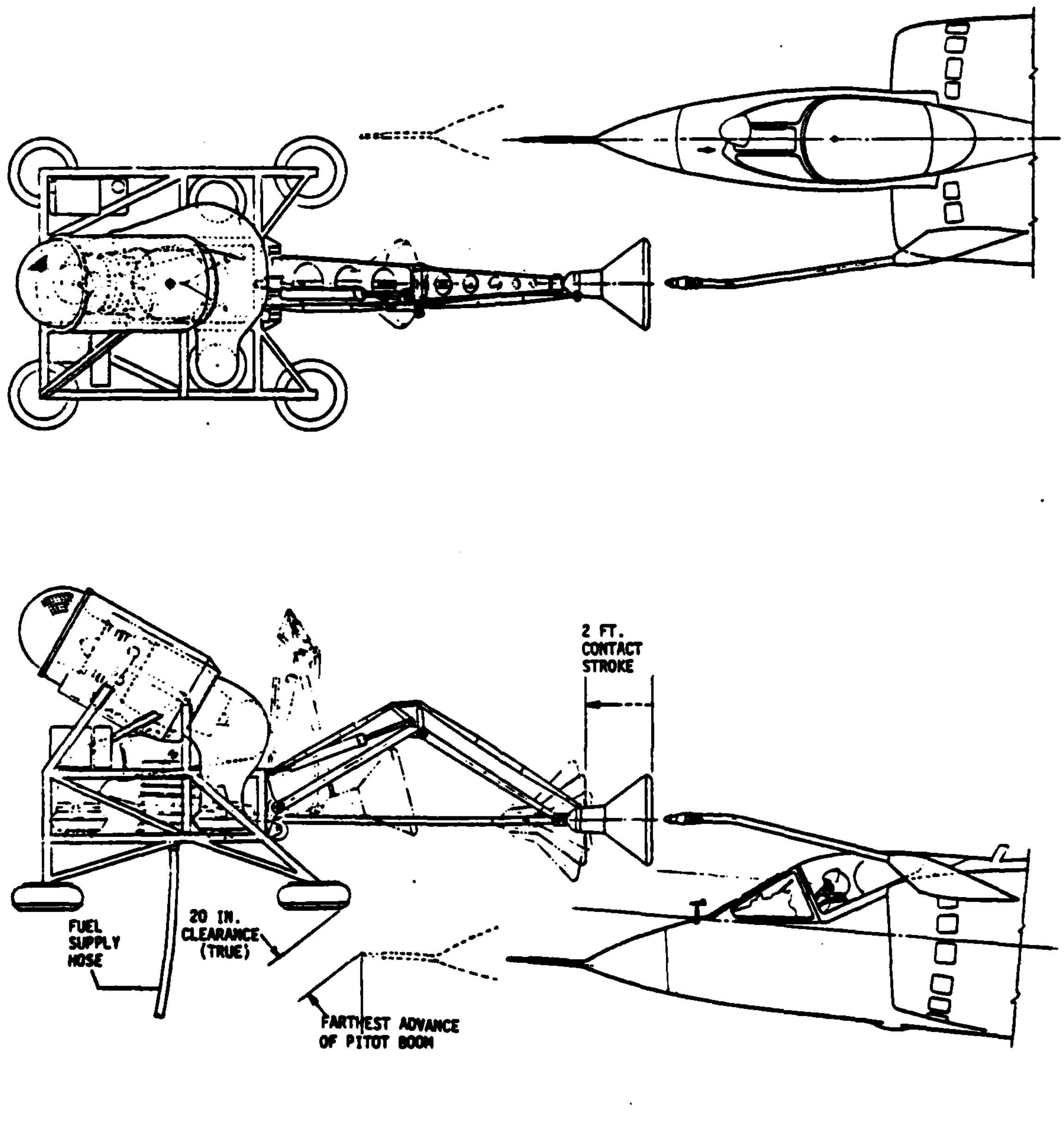


Figure 4-1 AV-8A Engaging Refueling Module

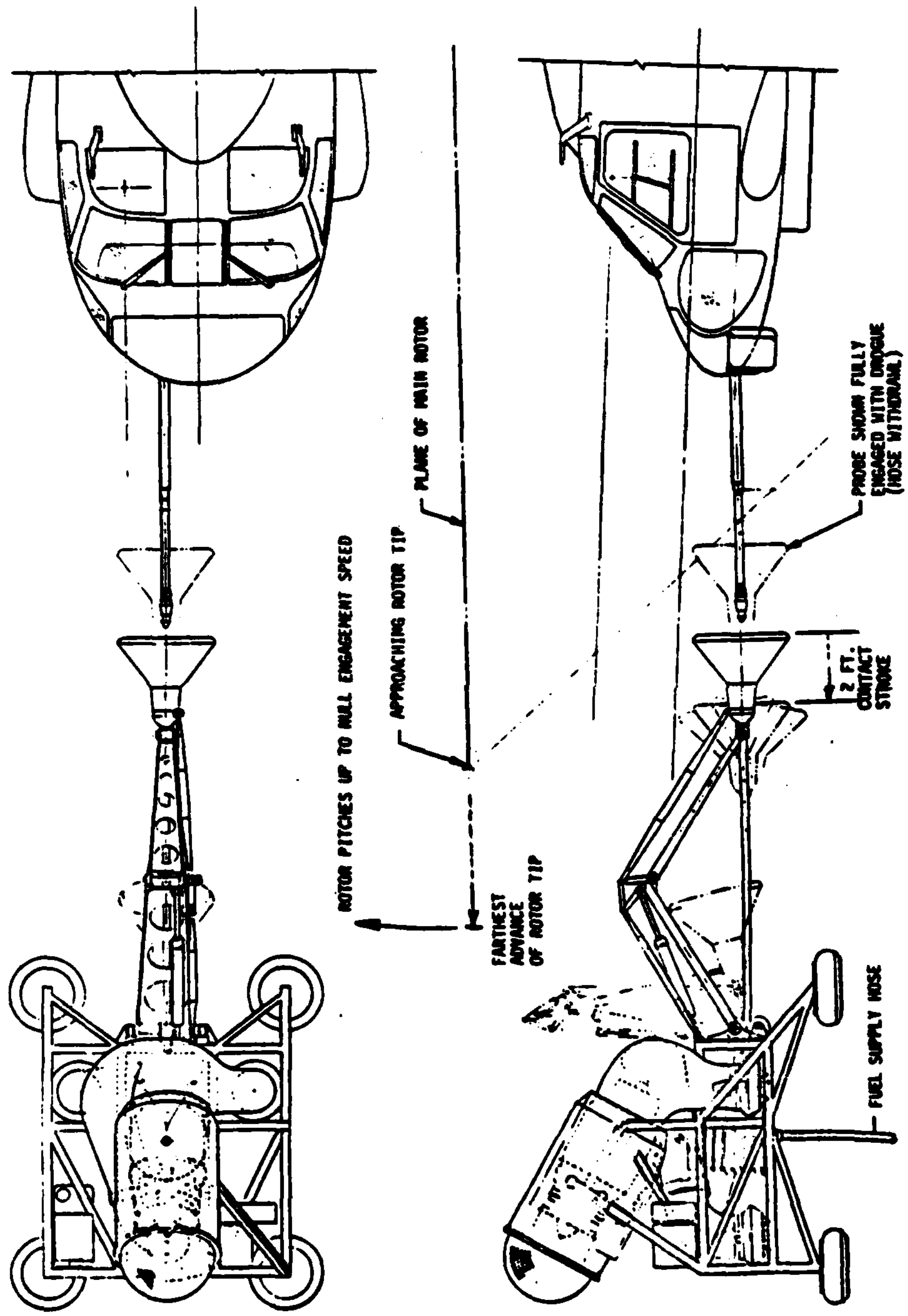


Figure 4-2 SH-60B Engaging Refueling Module

Secondary Requirement

1. The potential to provide optional payloads for alternate missions such as reconnaissance was considered in the configuration selection.

4.2 SYSTEM CONFIGURATION AND OPERATION

The module is launched from its stowed position on the refueling ship (port side, 311 feet aft of FP on 04 level for DD-963, see Figure 4-3). The operator is positioned in an enclosed flight control compartment which must be added to the DD-963 at a recommended location between frames 332 feet and 346 feet on the port side just aft of the module stowage platform. The upper section of the control compartment is enclosed with safety plate glass panels which permit unobstructed observation of the airborne refueling module from takeoff to the refueling station. The compartment overhead should be flush with the 04 deck level to avoid interference with the CIWS field of fire.

The module landing/stowage platform must be added to the ship. It is configured as a trapezoidal extension to the existing 04 deck. The platform extends six feet to port from the existing 04 level such that the extended deck edge is flush with the outboard shell plating in the plan view. The platform is 24 feet wide at 04 deck attachment and tapers to 15.5 feet outboard. In the center of this platform is the refueling hose roller fairlead which pays out the hose and tether attached to the underside of the refueling module. A hose reel containing 130 ft. of MIL-H-4495B fuel hose must be mounted directly beneath the platform. The deck extension permits installation and enclosure of the hose reel and fuel system outboard of the hangar area to avoid encroachment upon this valuable but limited space.

The module propulsion system is started by use of ship's power and may be operated for short periods from the small integral fuel supply and thereafter from fuel delivered by the refueling hose.

Launch and control up to the refueling station is accomplished by manual control of the platform systems with control signals supplied to the flight vehicle electrically through wiring integral with the fuel hose. The module is inherently stable by means of its autopilot system and requires only steering information from the operator. The operator also controls the hose extension.

Once the module is positioned in the refueling location depicted in Figure 4-3, the operator need only monitor its position and occasionally make minor corrections to maintain proper station keeping relative to the ship. At this point the drogue is extended and the refueling sequence may commence. Pre-hookup communications between the pilot and the platform operator are by UHF. Once hookup is made a direct tie-in to the aircraft ICom is provided by an inductive coupling in the drogue. The drogue also incorporates a latching device to "grab" the probe when it is inserted. Disengagement is made by controlled release or at a preselected tension.

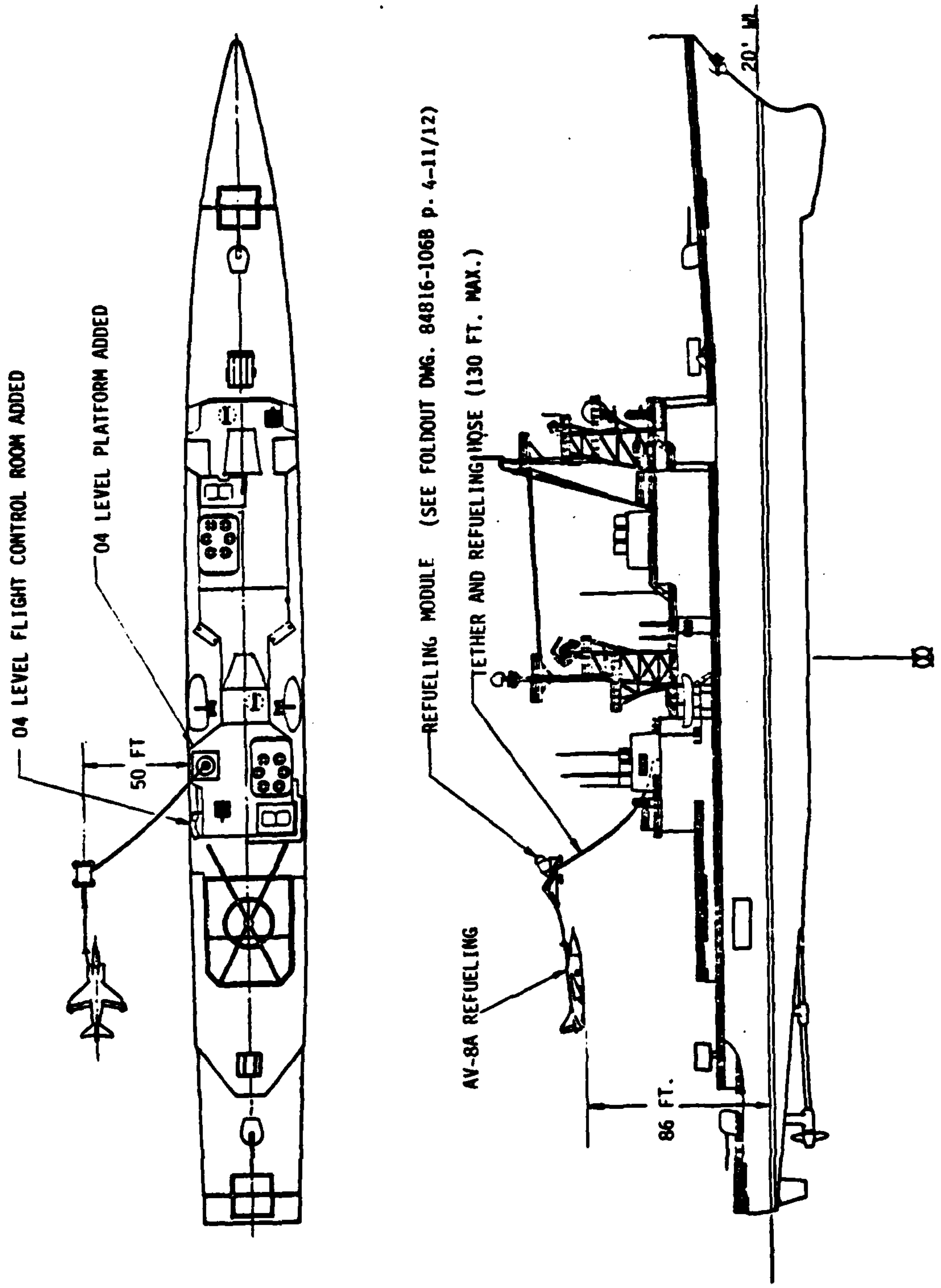


Figure 4-3 Airborne Refueling Module System Installed on DD-963

Engagement is controlled by the pilot of the refueling aircraft. The pilot approaches the drogue in much the same manner as in a standard flight refueling operation. The drogue is sufficiently separated from the module to allow safe operation during the critical hook-up period and the "latching" feature keeps the engagement forces to a minimum to prevent over-run of the module. After positive hook-up is accomplished the pilot backs off up to 20 feet, and flies formation with the module. Sufficient flexibility is provided between the vehicles to allow tracking and velocity errors to be detected and corrected by the refueling pilot. During the fuel transfer, communications are maintained relative to quantity transferred, weather condition, flight path cues and other pertinent information. When the cycle is completed, the operator retracts the drogue to the ready position and the cycle may be repeated with another aircraft. The module may be retained on station indefinitely drawing fuel from the hose, or returned to the ship.

Module recovery is in the reverse of the launch operation except that the module is controlled to a location directly over the launch position and "winched" down to the deck by retraction of the hose/control cable.

4.2.1 Module Description

The module, as shown in foldout Figure 4-4, page 4-11/4-12, uses a JT-15-5M turbofan engine as previously described. The engine is installed at an angle which is inclined 30° from horizontal. Greater inclination is desireable to reduce nozzle manifold weight and turning losses but would require modification to the JT-15 engine lubrication system. From requirement 8. of Requirements of the Overall System (page 4-1), only available equipment, which includes the power plant, should be selected for application to the module. Modification to the engine lubrication system would raise engine cost significantly and would not be responsive to these system requirements.

The fan and core discharge are gradually mixed and distributed through a manifold to three, variable area, vectorable nozzles. The nozzles are situated in planform to produce a resultant life vector directly coincident with the module center of gravity. Nozzle operation is coordinated by four hydraulic flight control actuators. Three of the actuators are mounted directly on the nozzle housings (not shown on 84816-006B) and proportionally vary nozzle area for pitch and roll control. The sum of the three nozzle areas is always equal to a constant area which is matched to the engine discharge requirements as set by the throttle. A fourth yaw control actuator is connected by linkage between the two rearward nozzles for nozzle vectoring. An engine throttle actuator is mounted in the engine compartment adjacent to the JT-15 fuel control unit for lift control.

Nozzle and throttle control signals are generated by the module autopilot system which consists of an inertial reference sensor unit, an inertial signal microprocessor and a servo amplifier which commands the control valves mounted on the actuators. Manual override provisions are incorporated for use by the module operator in steering and ascent/descent functions.

The drogue is suspended by a linkage and extended for presentation to the refueling pilot. The drogue suspension is designed to relieve probe/drogue impact loads on the module during engagment. The suspension will also accommodate refueling aircraft pitch excursions up to $\pm 10°$. Yaw excursions introduced by the refueling aircraft (which are to be avoided in the case of the AV-8A) will be detected by the module autopilot and damped by module yaw controls. The inertia of the module in the yaw plane is approximately 650 slug. ft^2 with a correspondingly low yaw control authority. This prevents module initiated yaw correcting moments large enough for radial overload of the aircraft mounted refueling probe.

Upon completion of drogue engagement the refueling pilot may withdraw from the module to a refueling position up to 20 feet downwind. As in the case of the refueling boom system, hose flexibility permits more relaxed control manipulation by the refueling pilot. The MS 24355 (ASG) drogue body is contained in a socket on the end of the drogue suspension linkage. When the refueling pilot withdraws from the module the drogue is released from its socket and the module mounted hose reel pays out hose on demand, up to 24 feet maximum. Fuel pressure is shut off automatically with extension of the last four feet of hose and the probe/drogue latch is released electrically. The hose reel is controlled by a hydraulic motor which maintains a slight tension on the hose for slack control. When the drogue is released by the refueling pilot the reel motor returns the drogue to the presentation position upon command by the module operator. Further hose retraction by the operator will also retract the drogue suspension linkage to a stowed position. This action reduces the overall length of the module to 12.4 feet in preparation for landing.

The system components of the module are all mounted on a simple tubular structure which is equipped with four landing pads. The landing pads are of pneumatic design and provide low contact pressures at touch-down and for parking. The normal static load imposed by the landing pads is 1.9 psi. Since the module is hauled-in by the hose and safety tether against JT-15 propulsive lift, the landing sink rate can be diminished by operator control of the reel rewind rate. Under high sea state conditions where an unexpected combination of ship motion is encountered at touch-down, the maximum single pad reaction will be 11.5 psi (equivalent to the total module weight being reacted by a single pad at 1.5 g).

The ramp weight of the module at takeoff is 2172 pounds. With an installed thrust available of approximately 2970 pounds, the vehicle thrust/weight ratio is 1.37 at takeoff and endowed with more than adequate control and acceleration margins while in ground effect. As the module is climbed to the refueling position, hose and tether deploy from the ship mounted reel at the unit weight of 2.5 pounds per foot. As the module arrives at the on-station altitude (approximately 120 feet of hose deployed) the hose is pressurized by a ship mounted fuel pump. The unit weight of the fuel in 120 feet of hose adds 1.68 pounds per foot for a total useful load of 502 pounds. The maximum design useful load is 544 pounds resulting in a maximum module hover weight of 2716 pounds.

4.2.2 Shipboard Control Station

The module operator is positioned in an enclosure with direct view of the module at all times - takeoff, maneuvering to station, refueling and recovery. The enclosure should provide an unobstructed view 270° in azimuth and 120° in elevation of the project/module operating quadrant relative to the ship.

A gunsight type "concentric ring/cross hair" device aids the operator in positioning and monitoring the flight of the module. Controls are provided to transmit signals directly to the module allowing the operator to both control its position in three dimensional space and to provide a redundant "sensor" for the autopilot. The operator also has control of the hose extension and is provided with communications and instruments which control and monitor all conditions critical to the module flight and the refueling operation.

The instrumentation data provided to the conventional instruments are also monitored to be within predetermined safe operating limits. Deviation of any parameter is immediately indicated to the operator on a dichromatic display within his field of view without the necessity to relinquish continuous observation of the flight vehicle.

4.2.3 Alternate Module Applications

The flying module configuration 006B is readily adaptible to missions other than refueling operations. For example, a reconnaissance capability can be achieved by replacement of the refueling hose, reel and drogue with suitable sensors and avionics. In this configuration, the module may be positioned several hundred feet above the ship with a line-of-sight range improvement of approximately 40 miles. The received data is supplied to the ship via a tether/signal cable. The control concept remains the same as for refueling mission with the module controlled and monitored by the operator on the ship. Fuel supply for alternate missions is provided by a smaller fuel line integral with the tether/signal cable.

Upon removal of all equipment peculiar to the refueling mission such as the hose reel, drogue and suspension linkage, an alternate mission useful load of 918 pounds can be lifted by the module. This amount must, however, include the tether/signal cable and JT-15 fuel feed line.

4.3 SAFETY

Safety has been of primary concern in the determining of the overall configuration and the detail system selections. The presence of the human operator with ability to continuously monitor and control the flight of the platform does much to assure safety.

The vehicle has a very good lift to weight relationship at the critical takeoff and recovery period (lack of hose weight supported by the vehicle). The flexible nature of the drogue support at hook-up avoids the need for the aircraft to engage a stationary object for probe plug-in. Direct communications of the platform operator with the pilot insure close coordination of the fuel transfer operation. The ability to separate the probe from the drogue and rapidly separate the vehicle with minimum transients, redundancies in selected functions, monitoring of critical parameters to detect impending performance deterioration, further enhance overall safety of the concept.

5.0 COST COMPARISON AND DEVELOPMENT PLAN

The following projections of Reliability and Maintainability (R&M) requirements are outlined for the two concepts of ship to air refueling. Personnel support requirements are estimated for each concept as well, based on the R&M projections which form the basis for the Operations and Support (O&S) cost analysis.

System failure rates were estimated from these two exploratory designs and are therefore cursory evaluations. The rates were developed with the aid of data contained in the (1) Nonelectronic Reliability Notebook, Report RADC-TR-75-11, (2) Reliability Analysis Center Report NPRD-1, and (3) 3M data from Navy aircraft.

Manning estimates are based on the following assumptions:

1. Either of the two refueling concepts must be maintained in the "ready" status on a 24 hour basis.

2. Maintenance personnel requiring special skills or technical training in refueling device systems would be added to ship's company. Only non-specialized skills would be assigned from within the ranks of the ship's crew.

3. The operator of the Airborne Refueling Module would be a commissioned officer trained to "fly" the vehicle but would not necessarily be a naval aviator as a prerequisite for the assignment. This officer would also be the detachment commanding officer and would train an officer from ship's company in operator skills for standby contingencies.

4. An officer from ship's company would be assigned collateral responsibility for the suspended refueling boom system and would likewise cross-train an alternate.

5.1 BOOM SYSTEM

The components of the boom system and the estimated failure rate of each are presented in Table 5-1. Conservative estimates, as may be reported by 3M, resulted in an estimated MTBF of 107 hours for the boom refueling system. Typically, the unscheduled mean-time-between-maintenance-action (MTBMA) is about half the MTBF, or 53.5 hours.

a. Maintenance Estimates - A mean-time-to-repair (MTTR) of two hours was assumed for repair of the system. Using a 40 hour per month utilization for the boom, the unscheduled maintenance requirements are estimated as follows:

PREVIOUS PAGE IS BLANK

Unscheduled Maintenance:

$$\text{Unsch MMH/Mo} = \frac{\text{Utilization/Mo}}{\text{MTBMA}} \times \text{MTTR} \times \frac{\text{Men}}{\text{Action}} =$$

$$\frac{40}{53.5} \times 2 \times 1.5 = 2.2 \text{ MMH/Mo}$$

Scheduled Maintenance:

Daily:	a. Clean/inspect drogue: 0.5 hr. x 30 days	= 15 MMH/Mo
	b. Wipe down/clean/lube actuator piston rods, mirrors or lamps, inspect for leaks, check diesel engine oil: 0.5 hr. x 30 days	= 15 MMH/Mo
30 day:	Fresh water wash, lube (fan, reel, etc.) 2 Men at one hour	= 2 MMH/Mo
90 day:	Change engine oil - one hour	= .3 MMH/Mo
	TOTAL MAINTENANCE	= 34.5 MMH/Mo

If a 12 hour day per man is assumed at 60 percent productivity, Required Maintenance Men =

$$\frac{\text{Required MMH/Mo}}{12 \text{ MMH/day/man} \times 30 \text{ day} \times .60} = \frac{34.5}{216} = 0.2 \text{ Men}$$

b. Crew Requirements - To assure optimum availability under a 24 hour operational environment, and to have qualified backup in the event of sickness or incapacitation of a crew member, the following personnel are required:

1 - Officer	- Monitor fueling operations, observe quantity transferred, communicate with aircraft.
1 - Electronics Technician	- Maintain electronics.
1 - Machinist Mate	- Maintain mechanical equipment.

5.2 AIRBORNE MODULE SYSTEM

The components of the airborne module system were estimated and the Mean Flight Hours Between Failure (MFHBF) for each are presented in Table 5-2. The MFHBF for the total system is estimated to be no less than 24 hours, with a MTBMA typically about one-half the MFHBF, or 12 hours.

Table 5-1 Suspended Refueling Boom System

SYSTEM COMPONENTS	FAILURE RATE ($F/10^6$ Hrs.)
Electric Motor	65.4
Drive Shaft and Coupliens (38 + 100)	138.0
Fan (includes Variable Pitch System	1529.0
90° GB - Fan Drive	10.0
Hub GB - Change Shaft Speed to Hub Speed	10.0
Hydraulic Motor - Hose Reel	62.9
Side Slip Actuator	57.0
Boom Extension Actuator	57.0
Diesel Power Unit (Eng = 1733, Gen. = 400, Hyd Pump = 280)	2413.0
Boom Structure	200.0
Lights/Mirror	18.6
ICOM	500.0
Hose	60.0
Micro Processor	500.0
Servo Amplifier	749.0
Servo Valves (3)	1260.0
Motion Accelerometers (2)	70.0
Wiring	100.0
Hydraulic Lines/Fittings	10.0
Side Slip Sensor	526.0
Fuel Pump + Motor	885.0
Fuel Transfer Indicators	25.0

TOTAL FAILURE RATE = 9345.9×10^{-6}

MTBF = 107 Hours
MTBMA = 53.5 Hours

a. Maintenance Estimates -

Assume: Utilization = 20 Hours/Mo.
MTTR = 2 Hours

Unscheduled Maintenance:

$$MMH/MO = \frac{U}{MFHBMA} \times MTTR \times \frac{Men}{Actions} = \frac{20}{12} \times 2 \times 1.5 = 5 \text{ MMH/Mo}$$

Scheduled Maintenance:

Daily:	Clean/inspect drogue: 0.5 hr. x 30 days	= 15 MMH/Mo
	Check engine oil Wipe down/lube actuator piston rods Inspect for hydraulic/fuel leaks	= 15 MMH/Mo
	System functional check (operate) .25 hr. x 30 days x 2M	= 15 MMH/Mo
Preflt:	Visual inspection - Leaks/damage .1 MMH x 80 flights	= 8 MMH/Mo
30 Day:	Fresh water wash, Lube - 2 hours	= 4 MMH/Mo
	TOTAL	= 62 MMH/Mo

Based on a 12 hours day/man at 60 percent productivity, 0.3 men required.

b. Crew Requirements - Organizational level maintenance requirements are less than one man; however, practical considerations regarding special skills will require assignment of five persons to each ship to assure the highest degree of availability. At least two persons of each enlisted classification would be required to provide backup ;in the event of sickness or incapacity of one of the qualified persons, and to provide 24 hour duty capability.

1 - Officer with training to operate the module system.

2 - Second Class AT or equivalent Electronic Technicians.

2 - Second Class AD or equivalent Engine Mechanics.

Intermediate level maintenance would be conducted at a central point; an on-shore location, or on a ship supporting the task group of which the tanker is a part. A maximum of two technicians in the IMA shops would support all refueling stations within the fleet command.

Table 5-2 Airborne Refueling Module System

MODULE SYSTEM COMPONENTS	FAILURE RATE ($F/10^6$ HRS.)
JT15D Engine	248
Generator	1,250
Hydraulic Pump - Accumulator	1,500
Ducts/Bellows	2,160
Nozzles (3)	476
Fuel Tank	3,000
Electrical Power Distributor/Regulator	2,000
Engine Instr. Sensors	400
Actuators (5) (3 Nozzle, 1 Yaw, 1 Throttle)	600
Hose and Reel	2,000
Reel Motor	2,850
Drogue - Boom Spring	1,000
Platform Structure	10,000
Inertial Sensor	250
Servo Valves (5)	200
Servo Amplitude	500
Micro-Processor	200
Wiring	5,000
Hydraulic Lines/Hoses	50,000
Ship Installation	
Control Stick	2,000
Control Electrical Components (Pots, etc.)	2,000
Multi-Function Display/HUD	120
Seat	10,000
Wiring	5,000
Fuel Pump and Motor	1,130

MFHBF = 23.95 = 24
MFHBMA = 12

5.3 COST COMPARISON

Rough order of magnitude cost estimates were made for comparison purposes of the airborne refueling platform and the refueling boom. System acquisition and unit annual operations and support costs, as well as ship installation costs were considered to provide an estimate of life cycle costs. Cost elements for the alternatives are summarized in Table 5-3. The Total Cost column includes development costs, production costs for 50 units, ship provision cost for 50 installations, and O&S costs for 50 units for 20 years.

5.4 ACQUISITION COSTS

The estimated development costs for the system cover such subjects as definition studies, engineering analyses and design, fabrication of test articles including the purchased system components, and test and evaluation efforts. The logistics support during development includes consideration for interim spares, training, technical manuals, and contractor technical services. Estimated development costs associated with ship installation are shown under Ship Provision Costs.

Projected production costs covers the providing of 50 system units and includes sustaining engineering. The ILS costs under production primarily consist of initial spares. Recurring ship installation costs are shown in the Ship Provision column for 50 installations.

5.5 O&S COSTS

O&S costs accounted for in the analysis included those personnel specifically associated with the operation and support of the refueling system, fuel, maintenance consumables, depot rework, and replenishment spares. NPRDC personnel costs (References (s) and (t)) were used which account for indirect as well as direct costs.

Fuel costs were based on advertised SFC data for the propulsion or power generation unit for each concept. Costs for maintenance consumables, part of depot rework and replenishing spares were extrapolated from recent analyses performed on the T-2C aircraft using relative AMPR, or equivalent, weights. JT15D rework costs were based on the engine manufacturer projections.

The O&S costs given are annual costs with the assumption that the airborne refueling platform operates 240 hours per year and the boom operates 480. This assumption was based on the consideration that the airborne platform would be retrieved following refueling whereas the boom would often remain deployed when further refueling operations were imminent

5.5 DEVELOPMENT PLAN

An overall plan for further acquisition of the suspended refueling boom system is outlined in Figure 5-1.

Table 5-3 Alternative Life Cycle Cost Estimates

COST ELEMENTS / ALTERNATIVE	ACQUISITION COST: DEVELOPMENT COST	ACQUISITION COST: UNIT PRODUCTION COST (QUAN. OF 50)	ANNUAL UNIT O&S COST	SHIP PROVISION COST **	TOTAL COST 50 UNITS 20 YEARS
AIRBORNE REFUELING MODULE	SYSTEM $13.4M T&E* .9M ILS 3.2M $17.5M	SYSTEM $ 798K ILS 180K $ 978K	(240 OPR.HRS/ YEAR) PERSONNEL $118K POL 65K MAINT.CONS. 2K DEPOT RE- WORK 13K REPLENISH.- SPARES 10K $208K	DEV. $300K UNIT $ 90K	$279.2M
REFUELING BOOM	SYSTEM $ 4.8M T&E * .9M ILS 1.5M $ 7.2M	SYSTEM $488K ILS 71K $559K	(480 OPR.HRS/ YEAR) PERSONNEL $ 67K POL 10K MAINT CONS. 3K DEPOT RE- WORK 5K REPLENISH.- SPARES 4K $ 89K	DEV. $500K UNIT $100K	$129.6M

* EXCLUDES SHIP OPS. COST ** EXCLUDES SHIPYARD

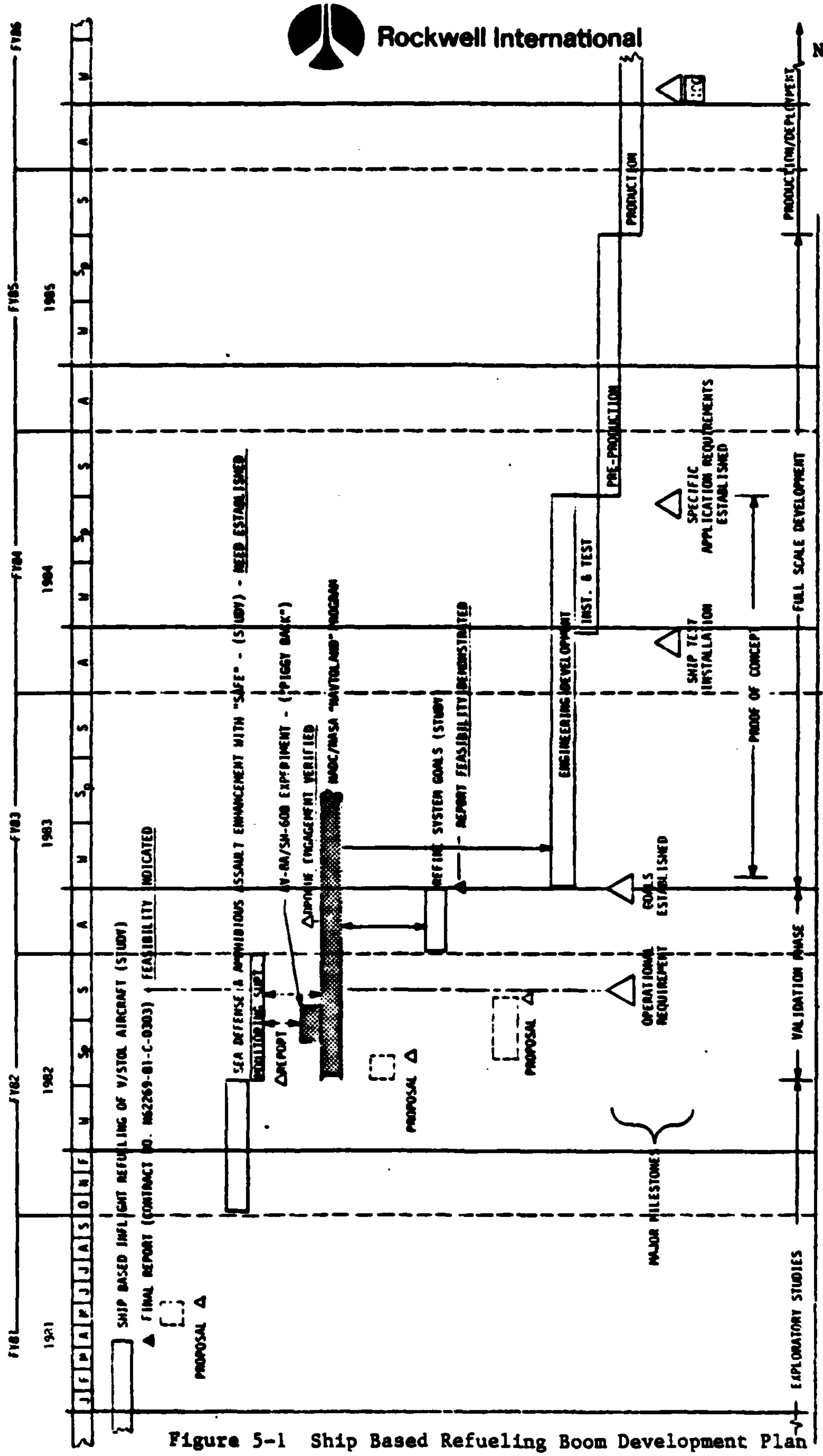


Figure 5-1 Ship Based Refueling Boom Development Plan

LIST OF REFERENCES

(a) A. E. Baitis, W. G. Meyers and T. R. Applebee; A Non-Aviation Ship Motion Data Base for the DD-963, CG-26, FF-1052, FFG-7 and the FF-1040 Ship Classes, DTNSRDC SPD-738-01, December 1976

(b) R. G. Brown, F. A. Camaratta; NAVAIRENGCEN Ship Motion Computer Program (Theory, Documentation and Users Guide), NAEC MISC-903-8, July 1978

(c) W. J. Pierson, Jr., G. Newmann, R. W. James; Practical Methods for Observing and Forecasting Ocean Waves by Means of Wave Spectra and Statistics, Department of the Navy, Hydrographic Office Publication No. 603, 1955

(d) M. A. Strano; Air Capable and Amphibious Aviation Ships - Aircraft Facility Resume, NAEC-ENG-7576, Revision P, January 1981

(e) J. J. Myers (Editor); Handbook of Ocean and Underwater Engineering, North American Rockwell Corp., 1969

(f) H. E. Saunders, Hydrodynamics in Ship Design, Volume I and II, The Society of Naval Architects and Marine Engineers, 1957

(g) J. Moore, Capt. RN, FRGS, Jane's Fighting Ships, Jane's Yearbooks, 1979-1980

(h) Shipboard Operating Bulletin No. 2, NAEC AV-8A

(i) AV-8A NATOPS Manual; NAVAIR 01-AV-8A-1; Change 3

(j) NATOPS Air Refueling Manual, Department of the Navy, Office of the Chief of Naval Operations, May 1972

(k) AV-8A Estimated Flying Qualities, McDonnell Douglas Corp., MDC A1411, January 1972

(l) TAV-8B Aircraft Description Report; McDonnell Douglas Corp.; MDC A6200, December 1979

(m) AV-8A Aerodynamic Characteristics; McDonnell Douglas Corp.; MDC A1410, January 1922

(n) J. V. Lebaeqz, R. C. Radford, J. L. Beilman; An Experimental Investigation of Control-Display Requirements for a Jet-Lift VTOL Aircraft in the Terminal Area, Calspan Corp., July 1978

(o) R. K. Heffley et. al.; A Compilation and Analysis of Helicopter Handling Qualities Data, Volume I, Systems Technology, Inc., Report No. 1087-1, March 1979

APPENDIX A

EXTENSION OF FLEET AIR DEFENSE EFFECTIVENESS THROUGH SHIP TO AIR REFUELING

CONFIDENTIAL REPORT SUBMITTED UNDER SEPARATE COVER

APPENDIX B

REFERENCES

LIST OF REFERENCES (Continued)

(p) CH-53D Standard Aircraft Characteristics

(q) I. K. Modni, R. H. Pletcher; Prediction of Turbulent Jets in Co-Flowing and Quiescent Ambients, ASME Publication 75-FE-35, May 1975

(r) R. L. Nave, Development and Analysis of a CVA and a 1052 Class Fast Frigate Air Wake Model, NADC Report 78182-60, September 1978

(s) Life Cycle Navy Officer Billet Costs: An Interim Report, NPRDC SR 79-20, May 1979

(t) Life Cycle Navy Enlisted Billet Costs, NPRDC SR 79-13, March 1979

(u) Military Specification MIL-A-19736A(WP); Air Refueling Systems, General Specification for; Amendment 2, 16 March 1966

(v) Military Specification MIL-F-17874B, Fuel Systems: Aircraft, Installation and Test of; 20 August 1965

(w) F. W. Hessman, Simplified Model for the Induced Downwash Field of Single Rotor Helicopter Configurations, Columbus Division, North American Rockwell Corp., TN 772MD-10-71, 17 September 1971

(x) J. W. Jewel, Jr., H. H. Hegson, Charts of the Induced Velocities Near a Lifting Rotor, NASA Memo 4-15-59L, May 1959

END

FILMED

1-85

DTIC