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RPV SHIPBOARD LAUNCH AND RECOVERY OPERATIONS STUDY

George C. Cota, et al

Teledyne Ryan Aeronautical Company

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13 ABSTRACT

Various methods for launch and recovery of remotely piloted vehicles (RPVs) from the decks of Naval ships were investigated. Eight RPV designs were developed to evaluate launch and recovery concepts from three classes of ships; the aircraft carrier, the sea control ship and the ocean escort. Two basic RPV missions were assumed for the study: (1) a 500-nautical-mile, high-low-high altitude, high subsonic penetration mission; and (2) a medium-high altitude 14-hour endurance surveillance mission.

The study considered the following launch and recovery concepts:

Launch Concepts

1. Catapult
2. RATO Assisted Deck Run
3. Zero-Length or Short Rail RATO
4. Vertical Take-Off Concepts
   a. Stopped Rotor
   b. Vectored Thrust
   c. Tail Sitter

Recovery Concepts

1. Conventional Carrier Landing
2. Aerial Track
3. Slow-Rate-of-Closure into Net
4. Vertical Landing Concepts
   a. Stopped Rotor
   b. Vectored Thrust
   c. Tail Sitter

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14 KEY WORDS	LINK A		LINK B		LINK C	
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Destroyer						
Drone						
Launch, Shipboard						
Ocean Escort Ship						
Recovery, Shipboard						
Remotely Piloted Vehicle (RPV)						
Sea Control Ship						
Vertical Take-off and Landing (VTOL)						

RPV SHIPBOARD LAUNCH AND RECOVERY OPERATIONS STUDY

FINAL REPORT

REPORT NO. TRA 29369-3

28 FEBRUARY 1974

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1.0 INTRODUCTION

The increased interest in recent years in the application of unmanned aircraft to perform a wide variety of tactical missions has stimulated interest in the shipboard use of RPVs by the Navy. It is recognized that a critical aspect of successful integration of the RPV into the fleet inventory is achieving a practical and economical solution to the problem of launching and recovering the RPV in a reliable manner from the decks of ships of various classes. This study addresses this problem by considering a variety of launch and recovery techniques for three classes of ships. In order to cover a wide spectrum of ship sizes, the three classes examined in this study are the aircraft carrier (CVA-63), the sea control ship (SCS) and the ocean escort (DE-1052). To evaluate the impact of the RPV mission on the launch and recovery techniques selected and the classes of ships which would be compatible, two diverse missions were selected as design missions for this study. The first mission is a low altitude, high subsonic penetration mission which could perform such tasks as photo-reconnaissance and weapon delivery. The second mission is a high altitude, long endurance mission to perform such tasks as ocean surveillance and high altitude relay platform. A total of eight RPV configurations were designed during the study to evaluate the various launch and recovery concepts. A fundamental constraint on this study was to evaluate recovery methods for direct landing aboard each of the three classes of ships, and while other non-direct methods of recovery such as landing in the sea, or helicopter mid-air retrieval (MARS), may be practical concepts, they were excluded from the scope of this study at the direction of the Navy.

The basic study objectives were to:

a. Investigate concepts for direct launch and recovery of RPVs from Navy surface ships.

b. Identify technical problem areas and propose solutions.

c. Evaluate candidate concepts and identify preferred concepts for launch and recovery for each of the three classes of ships.

d. Identify critical technical areas requiring additional research and development.

The study considered the following launch and recovery concepts:

Launch Concepts

a. Catapult
b. RATO Assisted Deck Run
c. Zero-Length of Short Rail RATO
d. Vertical Take-Off Concepts
   (1) Stopped Rotor
   (2) Vectored Thrust
   (3) Tail-Sitter

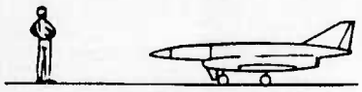
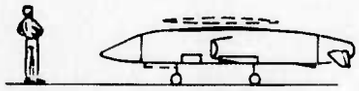
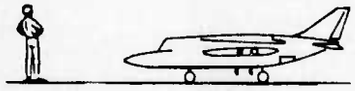
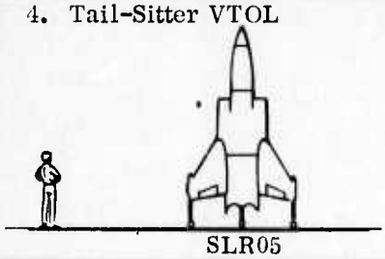
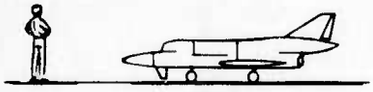
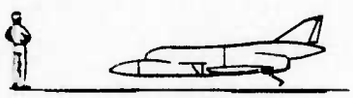
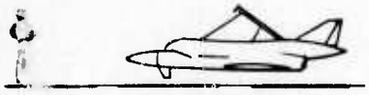
Recovery Concepts

a. Conventional Carrier Landing
b. Aerial Track
c. Slow-Rate-of-Closure into Net
d. Vertical Landing Concepts
   (1) Stopped Rotor
   (2) Vectored Thrust
   (3) Tail-Sitter

The results of the study show that for the high-altitude, long-endurance mission the RPV has a gross weight of nearly 8,000 pounds and a wing span of 44.50 feet. Due to its large size this configuration (SLR02) is not considered compatible with the Sea Control Ship (SCS) or the ocean escort class ships. For aircraft carrier operations with this RPV it is suggested that launch be accomplished utilizing existing steam catapults set at lower stream pressures than for the heavier manned aircraft. The preferred recovery technique for the high altitude, long-endurance vehicle is a conventional carrier landing with engagement of the carrier's existing deck pendants, but utilizing a RPV mounted brake assembly to dissipate the landing energy.

For the low-altitude, high-subsonic penetration mission a series of configurations, all sized to perform exactly the same mission, were designed and evaluated. The configurations for this mission result in air vehicles with gross weights in the 3,000-pound weight class. The study indicates that this size RPV would be compatible with the carrier and the Sea Control Ship. This size RPV appears to be feasible on ocean escort class vessels, but the high cost associated with a VTOL air vehicle and the higher operational risks inherent in the ocean escort's higher ship motion and small recovery area, would only be justified in order to satisfy unique, high-priority mission requirements.

Table 1-1 is an abbreviated summary of the Low Altitude Penetrator configurations and summarizes their suitability to the three classes of ships considered in this study. A more detailed summary is provided in the technical summary, Section 2.

RPV CONFIGURATION (ALL SHOWN TO SAME SCALE)	TAKE-OFF GROSS WEIGHT, POUNDS	MINIMUM APPROACH SPEED KNOTS, T.A.S.	AIRCRAFT CARRIER OPERATIONS		RANKING FOR CARRIER OPERATIONS	
			LAUNCH METHOD	RECOVERY METHOD		LAUN METH
1. Conventional  SLR01	2,252	97	Existing Steam Catapult	RPV Mounted Arresting System and Existing Deck Pendants	1st	Short Ra RATO Launche
2. Stopped Rotor VTOL  SLR03	3,088	Near Zero	Vertical Take-off Using Rotary Wing	Vertical Landing Using Rotary Wing	5th	Vertical Take-O Rotary
3. Vectored Thrust VTOL  SLR04	2,992	Near Zero	Vertical Take-off Using Vectored Jet Thrust	Vertical Landing Using Vectored Jet Thrust	4th	Vertical Take-O Vectore Jet Thr
4. Tail-Sitter VTOL  SLR05	2,881	Near Zero	Vertical Take-off Using Direct Jet Thrust	Vertical Landing Using Direct Jet Thrust	3rd	Vertical Take-O Direct Thrust
5. Slow-Rate-of-Closure  SLR06-1	2,729	60	Existing Steam Catapult	RPV Mounted Arresting System and Existing Deck Pendants	2nd	Short R RATO Launch
6. Slow-Rate-of-Closure  SLR06-2	2,627	60	Not Applicable	Not Applicable	Not Applicable	Not Applic
7. Slow-Rate-of-Closure  SLR06-3	2,649	60	Not Applicable	Not Applicable	Not Applicable	Not Applic

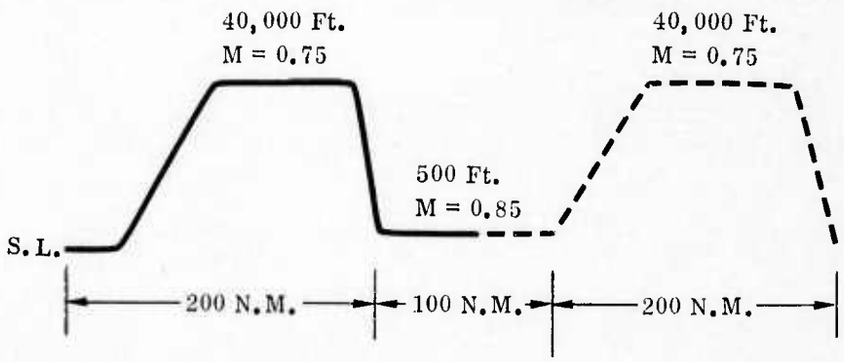
A

RANKING FOR CARRIER OPERATIONS	SEA CONTROL SHIP OPERATIONS		RANKING FOR SEA CONTROL SHIP OPERATIONS	DESTROYER OPERATIONS		RANKING FOR DESTROYER OPERATIONS
	LAUNCH METHOD	RECOVERY METHOD		LAUNCH METHOD	RECOVERY METHOD	
1st	Short Rail RATO Launcher	RPV Mounted Arresting System and Fixed Deck Pendants	2nd	Not Applicable	Not Applicable	Not Applicable
5th	Vertical Take-Off Using Rotary Wing	Vertical Landing Using Rotary Wing	5th	Vertical Take-Off Using Rotary Wing	Vertical Landing Using Rotary Wing	3rd
4th	Vertical Take-Off Using Vectored Jet Thrust	Vertical Landing Using Vectored Jet Thrust	4th	Vertical Take-Off Using Vectored Jet Thrust	Vertical Landing Using Vectored Jet Thrust	2nd
3rd	Vertical Take-Off Using Direct Jet Thrust	Vertical Landing Using Direct Jet Thrust	3rd	Vertical Take-Off Using Direct Jet Thrust	Vertical Landing Using Direct Jet Thrust	1st*
2nd	Short Rail RATO Launcher	RPV Mounted Arresting System and Fixed Deck Pendants	1st	Not Applicable	Not Applicable	Not Applicable
Not Applicable	Not Applicable	Not Applicable	Not Applicable	Short Rail RATO Launcher	Net Recovery	5th
Not Applicable	Not Applicable	Not Applicable	Not Applicable	Short Rail RATO Launcher	Aerial Track	4th

TABLE 1-1
LOW-ALTITUDE PENETRATOR STUDY SUMMARY

TROYER RATIONS		RANKING FOR DESTROYER OPERATIONS
	RECOVERY METHOD	
	Not Applicable	Not Applicable
	Vertical Landing Using Rotary Wing	3rd
	Vertical Landing Using Vectored Jet Thrust	2nd
	Vertical Landing Using Direct Jet Thrust	1st*
	Not Applicable	Not Applicable
	Net Recovery	5th
	Aerial Track	4th

LOW-ALTITUDE PENETRATOR DESIGN MISSION PROFILE



Payload = 150 Pounds, 4 Cu. Ft.

NOTE:

* Unless there is a unique and critical mission requirement for this weight class of RPV, it appears that the high cost and operational risks for this system outweigh other considerations for its employment in destroyer operations

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2.0 TECHNICAL SUMMARY

2.1 INTRODUCTION

The purpose of this section is to present a concise summary of the results and conclusions of the Shipboard Launch and Recovery Operations Study. The study is an investigation of concepts for the direct launch and recovery of Remotely Piloted Vehicles (RPVs) from Navy surface ships. The three classes of ships considered in the study are the aircraft carrier, the sea control ship and the destroyer. Two basic missions were used to size eight RPV configurations incorporating several launch and recovery concepts. The two missions are:

a. A 500-nautical-mile, high-low-high altitude, high-subsonic penetration mission.

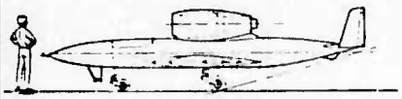
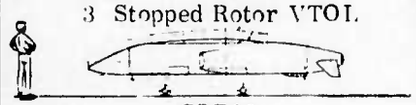
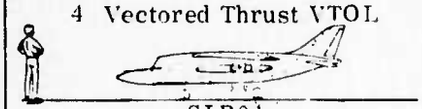
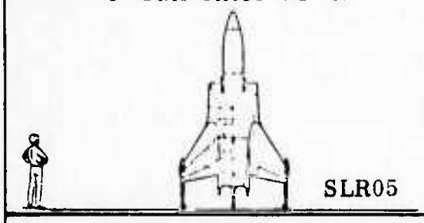
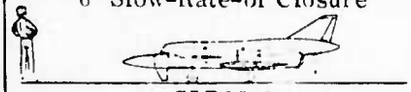
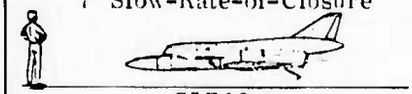
b. A medium-high altitude 14-hour endurance surveillance mission.

2.2 RPV CONFIGURATION SUMMARY

The eight RPV configurations considered in the study are summarized in chart form in Table 2-1. Take-off and landing techniques, RPV weights, dimensions, propulsion system identification, relative costs, and the ranking of each RPV for each class of ship are included.

2.3 SUMMARY OF AIRCRAFT CARRIER LAUNCH AND RECOVERY OPERATIONS STUDY

The evaluation of the six RPV configurations considered for the aircraft carrier is summarized in Table 2-2. The Conventional Low-Altitude Penetrator (SLRO1) was selected as the logical configuration for operations from the aircraft carrier for the low-altitude penetration mission. This RPV is catapult launched from existing steam catapults and recovered by landing in the same manner as the Navy's manned aircraft, engaging the existing deck pendants. The inertia of the carrier's arresting engines is too high to allow the lightweight RPVs landing energy to be absorbed by these deceleration devices without damage to the RPV. Therefore, the RPV is equipped with an airborne arresting device which allows the RPV to decelerate safely by paying out an arresting cable

RPV CONFIGURATION (ALL SHOWN TO SAME SCALE)	MISSION	TAKE-OFF TECHNIQUES APPLICABLE	LANDING TECHNIQUES APPLICABLE	TAKE-OFF GROSS WEIGHT, LBS.	ZERO FUEL WEIGHT, LBS.	MISSION FUEL WEIGHT LBS.
1 Conventional Long Endurance  SLR02	High Altitude, Long Endurance	1. Catapult 2. RATO-Assisted Deck Run	Cable Arrest-ment	7,890	4,020	3,870
2 Conventional Low Alt. Pene. SLR01	Low Altitude Penetrator	1. Catapult 2. RATO-Assisted Deck Run 3. RATO	Cable Arrest-ment	2,252	1,562	690
3 Stopped Rotor VTOL  SLR03	Low Altitude Penetrator	Vertical Take-Off Using Rotary Wing	Vertical Landing Using Rotary Wing	3,088	2,015	1,073
4 Vectored Thrust VTOL  SLR04	Low Altitude Penetrator	Vertical Take-Off Using Vectored Jet Thrust	Vertical Landing Using Vectored Jet Thrust	2,992	2,100	892
5 Tail-Sitter VTOL  SLR05	Low Altitude Penetrator	Vertical Take-Off Using Direct Jet Thrust	Vertical Landing Using Direct Jet Thrust	2,881	1,991	890
6 Slow-Rate-of Closure  SLR06-1	Low Altitude Penetrator	• Catapult • RATO Assisted Deck Run • RATO	Cable Arrest-ment	2,729	1,739	990
7 Slow-Rate-of-Closure  SLR06-2	Low Altitude Penetrator	RATO	Net	2,627	1,637	990
8 Slow-Rate-of-Closure SLR06-3	Low Altitude Penetrator	RATO	Aerial Track	2,649	1,659	990

ZERO FUEL WEIGHT, LBS.	MISSION FUEL WEIGHT, LBS.	PAYLOAD WEIGHT, LBS.	LAUNCH/ RECOVERY SYSTEM WEIGHT, LBS.	WING SPAN, FT.	MAX. WIDTH WINGS FOLDED, FT.	OVERALL LENGTH, FT.	HEIGHT ON DECK, FT.	NUMBER ACCOMMODATED IN HANGAR OF DE-1065	A KN
4,020	3,870	750	397	44.50	27.60	31.70	7.6	Not Applicable	
1,562	690	150	135	10.95	10.95 (No Fold)	19.83	5.75	Not Applicable	
2,015	1,073	150	100	13.50 (15.0 Dia. as Rotor)	13.50 (No Fold)	25.00	5.33	2	
2,100	892	150	150	12.25	12.25 (No Fold)	22.46	6.67	2	
1,991	890	150	80	10.67	10.67 (No Fold)	18.50.	18.00 (Shock Struts in Static Position) 12.33 (Nose Folded)	6	
1,739	990	150	165	12.50	8.00	21.17	6.29	3	
1,637	990	150	35	12.50	8.00	21.17	6.29	3	
1,659	990	150	50	12.50	8.00	21.17	6.29	3	

B

BER ODATED NGAR -1065	MINIMUM APPROACH SPEED KNOTS, T.A.S.	ENGINE DESIGNATION	SEA LEVEL STATIC THRUST, LBS.	PROPULSION SYSTEM DEVELOPMENT STATUS	RELATIVE RPV UNIT PRODUCTION COST	RPV DESIGNED FOR OPERATIONS FROM	F C
cable	62	JT15D-4	2,575	In Production	1.94	• Carrier	
cable	97	J69-T-25	1,025	In Production	1.00	• Carrier o Sea Control Ship	
	Near Zero	J69-T-41A	1,920	Extensive Development Required for Diverter Valve, and Power Conversion. Basic Engine in Production	1.85	• Carrier o Sea Control Ship • Destroyer	
	Near Zero	TCAE Model 490 Modified	3,400 Take-Off Rating 2 Min. Limit	Development Required for Tailpipe Nozzle Control and Reaction Jet Controls.	1.48	• Carrier • Sea Control Ship • Destroyer	
	Near Zero	TCAE Model 490 Modified	3,400 Take-Off Rating 2 Min. Limit	Development Required for Modifying Engine for Vectorable Nozzles and Engine Bleed for Reaction Controls	1.46	• Carrier • Sea Control Ship • Destroyer	
	60	J69-T-29	1,700	Minor Development Required for Diverter Valve. Engine in Production	1.26	• Carrier • Sea Control Ship	
	60	J69-T-29	1,700	Minor Development Required for Diverter Valve. Engine in Production.	1.26	• Destroyer	
	60	J69-T-29	1,700	Moderate Development Required for Diverter Valve. Engine in Production	1.26	• Destroyer	

C

TABLE 2-1

RPV CONFIGURATION SUMMARY

ULSION SYSTEM LOPMENT STATUS	RELATIVE RPV UNIT PRODUCTION COST	RPV DESIGNED FOR OPERATIONS FROM	RANKING FOR CARRIER OPERATIONS	RANKING FOR SEA CONTROL SHIP OPERATIONS	RANKING FOR DESTROYER OPERATIONS
tion	1.94	• Carrier	1st	Not Applicable	Not Applicable
tion	1.00	• Carrier o Sea Control Ship	1st	2nd	Not Applicable
Development Re- Diverter Valve, and nversion. Basic En- oduction	1.85	• Carrier o Sea Control Ship • Destroyer	5th	5th	3rd
ent Required for lozzle Control and Jet Controls.	1.48	• Carrier • Sea Control Ship • Destroyer	4th	4th	2nd
ent Required for Engine for Vector- les and Engine Bleed ion Controls	1.46	• Carrier • Sea Control Ship • Destroyer	3rd	3rd	1st
velopment Required er Valve. Engine in n	1.26	• Carrier • Sea Control Ship	2nd	1st	Not Applicable
velopment Required er Valve. Engine in n.	1.26	• Destroyer	Not Applicable	Not Applicable	5th
Development Re- Diverter Valve. Production	1.26	• Destroyer	Not Applicable	Not Applicable	4th

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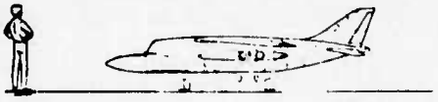
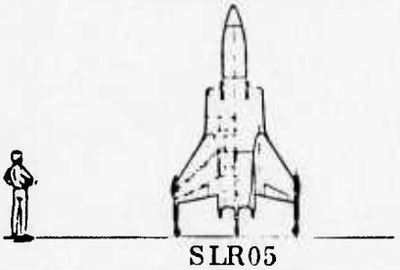
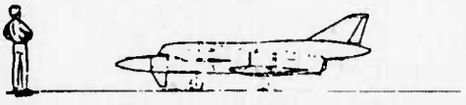
RPV CONFIGURATION (ALL SHOWN TO SAME SCALE)	LAUNCH METHOD	RECOVERY METHOD	APPROACH SPEED, KNOTS, T.A.S.	SHIP LOCATION, LAUNCH	SHIP LOCATION, RECOVERY
1 Conventional Long Endurance SLR02	Existing Steam Catapult	RPV Mounted Arresting System and Existing Deck Pendants	62	All Catapults	Canted Deck
2 Conventional Low Alt. Pene. SLR01	Existing Steam Catapult	RPV Mounted Arresting System and Existing Deck Pendants	97	All Catapults	Canted Deck
3 Stopped Rotor VTOL SLR03	Vertical Take-Off Using Rotary Wing	Vertical Landing Using Rotary Wing	Near Zero	Rear Flight Deck - Port Side	Rear Flight Deck - Port Side
4 Vectored Thrust VTOL  SLR04	Vertical Take-Off Using Vectored Jet Thrust	Vertical Landing Using Vectored Jet Thrust	Near Zero	Rear Flight Deck - Port Side	Rear Flight Deck - Port Side
5 Tail-Sitter VTOL  SLR05	Vertical Take-Off Using Direct Jet Thrust	Vertical Landing Using Direct Jet Thrust	Near Zero	Rear Flight Deck - Port Side	Rear Flight Deck - Port Side
6 Slow-Rate-of-Closure  SLR06-1	Existing Steam Catapult	RPV Mounted Arresting System and Existing Deck Pendants	60	All Catapults	Canted Deck

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SHIP LOCATION, RECOVERY	RPV DECK TRANSPORT PROVIDED BY	SPECIAL SHIPBOARD EQUIPMENT, LAUNCH	SPECIAL SHIPBOARD EQUIPMENT, RECOVERY	ADVANTAGES OF RPV/LAUNCH/RE SYSTEM COMBINATION
Canted Deck	RPV Landing Gear	• Holdback • Direct Control Umbilical	None	• Low approach speed due to low wing loading weight. • Low technical risk. • Launch and recovery very similar to manne tions. Maximum utilization of existing ship
Canted Deck	RPV Landing Gear	• Holdback • Direct Control Umbilical	None	Smallest and lowest cost RPV considered whic Altitude Penetrator mission. Minimal ship modifications. Low technical risk. Launch and recovery very similar to manned a Maximum utilization of existing shipboard equi
Rear Flight Deck - Port Side	RPV Landing Gear	• Holdback • Direct Control Umbilical	Docking Mechanism	• Near zero landing speed increases ship saf • Good hover efficiency. • Low downwash velocity and temperatures
Rear Flight Deck - Port Side	RPV Landing Gear	• Holdback • Direct Control Umbilical	Docking Mechanism	• Near zero landing speed increases ship saf • Moderate technical risk. • Horizontal fuselage attitude simplifies trans
Rear Flight Deck - Port Side	RPV Landing Gear	• Holdback • Direct Control Umbilical	Perforated Raised Landing Platform	• Near zero landing speed increases ship saf • Moderate technical risk. • Vertical fuselage attitude permits high den
Canted Deck	RPV Landing Gear	• Holdback • Direct Control Umbilical	None	• Lower approach speed than SLR01. • Lower cost than VTOL configurations. • Low technical risk.

SUMMARY OF AI
AND RECOVE

PV/LAUNCH/RECOVERY COMBINATION	DISADVANTAGES OF RPV/LAUNCH/RECOVERY SYSTEM COMBINATION	MAJOR REASO OR N
low wing loading at recovery imilar to manned aircraft opera- of existing shipboard equipment.	• Requires oversize landing gear to accommodate dimensions of launch/recovery equipment designed for manned aircraft. • Weight penalty for RPV	SELECTED FOR LON Simplest
considered which performs Low llar to manned aircraft operations. g shipboard equipment.	• Requires oversize landing gear to accommodate dimensions of launch/recovery equipment designed for manned aircraft. • Weight penalty for RPV mounted arresting system.	SELECTED FOR LOW MISSION Simplest
reases ship safety. temperatures	• Extensive development required for rotor wing and propulsion system. High technical risk. • High degree of mechanical complexity implies high maintenance costs.	NOT SELECTED • High • Conc • Addit neces
reases ship safety. simplifies transition.	• High velocity and high temperature jet exhaust. • High thrust engine required to provide vertical take-off and landing.	NOT SELECTED • Addit unnec
reases ship safety. ermits high density storage.	• High velocity and high temperature jet exhaust. • Vertical fuselage makes maintenance less convenient. • High thrust engine required to provide vertical take-off and landing.	NOT SELECTED • Addit unnec
SLR01. igurations.	• 26% higher production unit cost than SLR01. • Larger and heavier than SLR01.	NOT SELECTED • Addit appr carr

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TABLE 2-2

SUMMARY OF AIRCRAFT CARRIER LAUNCH
AND RECOVERY OPERATIONS STUDY

OF RPV/LAUNCH/RECOVERY :M COMBINATION	MAJOR REASONS FOR BEING SELECTED OR NOT SELECTED	RANKING
landing gear to accommodate di-/recovery equipment designed for RPV	SELECTED FOR LONG ENDURANCE MISSION Simplest, lowest cost system.	1st
landing gear to accommodate di-/recovery equipment designed for RPV mounted arresting system.	SELECTED FOR LOW ALTITUDE PENETRATOR MISSION Simplest, lowest cost system.	1st
nent required for rotor wing and High technical risk. hanical complexity implies high	NOT SELECTED • High system development cost • Concept in early stage of development • Additional cost required for VTOL unnecessary for carrier operations.	5th
igh temperature jet exhaust. required to provide vertical g.	NOT SELECTED • Additional cost required for VTOL unnecessary for carrier operations.	4th
igh temperature jet exhaust. nakes maintenance less required to provide vertical g.	NOT SELECTED • Additional cost required for VTOL unnecessary for carrier operations.	3rd
ion unit cost than SLR01. than SLR01.	NOT SELECTED • Additional cost required to reduce approach speed unnecessary for carrier operations.	2nd

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against a friction force following engagement of the existing deck pendants. The additional development cost and unit production cost associated with VTOL and slow-rate-of-closure vehicles is not appropriate for carrier operations. The Long Endurance Configuration (SLR02) satisfies the mission requirements and is launched and recovered in the same manner as the Low-Altitude Configuration. Due to its large size and inherently low approach speed, VTOL and slow-rate-of-closure versions of the Long Endurance Configuration are not practical and were not considered. The SLR02 vehicle is very adaptable to carrier operations and would make maximum utilization of existing shipboard equipment.

2.4 SUMMARY OF SEA CONTROL SHIP LAUNCH AND RECOVERY OPERATIONS STUDY

The evaluation of the five RPV configurations considered for the sea control ship is summarized in Table 2-3. The slow-rate-of-closure (SLOROC) configuration (SLR06-1) was selected as the most suitable configuration for operations from the sea control ship to perform the low-altitude penetration mission. The SLR06-1 vehicle is RATO launched from a special short rail launcher, which permits loading the RPV without the requirements to hoist the RPV onto the launcher. The RPV is recovered by a conventional carrier type landing and engaging new, fixed deck pendants added to the aft flight deck of the sea control ship. An airborne energy absorbing device, identical in concept to the device used on SLR01 and SLR02 for recovery aboard the aircraft carrier, is incorporated in the SLR06-1 configuration. The additional cost of the SLOROC concept is required to permit safe recoveries in the limited deck space available on the sea control ship.

2.5 SUMMARY OF DESTROYER LAUNCH AND RECOVERY OPERATIONS STUDY

The evaluation of the five RPV configurations considered for the destroyer is summarized in Table 2-4. The Tail-Sitter VTOL Configuration (SLR05) was selected as the best candidate for operations from the destroyer class ship. One of the major reasons for selecting the tail-sitter configuration is the fact that the vertical fuselage attitude on deck permits high density storage of the SLR05 vehicle in the very limited hangar space. Vertical take-off and landing is considered to be essential, as it is much safer than the aerial track recovery system or the net recovery system evaluated in this study.

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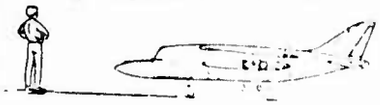
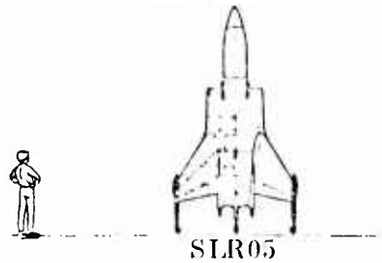
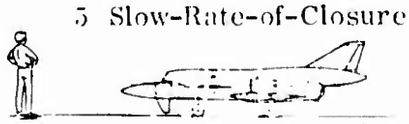
RPV CONFIGURATION (ALL SHOWN TO SAME SCALE)	LAUNCH METHOD	RECOVERY METHOD	APPROACH SPEED KNOTS, T.A.S.	SHIP LOCATION, LAUNCH	LOC REC
1 Conventional Low Alt. Pene. SLR01	Short Rail RATO Launcher	RPV Mounted Arresting System and Fixed Deck Pendants	97	Aft Starboard Deck	Aft F Deck
2 Stopped Rotor VTOL SLR03	Vertical Take-Off Using Rotary Wing	Vertical Landing Using Using Rotary Wing	Near Zero	Aft Starboard Deck	Aft S boar
3 Vectored Thrust VTOL  SLR04	Vertical Take-Off Using Vectored Jet Thrust	Vertical Landing Using Vectored Jet Thrust	Near Zero	Aft Starboard Deck	Aft S boar
4 Tail-Sitter VTOL  SLR05	Vertical Take-Off Using Direct Jet Thrust	Vertical Landing Using Direct Jet Thrust	Near Zero	Aft Starboard Deck	Aft S boar
5 Slow-Rate-of-Closure  SLR06-1	Short Rail RATO Launcher	RPV Mounted Arresting System and Fixed Deck Pendants	60	Aft Starboard Deck	Aft F Deck

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SHIP OCATION, LAUNCH	SHIP LOCATION, RECOVERY	RPV DECK TRANSPORT PROVIDED BY	SPECIAL SHIPBOARD EQUIPMENT, LAUNCH	SPECIAL SHIPBOARD EQUIPMENT, RECOVERY	ADVANTAGES OF RPV/L SYSTEM COMB
t Star-ard Deck	Aft Flight Deck	Landing Gear	Retractable Launcher and Umbilical	Fixed Deck Pendants	• Smallest and lowest cost RPV co Low Altitude Penetrator mission. • Low technical risk.
t Star-ard Deck	Aft Star-board Deck	Landing Gear	Prelaunch Holdback and Umbilical	Docking Mechanism	• Near zero landing speed increase • Good hover efficiency. • Low downwash velocity and temp
t Star-ard Deck	Aft Star-board Deck	Landing Gear	Prelaunch Holdback and Umbilical	Docking Mechanism	• Near zero landing speed increase • Moderate technical risk. • Horizontal fuselage attitude simp
t Star-ard Deck	Aft Star-board Deck	Landing Gear	Prelaunch Holdback and Umbilical	Perforated Raised Land-ing Platform	• Near zero landing speed increase • Moderate technical risk. • Vertical fuselage attitude permit
t Star-ard Deck	Aft Flight Deck	Landing Gear	Retractable Launcher and Umbilical	Fixed Deck Pendants	• Lower approach speed than SLR • Folding wings reduces storage s • Lower cost than VTOL configura • Low technical risk.

SUM
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ES OF RPV/LAUNCH/RECOVERY YSTEM COMBINATION	DISADVANTAGES OF RPV/LAUNCH/RECOVERY SYSTEM COMBINATION	MAJOR
t cost RPV considered which performs rator mission.	• Relatively high speed approach • Weight penalty for RPV mounted arresting system.	NOT SELECTED
peed increases ship safety. cy. city and temperature.	• Extensive development required for rotor wing and propulsion system. High technical risk. • High degree of mechanical complexity implies high maintenance costs.	NOT SELECTED
peed increases ship safety. risk. attitude simplifies transition.	• High velocity and high temperature jet exhaust. • High thrust engine required to provide vertical take-off and landing.	NOT SELECTED
peed increases ship safety. risk. ttitude permits high density storage.	• High velocity and high temperature jet exhaust. • Vertical fuselage makes maintenance less convenient. • High thrust engine required to provide vertical take-off and landing.	NOT SELECTED
eed than SLR01. ces storage size. TOL configuration.	• 26% higher production unit cost than SLR01. • Larger and heavier than SLR01	SELECTED

TABLE 2-3

SUMMARY OF SEA CONTROL SHIP LAUNCH
AND RECOVERY OPERATIONS STUDY

OF RPV/LAUNCH/RECOVERY EM COMBINATION	MAJOR REASONS FOR BEING SELECTED OR NOT SELECTED	RANKING
eed approach RPV mounted arresting system.	NOT SELECTED • Higher approach speed than SLR06-1.	2nd
ment required for rotor wing and . High technical risk. chanical complexity implies high .	NOT SELECTED • High system development cost Concept in early stage of development. Higher RPV unit cost than SLR06-1.	5th
high temperature jet exhaust. required to provide vertical ng.	NOT SELECTED • Higher RPV unit cost than SLR06-1.	4th
high temperature jet exhaust. makes maintenance less e required to provide vertical ng.	NOT SELECTED • Higher unit cost than SLR06-1.	3rd
ction unit cost than SLR01. er than SLR01	SELECTED • Slow approach speed safer for limited deck space of SCS.	1st

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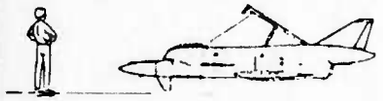
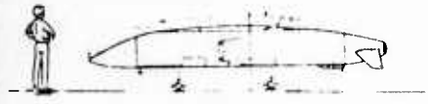
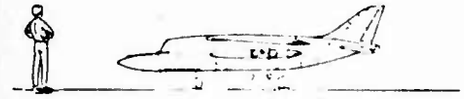
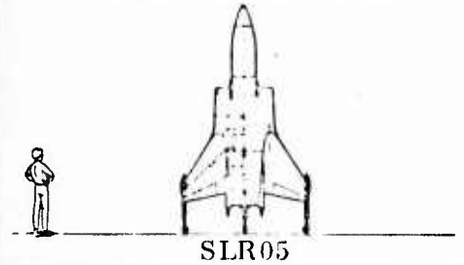
RPV CONFIGURATION (ALL SHOWN TO SAME SCALE)	LAUNCH METHOD	RECOVERY METHOD	APPROACH SPEED, KNOTS, T.A.S.	SHIP LOCATION, LAUNCH	SHIP LOCATION, RECOVERY	T P
1 Slow-Rate-of-Closure SLR06-2	Short Rail RATO Launcher	Net Recovery	60	Aft of Flight Deck	Above Aft Deck	
2 Slow-Rate-of-Closure  SLR06-3	Short Rail RATO Launcher	Aerial Track	60	Aft of Flight Deck	Off Port Side	
3 Stopped Rotor VTOL  SLR03	Vertical Take-Off Using Rotary Wing	Vertical Landing Using Rotary Wing	Near Zero	Flight Deck	Flight Deck	
4 Vectored Thrust VTOL  SLR04	Vertical Take-Off Using Vectored Jet Thrust	Vertical Landing Using Vectored Jet Thrust	Near Zero	Flight Deck	Flight Deck	
5 Tail-Sitter VTOL  SLR05	Vertical Take-Off Using Direct Jet Thrust	Vertical Landing Using Direct Jet Thrust	Near Zero	Flight Deck	Flight Deck	

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SHIP LOCATION, RECOVERY	RPV DECK TRANSPORT PROVIDED BY	SPECIAL SHIPBOARD EQUIPMENT, LAUNCH	SPECIAL SHIPBOARD EQUIPMENT, RECOVERY	NUMBER RPVS ACCOMMODATED IN HANGAR	ADVANTAGES O SYS
Above Aft Deck	Special Handling Dolly	• Retractable Launcher & Umbilical	• Large net with energy absorbing system • Recovery crane	3	• Permits low weight • RPV is simpler and
Off Port Side	Special Handling Dolly	• Retractable Launcher & Umbilical	• Support Masts • Aerial Track System	3	• Permits low weight • Deployment of reco other ship systems. • RPV is simpler and
Flight Deck	RPV Landing Gear	• Prelaunch Holdback & Umbilical	• Docking Mechanism	2	• Low downwash velo • Good hover efficien • Near zero landing s
Flight Deck	RPV Landing Gear	• Prelaunch Holdback & Umbilical • Protective Decking	• Docking Mechanism • Protective Decking	2	• Horizontal fuselage • Moderate technical • Near zero landing s
Flight Deck	RPV Landing Gear	• Prelaunch Holdback & Umbilical	• Perforated Raised Landing Platform	6	• Vertical fuselage at storage. • Moderate technical • Near zero landing s

ADVANTAGES OF RPV/LAUNCH/RECOVERY SYSTEM COMBINATION	DISADVANTAGES OF RPV/LAUNCH/RECOVERY SYSTEM COMBINATION
Permits low weight penalty for launch/recovery in RPV. RPV is simpler and lower cost than VTOL RPVs.	• High risk to ship on recovery. • Cost of expendable RATO motors. • Logistics required to resupply RATO motors. • Large deck space required for net installation. • Special handling dolly required to transport RPV on deck.
Permits low weight penalty for launch/recovery in RPV. Deployment of recovery system does not interfere with other ship systems. RPV is simpler and lower cost than VTOL RPVs.	• Recovery system sensitive to sea conditions. • Questionable feasibility of recovery in moderate sea states. • Ship top-side weight penalty adversely affects ship roll stability.
Low downwash velocity and temperature. Good hover efficiency. Near zero landing speed increases ship safety.	• Extensive development required for rotor wing and propulsion system. • Large size limits hangar storage to 2 RPVs. • High degree of mechanical complexity implies high maintenance costs.
Horizontal fuselage simplifies transition. Moderate technical risk. Near zero landing speed increases ship safety.	• High velocity and high temperature jet exhaust. • Large size limits hangar storage to 2 RPVs. • High thrust engine required to provide vertical take-off and landing
Vertical fuselage attitude permits high density hangar storage. Moderate technical risk. Near zero landing speed increases ship safety.	• High velocity and high temperature jet exhaust. • Folding nose required for vertical hangar clearance. • Vertical fuselage makes maintenance less convenient. • High thrust engine required to provide vertical take-off and landing.

* Conclusion:

The study indicated that destroyer-based RPV's in the 3,000-pound weight class are feasible. However, the system requires the development of expensive VTOL air vehicles and the system would be restricted to operations in low to moderate sea states.

Unless it appe
conside

TABLE 2-4

SUMMARY OF DESTROYER LAUNCH AND RECOVERY OPERATIONS STUDY

PV/LAUNCH/RECOVERY OMBINATION	MAJOR REASONS FOR BEING SELECTED OR NOT SELECTED		RANKING
very.) motors. supply RATO motors. ed for net installation. uired to transport RPV on deck.	NOT SELECTED	• High risk to ship on recovery. • Recovery net occupies valuable deck space and interferes with missile launcher on ships modified for BPDMS.	5th
ve to sea conditions. f recovery in moderate sea lty adversely affects ship	NOT SELECTED	• Low probability of successful recovery due to ship motion. • Top-side weight penalty on ship.	4th
equired for rotor wing and storage to 2 RPVs. al complexity implies high	NOT SELECTED	• High system development cost. • Concept in early stage of development. • Large RPV size limits hangar storage.	3rd
mperature jet exhaust. storage to 2 RPVs. red to provide vertical	NOT SELECTED	• Large RPV size limits hangar storage.	2nd
mperature jet exhaust. r vertical hangar clearance. maintenance less convenient. red to provide vertical take-	SELECTED	• Vertical attitude permits high density storage. • Relatively low technical risk.	1st *

nd weight class
expensive VTOL
ow to moderate

Unless there is a unique and critical mission requirement for this class of RPV, it appears that the high cost and operational risks for this system outweigh other considerations for its employment in destroyer operations.

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The study indicates that destroyer-based RPVs in the 3,000-pound class are feasible. However, the system requires the development of expensive VTOL air vehicles and the system would be restricted to operations in low to moderate sea states.

Unless there is a unique and critical mission requirement for this class of RPV, it appears that the high cost and operational risks for this system outweigh other considerations for its employment in destroyer operations.

Other Teledyne Ryan studies have shown that smaller, lighter RPVs with reduced mission capability appear to be practical for operation from destroyers (Reference 11). The smaller vehicles, because of their lightweight and low landing speeds, are suitable for launch from small catapult launchers and recovery using systems such as the net recovery system discussed in Reference 11.

2.6 RPV AVIONICS SYSTEM SELECTION

The recommended RPV avionics system is one based on the use of general purpose digital computer-oriented hardware. The unique features of this approach are:

a. The use of a general purpose minicomputer.

b. Modular approach to software that minimizes the cost for software changes to incorporate growth capability or changes in requirements.

c. Replacement of hardware processing functions with software routines.

This advanced multipurpose RPV avionics system emphasizes the following benefits:

a. Low acquisition and life cycle costs.

b. High degree of mission modularity and flexibility.

c. Fast turnaround.

d. Simple and inexpensive to modify, easy to grow functionally.

e. Improved reliability, readily adaptable to redundancy.

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f. High function density to meet vehicle volume constraints.

g. Readily adaptable to a variety of navigation systems and payloads.

h. Highly suitable to automatic checkout.

Important additional benefits of this approach in shipboard operations, where space and safety are premium commodities, include an improvement in reliability and a reduction in electromagnetic interference, maintenance turnaround time, and number of maintenance personnel required.

2.7 LANDING GUIDANCE STUDY CONCLUSIONS

The multilateration radio command and control system is recommended for applications to all new vessels having an RPV detachment. It provides a nearly universal application to several types of vessels; provides close-in guidance; permits operation in a jamming environment, and provides multiple vehicle service and functional duality with the primary command guidance and control data link. The ship motion compensation and prediction can be individually addressed to any incoming RPV in the approach pattern; multiple approach paths and multiple air vehicles can be handled simultaneously. Missed approach guidance can therefore be easily included. The system can operate cooperatively with the launch and recovery control/display console. Simple omni antennas, accurately sited, are the only critical installation requirements.

However, the RPV can utilize any of the existing or planned landing aids which provide deck motion compensation and touchdown prediction capability.

Some aircraft carriers are currently equipped with the AN/SPN-42 automatic carrier landing system. It should be used if it is installed and available.

In the event the Sea Control Ship mounts the Co-Scan landing aids, the RPV can share this facility as well.

2.8 RPV CONTROL CENTER STUDY SUMMARY

2.8.1 RPV CONTROL CENTER LOCATIONS

To be operationally acceptable, the RPV detachment control center for all vessels should provide:

a. Central operations from which all aspects of the repair test, launch control, mission control, and recovery control can be made.

b. Minimum vessel modifications with visual monitor of all operations.

c. Minimal interference with present manned aircraft operations or in the conduct of other ship operations.

d. Ship's motion interface to the RPV operations processor for landing aid guidance computations, as well as for airborne gyro tests during organizational maintenance.

2.8.1.1 For Carrier Operations

The control center should be located in the hangar deck area, preferrably in the forward mezzanine area. In order to provide visual monitor during launch and recovery, the deck edge operator will enforce override control utilizing the RPV operations processor.

With RPV operations, the launch function is formalized by the RPV captain; voice or hand signal instructions are given to the catapult control officer. The RPV captain monitors the RPV progress through the preflight readiness check and prelaunch initialization. The visual RPV post launch monitor progress is followed by the RPV captain using a voice link to the control center. Similarly, the landing safety officer (LSO) can monitor the approach path and conduct vehicle override commands.

2.8.1.2 For Sea Control Ship

An enclosed, glass-lined observation control room is installed. The platform is suspended from the radar antenna base. It is a complete, self-sufficient control installation.

The forward observation platform can easily fit 5 multimode consoles, with ample seating facilities and walk-around servicing areas. The

modular design permits an orderly escalation of one to six consoles for high sortie rate of operations.

Communication and control to the below decks ready maintenance area employ the digital data bus and voice grade intercommunications. The organizational support maintenance specialized equipment is interfaced to the console complex for display and control.

2.8.1.3 For Ocean Escort Vessel

An observation control tower is added to the hangar. The console operator can visually monitor the conduct of all operations. The limited manual interconnect and operator assist functions that are necessary for digital avionics vehicle checkout can be easily monitored because of the relatively close proximity to the checkout area.

2.8.2 RPV CONTROL CONSOLE

Shipboard installation(s) with critical operational and storage space limitations demands a central RPV control complex.

A multipurpose, computer-aided control console offers flexibility, growth capacity and efficient space utilization when used with an RPV employing the digital avionics concept. This permits organizational maintenance, prelaunch checkout, launch phase support, remote link control during the conduct of the mission, and the approach and landing during the recovery phase to be controlled from a central location.

Modular, interchangeable control panels are used for critical functions providing an extremely flexible control console configuration capability. The graphic display will utilize a basic CRT and provide horizontal and a vertical situation display depicting vehicle attitude and typical flight data monitoring for vehicle flight control. This allows the operator to folow the behavior of the vehicle when under automatic control, in addition, it allows the easy transition to manual control when required.

2.8.3 CHECKOUT AND REPAIR TEST

The RPV operations control console and the RPV operations processor can be used for full prelaunch checkout and on-vehicle repair test functions in addition to the primary command control operations.

The RPV will be prepared for flight and refurbished in the hangar or readiness area employing conventional inspection techniques. Three

levels of avionics checkout are recommended; repair test, confidence checkout, and prelaunch validation.

The prelaunch checkout will contain the minimum number of tests practical and consistent with a high confidence level for subsequent flight. The confidence level tests are more thorough, containing monitor functions. The repair test routines are very extensive, containing external stimuli and specification compliance measurement requirements.

2.9 RPV MAINTENANCE AND OPERATIONS CONCEPTS

2.9.1 CARRIER

RPV operations and maintenance are compatible with the aircraft support activities existing aboard carriers. The standard between-flight servicing and organizational/intermediate maintenance functions available for manned aircraft are directly usable for RPV support. The major difference is in operation of RPVs and manned aircraft, where the absence of a live operator on-board the RPV results in a need to maintain a data link either by hardware or by radio frequency transmission between a live operator and an operating RPV aircraft. This man-machine interface is provided for the maintenance and preflight functions in the form of a control center located on the hangar deck and connected simultaneously to multiple RPVs at either the catapult launch station, the flight deck operational readiness check stations or the hangar deck maintenance test stations.

Organizational and intermediate maintenance is carried out on the hangar deck while between-flight servicing is carried out on the flight deck to facilitate immediate turnaround. The RPV is instrumented with a test access system to permit the carrier mounted RPV control center to verify equipment operational readiness or conduct preventive maintenance/ corrective maintenance testing.

2.9.2 SEA CONTROL SHIP

For operations and maintenance aboard SCS, RPV design must be oriented toward independence from non-RPV ship based shop facilities. The limitations on organizational and intermediate maintenance facilities aboard the ship and the restrictions on weight of VTOL aircraft require that the RPV test facilities be concentrated in the RPV control center. All RPV unique components are thus tested by the RPV control center as LRUs of the RPV and bench test of RPV unique components on board ship is minimized. For VTOL launch and recovery and arrested recovery

operations, line-of-sight visual contact with the RPV is required from the RPV control center. The control center is thus located above the flight deck with unrestricted view aft and also forward on the port side.

RPV operations support is conducted on the aft end of the flight deck where presently planned aircraft support facilities are sufficient for RPV support. Maintenance of RPVs is conducted on the hangar deck using the container facility concept planned for the SCS.

2.9.3 DESTROYER

Support of RPVs on destroyers consists of operations support and limited organizational maintenance. With the space and weight restrictions on ship installations, RPV design must be oriented to minimize ship mounted support equipment which occupies valuable space without increasing the ship's capabilities. Test equipment will therefore be designed into the RPV, to be operated by minimal control equipment installed in the ship. The RPV control center is located to facilitate flight control and test control with line-of-sight visibility for both functions. RPV flight support is compatible with existing helicopter support facilities such as fueling equipment, hangar and flight deck, but handling aids must be added to provide for safe RPV movement in heavy seas.

3.0 SHIP SELECTIONS AND SHIP MOTION CRITERIA

The Shipboard Launch and Recovery Operations Study is tasked to examine various launch and recovery methods for representative ships of the aircraft carrier, sea control ship, and destroyer types. These ships not only vary in size, but they also differ in their support and interface with airborne vehicles. The study of launch and recovery of RPVs from these ships will involve essentially all the considerations necessary for the integration of the RPVs into normal shipboard operations.

3.1 AIRCRAFT CARRIER AND SEA CONTROL SHIP

Of the three types of ships considered, only the carrier and sea control ship are dedicated to aircraft support as their prime purpose. Obviously, RPV launch and recovery operations can be more readily adaptable to the carrier and sea control ships than to the destroyer. Therefore, the selection of a specific carrier class is not nearly as significant to this study as the selection of the destroyer class. The only class of sea control ship has yet to be built. Therefore, effort was centered on obtaining information on the proposed sea control ship. Adequate engineering drawings and other information were obtained from Naval facilities to serve as a basis for this study.

The USS KITTY HAWK (CVA-63) was selected as the representative aircraft carrier for the RPV launch and recovery operations study. This carrier is typical of the large deck attack carriers and its local berthing permitted ready access for first hand observations and interviews with ship personnel. The interfaces with the CVA-63 are expected to produce valid study results applicable to other carriers.

3.2 DESTROYER CLASSES REVIEW

The choice was made from among those classes of combatants under 10,000 tons which are configured in the manner of destroyers, and are not nuclear-powered. Referring to U. S. Naval Air Engineering Center publication NAEC-ENG-7576, and to Jane's FIGHTING SHIPS (1971-72) these include:

DLG (Guided Missile Frigates), about 5800-8000 tons full-load displacement

DL (Frigates), 4500-7500 tons
DDG (Guided Missile Destroyer), 4000-5200 tons
DD (SPRUANCE Class; current construction), 6900 tons
(FORREST SHERMAN Class: 1959-65), 3950 tons
(GEARING, conversions: 1944-46), 3044-3500 tons
(SUMNER, conversions: 1943-45), 3320 tons
DEG (Guided Missile Escort Ships)
(BROOKE Class/DEG 1: 1963-66), 3425 tons
DE (Escort Ships)
(KNOX Class/1052: 1965-72), 4011 tons
(GARCIA Class/1040: 1964-68), 3400 tons
(BRONSTEIN Class/1037: 1962-), 3650 tons

3.3 CRITERIA FOR SELECTION OR REJECTION

The criteria used for elimination of inappropriate classes recognize that the ships studied should:

a. Be active vessels, with prospects for continued service in numbers large enough to allow for system growth into a significant capability.

b. Offer the potential of enough available space for RPV system support so that adaptation to this role could be made without prohibitive expenditures and without unacceptable decreases in other operational functions. Thus, existence of helicopter facilities which can be adapted to RPVs is a positive factor, while any need to remove effective firepower would be a negative one.

c. Offer a favorable system environment so that reasonable variations in weather combined with tactical maneuvers of the ship will not restrict RPV operations. Therefore, placement of the landing and work areas as well as the size of the ship will be significant factors.

d. Possess sufficient vertical stability to accommodate necessary weight above the ship center of gravity; without requiring the addition of excessive ballast, or unacceptable removals of other facilities.

e. Not be so valuable a ship (either operationally or in dollars) so that partial commitment to RPV operations is inappropriate. Example: nuclear-powered Frigates are not appropriate

candidates because they will, in emergencies, be in short supply for performing other functions for which they possess unique capabilities.

f. Possess sufficient speed to be compatible with promising RPV launch/recovery techniques. Example: in zero-wind conditions, a technique requiring a relatively low rate of closure for recovery operations may constrain acceptable ship speed capability, depending upon the minimum landing-speed which can be incorporated into RPV design.

3.4 GUIDED-MISSILE FRIGATES (DLG) AND FRIGATES (DL)

These ships are large enough and fast enough for RPV purposes, but it is possible that commitment to this additional mission would be illogical due to interference with other missions and with helicopter operations. The nine BELLKNAP-class DLGs have full helicopter support facilities; and the LEAHY (9 ships) and COONTZ (10 ships) classes, of somewhat smaller tonnage, have correspondingly less support capacity. The two remaining DLs of the MITSCHER class (4730 tons, full load) also have helicopter facilities. Taken together, the 30 ships of these four classes may be the easiest to adapt to RPV purposes, particularly the 7930-ton BELLKNAPS.

3.5 GUIDED-MISSILE DESTROYERS (DDG)

Most numerous of the existing DDGs are the 23 ships of the C.F. ADAMS class. At 4500 tons full-load displacement, these ships are not configured for helicopter operations. JANE'S points out that they are considered to be excellent multipurpose ships, a fact which makes it improbable that the required conversion work would or should be undertaken to reconfigure this design for RPVs.

DDG35 and DDG36, two ships of the MITSCHER class, were converted from Frigates to DDGs, but were decommissioned in 1969. The conversion process included the improvement of ASW capability; but ASROC was selected as a weapon instead of the DASH system. Therefore, helicopter facilities may be less adequate than on the two MITSCHER type Frigates (DL4 and DL5). These two ships, although decommissioned, may merit consideration in view of:

a. Size (about 5000 tons full-load displacement)

b. Adaptability to the mission

c. Noncommitment to other missions

d. Basic similarity to two active Frigates, which could allow the establishment of a class of four ships for RPV support

Somewhat less adaptable than the MITSCHER class ships, but more numerous, are the 18 vessels of the FORREST SHERMAN type. Helicopter facilities are lacking. Four of the ships have been converted to DDGs with ASROC launchers rather than DASH helicopters systems. Eight of the remaining 14 DDs have been modernized for improved ASW capability, again with ASROC instead of DASH. Significant conversion would have to be undertaken to utilize the class for RPVs. The ships offer suitable size (about 4000 tons) and speed.

3.6 DESTROYER (DD) AND GUIDED MISSILE ESCORT (DEG)

Newest among the DDs is the large-displacement SPRUANCE class, at 6900 tons, full-load. Hopefully, this class would become available as the GEARING and SUMNER classes of "modernized" older destroyers are phased out. SPRUANCE ships will have helicopter facilities and adequate speed. But it will be a valuable as well as a costly ship, and the number which will exist remains problematical. Diversion to the RPV mission is an unlikely course of action; but RPV capability may be included among this ship's characteristics, in manner similar to the DL and DLG classes.

The SUMNER class and the enlarged-version GEARING class represented well over 100 ships, many of which are still active. These ships were commissioned in 1944-46; and while facilities for small-helicopter (DASH) operations were installed during modernization programs, these ships are approaching the 30-year mark. Most of the SUMNER class and a number of the GEARINGs have been decommissioned or are now in reserve. Existing helicopter facilities are inadequate for the present purpose, so that conversion work would be required. Work which would involve reallocation of space and which is likely to involve costs not justifiable in view of the ships' short life-expectancy considering age and budget prospects. It is concluded that these ships are not prospective candidates.

The BROOKE (DEG-1) class of Tartar missile-firing ships are candidates, but lower priority should be given to utilization of these six vessels, because of possible interference with their present missile capability.

3.7 ESCORT SHIP (DE)

The GARCIA (DE-1040) class of Escort Ship (ten vessels) are only slightly older than the 1052 class, having been launched 1964-68. They are about 600 tons lighter, and no faster. They are provided with DASH helicopter facilities, which at one time were in use on DE-1041. The same vessel also carried the BPDMS for a time, at another location on the ship. Subject to space and stability comparisons, the 1040 class should be satisfactory.

The two-ship BRONSTEIN (DE-1037) class, at 2650 tons full-load displacement is not a likely candidate for RPV recovery operations. But it may prove desirable under some operational concepts (e.g., when attrition will be high or when some RPVs may be launched on one-way missions) to have greater capacity to launch than to recover. BRONSTEIN and MC CLOY have small helicopter landing areas but no hangar facilities at the present time. Launched in 1962, they have a longer prospective period of service remaining than do the GEARING class DDs, which are at least 16 years older. For study purposes, they may be regarded as representative of a possible launcher of RPVs which could be recovered by a larger ship with more complete facilities.

There is one obvious candidate remaining, it is the 1052 class Ocean Escort Ship. At 4011 tons full-load displacement, it is fully as large as the FORREST SHERMAN class of destroyers, and is of later construction (commissioned 1965-72). It possesses a relatively generous ASW helicopter space, which has been adapted for LAMPS helicopters (Light Airborne Multipurpose System) and BPDMS (Basic Point Defense Missile System). These have not been implemented in significant numbers, so that RPV utilization would not negate present capabilities.

3.8 SELECTION

In choosing the prime candidate, the objective is not necessarily to find the class of ship which could most obviously perform the tasks of RPV launch, recovery and support; but rather to identify the class of ships whose successful adaptation to these tasks would not only have a very good prospect for feasibility, but would also contribute most significantly to the Navy's total capabilities. Therefore, some promising possibilities are bypassed as prime candidates. Among such ships may be counted the CHARLES F. ADAMS class of DDGs. Use of these 23 ships might well result in no better than even trade of capabilities loss versus gain. In a somewhat different category are the large new SPRUANCE class of DDs; the BELKNAP, LEAHY, and COONTZ classes of DLGs; TRUXTAN

and BAINBRIDGE classes of DLGNs; and perhaps the inactive DL, NORFOLK. Such vessels might absorb RPV capability without appreciable loss of other potential, individually; but greater flexibility in projecting Naval firepower will be attained if other suitable platforms can be found.

The selection of the DE-1052 (KNOX) class of Escort Ship is prompted by a number of favorable considerations. At 4011 tons full-load displacement, it is large enough to serve as a good platform and is of later construction (commissioned 1965-1972). Numerically, the class is larger than any other of vintage later than 1946. It is equipped with stabilizing fins which are effective enough to reduce roll under many conditions, to lower values than those encountered on vessels of greater displacement. There is a relatively generous ASW helicopter space and adequate aircraft related facilities. It is clear than the discovery of an important new mission for the forty-six ships involved should provide an effective way of increasing Naval capabilities within present force levels using existing active hulls.

3.9 SHIP MOTION CRITERIA

In tabular and diagrammatic form, References 1, 2, 3 and 4 provide partial data on ships' motions to be expected depending upon wind velocity/sea state/wave height; ship speed; ship heading with respect to predominant sea direction; and activation of devices such as stabilizing fins or passive tanks. Motions dealt with are roll and vertical motion with a few indications of limiting values (e.g., maximum acceptable roll or vertical acceleration). Based on information in these documents, selection of related criteria for use in this study is discussed below and summarized in Table 3-1.

Nominal ship speed during recovery is taken to be 20 knots. (Reference 1, and a range of 10 to 30 knots, can be expected to be used in order to achieve a favorable wind across the deck.) Sea state 6 can be considered a design constraint, since less favorable conditions are expected no more than ten percent of the time.

State 6 seas are likely to be accompanied by winds from 29 to 33 knots (Reference 4) however, the design should allow handling of the vehicle on deck with any wind velocity less than 45 knots (Reference 1). Handling will take place at helicopter platforms for destroyer-type ships: but for vessels with carrier decks, favorable stations may be selected (e.g., 10 to 14, on a 20-station ship, per Figure 3, Reference 1). Handling should be feasible up to 5 degrees roll (Reference 1), although landings may not

TABLE 3-1

SHIP-RELATED RPV DESIGN CRITERIA

	CARRIER	SCS	DESTROYER
Sea State	6	5	4
Maximum Ship Roll Angle for Deck Handling (Deck Iced)	5 degrees	5 degrees	7 degrees
Maximum Ship Pitch Angle	4 degrees	4-1/2 degrees	5-1/2 degrees
Vertical RPV Acceleration at Landing	2.3	2.3	2.3
Relative Wind Over Deck	20 knots	20 knots	20 knots
Maximum Ship Roll Angle for Take-Off and Landing	3 degrees	5 degrees	5 degrees

normally be made while the ship is more than 3 degrees from vertical (Reference 4).

For design purposes, it may be considered that the ship can be brought to a favorable heading with respect to the seas (e.g., seas within 30 degrees of the bow or 15 degrees of the stern depending on conditions; see Figure 1, Reference).

Vehicles should be able to withstand up to 2.3 vertical g's at landing (Reference 1). General magnitudes of vertical accelerations due to ships' motions can be seen in Figure 4, Reference 1; with more detailed data tabulated in documents reviewed. The same applies to roll motions; with general magnitudes in bow seas at 20 knots in state 6 seas appearing in Figure 2 of Reference 1.

Although a number of the figures in the documents reviewed take note of the "Significant Wave Height" (page 55 of Reference 4 shows Significant Wave Heights of 16 to 20 feet for sea state 6, and Figures 2 and 4 of Reference 1 use 16.9 feet), the design point can be taken on the Root Mean Square (rms) amplitude, per the argument given in Reference 2:

> "....the selection of realistic design values for vertical and lateral loads on the aircraft landing gear is strongly dependent

on the operational procedures employed during the launching and recovery of the aircraft. The takeoffs and landings are timed to occur in the lulls of the irregular ship motion cycles."

"For aircraft launch/recovery operations in extreme seas, the design amplitudes should be the most frequently occurring amplitudes (i.e., the rms responses) rather than the much larger significant amplitudes or the even larger amplitudes that may not be exceeded but once in a thousand consecutive cycles. The reason for the choice of the rms values rather than the more severe values is that the hundreds of landings and takeoffs of Harrier on the LPH-9 in both mild and very rough seas suggest that the LSO/LSE and the aircraft pilot are quite capable of performing landing or takeoff operations during the lulls of ship motions. For any given sea state, the lulls in the ship motion are less than the rms values of the ship motions. The use of rms values is therefore a conservative approach backed up by considerable VSTOL operations experience."

Where needed, stabilizing fins will be considered as operational on the DE-1052 class vessels, but not on other ships. Passive tanks are not to be considered. Reference 4 indicates that at 18.2 knots there is a 65 percent reduction in roll when stabilizing fins are activated on the DE-1052. Although Reference 3 discusses both passive tanks and fins with respect to the Sea Control Ship, recent informal information has not indicated that either one will necessarily be present.

4.0 MISSION PROFILE

The two basic profiles used to size vehicles for this study include (a) a long-endurance mission, with immediate climb after launch to economical cruise altitude for a total endurance of 14 hours; and (b) a low-altitude penetration mission, involving a low-altitude dash of 100 nautical miles at Mach 0.85 plus cruise at 40,000 feet for 400 nautical miles at Mach 0.75.

For the penetration mission, the dash of 100 nautical miles at 500 feet takes place half-way through the flight. The mission could then be described as follows:

a. Launch at sea level

b. Climb to 40,000 feet

c. Cruise at Mach 0.75 at 40,000 feet to a range of 200 nautical miles

d. Descend to 500 feet, increasing speed to Mach 0.85

e. Dash 100 nautical miles at 500 feet, Mach 0.85

f. Climb to 40,000 feet, decreasing speed to Mach 0.75

g. Cruist at 40,000 feet Mach 0.75, to a total range of 500 nautical miles

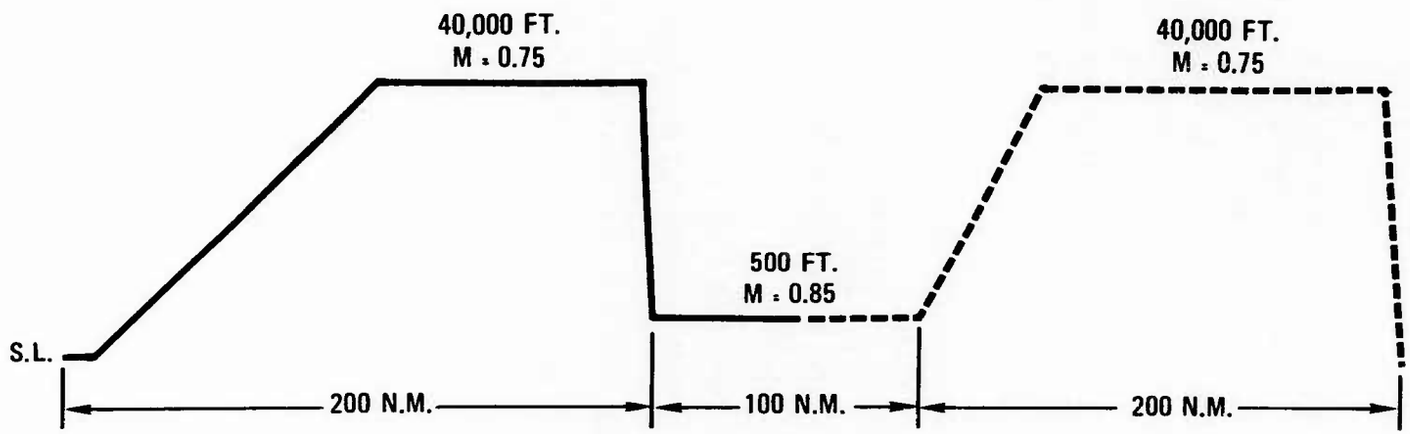
h. Descend and recover

The profile is pictorially shown in Figure 4-1. This type of profile is appropriate for reconnaissance missions, including damage-assessment runs over known targets. With a buoy payload, it could be applied to the replacement of buoy which has malfunctioned while part of a distributed ASW sonobuoy field.

The long-endurance profile encompasses the requirements of more than one mission:

a. It is directly applicable to a medium-high-altitude Ocean Surveillance mission.

A. LOW ALTITUDE PENETRATOR



PAYLOAD = 150 POUNDS, 4 CU. FT.

Figure 4-1. Low Altitude Penetrator Design Mission

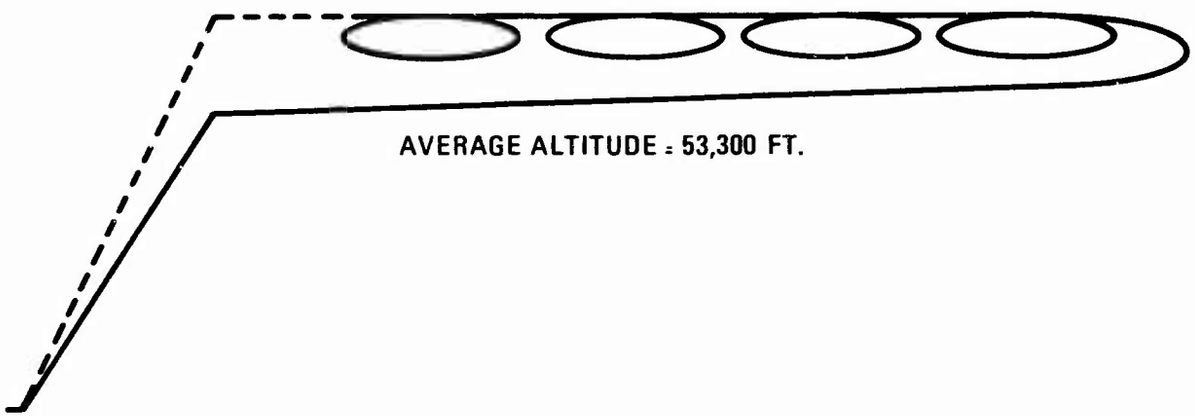
b. Trading 4 to 4-1/2 hours' fuel for a sonobuoy payload, it lends itself to a buoy deployment and monitoring sortie, requiring approximately 9-1/2 hours; as well as a variation on the same sortie which requires shorter flight time in exchange for an 80-mile sortie leg at low altitude during deployment.

c. It is applicable to relay tasks; either in connection with the above or for other relay of data or communications between fleet surface or airborne units.

d. Modified to the requirements of the sensors involved, it can be adapted to barrier and area search functions, to relieve valuable manned units of tedius use of sensors of various non-acoustic types which offer detection capabilities over relatively small swath-widths.

The long-endurance profile is shown in Figure 4-2.

B. HIGH ALTITUDE, LONG ENDURANCE



14 HOURS TOTAL ENDURANCE
PAYLOAD: 750 POUNDS, 20 FT.^{3}

Figure 4-2. Long Endurance Design Mission

5.0 RPV DESIGN STUDIES

5.1 INTRODUCTION

Air vehicle design studies were performed to define a series of RPV designs for use in evaluating different air vehicle concepts with respect to practical shipboard launch and recovery and to provide realistic RPV models for the study of other launch and recovery related problems.

Since landing and takeoff speeds have a direct bearing on the complexity of the launch and recovery systems, the study was structured to cover the three common takeoff and landing speed regimes, i.e., conventional takeoff and landing (CTOL), short takeoff and landing (STOL), and vertical takeoff and landing (VTOL). Table 5-1 lists the configurations analyzed in the course of the study and notes the ships from which each RPV could operate. The figure numbers corresponding to the applicable RPV three-view drawing are also listed in Table 5-1.

The study consisted of sizing analyses to determine the minimum weight and size RPV for each vehicle concept, takeoff and landing performance analyses, performance sensitivity studies, and a general arrangement drawing for each of the candidate configurations.

5.2 VEHICLE SIZING STUDIES

Teledyne Ryan Aeronautical has developed a synthesis type design analysis computer program (AVSYN) for the rapid sizing, parametric analysis, and optimization of aircraft configurations for a specified mission profile and payload. This program was used to size the candidate configurations listed in Table 5-1.

The AVSYN program is described by the block diagram presented in Figure 5-1 and the flow chart of Figure 5-2. Essentially, the program consists of self-contained geometry, aerodynamics, and weight modules; performs parameter trade-offs for certain constraints and sizing options, and finally converges on a gross weight and size for a given mission.

Input consists of a total of 140 variables describing the geometric, aerodynamic, and weight characteristics (independent variables) of the baseline configuration, and the speeds, altitudes, and distances of the mission

TABLE 5-1

AIR VEHICLE STUDY CONFIGURATIONS

CONFIG-URATION NO.	TAKEOFF AND LANDING CONCEPT	CONFIGURATION FEATURES	MISSION	SHIPS FROM WHICH RPV CAN OPERATE			RPV THREE-VIEW FIGURE NO.
				Carrier	SCS	Destroyer	
SLR01	CTOL	Close Coupled Canard	Low Altitude Penetrator	X	X		5-9
SLR02	CTOL	Conventional Wing-Tail	High Altitude, Long Endurance	X			5-12
SLR03	VTOL	Stopped Rotor	Low Altitude Penetrator	X	X	X	5-15
SLR04	VTOL	Vectored Thrust	Low Altitude Penetrator	X	X	X	5-16
SLR05	VTOL	Tail Sitter	Low Altitude Penetrator	X	X	X	5-17
SLR06	STOL (SLOROC)	Deflected Thrust	Low Altitude Penetrator	X	X	X	5-18

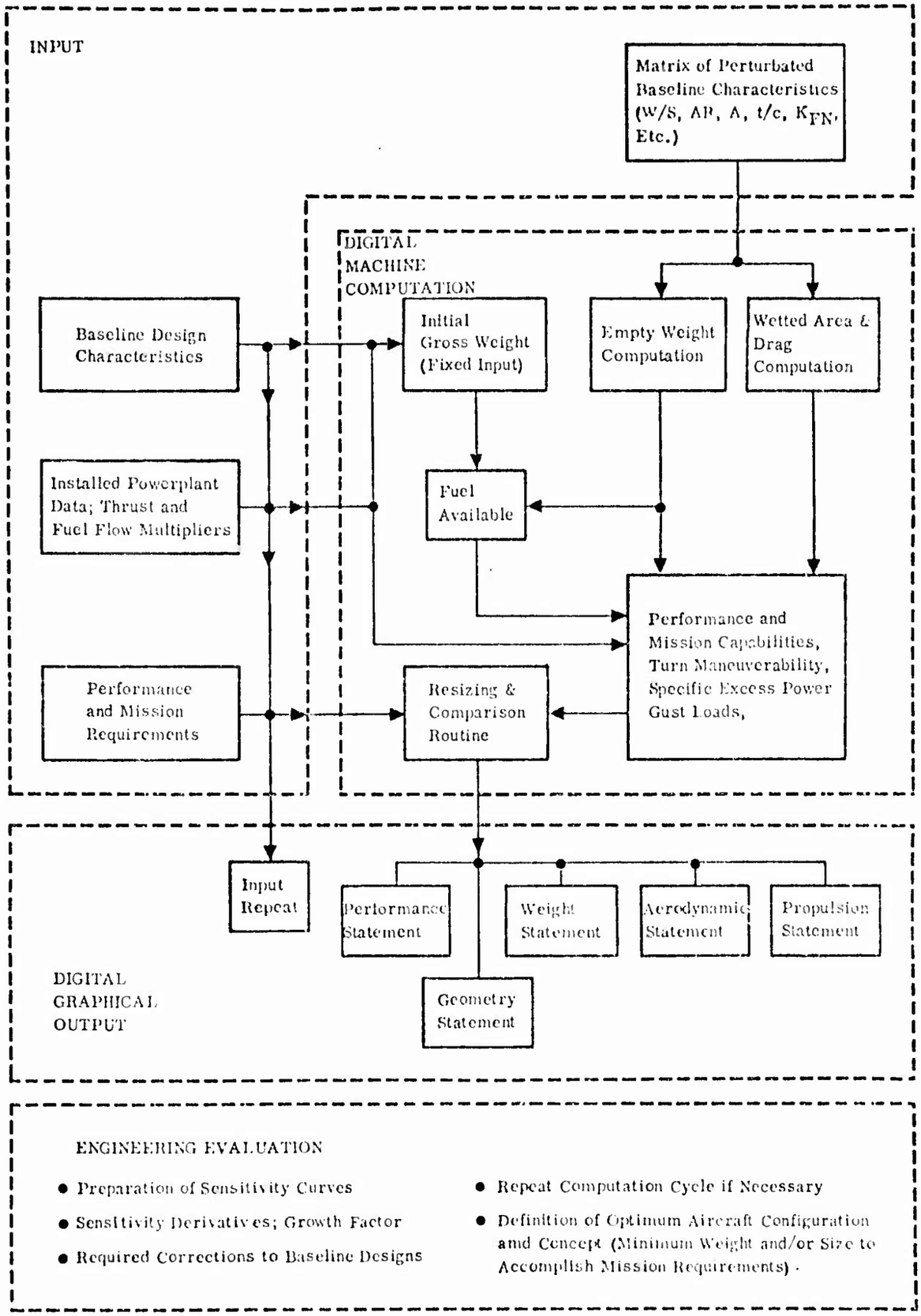


Figure 5-1. Configuration Optimization Program

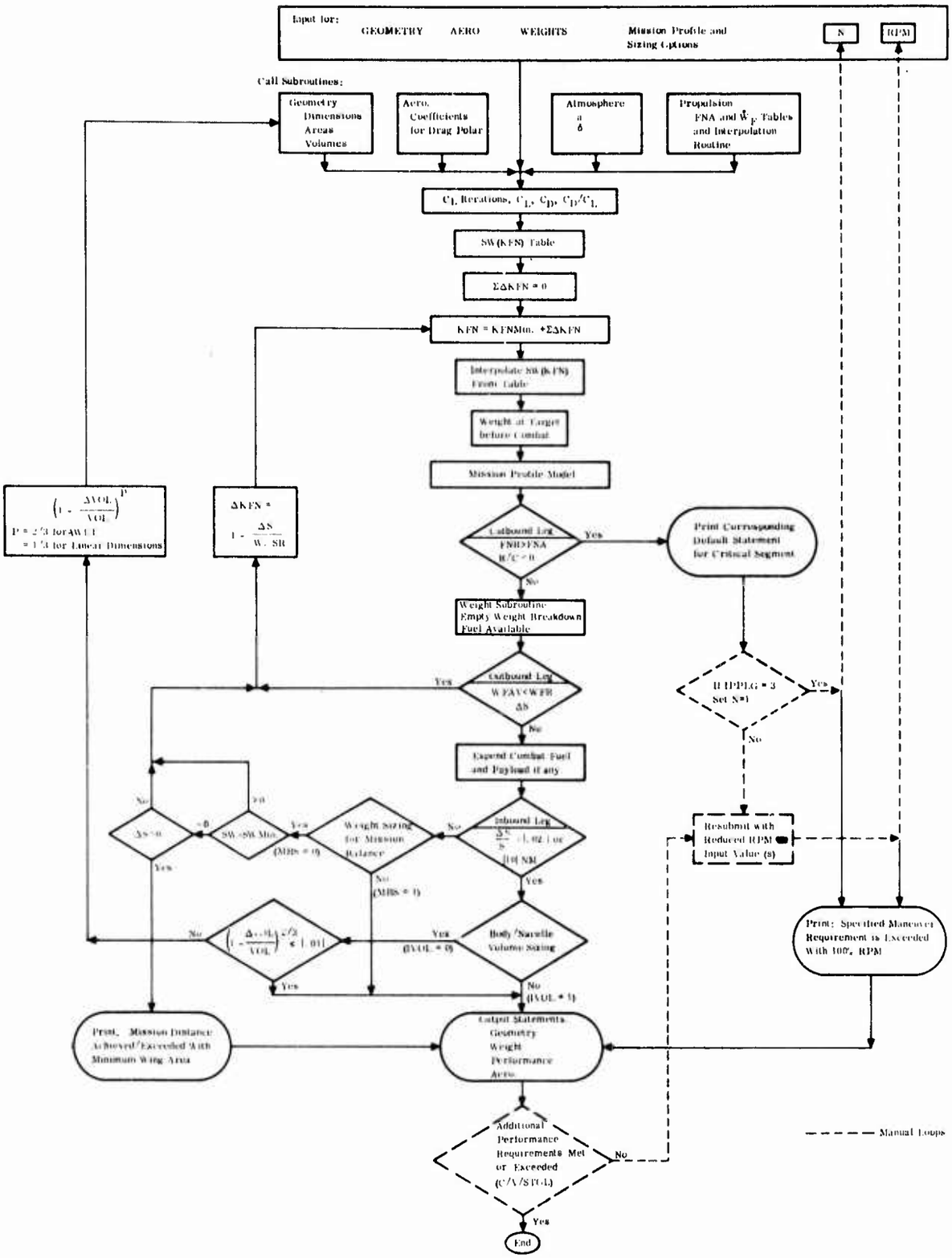


Figure 5-2. AVSYN Master Flow Chart

segments. Output consists of a dimension statement, weight statement, performance statement, and aerodynamic statement for each final solution. The results of the subject RPV sizing studies are presented in the sections covering the individual candidate configurations (Paragraphs 5.6 through 5.1.1).

5.3 TAKEOFF PERFORMANCE

Analyses were performed to determine the deck takeoff performance of the non-VTOL configurations. The analysis covers unassisted and rocket assisted deck takeoffs for the CTOL low altitude penetrator (Configuration SLR01), the SLOROC low altitude penetrator (Configuration SLR06), and the CTOL long endurance RPV (Configuration SLR02). The requirements for short rail rocket launch of Configuration SLR01 were also investigated.

Figure 5-3 presents takeoff time, RATO bottle impulse, and deck roll required for the low altitude penetrator as a function of RATO bottle thrust. Bottle impulse was included to provide an indication of the size of the RATO unit required. The bottle impulse required for short rail launch was determined to be approximately 17,900 pound seconds. Figure 5-4 presents similar takeoff data for the long endurance RPV (Configuration SLR02).

The SLOROC RPV (Configuration SLR06) was designed to provide slow rate of closure with the recovery ship through the use of high lift devices, low wing loading, and deflected engine thrust. The takeoff performance for this configuration presented in Figure 5-5, however, suggests that deck takeoffs, if required, would be performed without thrust deflection. This is due primarily to the unfavorable trade-off resulting from diverting acceleration thrust to gain additional lift component.

One aspect of free deck takeoffs that must be considered is the possibility that the RPV could be diverted from the programmed takeoff trajectory by excessive ship motion or possibly by a failure in the RPV guidance system. The danger of such a situation to shipboard equipment and personnel is obvious and puts the concept of a free deck takeoff in doubt. One solution to the problem is to install a restraining track. The system consists of a deck-mounted guide track and an engagement strut which is restrained from movement in the lateral direction but is free to move on rollers along the length of the track. The strut is engaged to the RPV prior to initiating takeoff and it is automatically disengaged when it reaches the end of the track. The track system requires no power and can be mounted near the edge of the deck leaving the main deck area clear for other operations.

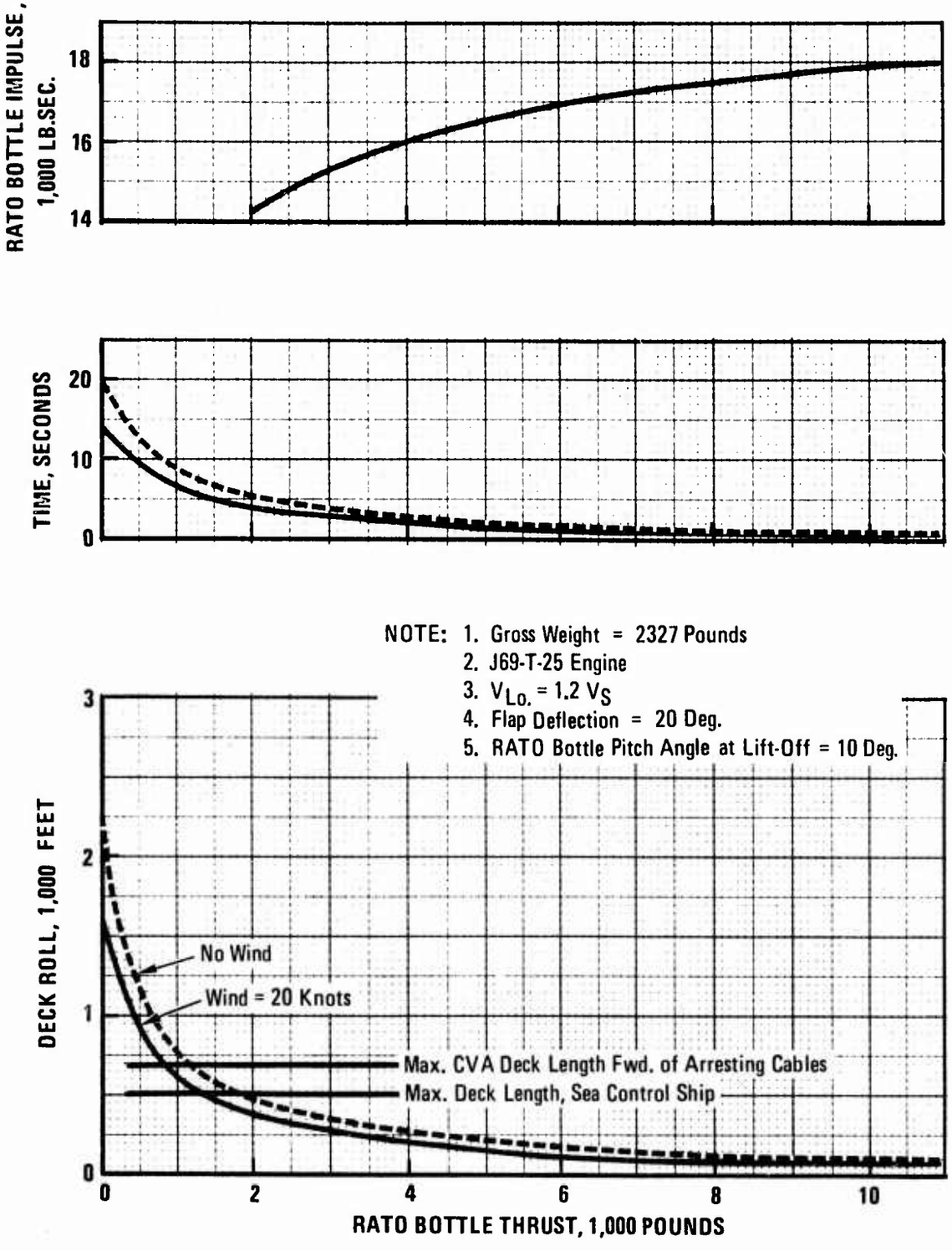


Figure 5-3. Deck Take-Off Performance, Low Altitude Penetrator

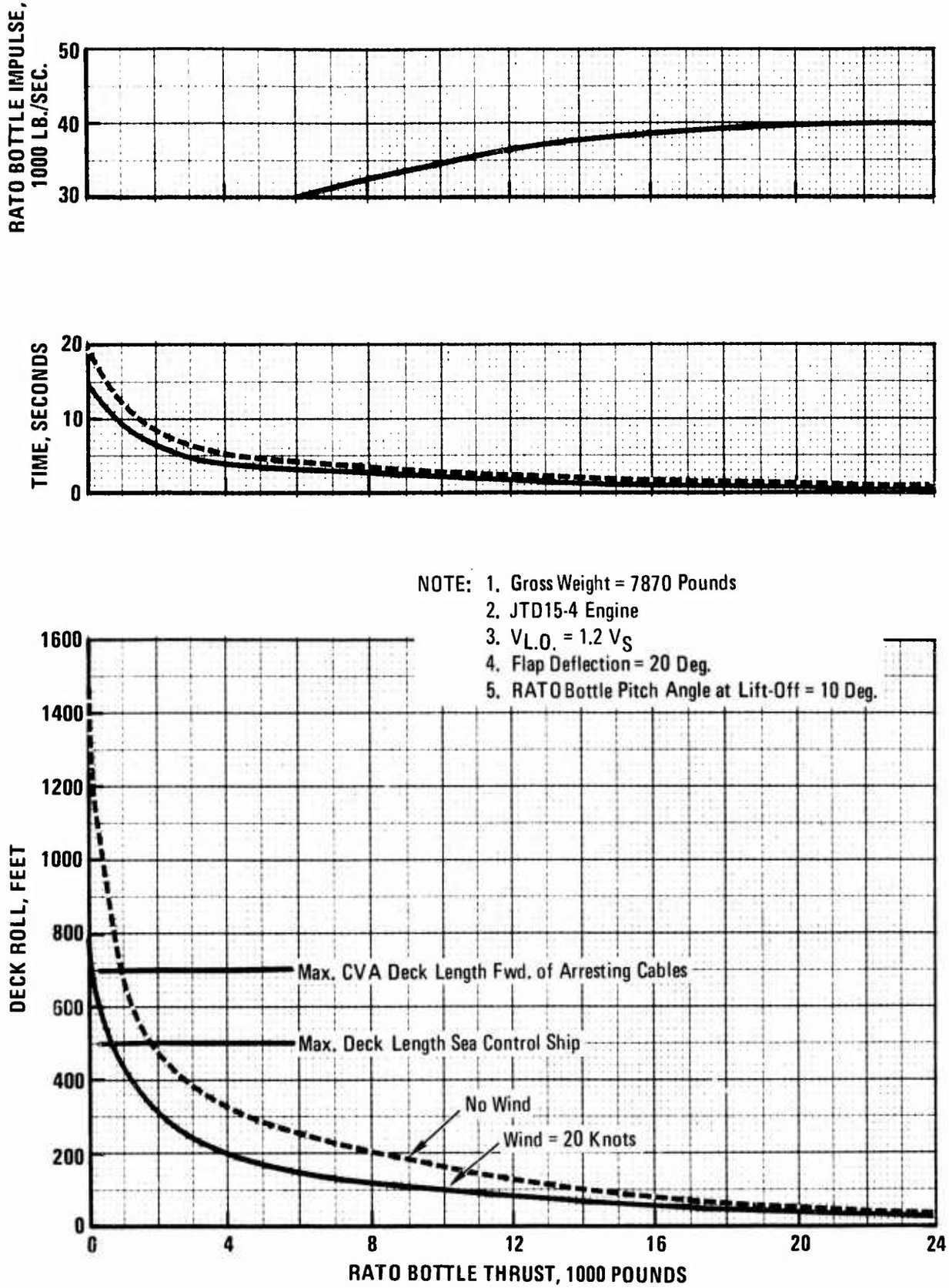


Figure 5-4. Deck Take-Off Performance, Long Endurance Configuration

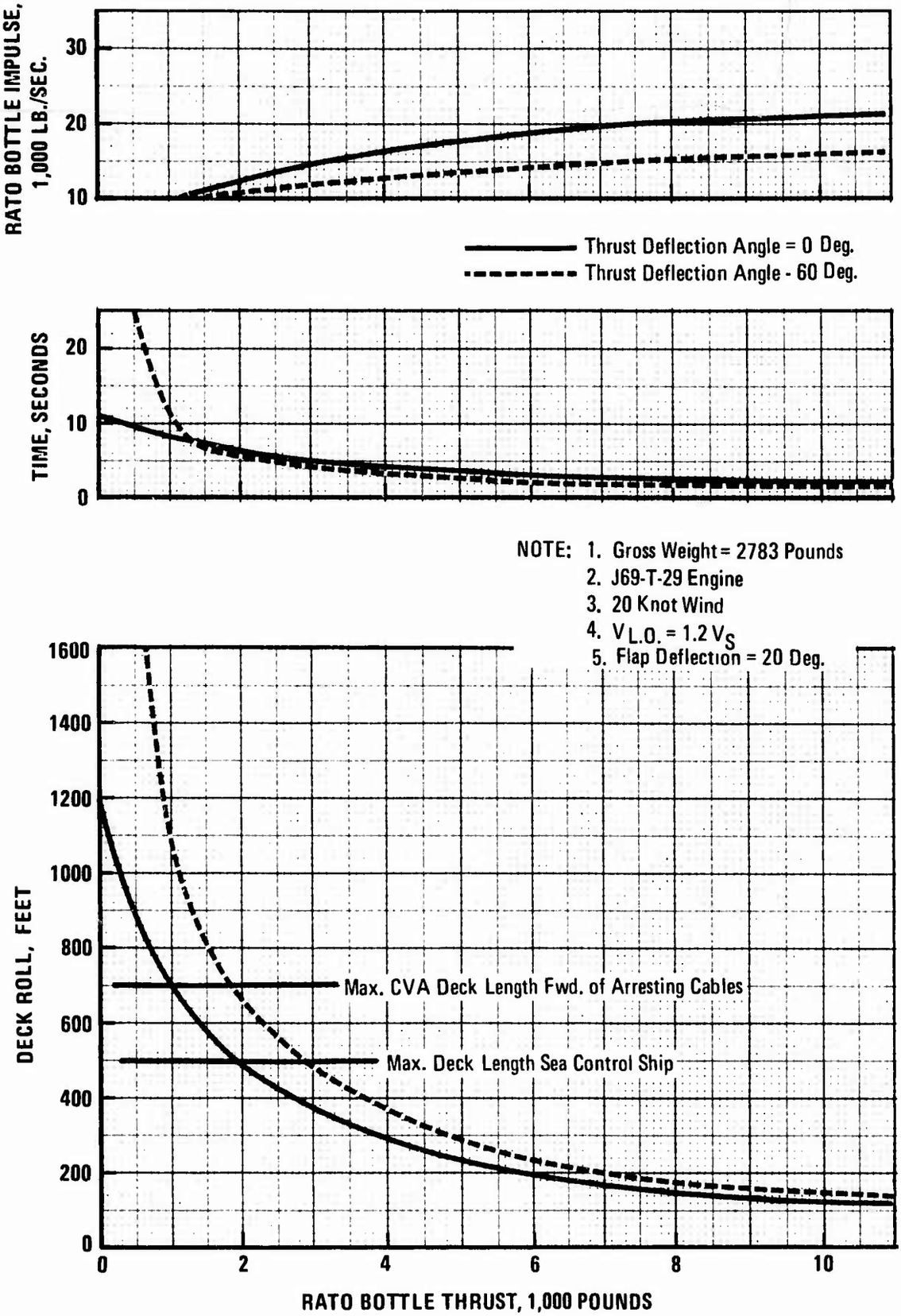


Figure 5-5. Deck Take-Off Performance, Slow-Rate-of-Closure Configuration

5.3.1 TAKEOFF STUDY CONCLUSIONS

1. It is apparent from the deck-roll distances presented in Figures 5-3 through 5-5 that RPVs optimized for minimum weight and thrust would require rocket assist to provide acceptable deck take-offs from the carrier and sea control ship.

2. Aircraft carriers have catapults capable of launching RPVs, and RATO assisted deck takeoffs are not required or recommended. (Carrier launches are discussed further in Section 9.0, "Aircraft Carrier Studies".)

3. Deck-roll takeoffs can be performed from the Sea Control Ship using rocket assist and a guide rail. Other launch methods compatible with the Sea Control Ship include short-rail and zero-length RATO launches, and vertical takeoff aircraft. (Discussed in Section 10.0, "Sea Control Ship Studies".)

4. Since flight decks on destroyer type ships were designed primarily for helicopter operations and are inadquate for conventional aircraft operations, this class of ships cannot be considered as a platform for deck-roll takeoffs. Launch methods compatible with destroyers include short-rail and zero-length launchers, and vertical takeoff aircraft. (Discussed in Section 11.0, "Destroyer Studies".)

5.4 LANDING PERFORMANCE

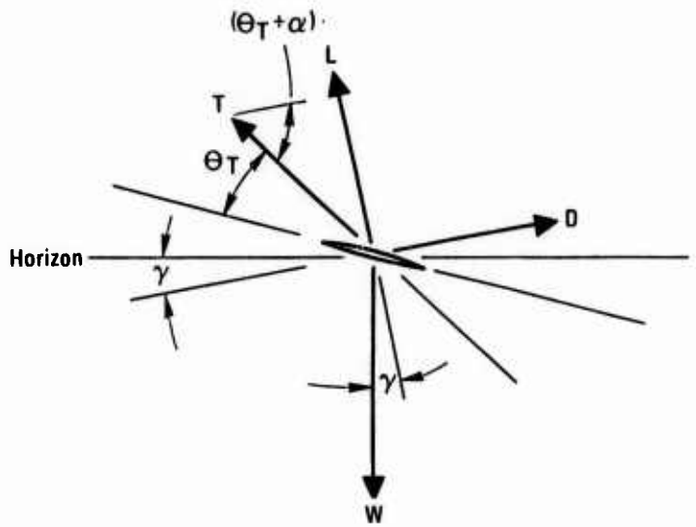
One of the most important considerations in the design of RPVs for shipboard recovery is approach speed. This parameter affects almost every aspect of the recovery problem and should be of prime concern beginning at the earliest design stages. Some of the factors most affected by the magnitude of approach speed are:

a. Safety - Lower approach speeds allow more time for approach flight path corrections and the corresponding lower vehicle energy reduces damage potential.

b. Ship Mounted Recovery Equipment - Vehicle energy to be dissipated at touchdown is proportional to velocity squared, thus the energy levels drop sharply with reduced speed. This results in smaller, lighter, less complex ship mounted energy absorbing devices.

c. Airborne Systems - The lower energy levels associated with the lower approach speeds reduce design requirements for the airborne recovery gear such as landing gear, arresting hook, and energy absorbing friction brakes. Structural weights are also favorably affected.

Expressions for approach-thrust required and for approach-speed were developed from the following force diagram.



Where

L = lift, pounds
T = net thrust, pounds
θ_T = angle between wing chord line and thrust line, degrees
α = wing angle of attack, degrees
W = vehicle weight, pounds
γ = flight path angle relative to horizon (negative value for descent), degrees
D = drag, pounds

Summing the forces in the lift direction gives,

$$L + T \sin(\theta_T + \alpha) - W \cos\gamma = 0 \quad (1)$$

and summing forces in the drag direction,

$$D - T \cos(\theta_T + \alpha) + W \sin\gamma = 0 \quad (2)$$

solving equation (1) for lift gives,

$$L = W \cos\gamma - T \sin(\theta_T + \alpha) \quad (3)$$

and solving equation (2) for drag,

$$D = T \cos(\theta_T + \alpha) - W \sin\gamma \quad (4)$$

now, substituting $(\frac{L}{D})D$ for lift, L, in equation (3),

$$(\frac{L}{D})D = W \cos\gamma - T \sin(\theta_T + \alpha) \quad (5)$$

substituting equation (4) for D in equation (5) gives:

$$(\frac{L}{D})\, T \cos(\theta_T + \alpha) - (\frac{L}{D})\, W \sin\gamma = W \cos\gamma - T \sin(\theta_T - \alpha) \quad (6)$$

Collecting terms and solving for T gives the expression for thrust required during approach,

$$T = \frac{W\left[\text{Cos}\,\gamma + (\frac{L}{D})\,\text{Sin}\,\gamma\right]}{(\frac{L}{D})\,\text{Cos}\,(\theta_T + \alpha) + \text{Sin}\,(\theta_T + \alpha)} \tag{7}$$

By definition,

$$L = C_L\, q\, S = C_L\, \frac{V_{KTS}^{\,2}\,\sigma\, S}{295} \tag{8}$$

where,

C_L = lift coefficient

V_{KTS} = velocity, knots

σ = atmospheric pressure ratio

S = reference wing area, ft^2

Substituting equation (3) for lift, L, in equation (8) results in the following expression for approach speed,

$$V_{approach} = \left[\frac{\left[W\,\text{Cos}\,\gamma - T\,\text{Sin}\,(\theta_T + \alpha)\right]\quad (295)}{C_{L_{approach}}\qquad \sigma S}\right]^{1/2} \tag{9}$$

These equations apply to either conventional or vectored thrust configurations; the only difference in application being the thrust angle, θ_T, which is zero or close to zero for the conventional designs.

Utilizing the above equations, approach speeds were calculated for each of the non-VTOL configurations considered in the study; the conventional landing low altitude penetrator (Configuration SLR01, Figure 5-9), the long endurance vehicle (Configuration SLR02, Figure 5-10), and the slow rate of closure design (Configuration SLR06, Figure 5-14).

Configuration SLR01 was designed for minimum weight and size, and features a close-coupled canard, an aspect ratio 3 wing with large nose-radius super-critical type airfoils, flaps, and wing leading edge slats

outboard of the canard to provide a maximum of lift coefficient of 1.85. Wing area is 40 ft^2, but this could be increased to a maximum of 43 ft^2 and still be compatible with the high speed cruise requirement.

The long endurance configuration (SLR02) is a conventional wing-body-tail design featuring an aspect ratio 9 wing with partial span trailing-edge flaps designed for a maximum lift-coefficient of 2.20.

Figure 5-6 presents approach speed as a function of wing loading for configurations SLR01 and SLR02. The approach speed capabilities of the low altitude penetrator (SLR01) are shown to range from 96.5 knots for the minimum weight design to 93.4 knots for the same vehicle with the minimum wing-loading wing. The long endurance RPV will be capable of approach speeds as low as 61.5 knots due in large part to the low landing wing-loading.

The approach speed capabilities of the vectored thrust, low altitude penetrator (SLR06) are summarized in Figure 5-7. This figure presents approach speed and thrust-required to maintain a 3.5 degree approach path angle at any thrust vector angle between zero and 80 degrees. The lower curve of Figure 5-7 shows that vectored thrust will provide substantial reductions in approach speed and that by using a high enough thrust vector angle, the approach speed of configuration SLR06 could be reduced below that for minimum control speed with conventional controls.

It is apparent from the upper curve of Figure 5-7 that increased amounts of thrust are required to trim the aircraft on the selected approach path as thrust-vector angle is increased. As a result, thrust available for wave-off is greatly reduced at the higher thrust-vector angles. Thus, thrust margin available for wave-off can become the limiting factor in determining the maximum usable thrust vector angle.

The data presented in Figure 5-7 also show that Configuration SLR06 provides a thrust margin of 21 percent of maximum thrust available at a thrust vector angle of 74 degrees and an approach speed of 60 knots. Lower approach speeds can be attained but these speeds would definitely be below minimum control speed for conventional aerodynamic controls. For example, a 10 percent thrust margin is available at 53 knots, and the same margin can be retained at 45 knots with the engine operating at a 4 percent overspeed condition, but with some penalty in engine life.

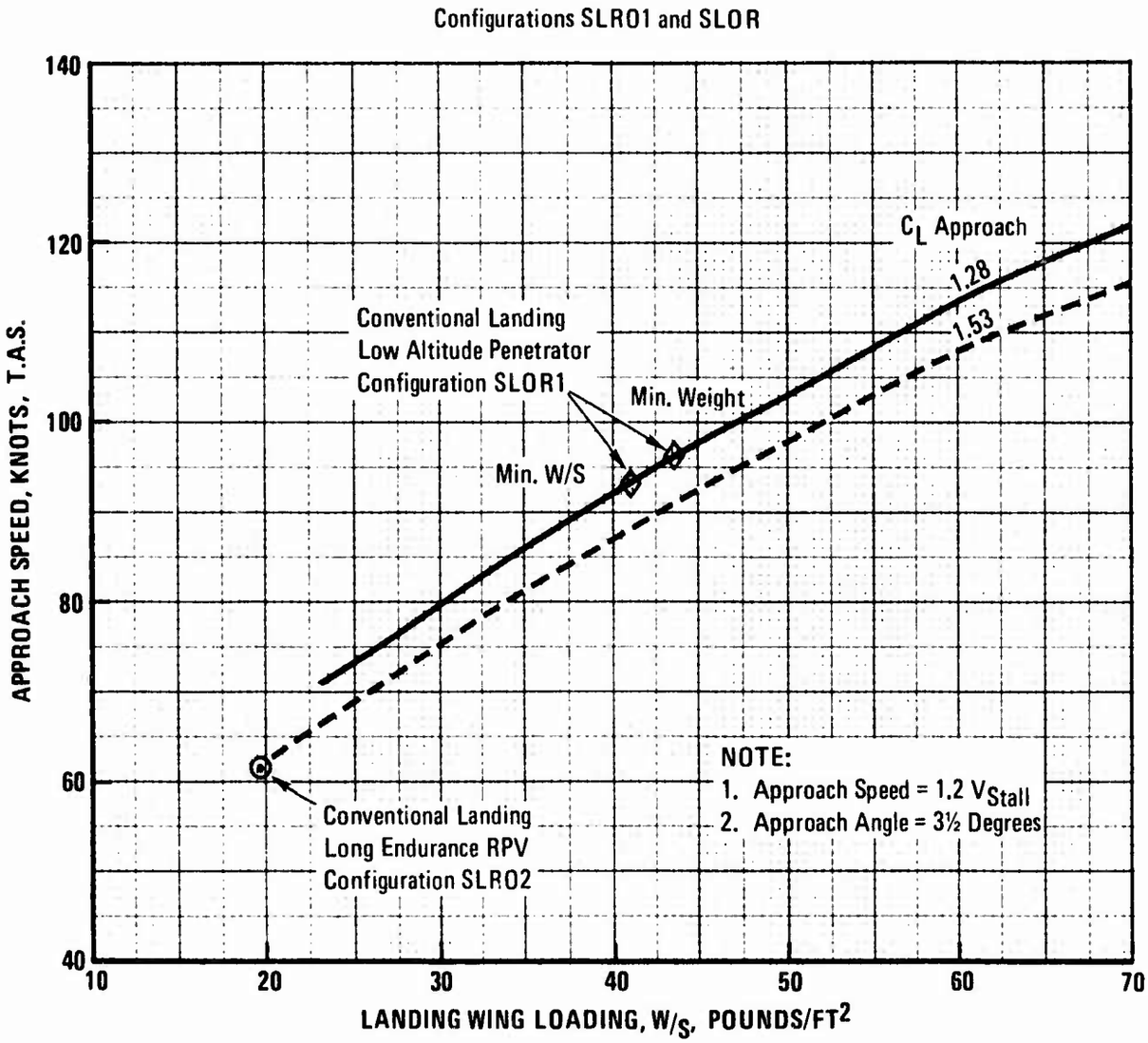


Figure 5-6. Landing Approach Speeds

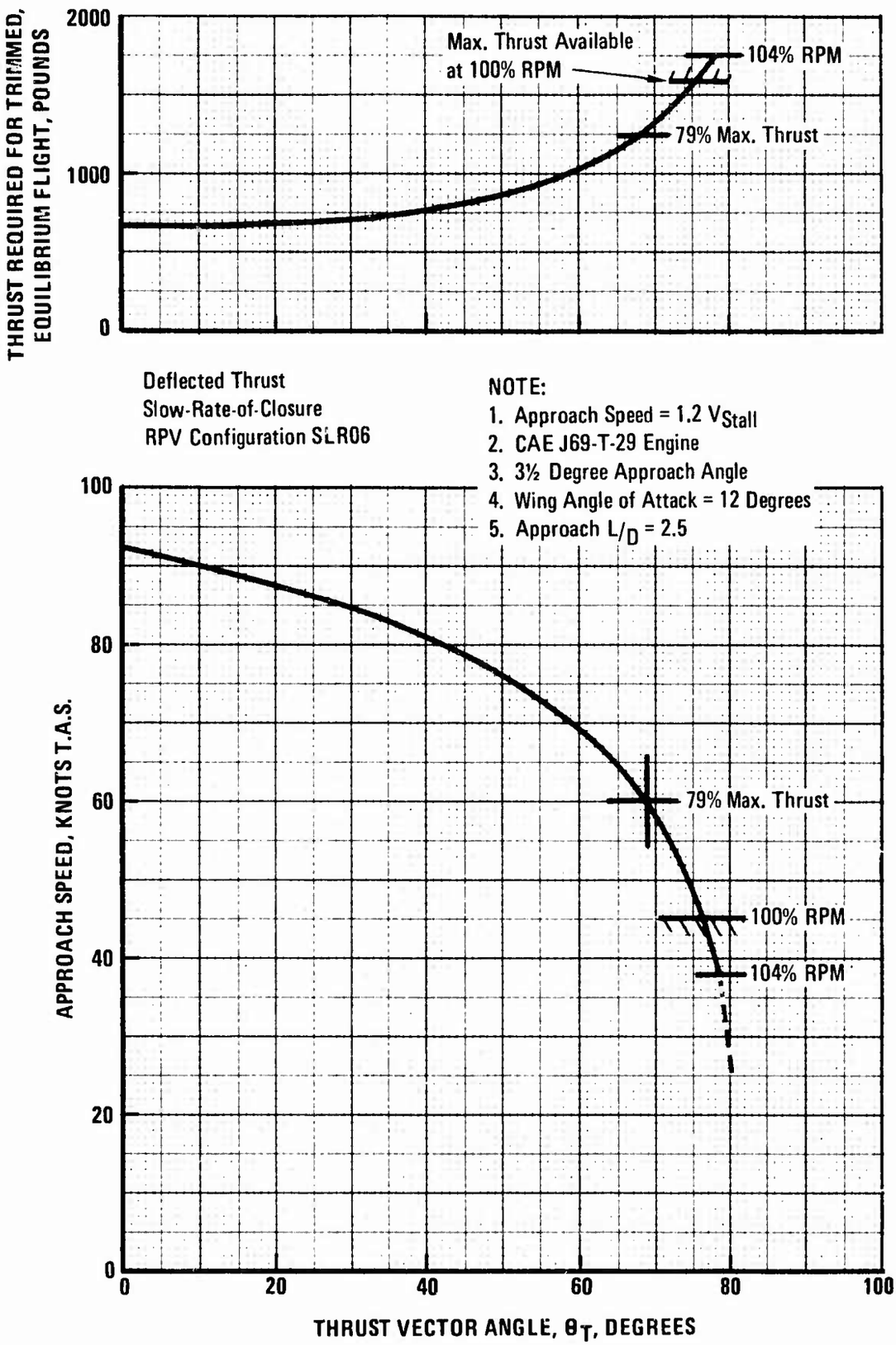


Figure 5-7. Approach Speed and Thrust Required vs. Thrust Vector Angle

The trends illustrated in Figure 5-7 show that vectored thrust aircraft with proper engine/airframe matching and with reaction control systems could completely fill in the approach speed range from minimum aerodynamic control speed to the zero-speed capability of the VTOL designs.

The technical features of SLOROC type vehicles with reaction controls are practically identical with those of the vectored thrust VTOL designs with the exceptions that the VTOL version requires a larger engine and must provide the capability to continuously vary the thrust vector angle in flight from zero to over 90 degrees. A common requirement for both vehicles is that the thrust line at any angle be at or very near the vehicle center of gravity. For comparison purposes, the approach speed capabilities of all the non-VTOL configurations studied are summarized in one chart, Figure 5-8.

5.5 VEHICLE AERODYNAMIC CONTROLS

The fundamental requirement of flight control systems designed for shipboard RPVs is the same as for any aircraft, that is, adequate control throughout the vehicle flight envelope. Practical shipboard recovery of RPVs, however, requires that closing speeds between the RPV and the ship be minimized in order to increase the safety of the operation and to generally simplify the recovery problem. These low approach speeds, in some cases just above minimum control speeds, represent the critical requirement for the flight control systems of the non-VTOL configurations.

An in-depth analysis of RPV aerodynamic control-systems is beyond the scope of this study, but sufficient data are available from TRA in-house studies and from government and industry sources to provide the basis for identifying concepts which show particular promise of solving those control problems peculiar to shipbased RPVs.

The control philosophy established for the study RPVs is as follows:

a. Directional flight-path control during final approach will be achieved without banking to turn. Direct side-force may be utilized to provide lateral translation capability.

b. Vertical deviations from the approach path will be corrected by fast acting direct-lift controls without changes in pitch attitude or throttle setting.

c. Speed variations during approach will be controlled by engine throttle setting.

SYMBOL NO.	CONFIGURATION	MISSION
1.	SLRO1, Min. Wt. Configruation	Low Alt. Penetrator
2.	SLRO1, Min. W/S Configuration	↓
3.	SLRO6, 21% Thrust Margin	
4.	SLRO6, 10% Thrust Margin	
5.	SLRO6, 10% Thrust Margin 4% Engine Overspeed	
6.	SLRO2	Long Endurance

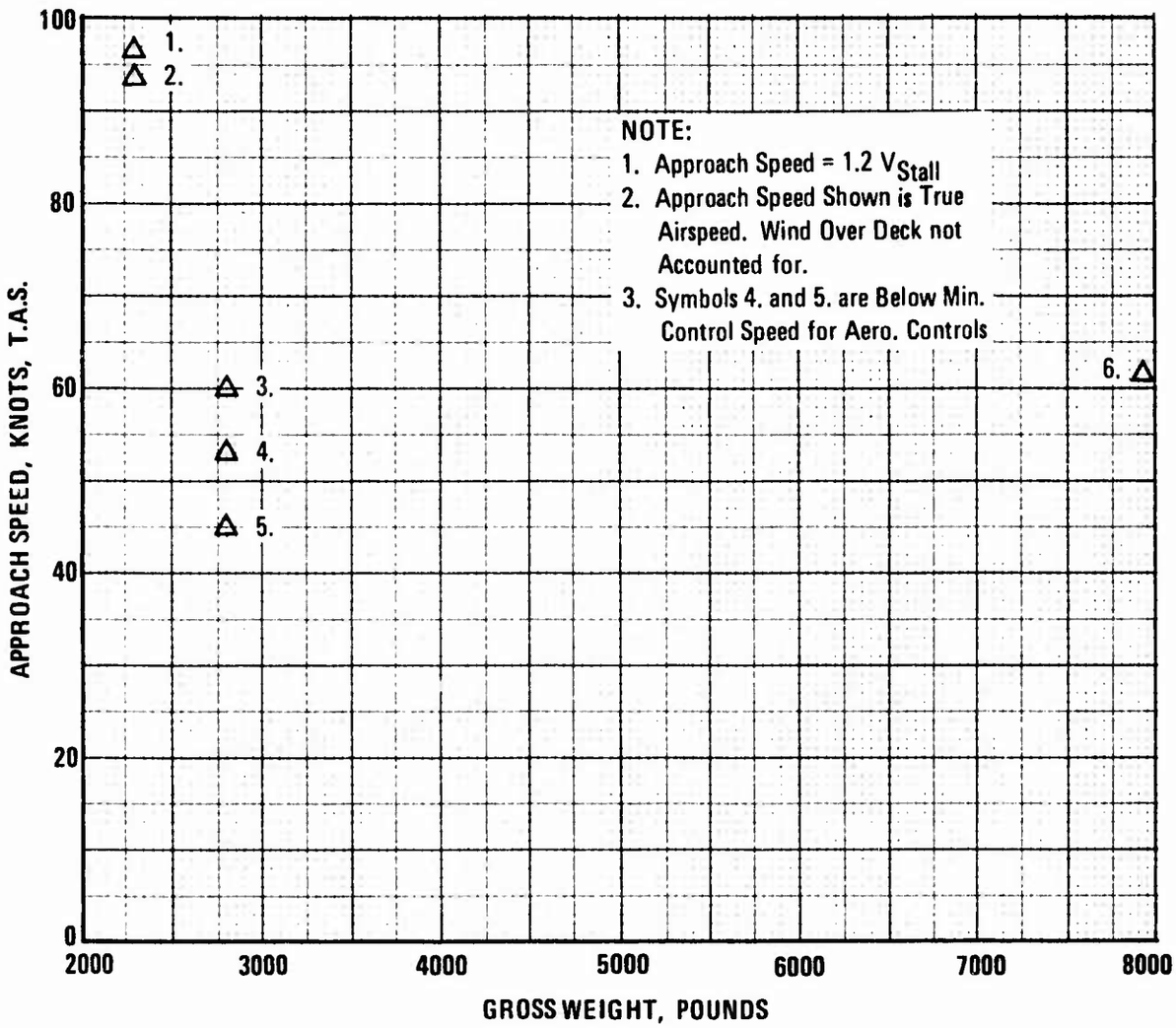


Figure 5-8. Approach Speed Summary

The direct side motion will provide lateral flight-path corrections more rapidly than can be obtained with normal bank-to-turn maneuvers since the time lags associated with banking are completely eliminated. Another benefit of side force controls, which is related to the lower time lags, is a reduced tendency of the aircraft to overshoot the desired glide path during the corrective maneuvers.

The direct-lift controls provide immediate vertical acceleration capability. This is in contrast to the conventional control system which must either vary engine power with an attendent lag in rpm or which must develop a tail-load to produce rotation. This rotation takes a finite time before enough wing loads are generated to overcome weight, inertias, and opposing tail loads; and again, a response time-lag is developed. The quick response capabilities of direct-lift controls result when large forces are developed by simultaneously deflecting both the wing flaps and canard surfaces in the same direction to provide faster load factor buildup.

The physical aerodynamic controls required to implement the control philosophy discussed above consist of:

a. A controllable side-force fin mounted on the forward portion of the fuselage which acts in conjunction with the rudder to provide the required side-force without inducing aircraft rotation. This function can also be obtained by canting the existing canard surfaces downward to provide a side-force component capability.

b. Fast acting wing flaps and canard surfaces to provide the direct-lift capability.

A discussion of the automatic flight-control systems envisioned for the shipboard RPVs considered in the study is presented in Paragraph 6.4.

5.6 BASIC LOW ALTITUDE CONFIGURATION, SLR01

5.6.1 AIR VEHICLE DESCRIPTION

The basic low altitude penetrator vehicle as shown in Figure 5-9 was designed as a close-coupled canard configuration to obtain a design with high lift coefficients and low landing speeds. The vehicle features a single Teledyne CAE J69-T-25 turbojet engine having a sea level static thrust of 1,025 pounds. The engine is man-rated, and is a relatively low cost engine. The wing has gross wing area of 40.00 square feet and

WING	
GROSS AREA	40.00 SQUARE FEET
ASPECT RATIO	3.00
TAPER RATIO	0.15
THICKNESS RATIO	
ROOT	0.10
TIP	0.08

CANARD	
GROSS AREA	11.56 SQUARE FEET
ASPECT RATIO	2.46
TAPER RATIO	0.06
THICKNESS RATIO	0.08
TAIL VOLUME COEFFICIENT	0.25

VERTICAL TAIL	
GROSS AREA	8.89 SQUARE FEET
ASPECT RATIO	0.80
TAPER RATIO	0.24
THICKNESS RATIO	0.08
TAIL VOLUME COEFFICIENT	0.12

PROPULSION	
ENGINE DESIGNATION	T.C.A.E. J69-T-25
SEA LEVEL STATIC THRUST	1,025 POUNDS

WEIGHTS	
TAKE-OFF GROSS WEIGHT	2,252 POUNDS
FUEL WEIGHT	690 POUNDS

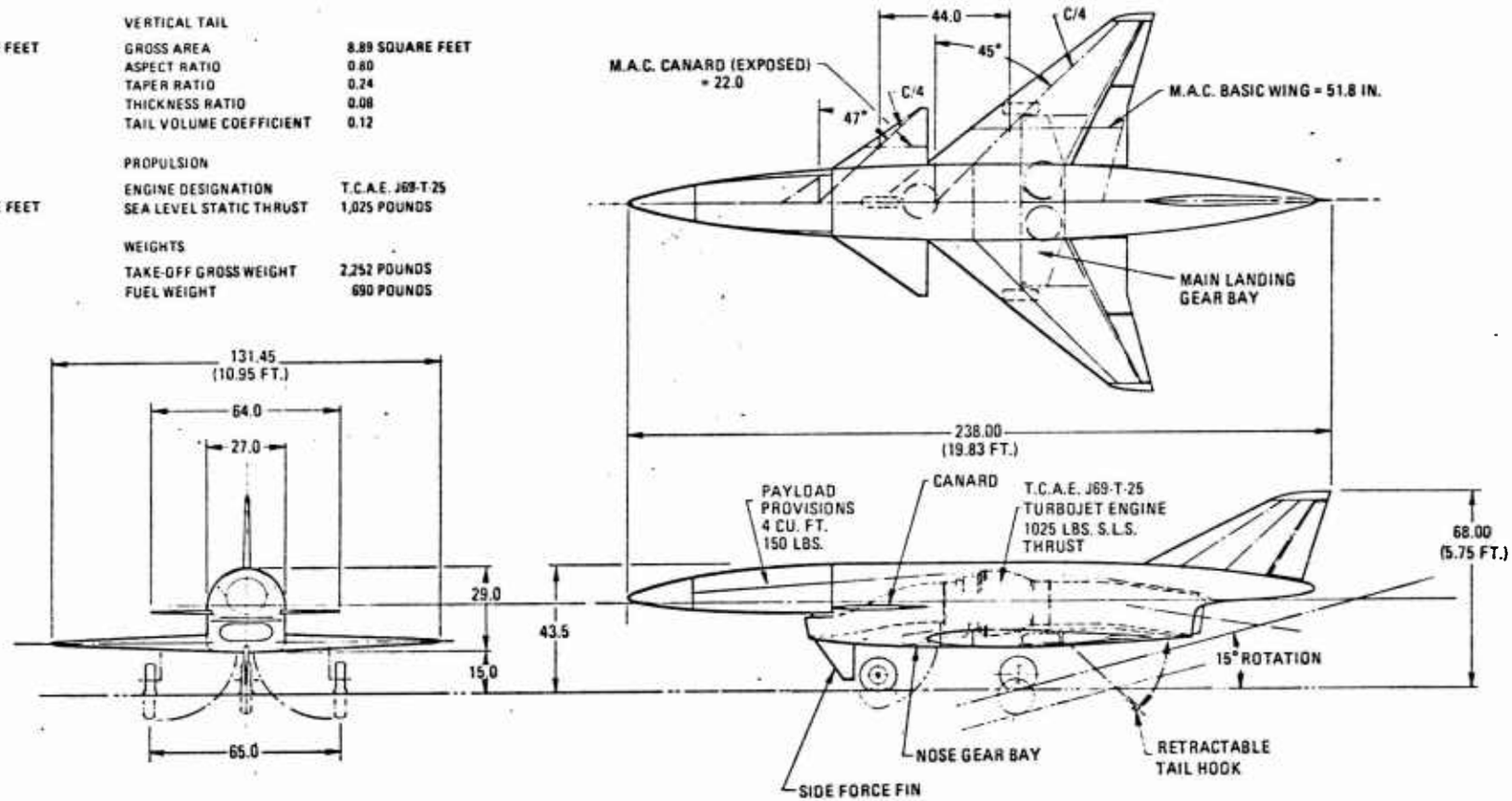


Figure 5-9. Low Altitude Penetrator, SLR01, General Arrangement

an aspect ratio of 3.00. The wing has trailing edge flaps slats and large span droopable ailerons for high lift and control at low speeds. The canards have all-movable surfaces and are located relative to the wing leading edge so as to increase the maximum useful lift coefficient of the wing. The low wing arrangement permits the installation of a wide-track, retractable main landing gear, which increases vehicle stability during takeoff and landing. The nose gear is located aft of the low mounted engine air inlet and rotates 90 degrees during retraction to minimize the height of the nose gear bay. A special retractable tailhook installation is located below the engine tailpipe in the aft fuselage. The overall length of the RPV is 19.83 feet, with an overall height of 5.75 feet. The wing has a span of 10.95 feet which can be reduced to less than 7 feet if wing tips are folded. Space is provided in the nose for the payload provisions of 4.0 cubic feet and 150 pounds. To provide greater control during landing approach, as well as for mission performance during target runs, an aerodynamic surface to create side forces is located on the fuselage lower surface. This side force fin, when coupled with the vertical tail can create direct side forces which can eliminate the conventional bank-to-turn maneuver, which will permit better vehicle response to correct for misalignment from a desired flight path. The side force fin has provisions for folding to a horizontal attitude to ease deck handling and launch. The group weight statement for the Basic Low Altitude Configuration is presented in Table 5-2.

5.6.2 VEHICLE SIZING STUDIES

The AVSYN computer program described in Paragraph 5.2 was used to size the conventional landing low altitude penetrator (Configuration SLR01). Results of the study are presented in Figure 5-10 showing that the minimum gross weight vehicle is obtained with a wing aspect ratio of 3.0. A study was also performed to determine the effects on gross weight of increasing the low altitude dash range above the nominal 100 nautical miles. The data presented in Figure 5-11 indicate that with the selected J69-T-25 engine, the dash range could be doubled by increasing the wing area to 41.3 ft^2, but at a penalty of 336 pounds in vehicle gross weight.

5.7 HIGH ALTITUDE CONFIGURATION, SLR02

5.7.1 AIR VEHICLE DESCRIPTION

The basic high altitude configuration is a conventional wing-body-tail design featuring a low-mounted high aspect ratio wing. A general arrangement of this vehicle is shown in Figure 5-12. A single United Aircraft JT15D-4 turbofan engine, having a sea level static thrust of 2,575 pounds, is mounted in a nacelle on top of the fuselage.

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NOTE:

- Mission

  400 Nautical Miles at 40, 000 Feet, Mach 0.75
  plus 100 Nautical Miles at 500 Feet, Mach 0.85
- Payload: 150 Pounds
- Engine Basis: J69-T-25
- △ Denotes Selected Configuration

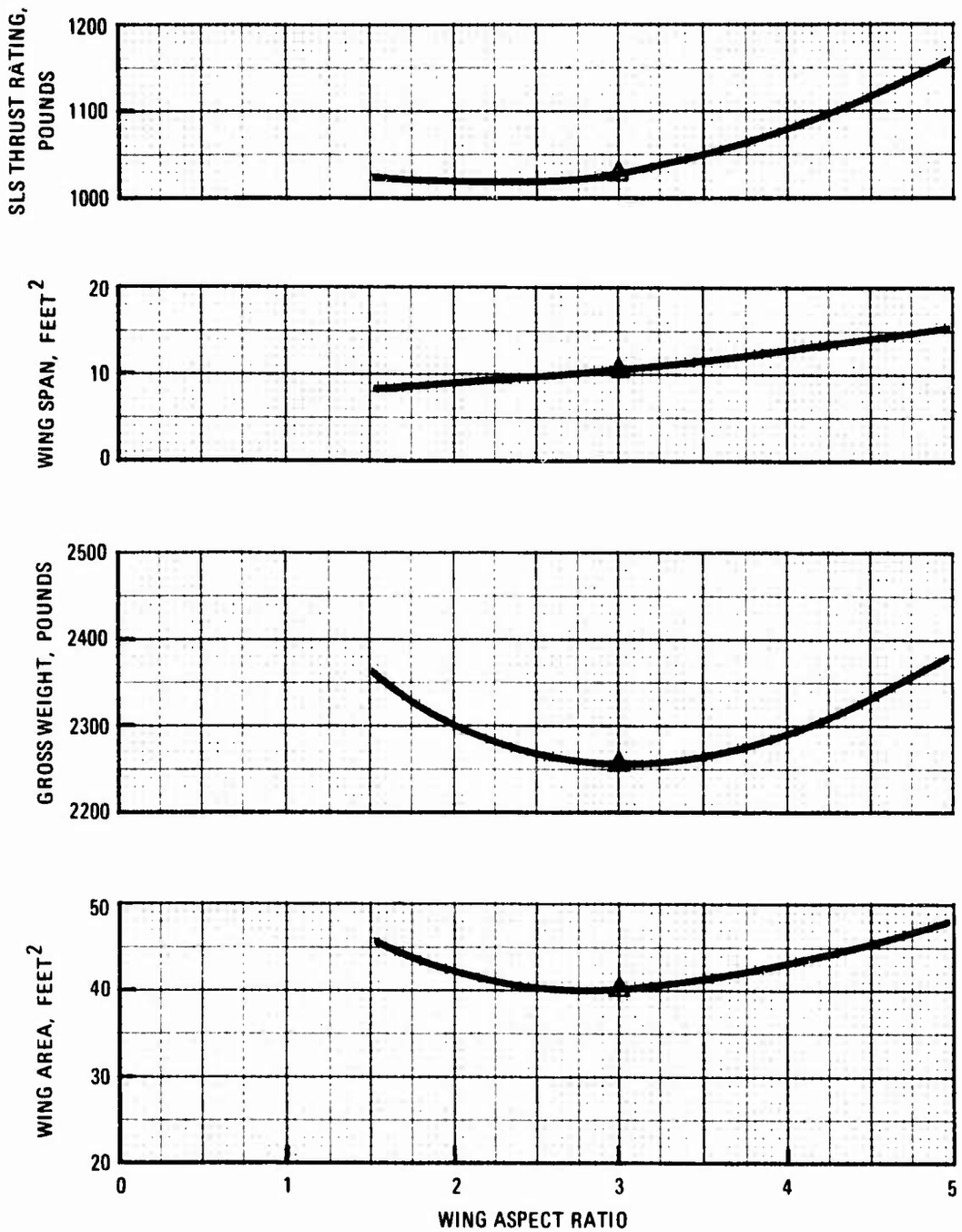

Figure 5-10. SLR01 Sizing Study

NOTE:

- Mission

  400 Nautical Miles at 40, 000 Feet, Mach 0.75
  plus Dash at 500 Feet, Mach 0.85

- Payload: 150 Pounds

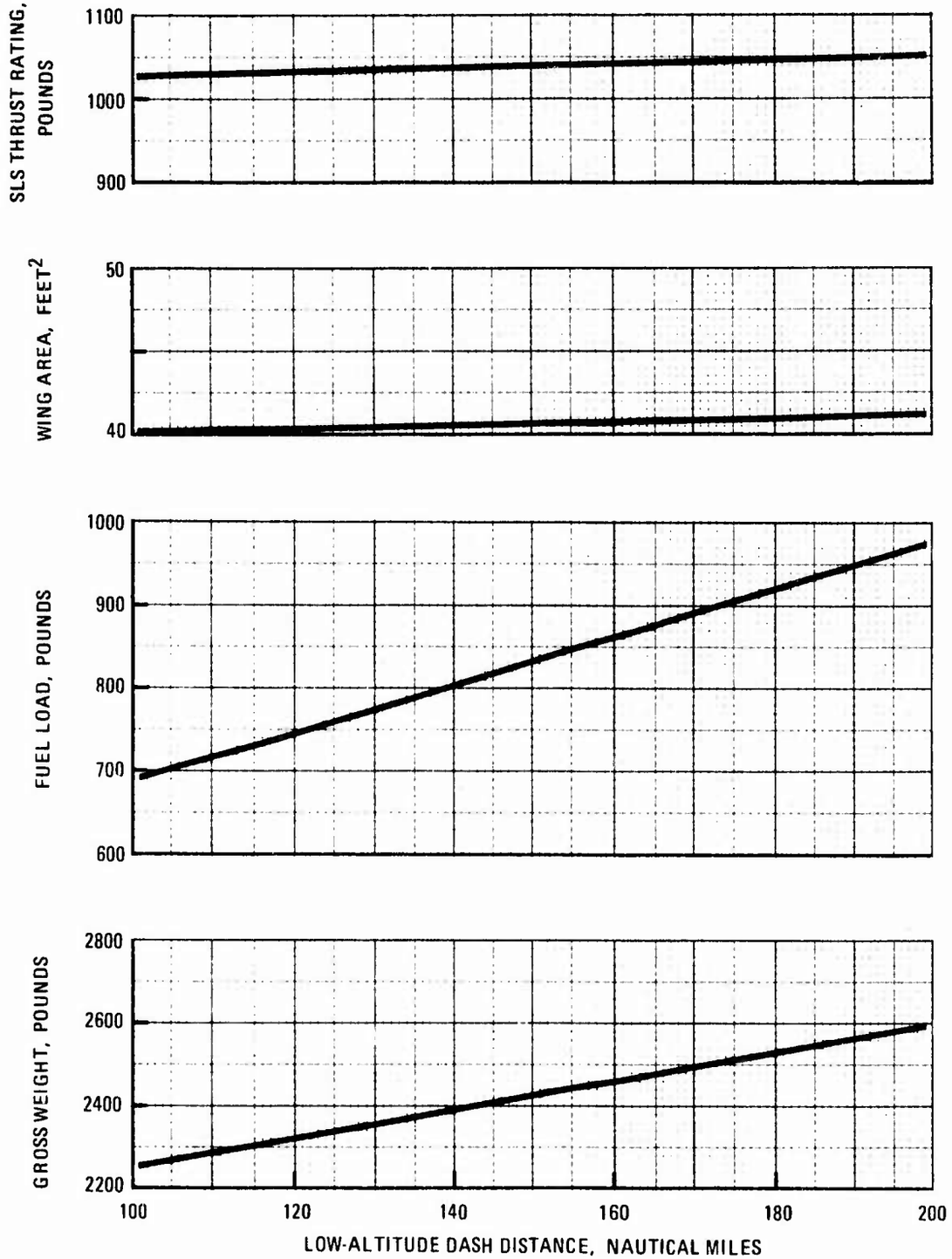

Figure 5-11. Effect of Increasing Dash Range on Configuration SLR01

WING	
GROSS AREA	220.00 SQUARE FEET
ASPECT RATIO	9.00
TAPER RATIO	0.35
THICKNESS RATIO	
ROOT	0.15
TIP	0.10

HORIZONTAL TAIL	
GROSS AREA	31.40 SQUARE FEET
ASPECT RATIO	4.30
TAPER RATIO	0.53
THICKNESS RATIO	0.08
TAIL VOLUME COEFFICIENT	0.36

VERTICAL TAIL	
GROSS AREA (TWO TAILS)	14.20 SQUARE FEET
GROSS AREA (ONE TAIL)	7.10 SQUARE FEET
ASPECT RATIO	1.83
TAPER RATIO	0.50
THICKNESS RATIO	0.08
TAIL VOLUME COEFFICIENT	0.02

PROPULSION	
ENGINE DESIGNATION	UNITED AIRCRAFT – JT15D-4
SEA LEVEL STATIC THRUST	2,575 POUNDS

WEIGHTS	
TAKE OFF GROSS WEIGHT	7,890 POUNDS
FUEL WEIGHT	3,870 POUNDS

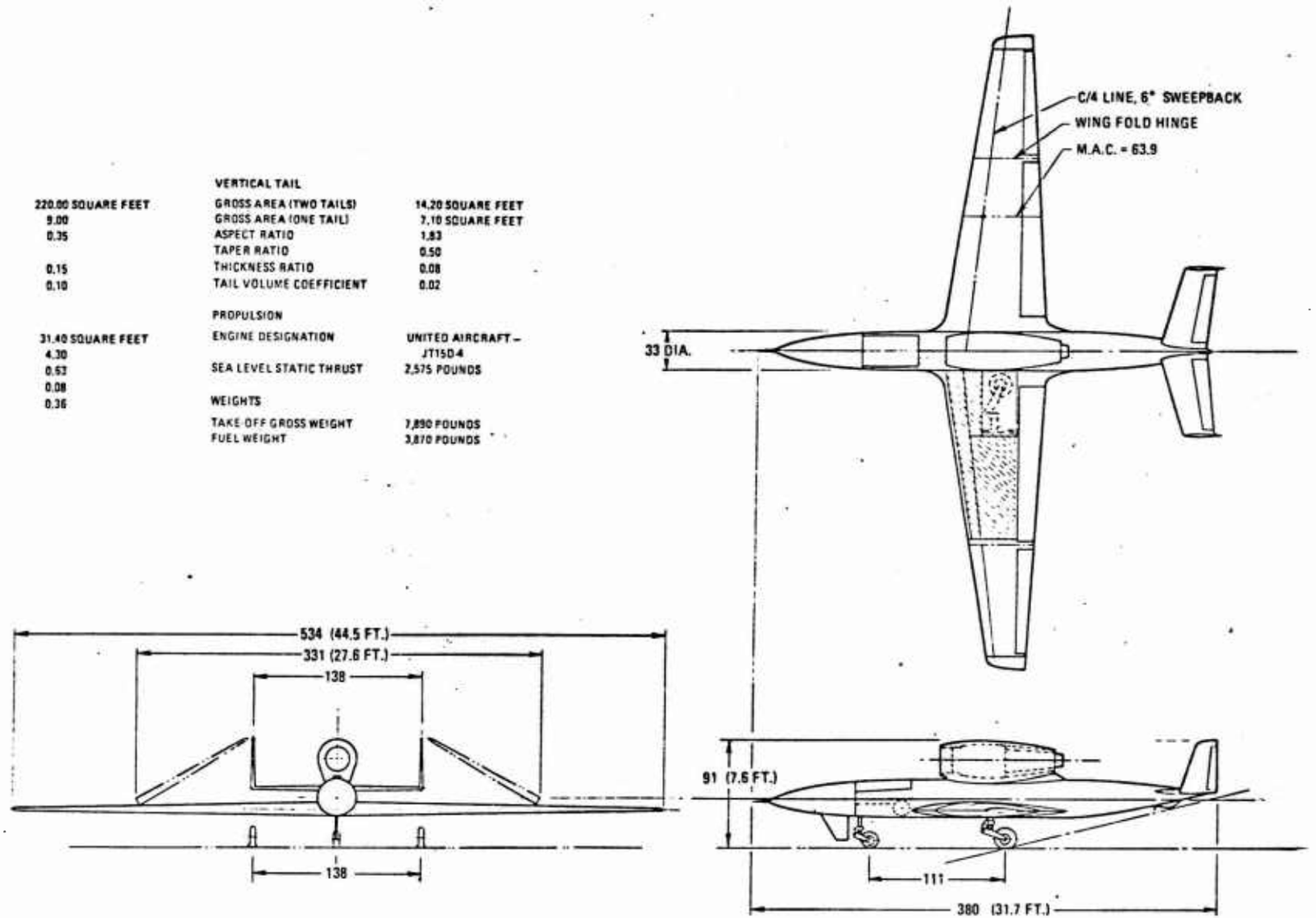

Figure 5-12. Long Endurance Configuration, SLR02, General Arrangement

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TABLE 5-2

GROUP WEIGHT STATEMENT BASIC LOW-ALTITUDE CONFIGURATION NO. SLR01

GROUP	WEIGHT-POUNDS
Structure	
Wing	105
Body	221
V. Tail + Canard	59
Surface Controls	51
Propulsion	473
Electrical	164
Electronics	90
Navigation/Guidance	28
Recovery/Launch	135
Environmental	21
Hydraulics	35
Payload (Installed)	165
Oil	8
Unusable Fuel	7
Zero Fuel Weight	1562
Fuel (Mission + Reserve)	690
Gross Weight	2252

The wing has a gross area of 220 square feet and an aspect ratio of 9.0. The twin vertical tails are mounted at the ends of the horizontal tail. The wing has a span of 44.50 feet for flight, but has wing-fold provisions to reduce the span to 27.58 feet for easier storage and deck handling. The wing is fitted with trailing edge flaps from the root fillet outboard to the wing fold hinge line. Large span ailerons are located outboard of the wing fold hinge line. A side force fin is located below the nose of the vehicle to provide a more precise control capability during final landing approach. The side force fin can be folded to horizontal attitude to facilitate deck handling and launch. Fuel is carried in the center fuselage as well as in integral wing tanks. A total of over 3,800 pounds of fuel can be accommodated.

The vehicle is equipped with retractable landing gear located in the wing and in the forward fuselage. Also provided are catapult bridle attach fittings, a launch holdback fitting, and a special arresting hook installation. The group weight statement for the High Altitude configuration is presented in Table 5-3.

TABLE 5-3

GROUP WEIGHT STATEMENT BASIC HIGH-ALTITUDE CONFIGURATION NO. SLR02

GROUP	WEIGHT-POUNDS
Structure	
Wing	651
Body	418
Tail	147
Surface Controls	174
Propulsion	749
Electrical	184
Electronics	192
Navigation/Guidance	28
Recovery/Launch	397
Environmental	71
Hydraulics	119
Payload (Installed)	825
Oil	27
Unusable Fuel	38
Zero Fuel Weight	4020
Fuel (Mission + Reserve)	3870
Gross Weight	7890

5.7.2 VEHICLE SIZING STUDIES

Trade studies were conducted by means of the AVSYN computer program outlined in Paragraph 5.2 to determine the effects of aspect ratio on the gross weight and wing span of the long endurance, high altitude RPV (Configuration SLR02). Figure 5-13 presents wing span, gross weight, average cruise altitude, and wing area versus aspect ratio. Figure 5-14 is a cross plot of Figure 5-13 showing how gross weight varies as a function of wing span. The engine assumed for the study is the Pratt and Whitney JTD15-4 turbofan rated at 2,575 pounds sea level static thrust. This engine was selected because it comes closer to meeting the ideal thrust and fuel flow requirements of the mission than does any other currently available off-the-shelf engine. An aspect ratio of 9 with a corresponding unfolded wing span of 43.96 feet and a folded span of 27.58 feet was selected based on considerations of ship space, safety, and handling.

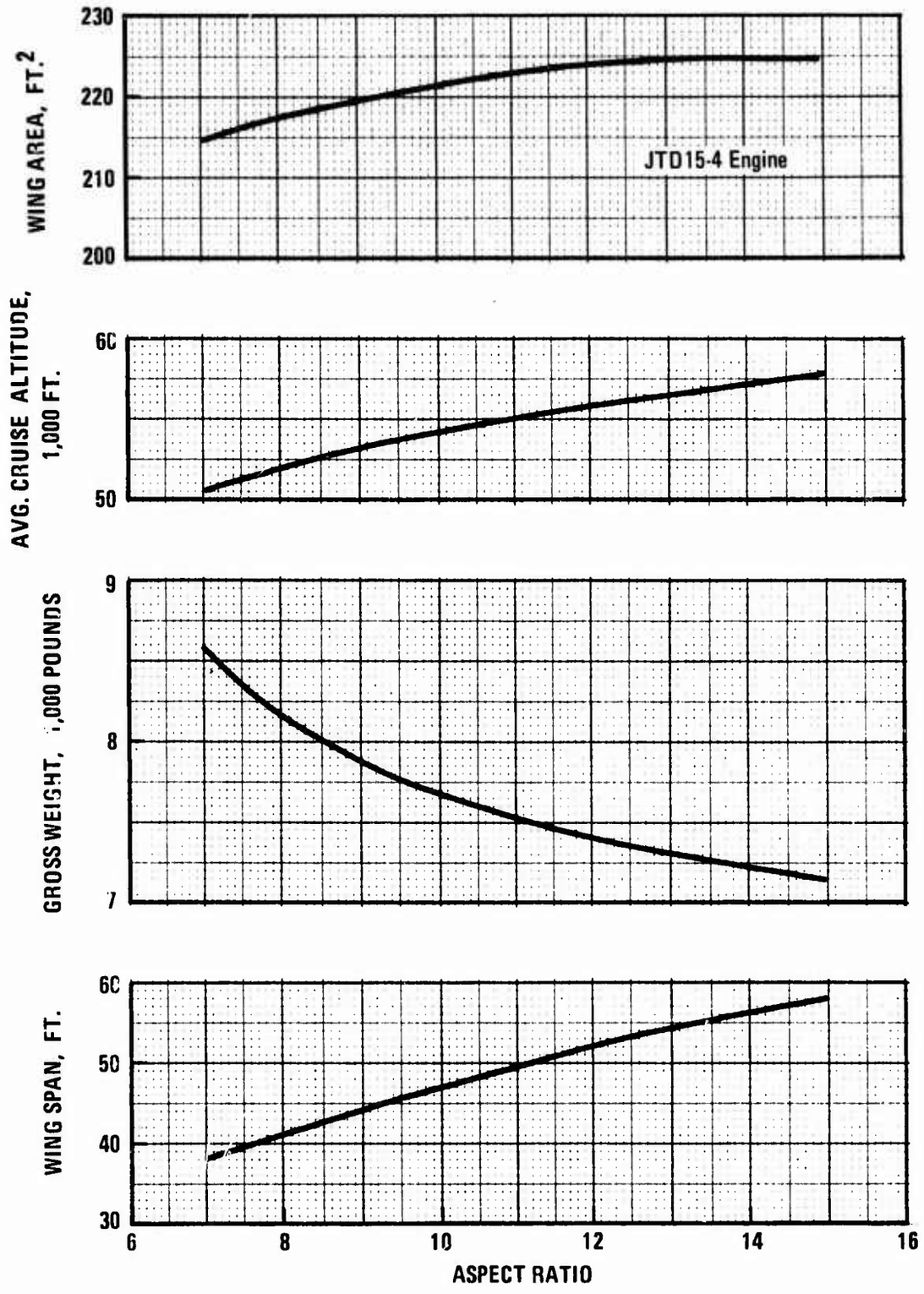

Figure 5-13. Aspect Ratio Study, Long-Endurance Configuration

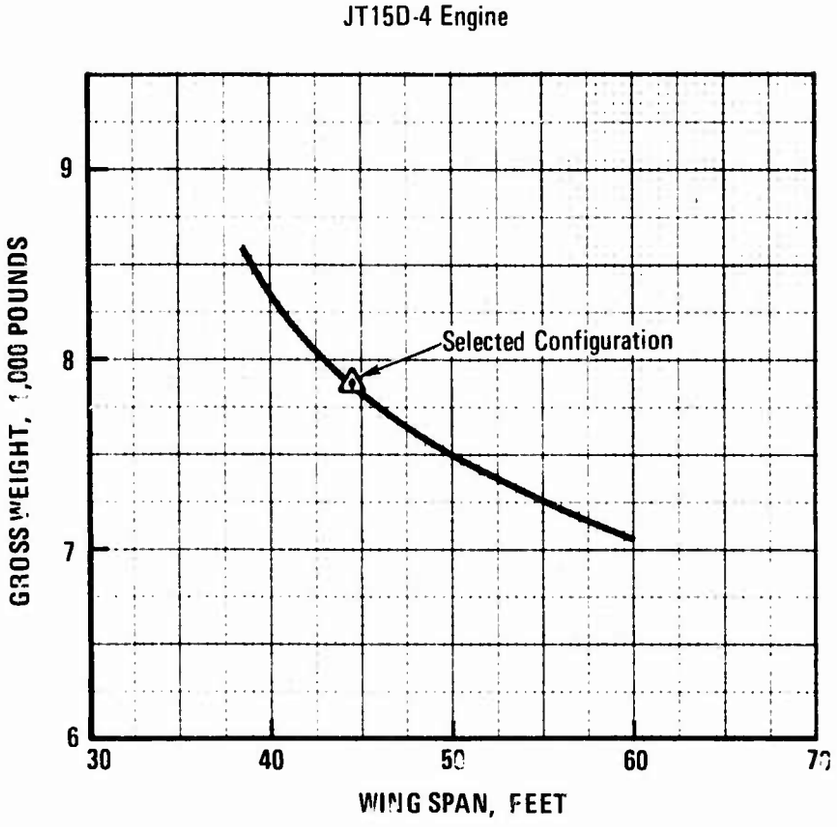

Figure 5-14. Gross Weight vs. Wing Span,
Long Endurance Configuration

5.8 STOPPED ROTOR VTOL CONCEPT, SLR03

5.8.1 AIR VEHICLE DESCRIPTION

The Stopped Rotor concept, as shown in Figure 5-15, incorporates the advantages of low disk loading hover capabilities of a helicopter with the high speed flight characteristics of modern jet aircraft. This VTOL concept features a rotor wing which remains deployed and supports the aircraft in the cruise mode of flight without recourse to an auxiliary wing or other lift-producing devices.

Perhaps the most significant characteristic of this type of craft would be its ability to hover as a rotary-wing aircraft at a disc loading on the order of 10 to 20 pounds per square foot (with a corresponding lift capability in the region of 5 pounds per equivalent horsepower), yet cruise as a pure, fixed-wing aircraft at a wing loading approaching 70 pounds per square foot, all without recourse to variable-wing geometry or retracting of a rotor.

The distinguishing feature of the stopped rotor concept is a high-mounted, rotor wing which is capable of rotation (shaft-driven, jet-reaction-driven, or in auto-rotation) about an approximately vertical axis through the center of its area. The wing is a three-bladed modified delta design. The movable tips of this wing are capable of independent pitch changes about essentially radial axes with respect to the center section. Thus, they act in the manner of a helicopter rotor.

The entire rotor wing can be stopped and locked in a symmetrical position with the tips at zero pitch, to operate as a more or less conventional delta wing in the cruising and high-speed flight modes. This is made possible by the unique aerodynamic properties of the delta-shaped rotor wings. The longitudinal and lateral positions of the aerodynamic centers of this wing must be controlled so as to provide that the resulting pitching and rolling moments are within acceptable levels. The means used to accomplish this involves a collective spoiler system, in conjunction with blade cyclic pitch changes. This spoiler system modulates rotor-blade lift automatically by fully aerodynamic means to minimize wing center-of-pressure shift with relative wind azimuthal angle.

The positioning of the rigid rotor-wing gives the aircraft static stability in pitch and roll as well as good damping about these same two axes in hovering and low-speed flight, much as the rigid rotor does for that type of helicopter. Longitudinal and lateral control powers and trim are high and a wide range of center-of-gravity positions is possible.

WING		VERTICAL TAIL	
GROSS AREA (BASIC)	50.26 SQUARE FEET	GROSS AREA, ONE SIDE	4.07 SQUARE FEET
ASPECT RATIO	3.63	GROSS AREA, TOTAL	8.14 SQUARE FEET
THICKNESS RATIO		ASPECT RATIO	1.12
ROOT, INBOARD PANEL	0.10	TAPER RATIO	0.30
ROOT, OUTBOARD PANEL	0.06	THICKNESS RATIO	0.06
TIP, OUTBOARD PANEL	0.04	TAIL VOLUME COEFFICIENT	0.12
		PROPULSION	
HORIZONTAL TAIL		ENGINE DESIGNATION	TCAE J69 T41A
GROSS AREA	12.67 SQUARE FEET	SEA LEVEL STATIC THRUST	1,920 POUNDS
ASPECT RATIO	3.50		
TAPER RATIO	0.30	WEIGHTS	
THICKNESS RATIO	0.06	TAKE OFF GROSS WEIGHT	3,038 POUNDS
TAIL VOLUME COEFFICIENT	0.50	FUEL WEIGHT	1,073 POUNDS

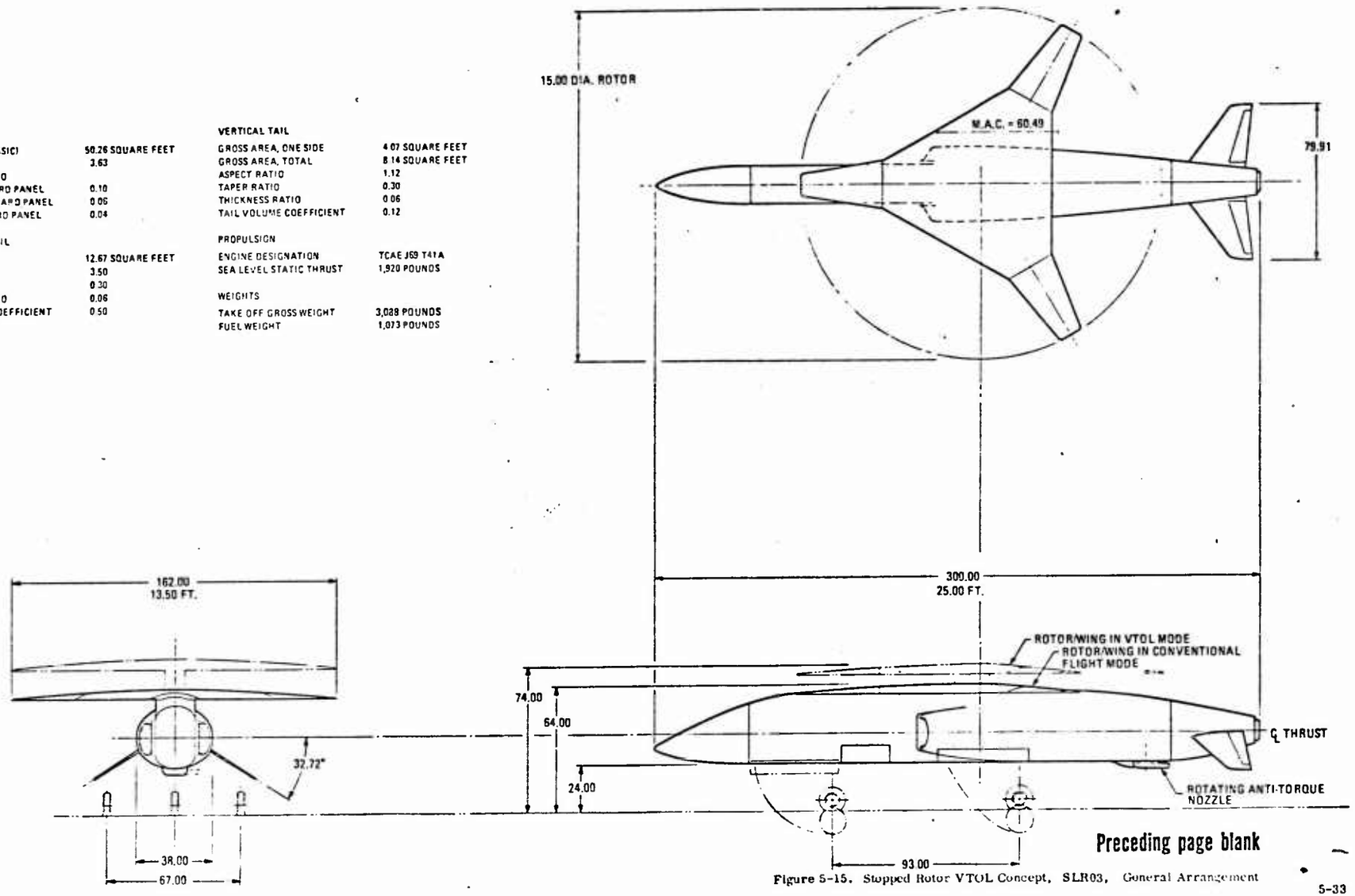

Figure 5-15. Stopped Rotor VTOL Concept, SLR03, General Arrangement

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The wing for the stopped rotor design in this study has a gross wing area of 50.26 square feet and an aspect ratio of 3.63. In the VTOL mode the wing becomes a 15 foot diameter rotor providing a disk loading ranging between 11 and 18 pounds per square foot. The wing extends vertically approximately 10 inches when in the VTOL mode to provide fuselage clearance for the rotor.

The propulsion system incorporates a TCAE J69-T41A turbojet engine with a unique diverter valve arrangement which converts the gas flow to shaft power to drive the rotor in the VTOL mode. The diverter valve also can be selected to permit the gas to exhaust through a conventional tailpipe and nozzle for cruise flight. During the VTOL mode the diverter valve doors are positioned to force the jet exhaust to impinge on a turbine stage to drive a shaft system to a gear box which drives the rotor shaft. The residual gas downstream of the shaft turbine is ducted to a rotatable nozzle used to produce anti-torque forces. The engine air inlet ducts are bifurcated side inlets to minimize the overall size of the vehicle. Approximately 1100 pounds of fuel is located in the center fuselage.

The vehicle is equipped with retractable landing gear which is housed in the fuselage just below the inlets and in the nose section. The RPV has a wing span of 13.50 feet, and since the wing tips have cyclic pitch control mechanisms and rotate about a shaft along a wing element line, it does not appear practical to fold the wing to reduce wing span. The overall length is 25.00 feet and an overall height of less than 5.5 feet. The group weight statement for the Stopped Rotor VTOL configuration is presented in Table 5-4.

5.9 VECTORED THRUST VTOL CONCEPT, SLR04

5.9.1 AIR VEHICLE DESCRIPTION

The vectored thrust VTOL concept, as shown in Figure 5-16, is a conventional wing-body-tail design which performs transition, and VTOL flight operations while maintaining a horizontal fuselage attitude. The propulsion system includes a turbofan engine based on the Teledyne CAE 490 engine, but modified to incorporate four vectorable exhaust nozzles. The capability for VTOL flight is achieved by directing the jet efflux of the engine through nearly 100 degrees of movement from aft to forward of the vertical. The nozzles are rotated by shafting and chains, powered by an air motor in a manner similar to the Rolls-Royce Pegasus engine used in the AV-8 Harrier aircraft. The two front nozzles exhaust the turbo-fan efflux, while two rear nozzles exhaust the turbojet efflux. The center of gravity of the vehicle is located between the fore and aft nozzles in such a way that the resultant engine thrust

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TABLE 5-4

GROUP WEIGHT STATEMENT STOPPED
ROTOR VTOL, CONFIGURATION NO. SLR03

GROUP	WEIGHT-POUNDS
Structure	
Wing	236
Body	480
Tail	62
Surface Controls	99
Propulsion	492
Electrical	164
Electronics	90
Navigation/Guidance	28
Recovery/Launch	100
Environmental	28
Hydraulics	47
Payload (Installed)	165
Oil	13
Unusable Fuel	11
Zero Fuel Weight	2015
Fuel (Mission + Reserve)	1073
Gross Weight	3088

creates no pitching moment on the vehicle for any of the possible nozzle positions. Hover control during VTOL operations is provided by reaction control nozzles supplied by engine compressor bleed air. There are control nozzles located in the nose section (pitch), in the extreme tail end of the fuselage (yaw and pitch), and in each wing tip (roll).

The RPV is equipped with a retractable, tricycle landing gear system. The main gear has been positioned aft of the normal location of main gear for conventional takeoff vehicles to minimize any adverse effects of jet efflux impingement on the landing gear. It is anticipated that the landing gear will be retracted when the nozzles are rotated for transition from either conventional flight to VTOL, or vice versa. This will avoid direct impingement of the jet efflux on the main landing gear structure during transition. The problem of overheating landing gear members, and the flight deck surface, during pre-launch warmup can be minimized by running up the engine with the nozzles vectored aft, until just prior to actual lift-off.

WING	
GROSS AREA (BASIC)	50.00 SQUARE FEET
ASPECT RATIO	3.00
TAPER RATIO	0.30
THICKNESS RATIO	
ROOT	0.08
TIP	0.06
DIHEDRAL ANGLE	5 DEGREES

HORIZONTAL TAIL	
GROSS AREA	13.61 SQUARE FEET
ASPECT RATIO	3.50
TAPER RATIO	0.30
THICKNESS RATIO	0.08
TAIL VOLUME COEFFICIENT	0.50
DIHEDRAL ANGLE	-10 DEGREES

VERTICAL TAIL	
GROSS AREA	10.37 SQUARE FEET
ASPECT RATIO	1.00
TAPER RATIO	0.30
THICKNESS RATIO	0.08
TAIL VOLUME COEFFICIENT	0.12

PROPULSION	
ENGINE DESIGNATION	TCAE 490 (MODIFIED)
SEA LEVEL STATIC THRUST (T.O. RATING, 2 MIN. LIMIT)	3,400 POUNDS

WEIGHTS	
TAKE-OFF GROSS WEIGHT	2,992 POUNDS
FUEL WEIGHT	892 POUNDS

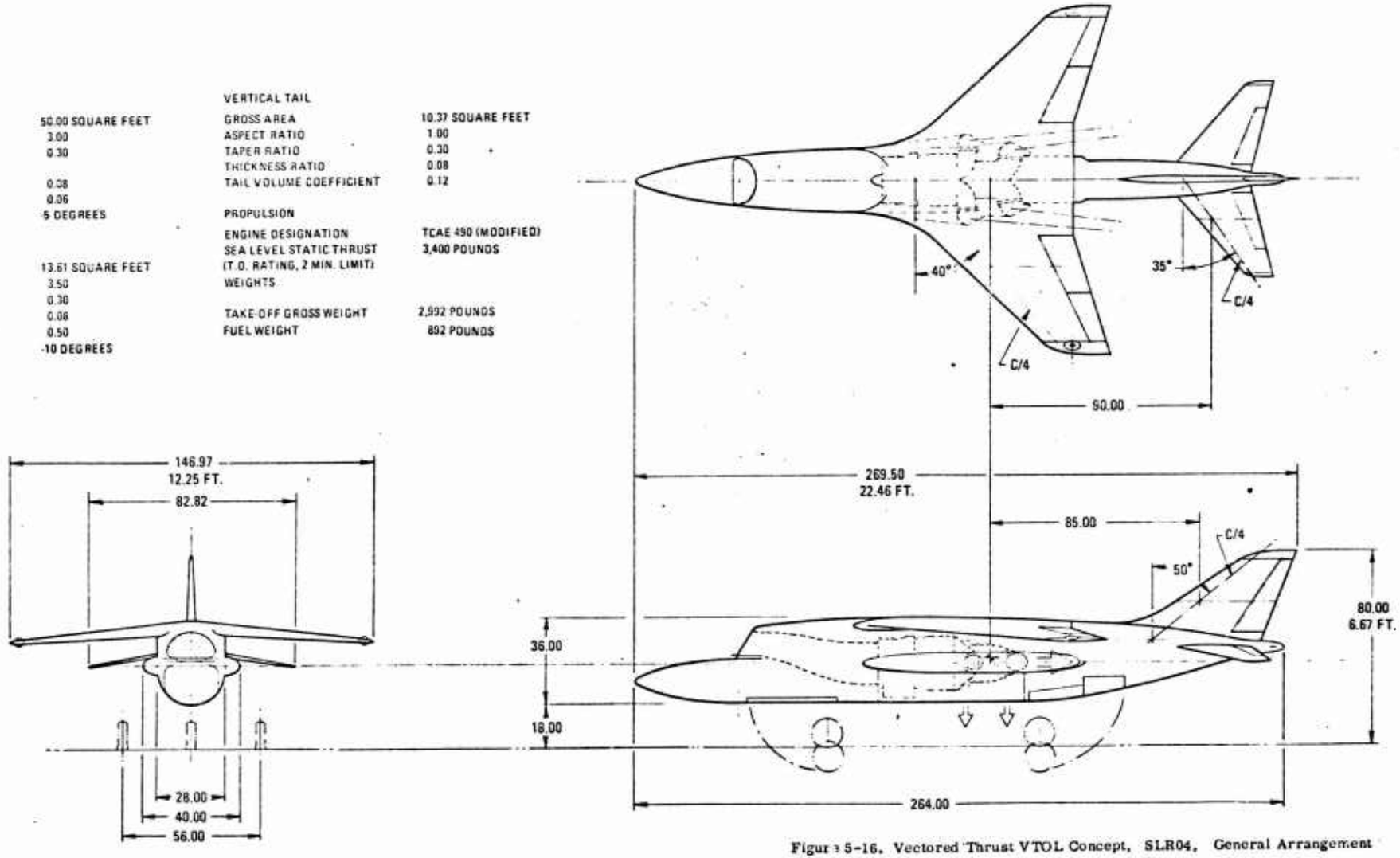

Figure 5-16. Vectored Thrust VTOL Concept, SLR04, General Arrangement

The payload of 150 pounds and 4 cubic feet is located in the fuselage nose section.

Fuel is located in the wing torque box and carry-through structure as well as the upper fuselage fore and aft of the wing.

The overall dimensions of the RPV include a wing span of 12.25 feet, an overall length of 22.46 feet, and an overall height of 6.67 feet. The wing has gross area of 50.00 square feet with an aspect ratio of 3.00. Wing folding was not considered practical for this design because of the added complexity which would be required to fold the ducting to the reaction nozzles located in the wing tips.

The group weight statement for the Vectored Thrust VTOL configuration is presented in Table 5-5.

TABLE 5-5

GROUP WEIGHT STATEMENT VECTORED THRUST VTOL, CONFIGURATION NO. SLR04

GROUP	WEIGHT-POUNDS
Structure	
Wing	150
Body	310
Tail	69
Surface Controls	66
Propulsion	796
Electrical	164
Electronics	90
Navigation/Guidance	28
Recovery/Launch	150
Environmental	28
Hydraulics	65
Payload	165
Oil	10
Unusable Fuel	9
Zero Fuel Weight	2100
Fuel (Mission + Reserve)	892
Gross Weight	2992

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5.10 TAIL SITTER VTOL CONCEPT, SLR05

5.10.1 AIR VEHICLE DESCRIPTION

The tail sitter VTOL vehicle as illustrated in Figure 5-17, is a single engine, modified delta wing design with both dorsal and ventral vertical tails. The combination of wing panels and vertical tail surfaces form a cross which supports the aircraft in a vertical attitude while resting on a landing gear members housed in the tips of each of the four surfaces. The wing has a basic wing area of 50.00 square feet and has an aspect ratio of 3.00. The engine air inlets are bifurcated ducts which are integrated into the wing root fairing. The engine is a modified Teledyne CAE 490 turbofan engine having a sea level static thrust of 3105 pounds. The jet exhaust is equipped with a gimballed nozzle which permits vectoring the hot gas portion of the exhaust ±15 degrees in two directions. Engine bleed air is ducted from the engine to the wing tips where it is exhausted through nozzles which can be rotated. The gimballed tailpipe nozzle and wing tip jet reaction nozzles provide the control forces for hover flight.

The vertical attitude of the vehicle while resting on its landing gear permits a reduction in hangar deck space required for storage. Provisions for folding down the fuselage nose forward of the engine inlets reduces the height of the vehicle from 18 feet to about 12 feet. The payload and avionics are located in the nose section.

The recovery gear also includes a pair of engagement hooks which secure the RPV to a metal grating which is mounted approximately 12 inches above the deck of the ship. The engagement hooks are designed to extend downward through the openings in the grating as the shock struts compress during initial contact with the ship. After extending through the grating, the engagement hooks automatically open by unfolding four arms. The unfolded arms form a means of trapping the engagement hook below the grating. The engagement hooks are spring loaded to take up any slack, so that the RPV is firmly secured to the landing deck.

Fuel is located in the center fuselage between the inlet ducts and in the wing root fairing area. Approximately 900 pounds of fuel can be accommodated internally.

The group weight statement for the Tail Sitter VTOL configuration is presented in Table 5-6.

WING	
GROSS AREA (BASIC)	50.00 SQUARE FEET
ASPECT RATIO	3.00
TAPER RATIO	0.30
THICKNESS RATIO	
ROOT	0.09
TIP	0.06
SWEEPBACK ANGLE C/4	50 DEGREES

VERTICAL TAILS	
GROSS AREA, TOTAL TWO TAILS	13.34 SQUARE FEET
GROSS AREA, ONE TAIL	6.67 SQUARE FEET
ASPECT RATIO	1.00
TAPER RATIO	0.31
THICKNESS RATIO	0.08
SWEEPBACK ANGLE C/4	50 DEGREES
TAIL VOLUME COEFFICIENT	0.093

PROPULSION	
ENGINE DESIGNATION	TCAE 490 (MODIFIED)
SEA LEVEL STATIC THRUST (T.O. RATING, 2 MIN. LIMIT)	3,400 POUNDS
WEIGHTS	
TAKE-OFF GROSS WEIGHT	2,881 POUNDS
FUEL WEIGHT	890 POUNDS

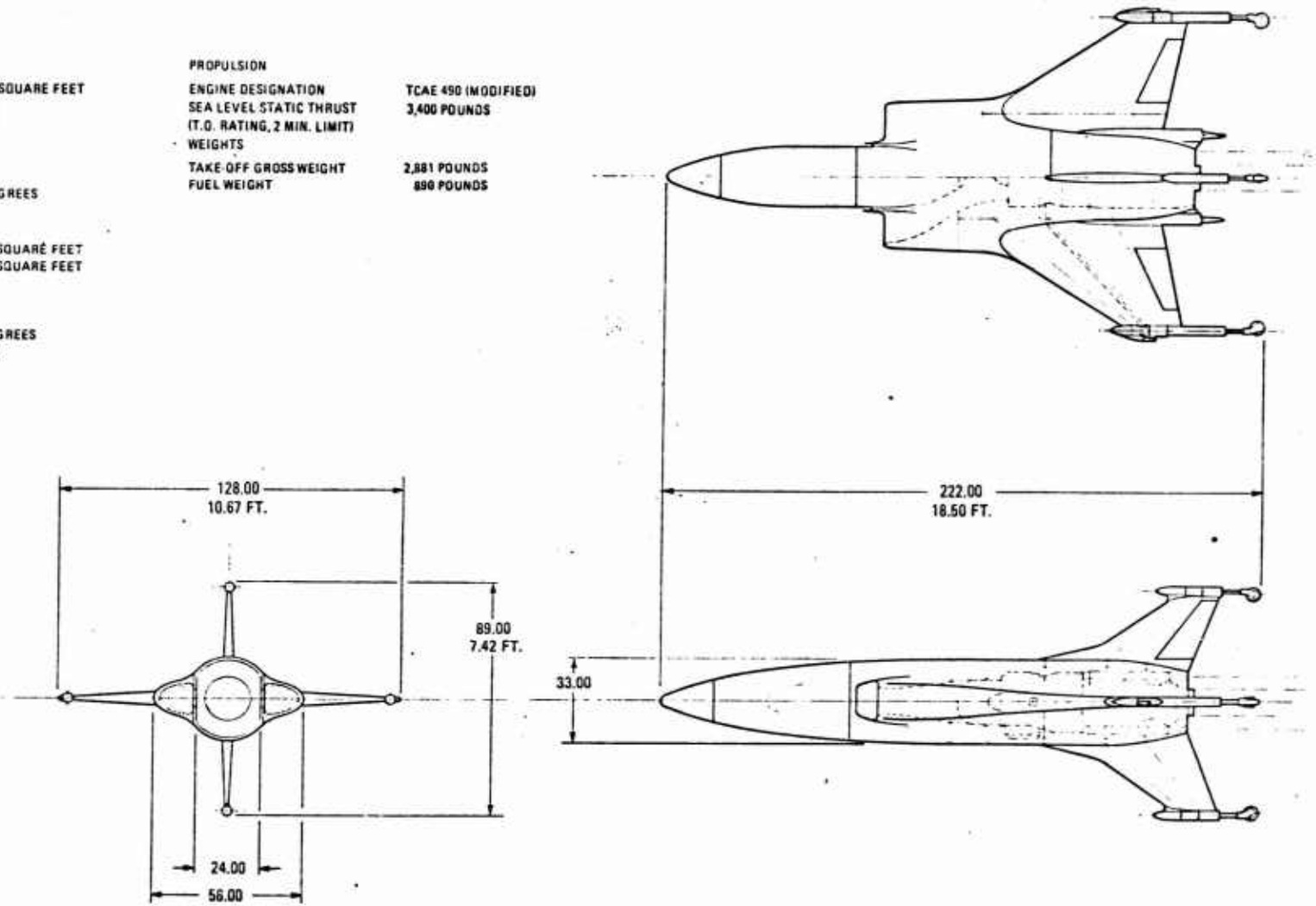

Figure 5-17. Tail Sitter VTOL Concept, SLR05, General Arrangement

TABLE 5-6

GROUP WEIGHT STATEMENT TAIL SITTER
VTOL, CONFIGURATION NO. SLR05

GROUP	WEIGHT-POUNDS
Structure	
Wing	152
Body	296
Tail	79
Surface Controls	75
Propulsion	760
Electrical	164
Electronics	90
Navigation/Guidance	28
Recovery/Launch	80
Environmental	28
Hydraulics	47
Payload	165
Oil	18
Unusable Fuel	9
Zero Fuel Weight	1991
Fuel (Mission + Reserve)	890
Gross Weight	2881

5.11 SLOW RATE OF CLOSURE (SLOROC) CONCEPT, SLR06-1, -2 AND -3

5.11.1 AIR VEHICLE DESCRIPTION

The SLOROC vehicle is designed to minimize approach speed during a conventional landing approach. The configuration, as shown in Figure 5-18, is a close-coupled canard arrangement to maximize the lift coefficient at high angles of attack. The wing has a gross area of 50.00 square feet and an aspect ratio of 3.13. The span of the wing is 12.50 feet, but folds to a maximum dimension of 8.00 feet. The overall length is 21.17 feet and the overall height is 6.29 feet. A side force fin, which provides lateral control during landing approach, is located on the underside of the fuselage forward of the nose gear. The side force fin folds to a horizontal attitude to facilitate deck handling and launch.

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WING		VERTICAL TAIL	
GROSS AREA	50.00 SQUARE FEET	GROSS AREA	8.40 SQUARE FEET
ASPECT RATIO	3.13	ASPECT RATIO	0.79
TAPER RATIO	0.18	TAPER RATIO	0.27
THICKNESS RATIO		THICKNESS RATIO	0.08
ROOT	0.10	TAIL VOLUME COEFFICIENT	0.08
TIP	0.08		
		PROPULSION	
CANARD		ENGINE DESIGNATION	TCAE J69-T-29
GROSS AREA	15.31 SQUARE FEET	SEA LEVEL STATIC THRUST	1,700 POUNDS
ASPECT RATIO	3.20		
TAPER RATIO	0.33	WEIGHTS	
THICKNESS RATIO	0.08	TAKE OFF GROSS WEIGHT	2,729 POUNDS
TAIL VOLUME COEFFICIENT	0.29	FUEL WEIGHT	990 POUNDS

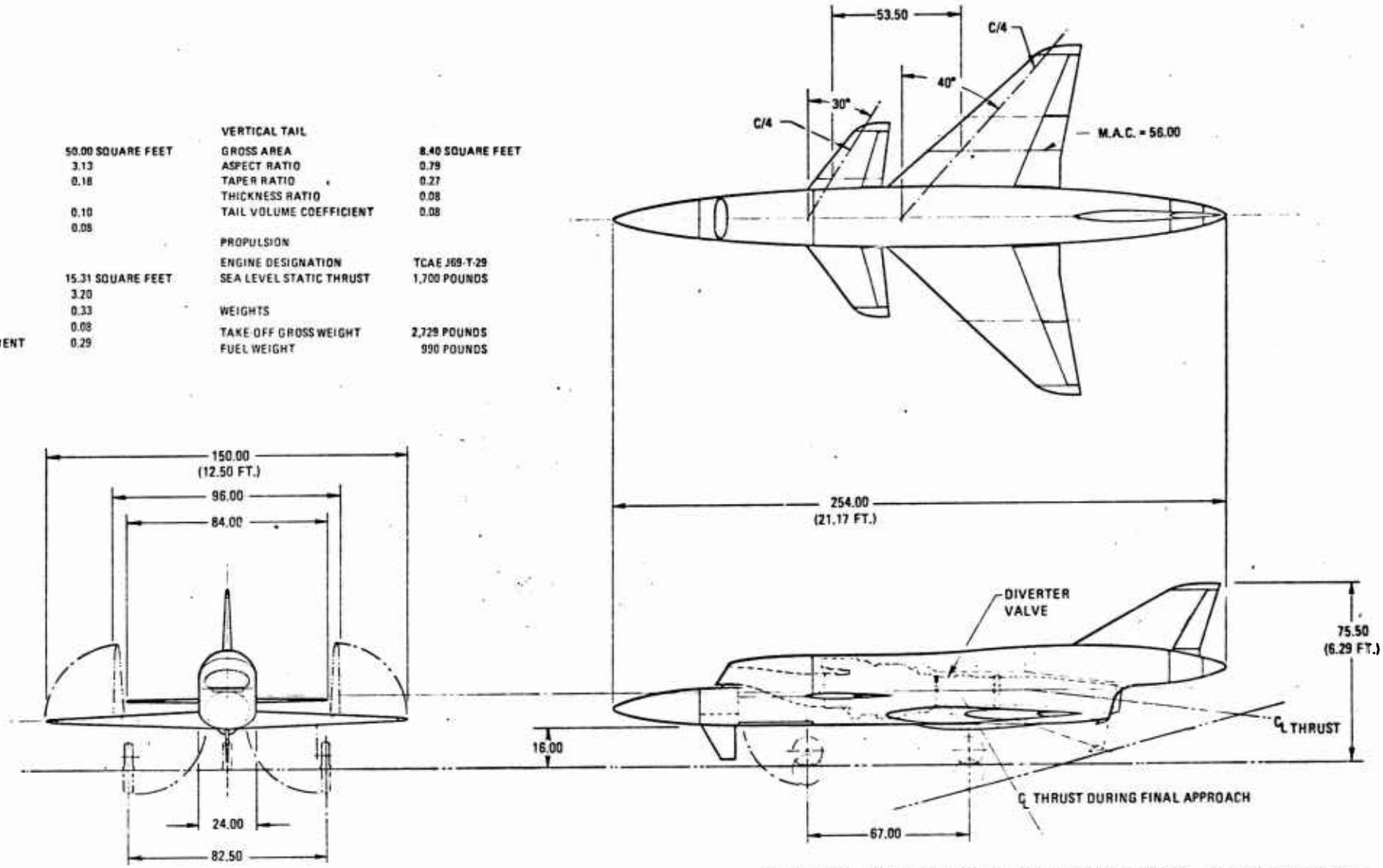

Figure 5-18. Slow-Rate-of-Closure Configuration, SLR06, General Arrangement

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The vehicle is equipped with a single Teledyne CAE J69-T-29 turbojet engine having a sea level static thrust of 1,700 pounds. The propulsion system includes a diverter valve installation mounted to the rear flange of the engine. The diverter valve has two exits; one exit, used during cruise flight, allows the jet exhaust to flow through a conventional tailpipe and exhaust through a tailpipe nozzle located near the end of the fuselage; while the second exit, used during landing approach, allows the gas to exhaust downward through a nozzle located near the center of gravity of the vehicle. The later nozzle position provides a strong increase in the lift component. This additional lift force permits a much slower approach speed with a corresponding reduction in kinetic energy to be dissipated during landing. The diverter valve has two internal valve doors which are hydraucially actuated to select the desired exhaust position. In the cruise position, the two valve doors are essentially horizontal, sealing off the lower diverter valve exit. In the slow flight condition, the two valve doors are rotated toward a vertical position, sealing off the exit to the tailpipe and opening the exit to the high lift nozzle. The resultant thrust force of the engine in the slow flight mode acts through or near the vehicle center of gravity, with any pitch down moments trimmed by increased lift provided by the canard surfaces.

The basic SLOROC configuration, SLR06-1, is equipped with retractable landing gear and a special tail hook installation. Additional SLOROC configurations include a version, SLR06-2, to be used with a landing net, which would have only a tail hook to engage the net system.

Another version, SLR06-3, would have an engagement hook mounted on a retractable arm, located in the upper fuselage, for recovery with the Aerial Track Recovery System. In all three versions, provisions are made for RATO launch.

The group weight statements for the three versions are presented in Table 5-7, Table 5-8, and Table 5-9.

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TABLE 5-7

GROUP WEIGHT STATEMENT SLOW RATE OF CLOSURE CONFIGURATION NO. SLR06-1

GROUP	WEIGHT-POUNDS
Structure	
Wing	180
Body	239
V. Tail + Canard	70
Surface Controls	62
Propulsion	487
Electrical	164
Electronics	90
Navigation/Guidance	28
Recovery/Launch	165
Environmental	25
Hydraulics	42
Payload (Installed)	165
Oil	12
Unusable Fuel	10
Zero Fuel Weight	1739
Fuel (Mission + Reserve)	990
Gross Weight	2729

TABLE 5-8

GROUP WEIGHT STATEMENT SLOW RATE OF
CLOSURE CONFIGURATION NO. SLR06-2

GROUP	WEIGHT-POUNDS
Structure	
Wing	192
Body	246
V. Tail + Canard	79
Surface Controls	62
Propulsion	487
Electrical	164
Electronics	90
Navigation/Guidance	28
Recovery/Launch	35
Environmental	25
Hydraulics	42
Payload (Installed)	165
Oil	12
Unusable Fuel	10
Zero Fuel Weight	1637
Fuel (Mission + Reserve)	990
Gross Weight	2627

TABLE 5-9

GROUP WEIGHT STATEMENT SLOW RATE OF CLOSURE CONFIGURATION NO. SLR06-3

GROUP	WEIGHT-POUNDS
Structure	
Wing	180
Body	261
V. Tail + Canard	70
Surface Controls	62
Propulsion	487
Electrical	164
Electronics	90
Navigation/Guidance	28
Recovery/Launch	50
Environmental	25
Hydraulics	55
Payload (Installed)	165
Oil	12
Unusable Fuel	10
Zero Fuel Weight	1659
Fuel (Mission + Reserve)	990
Gross Weight	2649

6.0 COMMAND AND CONTROL STUDIES

6.1 RPV AVIONICS

6.1.1 INTRODUCTION

This section discusses the elements of RPV avionics which are most important for ship-based operations. RPV launch is a relatively straightforward operation, hence it will not be discussed. However, shipboard recovery is the critical phase of RPV flight where vehicle controllability, ease of operator handling, and ship safety are key considerations. Vehicle controllability is optimized so as to minimize dispersion in the touchdown point and in impact velocity from nominal values. While the techniques for maximizing maneuverability and control precision are the same for RPV as for tightening path control. Similarly good handling qualities criteria for the remote operator on board the ship will differ from the criteria for manned aircraft. More importantly however, the man-machine interface is simplified to allow one man operation from launch through recovery with minimal training. This minimizes the size and skill requirements of the RPV crew. Good handling qualities, maneuverability, and control precision also enhance ship safety. Other key factors are reliability and contingency operations. These factors which are all very important to assuring precise positive RPV control at all times, will be discussed in this section.

The study indicates that further work is needed in certain areas to help quantify the recovery technology and capabilities. Such areas include the following:

- Dynamic error analysis to estimate error dispersions, taking into account vehicle dynamics, ship motion, turbulence, and guidance and control errors.

- An adjunct to the dynamic error analysis is a man-machine interface study to include operator characteristics and man-in-the-loop dynamics for contingency operations.

- Reliability analysis to determine the level of redundancy and backup control needed to assure ship safety as a function of cost.

During the past several years, a number of efforts have addressed the task of improving the avionics in RPV. This has resulted in the identification of several technical approaches, based on the use of general purpose digital computer-oriented hardware. The most cost-effective architecture for an advanced multipurpose avionics shipborne system emphasized the following benefits:

- Low acquisition and life cycle costs
- High degree of mission modularity and flexibility
- Fast turnaround (goal < 30 minutes)
- Simple and inexpensive to modify, easy to grow functionally
- Improved reliability, readily adaptable to redundancy
- High function density to meet vehicle volume constraints
- Readily adaptable to a variety of navigation systems and payloads
- Highly suitable to automatic checkout

The unique features of this approach are:

- The use of a general purpose minicomputer
- Modular approach to software that minimizes the cost for software changes to incorporate growth capability or changes in requirements.
- Replacement of hardware processing functions with software routines.

Important additional benefits of this approach in shipboard operations, where space and safety are premium commodities, include an improvement in reliability and a reduction in electromagnetic interference, maintenance turnaround time, and number of maintenance personnel required.

The digital avionics architecture is indicated in Figure 6-1.

The modular approach provides a high degree of adaptability to various navigation schemes, command/control links, and payloads. The basic navigation mode is dead reckoning (Doppler/heading, inertial, or airspeed/heading) working synergistically with one or two position update schemes, such as a radio navaid (loran, trilateration, NavSat), map matcher (TERCOM or optical correlation), or visual update via TV. The choice of scheme depends on the availability of navaid support systems in the operational area at the time. Hence, the adaptability feature provides a significant operational flexibility.

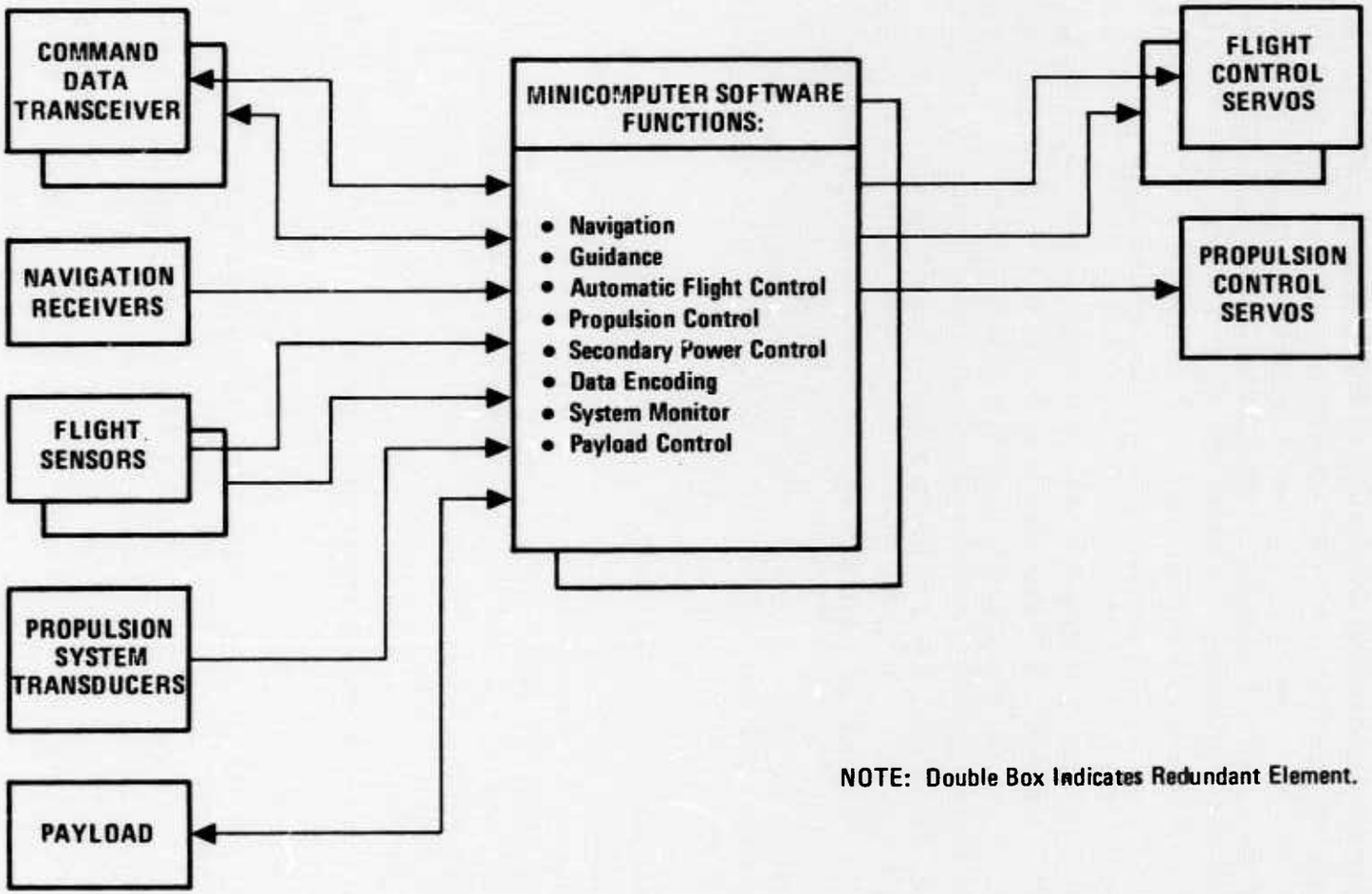


Figure 6-1. Digital Avionics Architecture

All of the automatic flight control system (AFCS) computation and logic functions are implemented by software programs in the digital controller. These routines accomplish signal filtering, autopilot mode control, and control law calculations. The flight control routines interface with other subsystems software, including the mission programmer routine, the air data processing routine, the various navigation and guidance routines and the executive programs. Previous drone autopilots required special purpose analog hardware to accomplish these functions, however, once a digital computer is on board the RPV, for any reason, the recurring cost of implementing the AFCS computations in software is negligible.

The avionics architecture provides the flexibility for incorporating any of the "standard" AFCS functions as well as the control configured vehicle functions which are important to precision shipboard recovery. CCV functions can include side force control, direct lift control, relaxed stability margins, and flutter suppression. Other software functions include energy management and monitoring flight condition with respect to the allowable flight envelope to avoid stall, flutter, or excessive loads. In this way, the RPV system can be optimized for performance and precision control, especially during weapon delivery and shipboard recovery. The AFCS implementation in Navy RPV is explored in greater depth in the remainder of this section.

Other subsystems in the avionics include electrical power, environmental control, and propulsion control. The concepts of computer control and power bus minimizes the number of switching elements, particularly those required to handle large currents. The integrity of those functions in the computer that are critical to RPV reliability are preserved in a backup microcomputer. Such functions include AFCS, recovery, power bus control.

6.1.2 RPV AFCS: GENERAL DISCUSSION

The RPV avionics, particularly AFCS, are very similar in function, hardware and performance as are found in manned aircraft. However, the basic nature of the RPV leads to differences in performance, functions, and design criteria. The RPV AFCS provides both the automatic and primary flight control functions. In manned vehicle control parlance, it is equivalent to a combination of an autopilot and a fly-by-wire manual flight control system (which in RPV parlance becomes fly-by-wireless manual control). This section summarizes the technology and trends in AFCS and design flight path guidance that are applicable to Navy RPVs.

Although autopilots have existed since 1912, AFCS design is yet to be routine. The role of the AFCS has expanded in recent years due to greater emphasis on man-in-the-loop control. The AFCS has played an increasing role in optimizing vehicle performance particularly in such demanding tasks as weapon delivery, air combat, terrain following, and automatic carrier landing.

Initially, autopilots were designed to relieve pilot loads by holding a set heading and altitude. With the advent of high performance jet aircraft, techniques were developed to control the short period and Dutch roll oscillations (stability augmentation) and to counter such phenomena as inertial cross-coupling and body bending. Recent concepts for improving aircraft response and handling characteristics include command augmentation, direct lift control and side force control. Advanced developments in the general field of automatic controls are being adapted to aircraft control technology; these include adaptive, optimal and self-organizing control techniques.

The arrival of compact, high speed digital computers, strapdown attitude sensors, solid-state sensors, and digital actuators have provided the designer with a wealth of alternatives and opportunities to meet the demanding requirements of RPV AFCS design.

The primary reasons for the existence of RPVs are to remove the pilot from a highly dangerous environment and/or to accomplish certain tasks or missions at greatly reduced costs. For both reasons, RPVs tend to be small, simple, and have restricted capabilities.

Having no pilot or crew and their associated controls, displays, safety, and life support equipment inherently reduces size and cost. Relaxing reliability requirements and complexity also reduces cost. However, as we become more confident and clever in RPV design technology and applications, more tasks will be and are being performed by such vehicles. Projected multi-purpose RPV designs have the functional complexity and capability to perform nearly any role that an F-4 can (albeit with considerably less range and payload carrying capacity). Therefore, applications of such strike/recce RPV can provide a strong supplement to manned aircraft in naval operations.

The consequences of remoting the pilot are several:

a. He is removed from a constrained and undesirable environment and placed in a more comfortable unconstrained one.

b. His visual, aural, and physical (dynamic) feedback or "sent of the pants" cues are gone.

c. The complexity and constraints of telecommunication links have been added.

d. His capability to "see" is restricted with some RPV sensors and improved with others; data transmission link characteristics have significant impact.

e. Vehicle design requirements are relaxed - such as for flight safety, reliability, ridingqualities, and environmental control

f. The optimum control laws, handling qualities criteria, and controls/displays configuration for the RPV are different due to b, d, and e above.

g. The overall vehicle costs are reduced by an order of magnitude.

In an RPV, the AFCS is considered a basic part of the vehicle. Since mechanical control systems are not required, the RPV inherently utilizes fly-by-wire techniques. Furthermore, a single (albeit redundant) servo-actuator drives each set of control surfaces, thus combining inner and outer loop and trim control. RPVs currently in development and future designs will utilize virtually the gamut of the advanced control techniques, including optimal control and control configured vehicle concepts, and adaptive control techniques (the latter in a more restrictive sense because of the relatively high complexity and cost). Of particular interest to shipboard recovery are those techniques which optimize vehicle control response at approach speeds, such as side force control and direct lift control. The newer techniques may find applications in RPV before manned aircraft because of the higher risk tolerance level, especially where the fringes of safe flight are being penetrated.

New techniques for implementing control functions are also being utilized, including integrated hydraulic power/servo packages and digital technology, as was discussed previously. Implementing control logic and computations in software is currently underway in several developmental RPVs. A central system computer is used to satisfy as many of the on-board computational and logical requirements as possible as opposed to being dedicated to flight control. This of course includes approach guidance where an advantage is gained in doing so.

The important features of a software AFCS are minimization of required hardware, flexibility of computation and of implementing changes, and the ease of introducing nonlinear constraints and functions. For example, the safe flight envelopes are stored in memory. Flight conditions are continuously compared with the stored envelopes. Control actions are modified or constrained as the safe boundary is approached or penetrated. This allows maximum use of the RPV performance capabilities without incurring stall, buffet, or excessive vehicle loads. It prevents the pilot from accidentally driving the vehicle beyond a safe limit - a natural consequence of not having "seat of the pants" feel.

6.1.3 CONTROL TECHNIQUES

The discussion of control techniques centers around the inner and outer control loops. These loops are so called because the low frequency outer loops, which provide flight path control, close around the higher frequency loops, which dominate the aircraft handling qualities and control precision.

The situation may be described as follows: In general, if the period of oscillation inherent in the vehicle exceeds 10 seconds (such as in sprial divergence and "phugoid" modes), a pilot can adequately control or damp motion, but if the period is less than 4 seconds (as in the "short period" or "Dutch roll" modes), the pilot's reaction time is not adequate to continuously cope with the oscillation. Because of the latter situation, nearly all jet aircraft have augmented damping. The importance of inner loop dynamics to handling qualities has fostered considerable development leading to such concepts as adaptive control, command augmentation, and direct lift control among others.

Inner Loop Control

The inner loop characteristics are normally vehicle dependent. For many vehicles, fixed gains have proven adequate for the inner loops. Others have used gain scheduling of the damping terms over the dynamic pressure range expected. In general, the detail gains are different from vehicle to vehicle and this is where detailed design is required. Typical ways in which gain changes have been handled are:

- Mission dependent gain switches and/or logic in the autopilot
- Plug-in gain adaptors which are different for each type of mission

- For digital systems, the constants involved are stored in memory and a notification of mission type is required before flight to activate the appropriate set.

- Self-adaptive control techniques which automatically set gains and hold stability within acceptable bounds. The complexity of these techniques is normally not justified in RPV, since one of the more simple alternates above usually provides acceptable realizable solutions.

Command Augmentation

A recent concept now finding increasing application is the CAS (Command Augmentation System). Designers have known for many years of the advantages of SAS (Stability Augmentation Systems) for ensuring adequate vehicle dynamic response and stability. CAS extends the SAS advantages.

The CAS combines three-axis stability augmentation, command shaping compensation to minimize cross coupling and undesirable moment generation in direct lift and side force controls. Typically angular rate and linear acceleration are combined in a complimentary filter so as to maintain approximately constant flight load response to input commands over the vehicle's flight envelope. Some gain adjustment (usually as a function of dynamic pressure) is also required in some cases. The combined feedback term is sometimes referred to a C* feedback; it is used in the longitudinal axis and in the lateral axis side force control loop. The CAS intentionally slows the aircraft responses to pilot commands so as to tailor the control feel. However, RPV CAS response is optimized for best flight path control, which provides a relatively quicker short period response than is normally experienced in a manned aircraft.

In essence, the shaped command signals buck the SAS signals so as to effectively reduce damping during maneuvers when reduced damped is desired for fast response while retaining the well damped gust response. Other advantages of CAS include:

- Nearly neutral speed stability which permits rapid speed changes without trim adjustment.

- Aircraft pitch response conforms to angular rate at low speed and to normal acceleration at high speeds.

- Control response is relatively independent of altitude and airspeed.
- Responsiveness is relatively independent of aircraft configuration.
- Signals from other subsystems can be added.

Adaptive Control

Adaptive control provides a means for determining the vehicle flight condition and/or performance and for varying gains, filter time constants, or other control parameters to maintain best performance. Such a capability provides flexibility of operation and improved performance over fix-parameter control systems, but it suffers the penalty of increased complexity. A number of techniques have been demonstrated for obtaining self-adaptive control capability with varying degrees of success. At least eight systems have been flown since 1959, the best known of these include the X-15 and the F-111 systems. Experience gained from these programs do not clearly indicate whether the benefits gained from adaptive control, as implemented thus far, are worth the penalties incurred. While some applications may be worthwhile, indiscriminate use should be discouraged.

Direct Lift Control

DLC (Direct Lift Control) is any device that produces changes in lift without generating a significant pitching moment. Elevators control lift and consequently normal acceleration by rotating the vehicle to change its angle of attack. With large pitching motions and lag in lift build-up evident in some flight regimes, precise flight path control is difficult. Use of DLC, blended with elevator control, provides a means of speeding up normal acceleration response, reducing pitch rate overshoot, and eliminating the initial acceleration reversal due to elevator lift.

Lift force producers include flaps, spoilers, and collective ailerons. Unless specially designed, flaps tend to operate in one direction and hence must be biased and are slow. Ailerons work well if the available area is sufficient. Spoilers must be operated at a bias to achieve plus and minus values thus incurring a drag penalty.

The DLC surface is very effective at producing instantaneous normal acceleration, on a transient basis, proportional to surface deflection. It is much less effective than the elevator in producing steady state acceleration. That is, DLC is a more efficient short-term device, while the elevator is more efficient on a long-term basis.

Stated another way, when the elevator is used to maintain a constant attitude, a given DLC surface deflection will not generate a steady state normal acceleration. Rather, a flight path angle response results with a time constant inversely proportional to the acceleration. Therefore, a blended system generally yields the best results.

Blended DLC yields a marked decrease in acceleration response time, by a factor of 5 to 10 times, together with a decrease in pitch rate overshoot, by a factor of 2, with respect to conventional elevator only control. Further, gust response damping is increased by 1.5 to 2 times. Hence DLC-equipped aircraft will be less disturbed by turbulence.

Direct Side-Force Control

Direct side force control (DSFC) produces lateral acceleration with the wings level. It provides an additional maneuvering control to increase the precision and responsiveness of the RPV. Hence, it improves the pilot's effectiveness in target tracking and recovery approach control. The expected improvement in lateral control time response should be similar to the improvement in longitudinal response provided by DLC.

Side forces can be generated by deflected thrust or vertical surfaces in a manner analagous to direct lift force generation. For example, configurations SLR01 and SLR06 utilize an active nose fin in conjunction with the rudder. When operated collectively such as to produce a net zero moment, a direct side force results. Aileron control automatically counteracts any residual roll moments generated by roll-yaw coupling, thus providing a roll-stabilized control mode. Configuration SLR04 and SLR05 utilize vectored thrust, although the latter uses it in the hover mode only. Tip jets produce control moments to counteract undesirable cross-coupled moments.

DSFC capability is particularly important for the SLOROC SLR06 configuration. Lateral control response tends to become sluggish at the lower approach speeds achieved by STOL aircraft. This would be detrimental to shipboard recovery where the allowable lateral touchdown (or impact in the case of the Brodie system) is quite small. DSFC increases directional control stiffness and responsiveness so as to correct the deficiency.

Control Configured Design

The concept of control configured design is to optimize the vehicle and AFCS as a unit rather than treat them independently as is normally done. All of the previously discussed techniques plus those not discussed are brought together under control configured design. The primary objectives are: (1) to minimize stability margins so as to minimize control power requirements, and (2) to alleviate loads (gust and maneuver) so as to minimize structural strength requirements.

The following is a short summary of these techniques and an estimation of the benefits to be gained:

- Reduction in the horizontal and vertical tail size with the autopilot stabilizing for the resultant changes in both static and dynamic stability. For a large aircraft like a B-52 an approximate 2:1 reduction in both horizontal and vertical tail area is possible. This would cause a significant decrease in weight. To perform the same long range, high altitude mission, the gross weight at takeoff would be reduced 13.7 percent. Even greater reductions are predicted for low altitude, high speed flight where the drag penalty is a skin friction function and is reduced proportional to the wetted area reduction. The responsiveness of the vehicle would also increase which is important for the air-to-air mission.

- Maneuver load control has been projected as a technique to reduce wing structural weight. During high "q" pull-up maneuvers wing control surfaces are used to shift the load pattern toward the center of the wing and reduce wingroot bending. Estimates of weight reductions of as high as 2 percent of gross weight have been predicted for this technique. This technique if properly designed can improve the responsiveness of the aircraft by providing a direct lift component.

Redundancy

Much has been accomplished in mission dependability and safety in recent years in multi-channel redundant flight control systems. Fail-operational systems of triplex and quadruplex configurations have been designed which can sustain one and two failures and continue to operate. Automatic landing systems of the triplex channel configuration or dual-dual configuration are also fail operational for the first failure. These system are

much more complex than normal single channel systems but have greater integrity and increased probability of success in accomplishing a specific task. Determining the level of redundancy that is optimum for RPV in shipboard recovery requires a level of analysis that is beyond the scope of this study.

A less complex technique uses the concept of fail-passive design which inherently eliminates active or hardover failure modes. When two fail-passive control channels are operated in parallel, a failure in one channel will not affect operation of the other. Since neither monitors nor switching are required, the overall system is much less complex than a conventional monitored system. In fact, the complexity (and hence cost) is in general reduced by one control channel (either real or simulated) plus all of the associated voting, comparison, and switching mechanisms in comparison to a conventional redundant system of equivalent performance. Monitoring, in effect, is mainly relegated to the role of status reporting. Switching is used to change control modes rather than eliminating failures. The feasibility of fail-passive design was demonstrated in 1966 (Reference 5).

The benefits of redundancy accrue from the fact that the overall system failure rate decreases as the product of the failure rates of the individual channels, whereas the rate of need for maintenance actions and system cost increases linearly.

RPV reliability is normally significantly lower than the typical case in manned aircraft both by requirement and design so as to minimize system costs. The relative cost of redundancy in a simple vehicle can be devastating. Hence, redundancy and/or back up control is reserved for vehicles on which long endurance or special safety requirements, such as shipboard recovery, are imposed. Dual redundancy with a model monitor residing in a general purpose computer for resolving failure ambiguities has been implemented in one long endurance RPV at TRA to achieve reliability goals. Safety requirements on the other hand, are normally satisfied by simple backup systems, which provide reduced mission capabilities but are adequate for recovery.

6.1.4 AFCS CONFIGURATIONS

For the types of aircraft considered in this study, two classes of AFCS must be considered: conventional and VTOL. Control laws do not change appreciably over the speed range of fixed wing aircraft from supersonic to STOL. However, to get to the lower speeds of VTOL, an abrupt transition in control laws occurs. In fact, a VTOL AFCS must encompass both sets of control laws.

A functional diagram for the conventional AFCS is shown in Figure 6-2. The inner control loops comprise a command augmentation system (CAS) and the mixing function for integrating direct lift and side force control. The outer loop control modes are similar to manned aircraft AFCS modes: seek and hold of heading, airspeed or Mach number, and altitude or altitude rate (vertical velocity).

One of the key design parameters in obtaining good controllability of the approach path is the vehicle path control frequency response. It should be greater than the ship motion power spectra, which peaks in the vicinity of 0.5 radians per second. Aircraft path control responses typically fall into the same region. The relationship is shown in Figure 6-3. Reference 6 confirms the importance of this factor. It notes a significant decrease in carrier landing accidents as the dominant longitudinal axis transfer function numerator term, $\frac{1}{T\theta}$, increases. This term approximates the closed loop phugoid parameters. The values of $\frac{1}{T\theta}$ for four carrier-based aircraft are indicated in Figure 6-3. Also shown is the range of desired values, which can be achieved using such techniques as DLC, high lift devices, and speed control. The "goodness" of controllability of any particular vehicle configuration is best determined in a dynamic simulation which is beyond the scope of the present study.

An important difference between RPV and manned aircraft AFCS is in the point of manual control input. While the RPV input could enter at the CAS, as it does in a manned aircraft fly-by-wire system, it normally enters in the outer loops. Typical inputs are roll angle (or lateral velocity for side force control), vertical velocity (sometimes pitch attitude), and airspeed or Mach number. The reason for this is that a remote pilot's task can be simplified by providing a time integration between control input and flight path vector that would otherwise have to be done by the pilot. Hence, he controls roll angle rather than roll rate (as from within the cockpit), vertical velocity or pitch attitude rather than normal acceleration or pitch rate, etc. This method is similar to a pilot flying an aircraft through the autopilot rather than the control stick.

VTOL AFCS

As we discussed earlier an aircraft in the VTOL mode obeys a different set of control laws than when in a conventional mode. The VTOL aircraft is more difficult to fly, particularly when holding the aircraft in a fixed position with respect to the earth or a ship, because four time integrations exist between control inputs and vehicle position. The pilot's task can be simplified by reducing the number of integrations

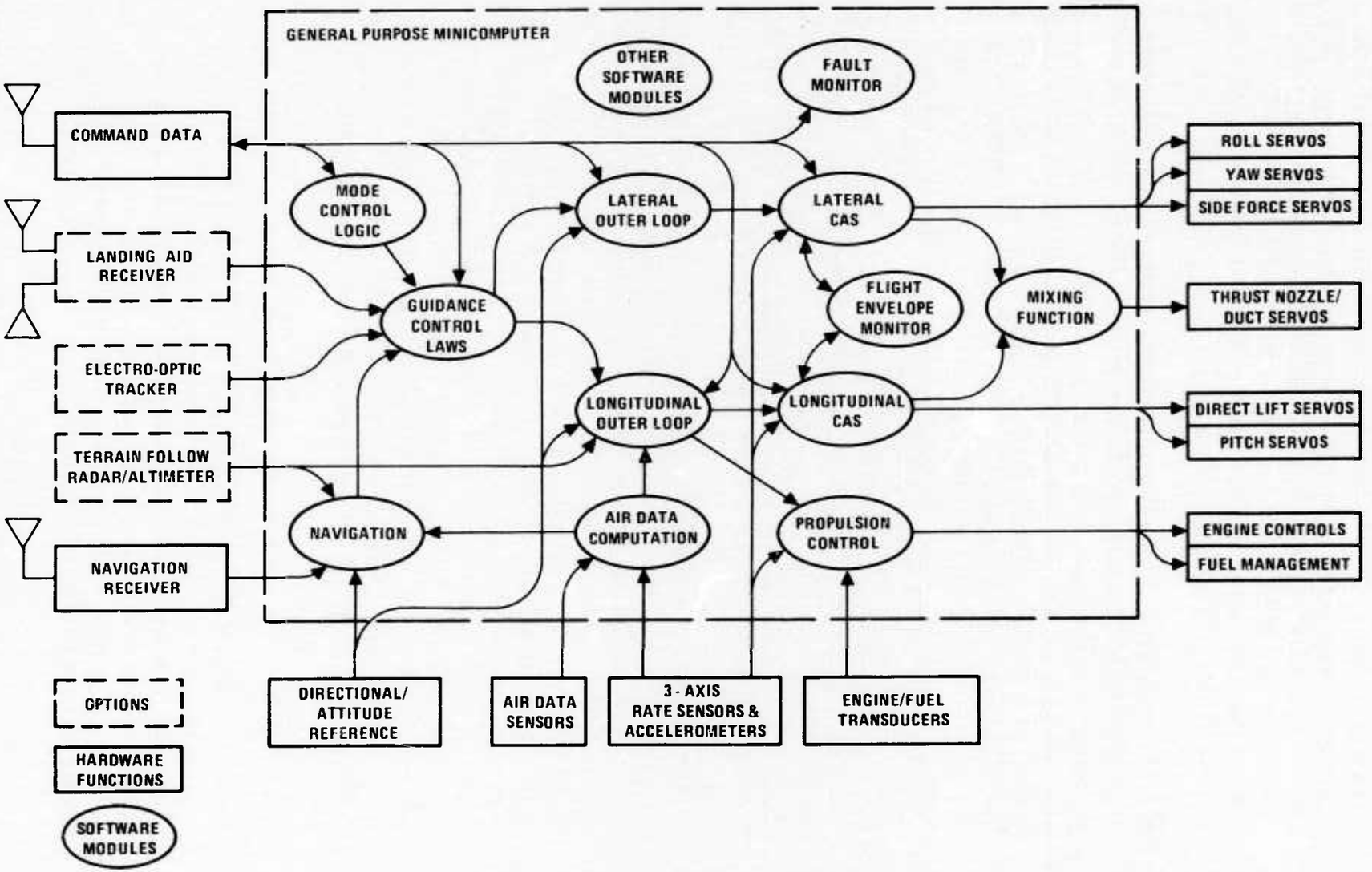


Figure 6-2. Simplified Functional Diagram for RPV Digital Avionics

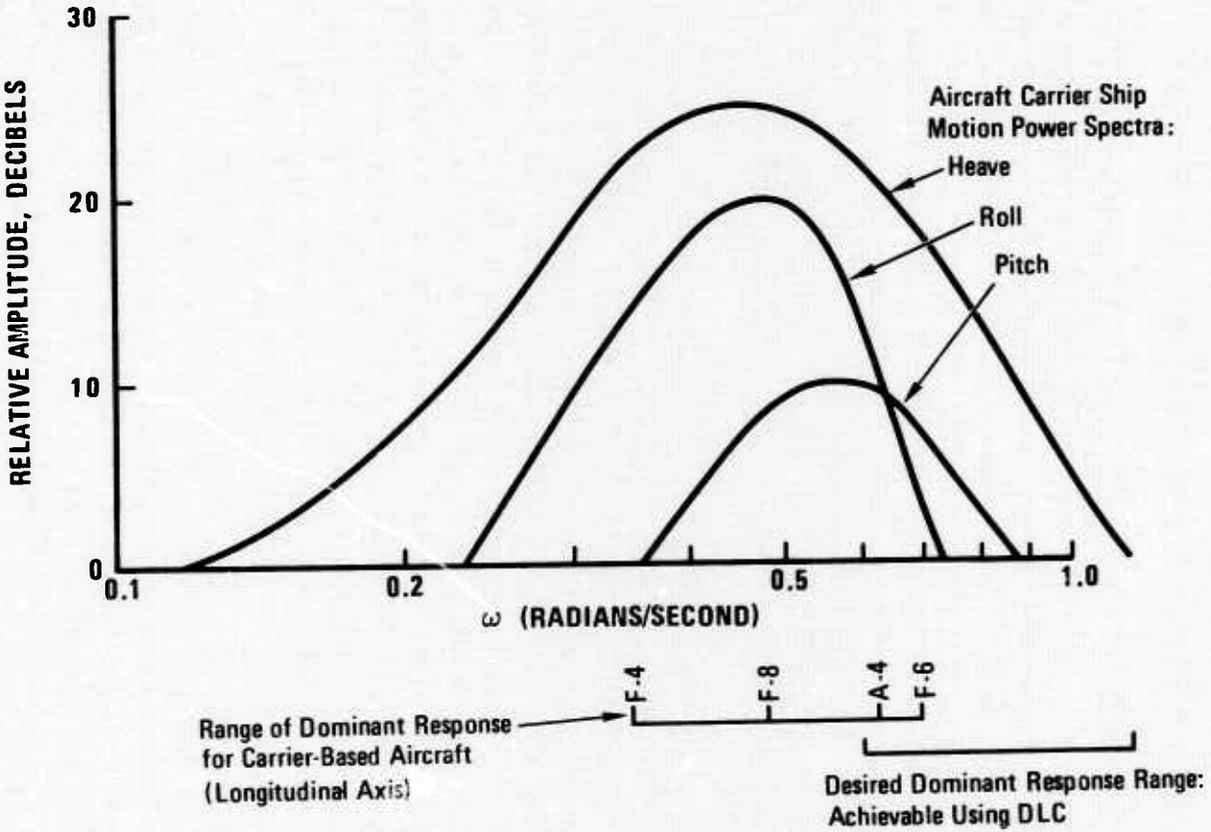


Figure 6-3. Optimum RPV Response vs. Ship Motion Power Spectra

involved. Feeding back (within the AFCS) inertially-derived translational acceleration and velocity, along with the familiar angular rate stability augmentation loops, provides three integrations. This type of system is sometimes referred to as a hover augmentation system (HAS). Hence instead of commanding attitude (to achieve lateral acceleration, velocity, and position), the pilot commands velocity directly. By adding response-shaping filters, a command hover-augmentation system results.

Since the velocity command/hold characteristic provides a linear relationship between control inputs and aircraft velocity (as opposed to nonlinear acceleration relationships), it is inherently easy to use for maneuvering. This factor is especially important for remote operations since the pilot lacks the physical cues which are so important to the typical attitude control. An important feature of the HAS is that the path control commands are directly compatible with the conventional flight mode commands. That is, both modes employ linear velocity commands. Therefore, pilot task loads and path guidance complexity are minimized as the vehicle travels through the transition speed region.

The flight sensors (attitude, angular rate, acceleration) for the VTOL mode are the same as those used for the conventional mode. Guidance inputs are also the same. What differs are the control law computation software package and the control servoactuators and their mixing functions. During control transition, the computer switches between control law software routines and the corresponding servoactuator sets in a controlled blending manner which is established in a transition routine. Once again, the flight performance envelope is stored and monitored; this is particularly important in and near the critical transition region. The difference between VTOL aircraft lies not in the flight sensors or control laws but in the unique propulsion and control moment generators and the associated control mixing functions.

One of the direct consequences of the HAS implementation, in addition to the desirable handling qualities and compatibility with the conventional AFCS mode, is excellent path damping. It improves performance in both automatic and manual approach and hover, which is very important to RPV operations. It also allows use of steep approach angles, exceeding 15 degrees, thereby reducing the time spent in ship's turbulence.

6.2 SHIPBOARD MOTION COMPENSATION

The recovery of shipbased RPV's safely on board Naval vessels becomes increasingly difficult as the sea state and the associated ship motion increase. The critical task is to synchronize aircraft motion with ship motion so as to minimize dispersions in impact point and velocities.

When conventional shipbased signals-in-space guidance systems are utilized, the incoming aircraft attempting to track a radio beam line of position will sense relative deviations from the desired path caused by either aircraft motion or by beam motion induced by ship motion. These typical landing guidance aids provide signals in space which are combined to form a squinted or scanning radio beam of a nominal one to two degrees width. This provides correcting approach guidance information to the electronic flight director indicator which the pilot uses directly or automatically through the automatic flight control system. Hence, the landing aid ties the terminal point of the aircraft's approach path to the flight deck. However, unless compensation is provided, ship motions will rotate and translate the reference beam which, acting as a long lever arm, amplifies the motions at the aircrfat location.

In land-based approach systems, the reference beam does not shift in spatial position, except for unusual reflecting or refracting phenomena. The air vehicle spatial position variations are attributed solely to the vehicle perturbations, typically, pilot response control lag, and the effects from the air mass. Accordingly, a smooth, predictable flight path to touchdown can be established.

For a shipbased approach system of this type, however, a more suitable system must satisfy two separate and diverse conditions:

a. When the aircraft is far out in approach path (4 to 10 miles), the reference beam should be fixed in space, independent of the vessel motion.

b. When the aircraft is near the touchdown zone, the reference guidance system should provide an indication of the vessel motion relative to the RPV and provide ship position prediction.

Additionally, a smooth transition from the stabilized approach path to the deck-phased touchdown maneuver is required. It is important, therefore, that a combination approach pattern be provided; stabilized in the far field, and with suitable motion and position prediction at/or near touchdown.

6.3 INSTRUMENT LANDING SYSTEMS

In 1970 the Department of Transportation (DOT), the Department of Defense (DOD) and NASA prepared a 5-year national plan for the development of a microwave landing system (MLS). The goal is to produce an approved and validated system design, together with production specifications for each of the various airfield and aircraft equipments. A limited number of preproduction equipments will probably be procured for evaluation at military and civil sites.

The requirements for this MLS have been assembled from the combined efforts of various user groups. Collectively, they postulated that cost and safety introduced the necessity for a common system signal format. Additionally, special or unique military requirements, i.e., weapons, vessel motion compensation, or theater of operations, can be accommodated with auxiliary data link channels, codes, or special operating modes. Traditionally, most military aircraft operate within the civil air traffic control (ATC) jurisdiction for a large portion of their useful life. Accordingly, military equipment and procedures should be compatible with the civil system enroute and landing concepts. The safety element is paramount, but economic values contribute heavily toward this requirement.

After extensive analysis, frequency and channelization requirements were established, together with a best-judgment signal format which provides for signal commonality among all users. Two signals in space system techniques were identified: the scanning beam and the Doppler; both of which can be expected to economically meet the requirements for a new MLS.

The MLS national plan provides for a 5-year study program with an $82,000,000 commitment. During the initial period, contract definition has resulted in four contractors to build feasibility demonstration equipments by mid-1974.

Several individual military requirements exist which may not be easily satisfied by the FAA national plan. Considerable controversy exists, and individual departments are actively pursuing their unique requirements. The probable large physical size and C-band implementation to satisfy civil long-range heavy precipitation requirements will force the military to continue interim MLS developments and procurements based around K_u band. Because of this controversial status, it is difficult to postulate the outcome of any flyoff demonstration.

Due to worldwide applications and high production rates, however, the RPV community can benefit from the economics and logistics afforded from the adopted system if special requirements can be easily introduced.

Insofar as naval warship installations are concerned, the requirement for deck motion compensation separates the conventional land-based systems from a system satisfying shipboard requirements.

Study recommendations (RTCA SC117) recognizing the international scope of its advisory/regulatory effort, provided for multiple air vehicle approach geometry to satisfy the many envisioned users. The horizontal tracks studied included:

• Simple, linear -- straight approaches	Figure 6-4a
• Multiple angled linear	Figure 6-4b
• Circular	Figure 6-4c
• Complex curved tracks	Figure 6-4d
• Combinational approaches	Figure 6-4e

The vertical profiles that were investigated are illustrated in Figure 6-5.

The most desirable approach paths for RPV recovery are as follows:

a. The constant angle approach Figure 6-5a for the conventional landing configurations.

b. The multiple angle approach (Figure 6-5c) for the SLOROC vehicle.

c. The multiple angle (Figure 6-5e) for the vertical takeoff/landing and tailsitter configurations.

The first and third approach path are representative of current practice. The multiple angle approach requires further study, but it would facilitate more flexibility in recovering relatively slow aircraft at high recovery rates.

The three basic control and guidance concepts which offer acceptable solutions to the landing/recovery of RPVs aboard a ship are:

- Signals-in-space format
- Precision approach radar
- On-board sensors

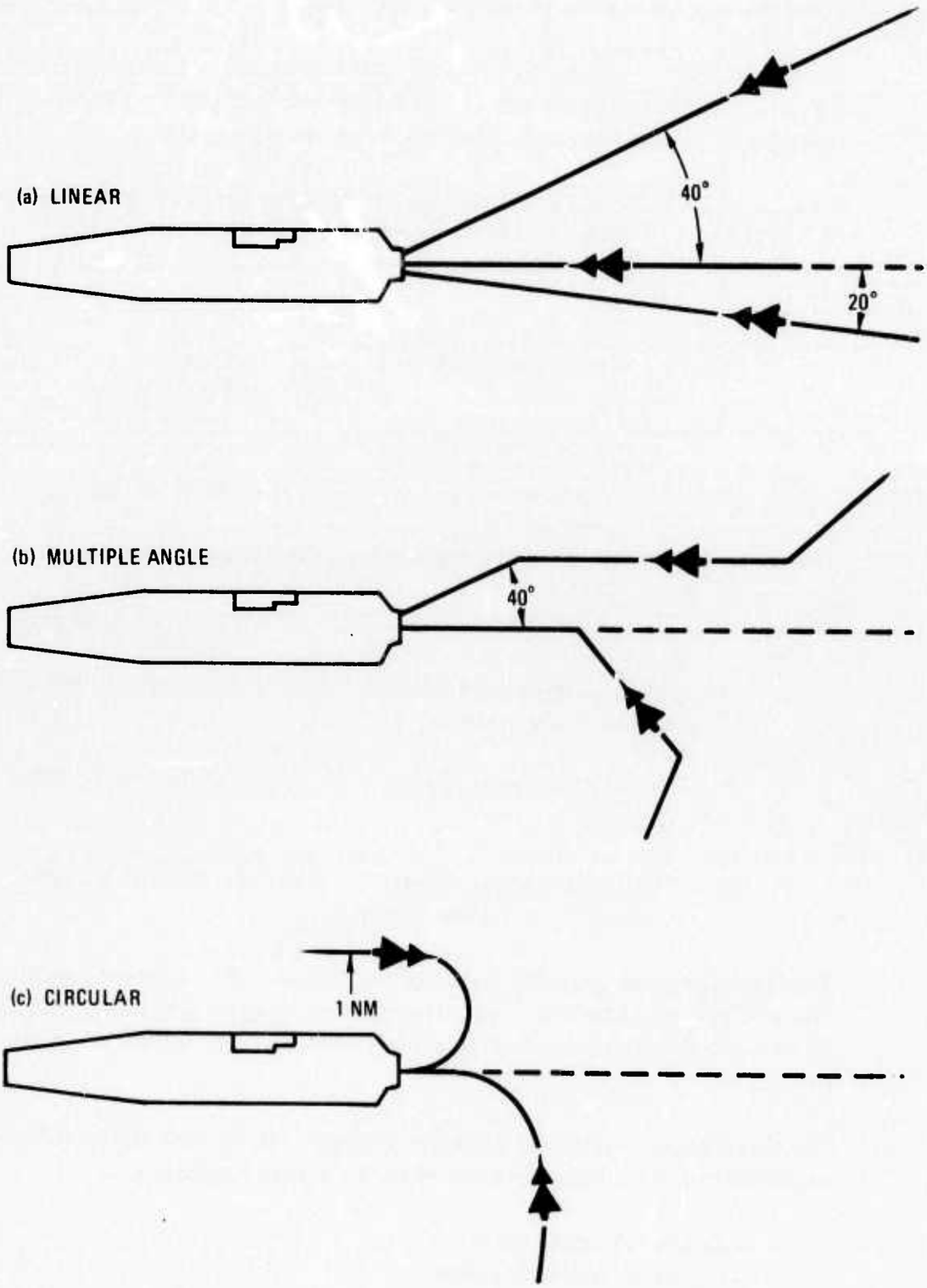


Figure 6-4. Plan Views of Approach Patterns, Sheet 1

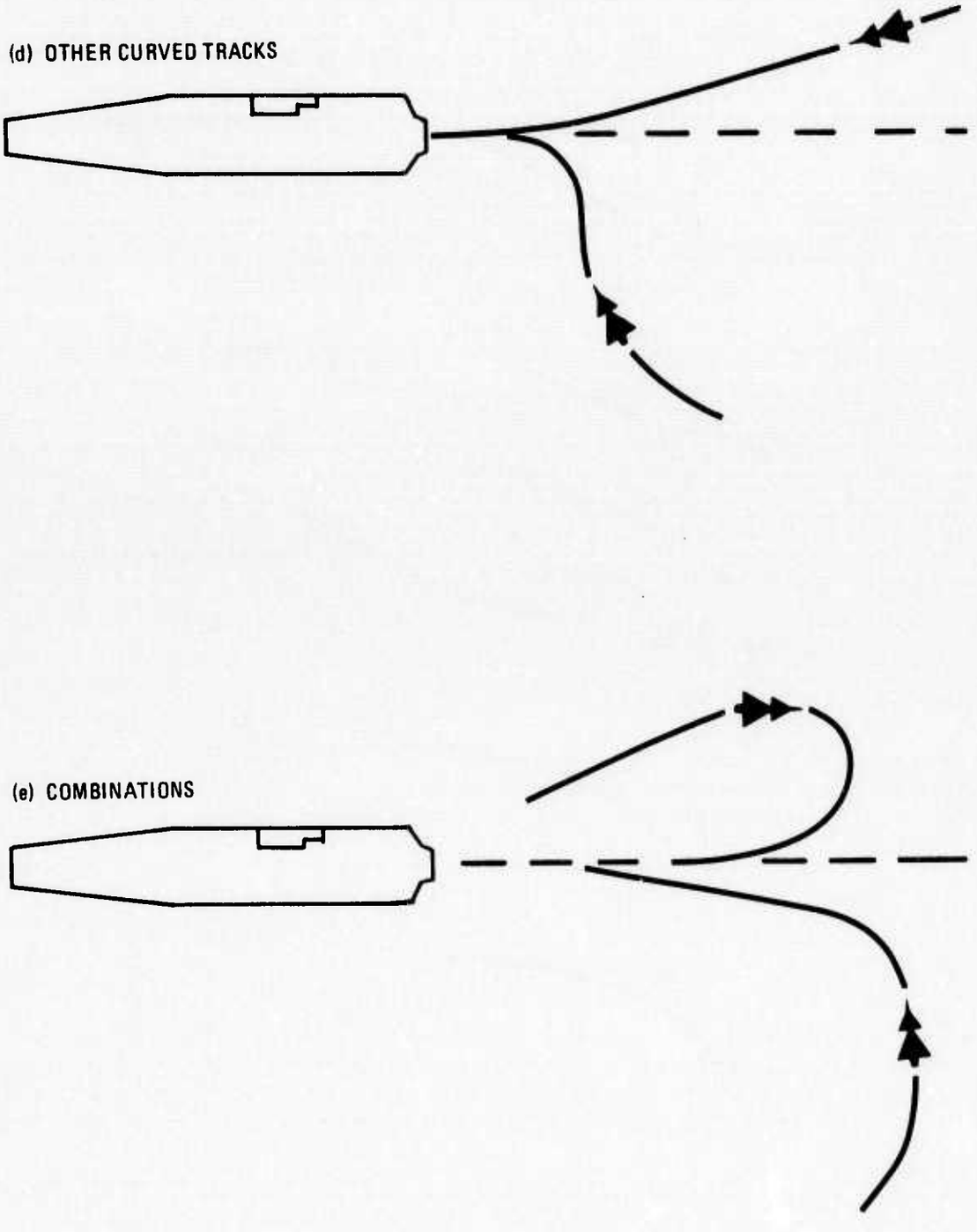


Figure 6-4. Plan Views of Approach Patterns, Sheet 2

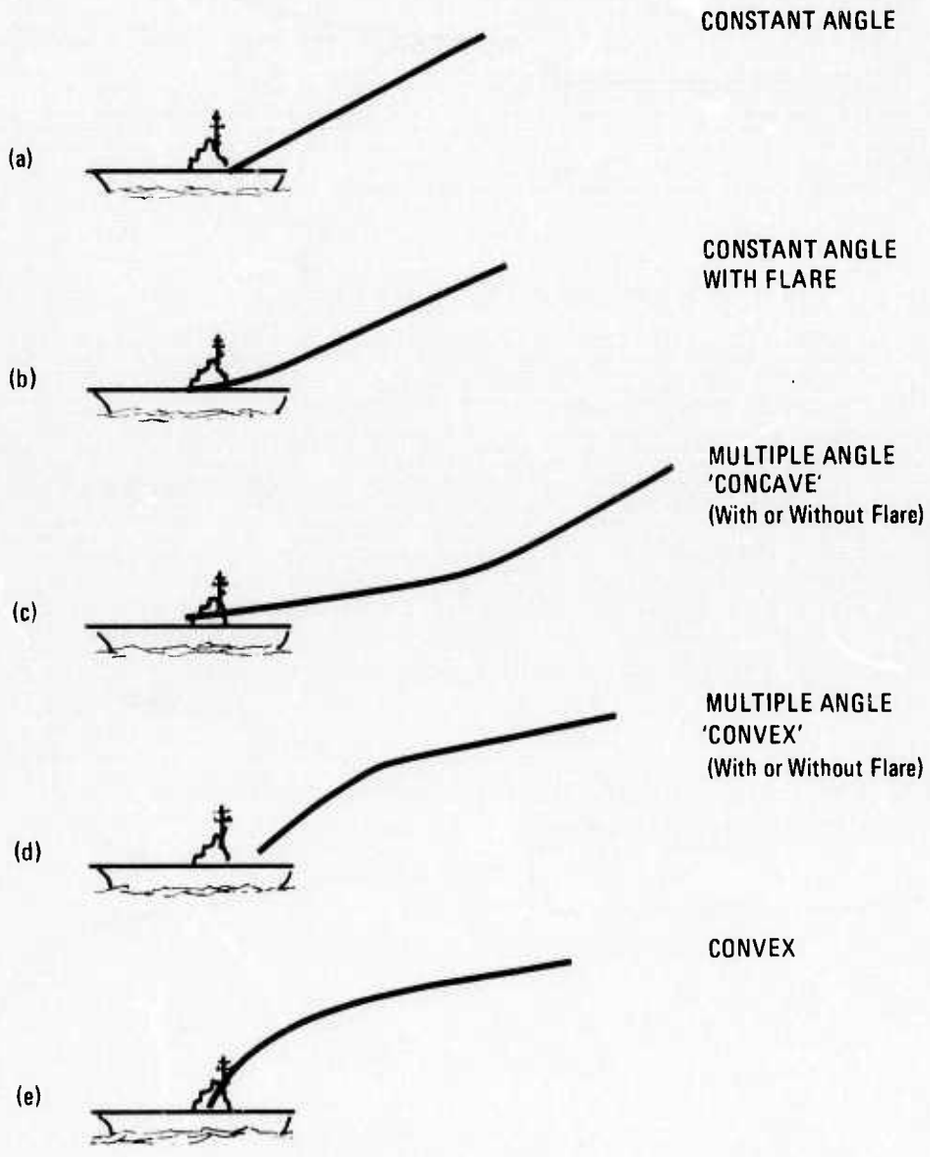


Figure 6-5. Examples of Approach Profiles

The signals-in-space concept is best illustrated by the AN/SPN-41 and VHF/UHF ILS navigational landing aid. Essentially, either a squinted beam or a scanning beam is radiated, and the aircraft equipped with a receiver and decoder is able to sense the beam position. These data are then fed to an auto flight subsystem or the pilot's cross-pointer indicator.

The precision approach radar scheme can best be illustrated by the AN/SPN-10, AN/SPN-42, and similar civilian precision all-weather approach radar systems. The AN/SPN-42 is a current naval operational automatic landing system which is installed on several carrier and land-based sites.

The on-board visual sensor is likened to a pilot operating in clear weather. He can see the landing site, remotely in the case of RPV's, and can visually resolve the relative motions to effect a touchdown.

The approach and landing guidance techniques considered during this study are:

a. The AN/SPN-42 Precision Approach Radar System
b. The AN/SPN-41 Microwave Scanning Beam System
c. Microwave Doppler Scanning Beam Systems
d. Multilateration Techniques
e. Vehicle-Mounted Sensor Guidance Aids
f. Range-Bearing Command and Control Systems

6.3.1 CANDIDATE LANDING AID SYSTEMS

Precision Approach Radars (PAR)

Precision approach radars provide for practical all-weather landing operations. The Navy AN/SPN-42-T2 is in final certification phase for IACO Category IIIc automatic landings on runways. It is now certified for Mode 1 (Category IIIc) "hands off" approaches on aircraft carriers within limited sea conditions. It is a ship- or shore-based precision tracking radar for both search and tracking modes. It can skin-track a standard size carrier aircraft to approximately 10 miles in clear weather or can operate in conjunction with a beacon transponder to extended range or operate in severe weather conditions.

The characteristics of the AN/SPN-42 landing system are listed in Table 6-1.

TABLE 6-1

AN/SPN-42 LANDING SYSTEM CHARACTERISTICS

Frequency Band	33.0 - 33.4 GHz
Environment	Tested to MIL-E-16400
Coverage	
Minimum Range	300 feet
Maximum Range	To 8 nautical miles
Azimuth	±55 degrees
Elevation	+30, -15 degrees
Auto Search	1 degree elevation by 25 degrees azimuth by 1200-foot range
Search Rate	20 scans per minute
Resolution	
Range	2 feet
Azimuth	0.022 degrees
Elevation	0.022 degrees
Stabilization	
(Shipboard Installation)	
Pitch	±7 degrees
Roll	±20 degrees
Heave	±7 feet
Yaw	±3/4 degree/second (360 degree range
Glide Slope	Auto or manual Selection 1 to 15 degrees
Minimum Aircraft Separation	1 mile or 30 seconds, whichever is less

During search, the radar antenna is directed by computer. When a target is detected, the radar switches to the track mode and automatically follows the target. The radar consists of transmitter, receiver, synchronizer, servo control, pedestal, and antenna sub-systems.

The returned video signal is tracked by an early-gate/late-gate range tracker which produces data proportional to slant range to the aircraft and a direct digital range count. Digital ranging circuits enable the computer to realize a resolution of two (2) feet in position.

The aircraft spatial location is determined from measurements of azimuth and elevation angles relative to the radar antenna and range measurement. The system includes a computer with a stored desired approach path with which it continuously compares the measured aircraft position. The appropriate signals are then generated and sent to the aircraft to correct its course.

A civil version identified as Advanced Integrated Landing System (AILS) has been in development and operation at the FAA test center for several years. This system also provides precision azimuth and elevation guidance with coverage throughout flare and touchdown, precision distance measurement, and a PAR function. The quality of guidance data has been proven to meet the requirements established for Category III operation: elevation angle ±0.028 degrees, azimuth angle ±0.021 degrees, and range ±75 feet (all expressed as one-sigma values).

The land-based version is identical to the carrier version except for the stabilization subsystem designed to compensate for the ship's pitch, roll, vertical, and yaw motions.

The advantages of the system are its precision, minimization of airborne equipment (since all the processing is done on the ship-based, or ground-based equipment), and the flexibility to set up any type of approach path which is not restricted to straight-line segments. Another advantage is the capability to provide both glide path and localizer guidance throughout flare and rollout although this capability is not required in shipboard applications.

The disadvantages are that it is very complex, expensive, and can be used only by one aircraft at a time, since it must point to that aircraft in order to determine its position. The system also requires a command link to the approaching aircraft for transmission of course correction signals. This factor is not of particular concern in RPV applications

since a data link is a pre-requisite for normal operations. An additional disadvantage of the PAR system is the large shipboard volume required to install the system. This volume may become critical on the smaller vessels.

Published data on the sea control ship concept does not include provisions for the installation of this equipment. Several exploratory discussions with the landing aid community has determined that several contractors are proposing other lower cost systems in lieu of the AN/SPN-42 ACLS for the sea control ship application.

The AN/SPN-42 system with motion compensation capability and a ±2-foot position accuracy is a practical solution. Mathematical models of the approach profile with wind turbulence, gusts, and ship motions are available, although the air vehicle characteristics for each aircraft using the system must be modeled and included.

AN/SPN-41 Microwave Scanning Beam System

The AN/SPN-41 system consists of two K_u-band transmitters and antennas on the ground and a receiver/decoder in the aircraft. The receiver/decoder in the aircraft provides deviation data from the selected path, typically on a crosspointer indicator. Selection of one of ten frequency channels in the 15.4 to 15.7 GHz band may be selected. The two transmitters operate on the same frequency which is time-shared. One transmitter and antenna, which provide elevation scan coverage, are located approximately 80 feet off from the touchdown point. Both antennas are mechanically scanned. The azimuth antenna has a 2-degree beam which is scanned ±20 degrees from the centerline of the landing area. The elevation antenna has a 1.3-degree beam which is scanned from 0 to +20-degree elevation. The antennas are vertically polarized and the azimuth and elevation antennas are respectively 2 feet and 3 feet in length. The mechanical scan of the antennas is greater than the electrical scan. The peak power of each transmitter is 2 kilowatts. Pulse pair coding is used to distinguish azimuth from elevation and azimuth left of centerline from azimuth right of centerline. The spacing between pulse pairs is a measure of the angle. Coding is also available for station identity and for obstacle clearance information. The antenna scan rate is 2-1/2 times/second and signals are transmitted in both locations of scan, thus providing an information rate of 5 scans/second.

Airborne equipment is the AN/ARA-63 which receives signals on the selected channel and decodes the information for display on the cross-pointer. For the RPV application, these data would be introduced into autoflight control system. Suitable compensation for extraneous beam data must be provided for Category III approaches. Flag alarms and cross-pointer deflection in the absence of a signal above threshold is also provided.

The use of the scanning beam technique permits the selection in the aircraft of any azimuth or elevation angle (within the scan coverage pattern) for approach. The optimum glide slope for a particular aircraft type may be pre-established.

Additional systems from the same family as the AN/SPN-41 (C-scan); A-scan, shorscan, and Co scan are all manufactured by AIL and use the same basic technique but differ in spatial coverage. C-scan was designed for single corridor carrier landings, A-scan for triple corridor V/STOL landings, shorscan for split location azimuth and elevation providing guidance and touchdown and rollout, while Co scan is a commercial version of C-scan.

The AN/SPN-41 system is in the military (Navy) inventory and a modernization plan for the AN/ARA-63 airborne decoder is in the IFB stage. The flexibility of scanning beam systems provide selectable glide slope and localizer courses permits various track captures without restricting the landing aid.

The two serious drawbacks are the sector scan width, ±20 degrees, airborne intercept capture angle ±30 degrees and Mode II minimums.

Scanning beam systems, like the AN/SPN-41, AN/TRN-28, Co-scan, and MRAALS, are systems that generate and scan a radio beam over a specified swept volume within a predetermined time period. These systems all sweep from a given reference. To establish a reference which can be biased so as to compensate for a moving platform is difficult. However, AIL, Division of Cutler Hammer, has proposed a simple modification to the existing AN/SPN-41 system which rotates and translates the beam so as to shift the glide path in elevation and azimuth. This modification is now being installed on a carrier for trial evalutions. The modification to the stabilization platform allows service to one approaching vehicle at a time; the beams are accurate for only one specific point in space at one instant. The shifted motions are: rotation of the path angle which changes the glide path and vertical translation of the glide

path which parallels the selected azimuth path without affecting the normal glide slope. The combined effect is to stabilize the selected touchdown point independent of the vessel motion, yaw, roll, pitch, or heave, and alter the glide path aiming point so that the air vehicle does not have to touch down at the landing aid aiming point. This technique can be applied to all conventional scanning beam systems.

Specification listings of the AN/SPN-41 scanning beam navigation landing aid are contained in Table 6-2.

Singer-Kearfott MRAALS

The Marine Aviation Detachment is sponsoring this scanning beam portable microwave landing aid development. It is difficult to obtain significant data other than that covered by the IFB because of the industry competition and flyoff demonstration which is now in process. The Singer-Kearfott prototype unit has been delivered for comments and some data have been obtained. Cost information will not be officially provided, again because of the impending competition; however, informal agreement as to a hypothetical cost has been obtained, i.e., approximately $83,000 for the ground station.

The Navy has circulated an IFB to upgrade the companion airborne unit, AN/ARA-63 receiver-decoder. Present inventory costs are $8,000. It is postulated that microcircuit, large-scale integration will reduce the size, weight, and power, and the acquisition cost to less than $2,800.

While the following description is based upon the Singer-Kearfott design, sufficient insight into the basic operating requirements and methods to satisfy the IFB are provided. The MRAALS ground subsystem will provide three major guidance parameters: azimuth angle, elevation angle, and slant range (DME). The ground subsystem generates two scanning, fan beams. These beams are encoded with a pulse modulation which uniquely defines their position in space. As the beam scans by, the airborne receiver detects and decodes this modulation and thereby establishes its position in space.

The scanning motion is provided by a single, low-inertia, low-friction scanner. This unit is contained in an integrated folded pillbox antenna assembly which provides the beam patterns required. The azimuth antenna feeds an additional stationary reflector which provides the elevation pattern shaping required for low angle coverage and minimal multipath contamination.

TABLE 6-2

AN/SPN-41 LANDING SYSTEM CHARACTERISTICS

GROUND STATION	
Frequency	15.4 - 15.7 (K_u)
Weight	550 ea. 1100 pounds
Power	115V/28V 1 KW
Size	3 x 2-1/2 x 4 feet each (2)
Range (10 mm rain)	10 nautical miles
Localizer	
Course Width	±2 degrees
Coverage:	
Horizontal	±20 degrees
Vertical	0 - 20 degrees
Glide Slope	
Course Width	±1.3 degrees
Coverage:	
Horizontal	±20 degrees
Vertical	0 - 20 degrees
Guidance (incl angle)	1.4 to 20 degrees
Indent Channels	20
Decision Height	50 feet (Mode II)
Type	Scan Beam
Cost	$100,000
AIRBORNE COMPLEMENT	
Antenna Type	Horn
Coverage	±20 deg. vert. - 100 deg. horiz.
Size	2.5 x 8 x 6 inches
Weight	3.6 pounds
Electronics/Cont. Amp	
Size	8.5 x 12.5 x 6.5 inches
Weight	9.35 pounds
Power	28 VDC 12 watts
Interface/Control Box	
Size	7 x 2.4 x 2.8 inches
Weight	0.8 pounds
Cost	$8,000 (AN/ARA-63)

The rotating scanner has a multiple feed arrangement which provides four scans of both azimuth and elevation for each revolution. This arrangement makes it possible to achieve four-to-one increase in system scan efficiency compared to a single scan per revolution and significant improvement in reliability.

The RF transmitter is pulse-modulated. The modulation consists of a series of pulse pairs in accordance with a specified format. The pulse trains are supplied to the transmitter modulator by the modulation generator. This module accepts inputs from the antenna position encoder and from the control panel in the form of channel identification, obstruction clearance angle setting, and guidance limits. These inputs are in turn used to generate the appropriate modulation, synchronized to the antenna.

Microwave switching is not required because of the self-switching action of the scanner. The antenna system accepts the microwave output of the transmitter and radiates the energy as two planar scanning fan beams. Both angle guidance and DME use a common supply which operates off either 28 Vdc power or 45 to 420 Hz ac power.

The airborne subsystem consists of an antenna, an ARA-63 Radio Receiver and ARA-63 Pulse Decoder. For RPV applications, an auxiliary assembly is required to permit interfacing to the multiplex terminal unit and provide the decoded guidance data, encoded selectable courses, and station vertification data. This, in effect, measures and displays deviation about fixed glide path in space. This path is defined by the center of the azimuth scan and a referenced coded glide slope from the ground.

A tabular listing of operational parameters are contained in Table 6-3.

Microwave Doppler Scanning Beam Systems

The SC117 committee recommendations, with respect to Doppler scanning beam systems, have been critically reviewed by ITT Gilfillan and ITT has elected to continue in its development.

The Doppler technique features simplicity of both ground and airborne equipment. The transmitting antennas consist of an array of switched radiators of the simplest kind. The transmitter provides a CW signal to the switches with no special modulation required. The airborne receiver determines angular position by a frequency measurement which is both easily performed and independent of amplitude. Multipath rejection is accomplished by filtering techniques, of which a wide variety is available.

TABLE 6-3

MRAALS

GROUND STATION	
Frequency	15.4 - 15.7 (K_u)
Weight	80 pounds
Power	175 watts 28V
Size	34 x 41 x 26 inches
Range (10 mm rain)	10 nautical miles
Localizer	
Course Width	±1 degree
Coverage	
Horizontal	±20 degrees
Vertical	0-20 degrees
Glide Slope	
Course Width	±1 degree
Coverage	
Horizontal	±20 degrees
Vertical	0-20 degrees
Guidance (incl angle)	2 to 18 degrees
Ident Channels	20
Decision Height	0
Type	Scan Beam
Cost	$83,000
AIRBORNE COMPLEMENT	
Antenna Type	Horn
Coverage	±20 deg. vert. -100 deg. hor.
Size	2.5 x 8 x 6 inches
Weight	3.6 pounds
Electronics/Cont. Amps	
Size	8.5 x 12.5 x 6.5 inches
Weight	9.38 pounds
Power	28 VDC 12 watts
Interface/Control Box	
Size	7 x 2.4 x 2.8 inches
Weight	0.8 pounds
Cost	$3,000 + ARA-63)

The transmitted Doppler signal is self encoded. The nature of the transmission uniquely defines a frequency at any point in space, and no special data take-offs or coding modulation need be employed. The self-encoding feature has important implications for the integrity and monitoring of the system. Since no moving parts or angle modulators need be employed, this system is less prone to failure. Also, the Doppler signal may be monitored at one point in the far field with an assurance that the transmitted signal is also accurate at all other points in the transmitted volume.

An important feature of the Doppler approach is the potential for selectable performance tailored to the needs of the individual user. Different classes of users, both civil and military, have varying requirements as to required coverage, accuracy, portability, and beam width. The Doppler equipment can accommodate these requirements and assure complete interoperability among them. Thus, ground antenna apertures may vary greatly in size according to the angular accuracy requirements, and in the airborne equipment a wide variety of signal processing methods may be employed with compatibility between all types of ground and airborne equipment. The critical factor, physical size of the antennas, is a restrictive element in consideration for shipboard use; a factor limiting its use to large aircraft carriers.

The aircraft carrier landing situation is unique in the siting limitations found on the types of ships where the system would be deployed. Multipath models in the shipboard situation determined the sizes of the MLS antennas to be used on an aircraft carrier. Stabilization techniques were also included with a possibility of both mechanical and electronic stabilization.

The large antenna elements rapidly discounted mechanical stabilization methods. Electronic stabilization requires considerable computational power to process the translation of Doppler-characterized signals.

The ease with which DME can be introduced into the system using a shared front end reduces the avionics complement.

Multilateration Techniques

Multilateration is a method of precise all-weather landing navigation available for those installations wherein the primary command and control link employs a compatible data link. The air vehicle spatial position is determined by time and phase difference measurements from a cooperative emitter. Usually three or more fixed ground transmitters (transponders)

are employed to obtain the spatial position in the three axes. The equipment operating frequencies are flexible since they are controlled by the frequency allocation board, but nominally UHF or X-band is used. For RPV applications, the handover problem is eliminated because the same equipment is used for mission control. All necessary equipment components are installed in the vehicle. The penalty to the air vehicle is minimal.

Two competitive multilateration navigation systems are in service today, but the extension of this technique for precision landing aids has been promoted by several companies. The published and projected vehicle spatial position accuracies are 5 feet and 2 feet, respectively.

The advantages of a multilateration system when considered for new installations, and in particular for destroyer class ships, are as follows:

- Small, simple omni-antennas can be easily located on the ship with minor concern for reflection and multi-path effect.
- The system provides hemispheric coverage.
- Measurement of three-dimensional spatial position, computation of steering commands and ship motion compensation can be conducted in the ship-based computer.
- RPV velocity and position information, together with steering correction data, are transmitted through the normal control command link.
- The system can readily accommodate ten or more incoming vehicles at one time, each individually addressed and identified.
- Ship motion compensation can be computed for each air vehicle in the approach phase and touchdown prediction information independently transmitted to that vehicle.
- A different approach path and profile can be individually assigned for each air vehicle.

For multiple control of air vehicles, the control and response data update rates must be an efficient mix: fast enough to permit accurate vehicle control, yet slow enough to permit multiple control of aircraft with

adequate data guard bands. Several studies have collectively agreed upon five updates per second as the optimum value. With this value, together with data averaging techniques, air vehicle position accuracy of 2-foot of position and 1/2-foot-per-second velocity accuracy can be obtained while operating at X-band.

If it becomes necessary that the RPV launch and recovery system operate in a secure mode, then additional communications modules can be provided. Spread spectrum and pseudo random coding techniques are possible methods. These are outside the scope of this study.

A simplified block diagram of the electronics interface is contained in Figure 6-6. The antenna geometry and typical navigation plot is shown in Figure 6-7. Specific characteristics are included in Table 6-4.

Vehicle Mounted Sensor Approach Systems

The cooperative utilization of the normal RPV equipment complement is very effective for the landing/recovery maneuver. For those vehicles which have a tracking TV or IR systems are weather limited, provisions are required for vectoring the incoming vehicle into the approach path. The vehicle-mounted sensor can track any assigned inbound bearing to the vessel. The RPV command and control subsystem can establish and monitor the approach path. The transition to the approach corridor is most easily effected from this display console.

Once the aircraft is within sensor acquisition range, the video tracker can lock onto a target light source which is pulse or spatially coded for identification. The airborne processor derives steering signals using modified proportional navigation for guidance laws and the target source for touchdown reference. The RPV controller monitors the approach via a heads-up flight director display overlaid electronically on the monitor video. This capability allows manual correction or contingency control where atmospheric visibility precludes or interrupts tracker operation. Guidance accuracy in this mode is greater than SPN-42 capability.

Range-Bearing Navigation

The range-bearing, RHO-THETA integrated command and tracking system offers excellent azimuth coverage for a potential landing aid; however, the lack of a precise elevation guidance capability is a serious handicap. Conventional air transport aircraft include an inertial complement which can be used for deriving vertical as well as horizontal velocity components.

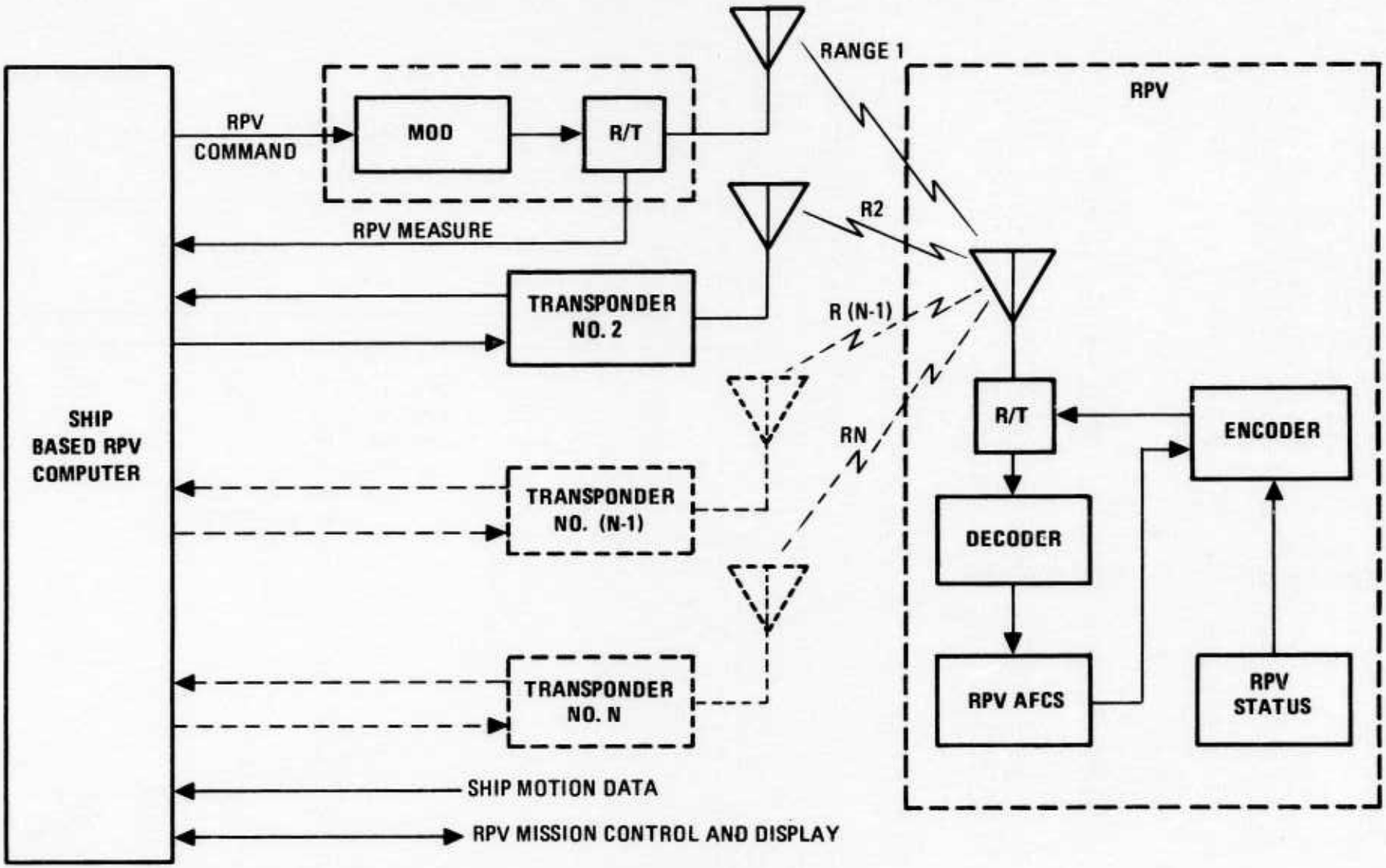


Figure 6-6. Multi-Lateration Functional Diagram

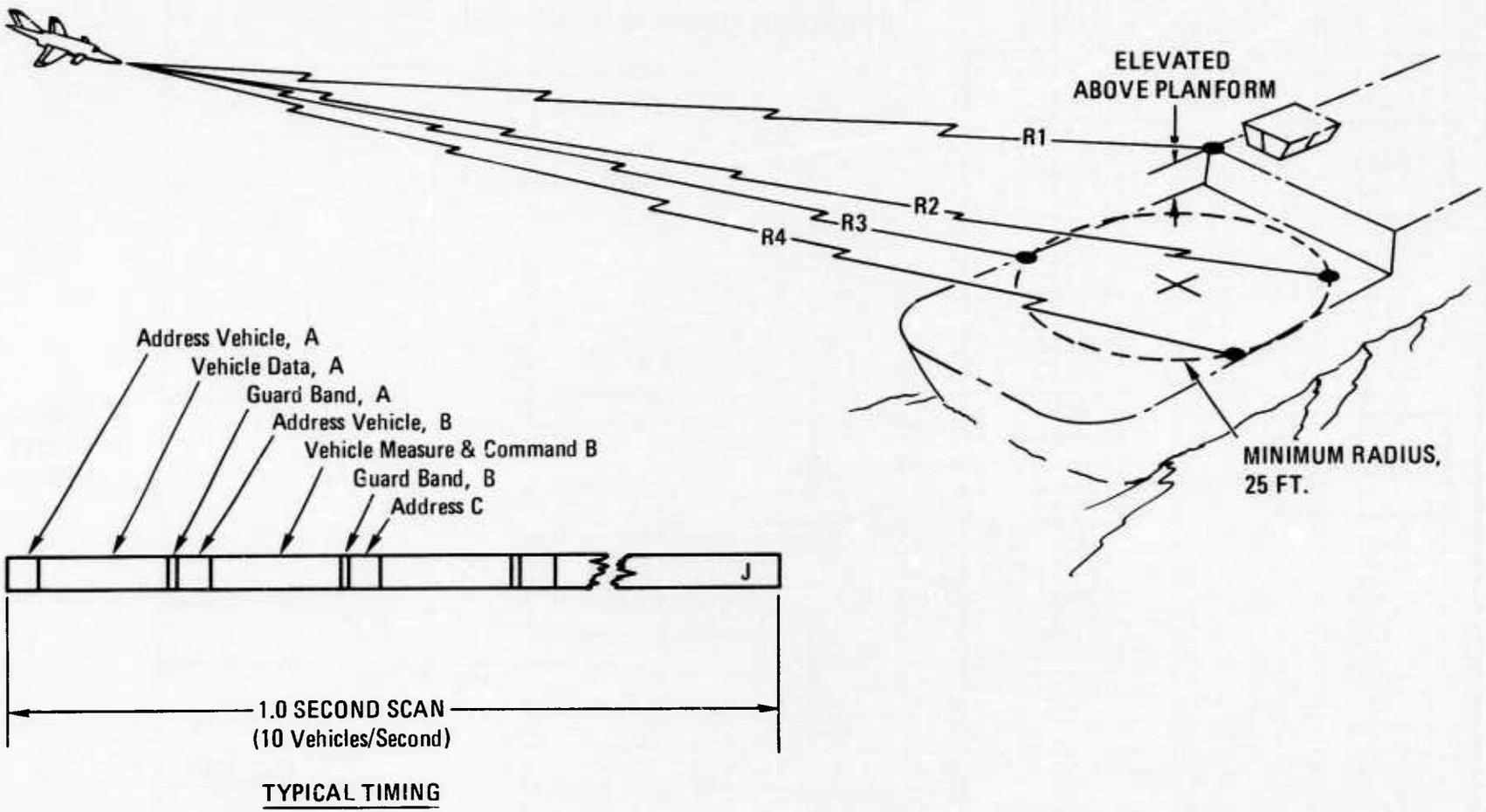


Figure 6-7. Multi-Lateration Ranging Diagram

TABLE 6-4

MULTILATERATION NAVIGATION SYSTEMS

	HIGH POWER	LOW POWER
Range	200 n.m.	20 n.m.
Transmitted Power		
Airborne	200 W	20 W
Ground	1 KW	200 W
Spatial Coverage	Hemispherical	
Position Accuracy		
4 stations		
Lateral Position		2 feet
Vertical Position		2 feet
Lateral Velocity		3 ft./sec.
Vertical Velocity		2 ft./sec.
2 stations		
Lateral Position	15 feet	
Vertical Position	15 feet	

Range-bearing navigation utilizes the time delay measurement between the RPV command messages and the response to a referenced synchronization bit to determine range. The bearing measure to the RPV is obtained by reference to a known sited reference. Relative bearing from the vessel is obtained using the vessel heading and referenced datum. This is illustrated in Figure 6-8.

In addition to the complex, wave-induced ship motion computations, an along-track vessel and RPV interception continuing solution is necessary. The RPV heading lead to assure deck touchdown intercept is more easily incorporated with the RHO-THETA system; albeit, this solution is required for all navigation landing aids.

A RHO-THETA system is under current USAF development funding. The system has demonstrated slant-range accuracy of 5 feet and angular accuracy of 1 milliradian. For a precision landing navigation aid, the system must also provide an elevation guidance (glide slope) capability. An on-board altimeter, together with a computer program, is necessary for this function.

In addition, for this system to be acceptable for shipboard applications, a method of providing ship motion compensation data linked to the RPV for its flight control computations to reduce touchdown impact is necessary. While a vertical profile can be maintained using reference RPV position data along a prescribed stored path, the coupling of these data with a heaving, rolling, pitching platform to effect a predicted touchdown point and vertical velocity is not simple. Techniques exist which can resolve the ship's motion and therefrom provide a pseudo-prediction of the deck position at a definite future time. Pseudo-prediction techniques are now used in the AN/SPN-42 ACLS. Extension of these techniques to data link to other approach systems is within practical limits.

The major driving factors to employ this system as a navigation landing aid are the reduction of airborne hardware and the simplification of mission control and handover from launch or recovery.

Insofar as RHO-THETA guidance is concerned, a means for establishing a referenced glide slope is necessary. A possible method is using interferometry techniques with the sensing antennas installed on the RPV to provide a rough angle reference. Refinement is accomplished using vertical velocity data obtained by integrating the flight control inertial references. The addition of a barometric or radar altimeter would provide an additional reference datum from which a descent profile can be computed and controlled to maintain the descent rate within specific limits.

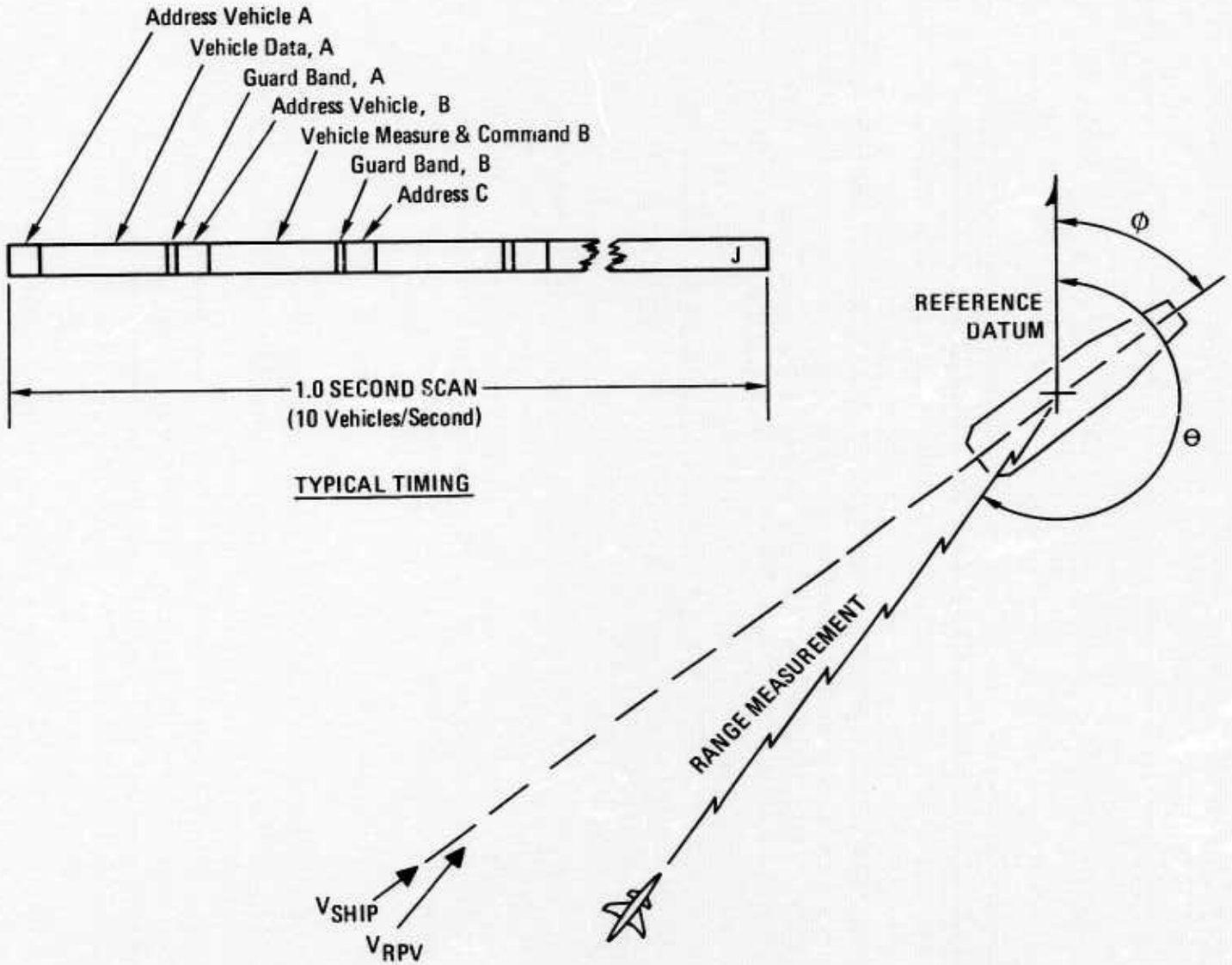


Figure 6-8. Range-Bearing (Rho-Theta) Navigation Guidance

6.3.2 LANDING AIDS TRADE-OFF ANALYSIS

A trade-off analysis between the candidate landing-aid systems was conducted. A weighted, scored matrix technique was employed. Each candidate was scored for each evaluation parameter based on a linear scale from 1 to 10, with graduations scaled as follows:

1 to 3 least effective or desirable
4 to 6 mean
7 to 10 most effective or desirable

Each score was then multiplied by the weighting factor assigned to the evaluation parameter under consideration. The weighting factor is an attempt to measure the relative importance of that parameter to the overall system evaluation. An arbitrary total of 100 was assumed for the weighting factors which were distributed among the individual parameters. The result of multiplying individual scores times the appropriate weighting factor is the ranking points. The scores are listed in the lefthand side of each candidate column, with the ranking points shown adjacent to the scores. A perfect score would occur if a candidate could score 10 for every evaluation parameter. When multiplied by the sum of all weighting factors (the arbitrary value of 100) the maximum number of ranking points achievable would be 1,000.

The trade-off evaluation matricies are presented later in this section as Table 6-5 indicating the scores and weights assigned to each evaluation parameter. An evaluation summary is provided in Table 6-6. The total ranking points for each of the candidate landing aids systems are indicated in the lower row of the table.

System Effectiveness

Range - Candidate No. 2, the long-range AN/SPG-60 track, while a scan radar by primary design and application, undeniably has the greatest acquistion range and tracking capability limited only to line-of-sight restrictions. Candidate No. 1, the AN/SPN-42 ACLS is a 50-KW pulse system and has a 4-mile tracking limit. Candidate Nos. 3, 4, 5, and 6 are all signals in space, formatted microwave signals, and have equal penetration range (at 100 mm rainfall). Candidate Nos. 7 and 8, multilateration and interferometry technique systems, are also signals in space but at UHF or X-band frequencies. Candidate No. 9, vehicle on-board visual sensor, has the lowest acquisition range, being dependent upon light or IR direction. In the visual spectrum, ranges of 3 to 4 miles at night during clear weather is possible; with IR the range can be extended to 6 miles

with drastic reduction attributable to weather/rain. Candidate No. 10, integrated RHO-THETA command and tracking system, has the greatest range limited only by the line of sight from the antenna.

Minimum Range "Key Effect" - Only Candidate Nos. 1 and 2, which operate on an illuminate-reply basis, have this effect. In practice, this results in a minimum effective range; typically, 200 to 300 feet for high-power radar system. This characteristic seriously limits the installation for aircraft carriers and sea control ships, and eliminates it entirely for destroyers of less than 300 feet in length.

Accuracy - All candidates rate high. Candidate No. 9, the IR or visual sensor homing device, when operated in the intercept (collision) mode, is the most accurate because the error is always being driven to zero. However, for tangential intercepts like a deck landing, the intercept angle is usually high with proportionately very large along-track errors. Accordingly, in this mode the candidate is rated low. This characteristic is difficult to rate competitively for this candidate; it is closely allied to the recovery technique employed.

Candidate No. 1, ACLS, provides the highest accuracy for the acquisition range of all systems.

Candidate No. 2, ship's tracking radar, is a long-range system and accuracy at close-in ranges is degraded, accounting for the low rating.

All remaining candidate systems are about equal.

Azimuth Coverage - Systems having the capacity for full 360-degree coverage are rated high: Candidate Nos. 2, 7, 8, and 10. Candidate No. 9 is a relative 360-degree system. That is, the on-board system, albeit a relatively narrow field of view (beam), can seek, sense, and track to any inbound bearing within its narrow tracking gate by correcting the vehicle course; hence, a 360-degree azimuth coverage, with no correcting of the ship-based systems.

Although Candidate No. 1 is a narrow-sector azimuth scan and track system, the specific sector of interest can be slewed to other quadrants; typically, an azimuth of 270-degrees is available, restricted only be antenna placement and masking by the ship's superstructure.

The remaining systems are scanning beam; signals in space formats having an azimuth scan of approximately 40 degrees. The sector cannot be reassigned without extensive alignment.

Elevation Coverage - Candidate No. 7, the multilateration system, offers the best coverage in elevation. The altitude is computed from time and phase differences from three or more radiating antennas. These data are used by the on-board computer to provide error correction data to the vehicle aerodynamic control system. Candidate No. 5, the MMRALS, is a new-generation scanning beam system offering very high elevation coverage, nominally 0 to 30 degrees. Extension of the elevation angle is possible by changes in initial set-up angle. Candidate Nos. 1, 3, 4, 6, and 9 are all equal in sector coverage, with possibly Candidate No. 9 having a slight edge since it is determined from the vehicle elevation above the ship-based target and Candidate No. 1 having a slight demerit since the elevation angle during track is less than the total elevation sweep angle. The remaining systems are, for practical purposes, out of the running since they do not have inherent elevation coverage without extensive assist from an on-board computer and altimeter.

Vehicle Installation Effects - Candidate Nos. 7 and 10 rate the highest because no additional equipment is necessary for landing guidance, albeit the on-board processor must be updated with the computations required for impact prediction.

Candidate Nos. 1 and 2 require only an identity beacon or reflector located to indicate the air vehicle touchdown point, i.e., hook or wheels. Candidate No. 9 is rated high but it is mandatory that the RPV include a sensor for the primary mission. It must be emphasized that an IR sensor will provide better all-weather performance than will a low-light-level TV sensor.

The remaining candidates all require extensive airborne equipments to be installed into the air vehicle. The receiver and antenna must be located with a high, forward-look angle and in a radome.

Simplicity of Introducing Ship Motion Compensation to the Air Vehicle - The complex problem of providing an accurate impact prediction to the air vehicle to preclude high touchdown velocities is usually handled in the ship-based computer system. Candidate No. 1 is rated highest, since it was a design goal of that system.

For the scanning beam systems (Candidate Nos. 3, 4, and 5), the technique is relatively straightforward but expensive. First, the transmitter is gyro-stabilized on a platform to compensate for roll, pitch, and yaw. Then the platform is tilted and/or rotated to introduce an intentional vertical beam translation and rotation to provide compensated,

deck-chasing beam paths. The translation is computed to provide a finite platform tilt or rotation which shifts the beam.

Candidate Nos. 6, 7, and 8 are electronically altered and coded to provide a variable approach path. Candidate No. 9 requires that a complex solution to the ship impact prediction point be continuously resloved in the on-board air vehicle processor. Simply stated, it is the reciprocal of the SPN-42 technique.

Accurate impact prediction for Candidate Nos. 2 and 10 are virtually impossible because of the lack of precise elevation data in the computation loop.

Multiple Approach Capability - The selected system must provide approach guidance to more than one incoming air vehicle at a time in the presence of wave-induced ship motions. The computed, predicted touchdown point must be available for transmission to the vehicle for its on-board dynamic computations in the approach cycle.

Candidate No. 8 offers the highest capacity. Up to 10 air vehicles in the approach path can be individually updated with the ship's motion for use in touchdown predictions. No additional on-board equipments are required. The basic command and control link can double in providing landing guidance information.

Candidate No. 9 is the next highest rated system. While multiple approach paths can be simultaneously monitored and individually controlled, this concept is severely limited by virtue of the on-board sensor range. The use of very large IR targets approximately 4-foot square, can improve the acquisition range to approximately 27,000 feet.

The addition of a precision altimeter is considered mandatory to ensure a decrement glide path for the case where the target is momentarily lost from the sensor. Candidate Nos. 2 and 10 also have a multiple track capability but the precision required for the approach phase also requires an accurate altimeter reference to maintain a decrement glide path. The on-board computer provides the decrement vertical profile which the RPV will follow on preplanned glide path. This limitation reduces the ratings of these candidates.

Candidate No. 1 can only track and control one vehicle at a time. In practice, aboard aircraft carrier vessels, two antenna groups are used to provide multiple approach capability. The system is complete; no additional equipment is necessary.

The remaining candidate systems are all signals in space formats. Thus, the ship's motion must be coded or otherwise conditioned to be compatible with the signals in space format. In practice, a stabilized platform is used with a "chasing-the-deck" routine to accurately predict the air vehicle touchdown. The land-based system, which normally can handle up to 40 aircraft, is reduced to one vehicle at a time when in the ship motion compensated mode.

Missed Approach Guidance - RPVs are considered by TRA to have a requirement for missed approach guidance to replace this function normally provided by the pilot in manned aircraft. Candidate Nos. 2, 7 and 10 all rate high for this parameter. By definition, the search radar, No. 2, is a 360-degree azimuth scan locator system. Both command and control systems, each having azimuth location capacity, can also provide the missed approach guidance function because it tracks the location of the vehicle. Candidate No. 8 is rated lower because the vehicle-mounted antenna location is a major consideration in determining the position of the vehicle with respect to the ship.

Candidate No. 1, SPN-42, is rated lower than Candidate No. 8. It can provide a missed approach monitor but it requires the redirection of the antenna scan to a new sector. The nominal antenna scan is 15 degrees.

In addition, there are blind antenna pattern paths which account for the lower rating.

Candidate No. 9 is an equally restrictive plot-location system. It is a forward-looking system which directly indicates its unsuitability for the missed approach and go-around procedure. The remaining candidate microwave systems are all one-way-looking systems. A missed approach procedure cannot be supplied without additional equipment(s) to provide back-course guidance which is necessary for climb-out.

Approach Path Offset Capability - For shipboard operations, the location of the landing aid is severely restricted when compared to the ideal radiation patterns sited with shore-based installations. The candidates were rated with the landing aid offset from the desired touchdown point by 25 feet. With this criterion, Candidate Nos. 1 and 7 rate highest. Both systems can direct the air vehicle to touchdown from a site remote form the navigation landing aid. Candidate Nos. 8 and 10 are partially directive, in that the azimuth position measurement is available. The elevation data is difficult and requires the addition of the on-board altimeter. The remaining systems are equally handicapped in this capability

in that they all must be somewhat near the touchdown point and the azimuth bearing must be in line with the expected approach path.

The elevation scanner can be remoted and as explained in that descriptive discussion, can provide elevation guidance translation which can remotely alter the predetermined hook-to-deck clearance on aircraft carriers.

System Simplicity - By definition, the simplest system is one that does not require additional equipment to conduct the landing maneuver. Accordingly, Candidate Nos. 2, 7, and 10 share equally. Candidate No. 1 employs one ship-based complex which includes the radar, computer, and reference ship motion platform subsystems. The data link is considered part of the basic system and not attributable to the landing aid. Candidate No. 8 is rated high because the sensor sub-system is a prime mission requirement and its use in the landing cycle is an effective utilization of the air vehicle on-board equipment. The remaining candidates all require additional equipment and installation hardware to conduct the landing maneuver. In addition, this equipment is used solely for the landing. It does not perform a dual function.

System Reliability - This category is rated based upon equipment parts count. Accordingly, Candidate Nos. 1 and 2, with little airborne hardware, are rated highest. Additionally, it is considered that the relatively protected environment of the ship will improve the system reliability.

Costs

RDT&E - Candidate Nos. 1, 2, 3, 4, and 5 are all rated high, primarily because they are all either developed or in the final completion cycle, although minor development will be required in the application of the translation and rotation unit to the scanning beam platform systems. Candidate No. 9 is relatively well advanced, accounting for its mid-rating.

Acquistion - Candidate Nos. 7, 8, 9, and 10 are rated high with the explanation that one of these systems are required for the primary RPV mission for control, and costs that can be attributed to the recovery/approach task can be sublimated therein. Candidate Nos. 8 and 9 have the lowest cost. Costs increase proportionately to Candidate No. 1, the highest cost and therefore the lowest rating.

Logistics - Candidate Nos. 1, 2 and 3 are now in military inventory. Candidate No. 5 is now in evaluation and provisioning should be forthcoming. The remaining systems are not in inventory and have no logistics support.

Training - Essentially the same analysis can be made as in the logistics discussion.

Operational Sufficiency

Multiple Landing - Candidate No. 7, with up to 10 simultaneous approaches, is rated highest. Candidate Nos. 8, 9, and 10 are rated equal because of the ability to track (in azimuth) several inbound RPV to the landing site. Candidate No. 1 can track and control two RPV simultaneously. The remaining systems have single vehicle tracking capability only.

Jamming Environment Operations - Only Candidate Nos. 7, 8, 9 and 10 have the ability to conduct recovery, and remote mission control in the presence of a hostile electronics environment. The conventional landing aids all are free radiators, and as such cannot operate covertly, or in presence of a jamming radiator.

Multiple Applications - Candidate No. 7 is a truly multiple application landing aid as it can be mounted on a variety of vessels. It is restricted, however, in that the radii of the transponder sitings must be greater than 25 feet. This is easily accomplished on any vessel under consideration. To improve vertical spatial accuracy, one of the transponders should be elevated from the main group. Candidate Nos. 5, 8, and 10 are rated lower, primarily due to the siting restriction of the antenna. This limits the available locations on smaller vessels like the Destroyer Escort. Candidate No. 4, Co-Scan, is an easily sited, one-unit system, but the stabilized platform is a shipboard installation requirement.

Flexibility - Candidate Nos. 7, 8, and 10 are flexible by virtue of their application. The frequency selection is relatively unrestricted, albeit lower frequencies limit the useable data band width. The antenna siting restrictions are minimal. Multiple approach paths and offsets can be provided. Candidate Nos. 1 and 2 are assigned in location, usage and ship's operating procedures; the flexibility for dedicated RPV applications is limited, albeit conceivable. The remaining candidates are about equal although No. 9 must, by economic considerations alone, be a multiple usage device.

Growth - It is difficult to rate the growth capability. All candidates can be improved to reflect state of the art developments. Accordingly, they are rated equal.

Modularity - Candidate No. 10 is truly modular. If the sensor is not installed, the visual mission can not be conducted. Candidate Nos. 7,

8, and 10 are rated midway in that the landing guidance can be considered the incidental benefit, the remote control function being the primary requirement.

Risk

Technical - Candidate Nos. 1, 2, 3, 4, and 5 are all rated high. They have been designed and placed into service, or will be shortly. The techniques are straightforward; documentation, provisioning and training with Navy manned line air vehicles exists. The Co-Scan and MRAALS systems are not in the military operational service at this time but simple adaptation is probable since they operate in the same manner and with compatible airborne equipment as the AN/SPN-41 system. The remaining candidates recognize some minor technical risk since they have not been specifically designed for the shipboard application; it is believed development effort will be minor because the proposed techniques and hardware are commonplace.

Cost - Candidate Nos. 1, 2, and 3 have all been built and delivered to the Navy; the predicted costs can be very accurately determined with no cost overrun risk, accordingly, they are rated high. Candidate Nos. 4 and 5 are minor extensions of the existing inventory scanning beam system. There is little technical or development risk and the ratings reflect this confidence in expecting a predicted cost to be achieved. The remaining candidates are all new in naval design philosophy and the possibility that they will encounter unforeseen cost risks is higher, hence the lower rating.

Schedule - Candidate Nos. 1, 2, and 3 have all been built and delivered to the Navy; accordingly, the predicted schedules can be very accurately determined with minor slippage risk. Candidate Nos. 4 and 5 are minor extensions of the existing inventory scanning beam system. There is little technical risk involved and the ratings reflect this confidence in accurately predicting a delivery schedule.

The remaining candidates, with the exception of No. 6, Doppler, recognize some development and application risk with comparable ratings. Candidate No. 6 is still in the formative development stage with associated high technical and schedule risk, accounting for the low rating.

Sensitivity to Weighting Values

Inspection of Table 6-6 shows close results for the highest ranking candidates. It is probable that with reassignment of weighting values the results will skew towards other candidates. However, the very large system effectiveness total, computed for Candidate No. 7, will probably not alter the final preferred selection.

6.3.3 RESULTS

Table 6-5 contains a landing aids trades analysis; it is in the form of a weighted rated matrix. An evaluation summary is presented in Table 6-6. The rationale for ratings are contained in the previous section. The evaluators weighting assignments are included, so that if subsequent reviewers desire to alter the assigned weight values, it may be easily accomplished; as for example, to vary the costs in favor of performance or to de-emphasize the importance of multiple vehicle approaches. These factors would skew the results dramatically. Among the leading candidates in this trade study, Multi-lateration appears to offer considerable promise based on the weighting factors assigned. It provides a quasi-universal application to several vessels, close-in guidance, multiple vehicle service and functional duality with the primary command and control data link. A prime attribute of the AN/SPN-42 Automatic Carrier Landing system is its all weather capability. This system should be used for RPV carrier operations but is an unlikely choice for use in other ships.

The conventional scanning beam systems, as a class, all rate low in this analysis, traceable to the single vehicle service. RPVs are considered by TRA to have a requirement for missed approach guidance capability to compensate for the absence of a pilot aboard the RPV. The lack of this capability in the conventional scanning beam systems also contributed to their low evaluation scores. It is understood that the Sea Control Ship contractor has selected the Co-Scan scanning beam landing aid for that application.

It is emphasized that the RPV can utilize any of the candidate systems discussed. In the event the Sea Control Ship mounts the Co-Scan landing aid, the RPV can share this facility as well. However, to this study, it appears that a major operational benefit lies in the exploration of the multilateration system. It can provide the RPV command and control link in addition to the precise navigation required for all-weather landing aboard a ship at sea with its wave induced motions.

TABLE 6-5

LANDING AIDS TRADES ANALYSIS

SYSTEM EFFECTIVENESS	RELATIVE WEIGHT		PRECISION RADAR AN/SPN-42		TRACK RADAR AN-SPG-60		CONVENTIONAL SCANNING BEAM: AN/SPN-41		CONVENTIONAL SCANNING BEAM: CO-SCAN		CONVENTIONAL SCANNING BEAM: MRAALS		DOPPLER SCANNING BEAM		MULTI-LATERATION WITH COMMAND AND CONTROL		INTER-FEROMETRY TECHNIQUES		VEHICLE MOUNTED VISUAL AIDS		RHO-THETA COMMAND AND CONTROL	
		#1		#2		#3		#4		#5		#6		#7		#8		#9		#10		
Range (10mm rain)	3	3	9	10	30	6	18	6	18	6	18	6	18	8	24	8	24	1	3	10	30
Minimum Range (Key Effect)	3	3	9	1	3	10	30	10	30	10	30	8	24	10	30	10	30	10	30	10	30
Position Accuracy	5	10	50	8	40	9	45	9	45	9	45	9	45	10	50	9	45	10	50	9	45
Azimuth Coverage	5	8	40	10	50	6	30	6	30	7	35	6	30	10	50	10	50	8	40	10	50
Elevation Coverage	5	8	40	3	15	8	40	8	40	9	45	8	40	10	50	4	20	8	40	4	20
Vehicle Installation Effects (weight, space, power, etc)	3	8	24	9	27	6	18	6	18	6	18	5	15	10	30	6	18	8	24	10	30
Simplicity of Introducing Ship Motion Compensation to Air Vehicle	6	10	60	1	6	6	36	6	36	6	36	4	24	6	36	3	18	5	30	1	6
Multiple Approach Capability (with ship motion compensation)	5	4	20	3	15	1	5	1	5	1	5	1	5	8	40	1	5	6	30	3	15
Missed Approach Guidance	2	6	12	10	20	1	2	1	2	1	2	1	2	10	20	8	16	1	2	10	20
Approach Path Offset Capability (landing site restrictions)	5	10	50	4	20	2	10	2	10	2	10	2	10	10	50	8	40	1	5	8	40
System Simplicity	3	8	24	10	30	7	21	7	21	7	21	7	21	10	30	6	18	8	24	10	30
System Reliability	3	10	30	10	30	8	24	8	24	8	24	7	24	8	21	8	21	8	24	8	24
Subtotal	48	368		286		279		279		289		255		434		305		302		340	

TABLE 6-5 (Continued)

LANDING AIDS TRADES ANALYSIS

		RELATIVE WEIGHT	PRECISION RADAR AN/SPN-42	TRACK RADAR AN/SPG-60	CONVENTIONAL SCANNING BEAM			DOPPLER SCANNING BEAM	MULTI-LATERATION WITH COMMAND AND CONTROL	INTERFEROMETRY TECHNIQUES	VEHICLE MOUNTED VISUAL AIDS	RHO-THETA COMMAND AND CONTROL
					AN/SPN-41	CO-SCAN	MRAALS					
			#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
COSTS												
RDT&E	8	10 80	8 64	10 80	9 72	9 72	2 16	2 16	2 16	5 40	2 16	
Acquisition	7	1 7	2 14	5 35	8 56	9 63	5 35	10 70	8 56	10 70	10 70	
Logistics	3	10 30	10 30	10 30	1 3	5 15	1 3	1 3	1 3	1 3	1 3	
Training	2	10 20	10 20	10 20	8 16	8 16	6 12	5 10	5 10	5 10	5 10	
Costs Subtotal	20	137	120	165	147	166	66	99	85	123	99	
OPERATIONAL SUFFICIENCY												
Multiple Landings	2	5 10	3 6	1 2	1 2	1 2	1 2	10 20	8 16	8 16	8 16	
Anti-Jam Operations	5	1 5	1 5	1 5	1 5	1 5	1 5	20 50	10 50	10 50	10 50	
Multiple Applications	4	4 16	2 8	4 16	5 20	6 24	1 4	10 40	6 24	4 16	6 24	
Flexibility	3	5 15	5 15	3 9	3 9	3 9	3 9	8 24	8 24	3 9	8 24	
Growth	4	5 20	5 20	5 20	5 20	5 20	5 20	5 20	5 20	5 20	5 20	
Modularity	2	1 2	1 2	1 2	1 2	1 2	1 2	5 10	5 10	10 20	5 10	
Subtotal	20	68	56	54	58	62	42	164	144	131	143	
RISK												
Technical	4	10 40	10 40	10 40	10 40	10 40	5 20	5 20	5 20	5 20	5 20	
Cost	4	10 40	10 40	10 40	8 32	8 32	4 16	4 16	4 16	6 24	5 20	
Schedule	4	10 40	10 40	10 40	8 32	8 32	1 4	6 24	4 16	6 24	6 24	
Subtotal	12	120	120	120	104	104	40	60	52	68	64	
Subtotal This sheet		325	304	339	309	332	148	323	281	322	299	

TABLE 6-6

LANDING AIDS TRADES ANALYSIS SUMMARY

TABLE6-6
LANDING AIDS TRADES ANALYSIS SUMMARY

	RELATIVE WEIGHT	PRECISION RADAR AN/SPN-42	TRACK RADAR AN/SPG-60	CONVENTIONAL SCANNING BEAM AN/SPN-41	CONVENTIONAL SCANNING BEAM CO-SCAN	CONVENTIONAL SCANNING BEAM MRAALS	DOPPLER SCANNING BEAM	MULTI-LATERATION WITH COMMAND AND CONTROL	INTERFEROMETRY TECHNIQUES	VEHICLE MOUNTED VISUAL AIDS	RHO-THETA COMMAND AND CONTROL
		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
System Effectiveness	48	368	286	279	279	289	255	434	305	302	340
Costs	20	137	120	165	147	166	66	99	85	123	99
Operational Sufficiency	20	68	56	54	58	62	42	164	144	131	143
Risk	12	120	120	120	104	104	40	60	52	68	64
Totals	100	693	582	618	588	621	403	757	586	624	646

Accordingly, the multilateration system is recommended for the quasi-universal application to all new vessels having an RPV detachment. It can furnish a combined command and control data link in addition to an all-weather guidance landing aid. The several benefits that can be identified with this technique include:

- The system can perform the dual function of a remote command link and the recovery guidance function.
- The system band width can be selected to provide a video link in addition to the narrow band control link.
- Ship motion compensation can be introduced into the data link which will permit accurate high response control of an incoming RPV.
- The system is self contained; no additional RPV equipment or functions are required for the touchdown maneuver.
- Multiple approach paths and multiple vehicles can be handled simultaneously.
- The system can provide hemispherical coverage with little concern of masking or siting effects.
- The antenna farm consists of from two to four simple omni-antennas.
- The RPV steering functions and commands are determined from a ship-based computer.
- The system can be cooperative with the launch/recovery and maintenance display and control console. The computer for the system should be in the RPV operations area.
- The airborne system weight can be summed with the command control assignment.
- The system can utilize anti-jam techniques and operate in a hostile electronic environment.

It must be recognized that the multiple approach of several aircraft will limit the total enroute strike force due to loading of the data link. However, ten vehicles can simultaneously be serviced by the multilateration

system. The use of a wide band data link for sensor image transmission will be in addition to the narrow band control data link.

Nonetheless, there are conditions like the CVA aircraft carrier installation where the AN/SPN-42 Automatic Carrier Landing System is installed. For these vessels, the utilization of the installed equipments are recommended. Undeniably, the AN/SPN-42 automatic carrier landing system is the best of the straight, conventional landing systems. It is also the most expensive and requires the greatest shipboard space. It obviously should be used if it is installed and available.

For the case where an on-board strike or real-time RECCE visual sensor is employed, the dual function of primary mission and recovery can be shared by the same sensor. The selection of a visual sensor is not practical for the landing maneuver on a flat deck because the operator visual disassociation can be severe. However, in the case of a vertical recovery net with a collision (intercept) course, the visual or IR sensor is a light-weight method which may be practical.

6.4 RPV COMMAND AND CONTROL MONITOR DISPLAY

The requirements for operator display during the launch, recovery, and mission of shipbased RPV's have been analyzed utilizing similarly directed manned aircraft studies and experience modified by a broad range of TRA drone control experience.

The display concept for the critical periods between RPV minimum control speed and stall speed must necessarily encompass a wide range of visibility conditions -- clear day through zero-zero-night. The basic intent of the override monitor control function is for standby or backup, in the event the RPV computer-directed approach, landing or launch maneuver deviates from the desired path. These deviations can occur from a multitude of sources, such as:

- Wind shear/turbulance
- Ship landing platform yaw
- Ship landing platform roll
- Ship landing platform pitch
- Ship landing platform heave

- Ship landing platform sway
- Ship landing platform surge
- RPV receiver masking
- Landaid transmitter masking
- Landingaid noise contribution
- Landaid misalignment
- RPV guidance control malfunction
- RPV airborne receiver malfunction
- RPV airborne computer malfunction
- RPV airborne engine control loss
- RPV aerodynamic control loss

The most critical period of shipboard operations of RPVs is during the landing maneuver. Accordingly, the monitor/display requirements for this period are the most comprehensive and therefore evaluated separately.

Aircraft performance data required for this critical period include:

Airspeed	Roll Attitude
Altitude	Pitch Attitude
Altitude Rate	Heading
Engine RPM	RPV Spatial Position (Track)
Localizer Deviation	Glide Slope Deviation
Localizer Status	Glide Slope Status

In addition, the status of selected RPV functions that must be known. These include:

Computer Status	Spoiler Position
Auto-Landing Function	Stall Warning
Status	Landing Gear Position
Landing Transition Status	Flap Position

This listing provides a minimum of monitor information required to provide override control. If the display does not provide this information in a manner suitable for rapid, manual response then it is not adequate for the monitoring function. This is not intended to imply that a highly refined automatic system would not be preferred over a display station directed by a human operator, but that for manual backup mode operation, human intervention is necessary, and suitable flight performance monitoring equipment is mandatory.

Simple interface to the navigational landing aid with either manual or autoflight control is essential to a horizontal situation display; the system should also provide for go-around guidance. The missed approach procedure would entail redirection of the RPV by the controller and subsequent revectoring to intercept the approach pattern.

A critical aspect of RPV automatic control is the override command characteristics that can be introduced into the vehicle attitude correction loop. Typically, in manned vehicle automatic landings, the pilot onboard can intervene and provide a "manual override" based upon his observations and "feel" of the aircraft. This condition cannot be applied in the case of the RPV. In an approach and landing of the RPV, the vehicle must remain under the control authorities programmed for the particular vehicle, and the desired correction command. The control override command is introduced into the autoflight control system such that the vehicle cannot exceed the authorized control law.

Typically, the conventional vehicle operating parameters are:

- Altitude, controlled by the variation of thrust and/or lift;
- Airspeed, controlled by pitch attitude;
- Thrust, controlled by the variation of engine RPM;
- Turns, controlled by variation of the directional aerodynamic surfaces or directional thrust.

For vertical lift vehicles, like the tailsitter VTOL and deflected thrust RPVs, the operating parameters are similar, except that vertical rate is an additional separate function.

Therefore, a tabular listing will show:

- Altitude, controlled by variation in vertical rate;

- Horizontal (longitudinal) motion controlled by variation in jet thrust directional and velocity;

- Horizontal (lateral) motion controlled by reaction jet controls;

- Vehicle pitch attitude, controlled by reaction jet controls.

The control commands to the vehicle cannot enter into the vehicle flight aerodynamic loops without first being processed by either the on-board vehicle flight safety module or the primary mission computer. This safe-guard procedure is also employed in the case of the external navigational landing aid guidance signals.

Accordingly, the vehicle will never exceed the allowable excursions of the particular planned maneuver.

This feature is schematically illustrated in Figure 6-9. All air vehicle commands are processed through the air vehicle processor. Up-linked command functions, such as the landing guidance and ship motion prediction, are integrated into the flight control loop. On this diagram, the landing aid receiver is shown as a separate entity to simplify the presentation. In the preferred system design, the data link and navigation receivers are used in conjunction with the vehicle processor to determine the spatial position during recovery. In the event a conventional scanning beam system is employed on the vessel, then a navigation landing aid receiver, compatible with that system will be required in the RPV.

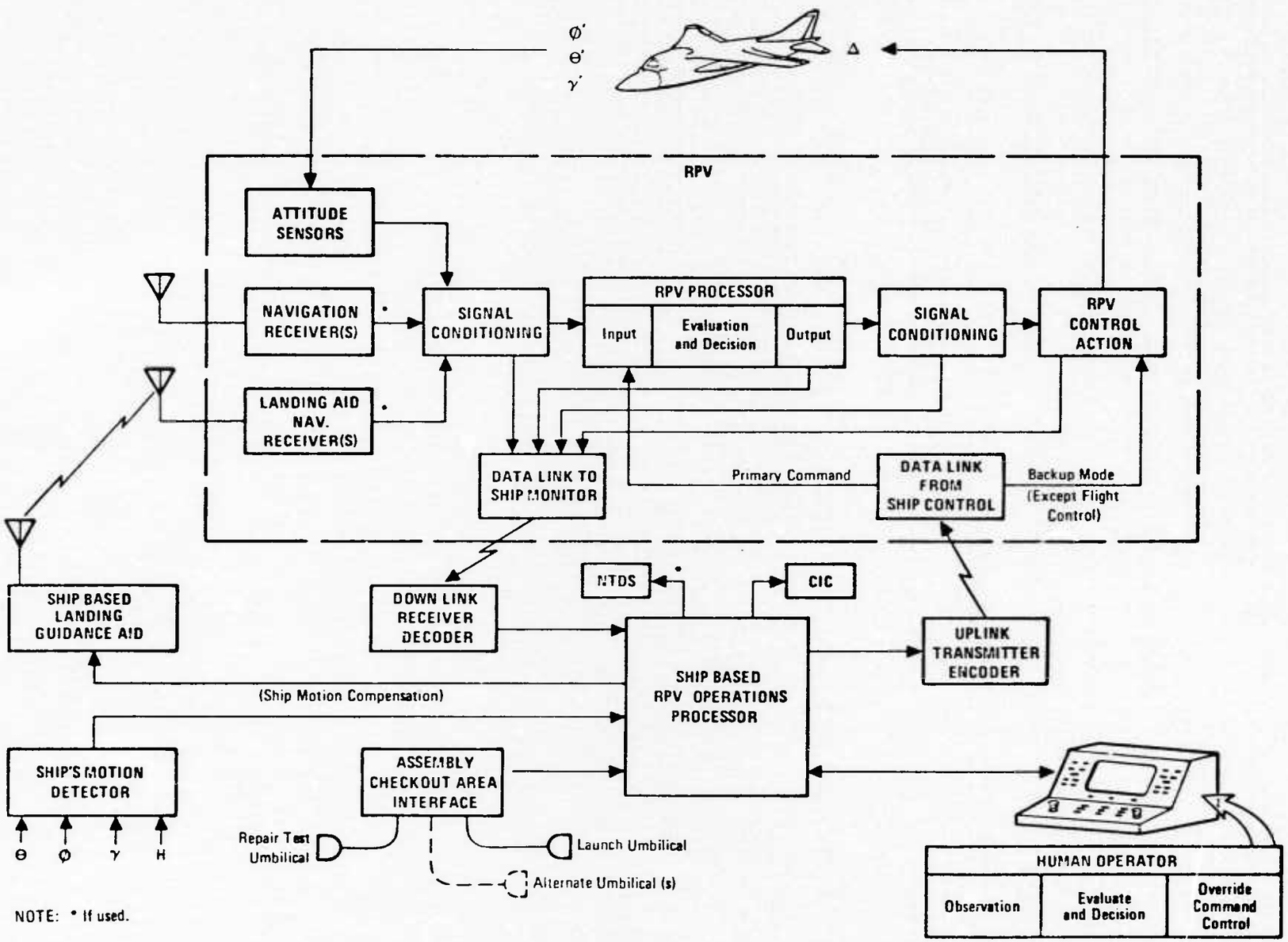


Figure 6-9. RPV Control Center Interface, Functional Diagram

7.0 MAINTENANCE AND OPERATIONS CONCEPT STUDIES

7.1 INTRODUCTION

The introduction of tactical remotely-piloted vehicles (RPVs) to shipboard use can provide the Navy with a versatile new resource for accomplishing its mission. Whether or not RPV systems will be viable candidates for shipboard use depends in part on the practicality of their operations and maintenance concepts in the open sea shipboard environment. This practicality will be attained by desiging the RPV systems to be compatible with the shipboard physical environment and with the other systems used on the ships. These requirements imply that the RPV systems must be designed to impose a minimum of inconvenience or constraint on the defense, offense and ship systems already existing on the ship. RPV system support should be carried on within existing manned aircraft supply and personnel training programs.

7.2 RPV/SHIP INTERFACE

The maintenance and operational environments to be encountered by RPVs aboard ship consist of highly specialized, well-developed routines to carry out the ship's mission under demanding conditions with a minimum of resources. The prime requisites for RPV compatibility in the at-sea shipboard environment are establishment of a maintenance concept broadly within the guidelines of the Naval Aviation Maintenance Program (NAMP), and formulation of operations procedures within the framework of the Naval Air Training and Operating Procedures Standarization (NATOPS) program.

7.2.1 IMPACT OF NAMP COMPATIBILITY

On existing Navy RPVs which are used for target or experimental missions, organizational and intermediate maintenance are largely combined at the operating level. This combined maintenance method provides a flexibility in scheduling the use of resources that facilitates maintenance in the unique target operational environment, which is characterized by stringent cost constraints, a diversity of vehicle configurations on successive flights, and non-critical long lead time flight scheduling. This environment is different from the environment that will be encountered by the tactical mission RPV operated from a shipboard base.

A second major difference is that the tactical mission RPV should be designed for mission versatility by the use of modularized mission kits which are interchangeable at the organizational level. With mission peculiar equipment modularized into quickly replaceable packages which can be calibrated off-vehicle and installed without affecting vehicle balance or operation, an RPV can be recycled to a different mission within a time delay acceptable to tactical mission operations.

Another consideration is that flight scheduling will be critical when tactical mission RPVs are flown in support of manned aircraft whose success is dependent on successful RPV missions. In this instance, the RPV system must operate reliably with a high probability of success at a point in time. It must therefore have a higher mission reliability and availability than target systems.

7.2.2 IMPACT OF NATOPS COMPATIBILITY

Immediate implication of the NATOPS compatibility requirement is that the tactical mission RPV must operate safely on a routine basis within the manned aircraft environment of the CVA/CVS, SCS and DE airspace control areas. It must therefore be a highly reliable system in which vehicle operating status can be determined at the ship's Air Traffic Control Center on demand during flight to maintain positive control over the RPV operation.

The dissimilar characteristics of Navy target and tactical shipboard RPV operations described above have been summarized in Table 7-1.

TABLE 7-1

OPERATIONS CHARACTERISTICS SUMMARY

CHARAC-TERISTIC	TARGET DRONES	SHIPBOARD RPVS
Availability	Long-lead scheduling, test environment, delays not critical.	No lead schedules. Delays critical. Success and safety of manned operations may depend on timeliness of RPV flight.
Cost	Emphasis on economy at acceptable performance.	Emphasis on performance at acceptable cost.
Vehicle Configuration	Diverse mission configurations with intermediate level equipment changes on successive flights required for special missions.	Standardized mission configurations limited to organizational level changes on successive flights.
Maintenance Concept	Combined organizational and intermediate maintenance during normal flight cycle with high incidence of unscheduled maintenance.	Optimize maintenance plan to accommodate all ships that will use RPVs. Low incidence of unscheduled maintenance.
Mission Reliability	Low reliability acceptable within cost constraints.	Must be highly reliable with repeatable high quality.
Safety	Remote operation in fair weather airspace,	Operate within the manned aircraft and ship environment in all weather.

TABLE 7-1 (Continued)

OPERATIONS CHARACTERISTICS SUMMARY

CHARAC-TERISTIC	TARGET DRONES	SHIPBOARD RPVS
Operations Sequence	Cumbersom integrated repair and servicing sequence with in-depth between flight main.	Streamlined between flight servicing with repair scheduled on an on-condition and per-missive environment basis.
Operational Life	Short life, few use cycles.	Long life, many use cycles.

8.0 EVALUATION METHODOLOGY

8.1 INTRODUCTION

Studies were conducted to determine the evaluation criteria to be used in selecting the RPV configurations and the launch and recovery methods which offer the highest potential for practical shipboard RPV operations. The methods of approach used to establish these criteria and the results of the evaluation study are presented in this section.

The evaluation of the launch and recovery techniques and of the ship interface requirements involves a large number of considerations, and an in-depth quantitative analysis and rating of each of these considerations is not possible within the budget limitations of the study. This leaves two alternative methods for conducting the evalaution study.

a. A quantitative analysis of a few factors.

b. A qualitative evaluation of all the factors that comprise the evaluation criteria.

The latter approach was taken since it was felt that this provides a broader insight into the launch and recovery problems than does the first approach which considers only a few of the evaluation criteria.

The scope of the evaluation includes two mission profiles, six candidate RPVs, and three ship types. Five launch and eight recovery techniques were investigated. In the case of the VTOL configurations, the basic launch and recovery techniques are an integral part of the vehicle concept.

8.2 METHODOLOGY

The evaluation methodology is essentially one that considers the RPV requirements for launch and recovery operations and compares them with the ship's accommodations and utilization imposed with safety implications, technical risks, and relative costs. For each of the many factors related to the above classes of items, a qualitative judgement scale was assigned signifying the degree of impact for each case. An evaluation matrix was then made for each of the ship types considered

in the study listing the items evaluated and indicating the qualitative rating assigned to each of those items.

It should be understood that the qualitative evaluation matrices serve only as a bookkeeping method for highlighting the major strengths and weaknesses of the system under evaluation and were generated primarily to aid the evaluator by providing visibility into the many factors involved. The evaluator must still use his experience and judgement to, in effect, weight the qualitative data provided, and to thus arrive at conclusions which permit the selection of the most promising launch and recovery systems.

8.3 RPV DATA

Eight candidate RPVs are used in the analysis to provide the intended variation in the launch and recovery operations study. A summary of some of the vehicle features and deck space requirements are tabulated in Table 8-1. Only one RPV is shown for the 14-hour long endurance mission which operates with landing gear in the conventional take-off and landing mode. Its large size and weight prohibits its operation from destroyers and makes it highly questionable with regard to operation from the sea control ships. Hence, it is only considered for aircraft carrier operation in this evaluation. The other seven configurations are for the low altitude penetration mission.

The carrier is well equipped to handle catapult launches and conventional hook and arresting gear landings, and the more complex slow rate-of-closure and VTOL concepts represent substantial increases in vehicle development and operational costs, for these reasons the SLOROC and VTOL concepts were elimintaed as candidates for the carrier based low altitude penetrator. However, evaluation of the SLOROC and VTOL concepts were made with respect to the sea control ship and the destroyer, and most of the conclusions reached in these studies apply to carrier operations with these RPVs.

The deck space requirements imposed by the RPVs are shown in Table 8-2 for both flight deck spot and hangar deck spot. The criterion chosen for the flight deck spot is a two-foot clearance around the maximum dimensions of the air vehicle. For hangar deck spot, the clearance is increased to four-feet to allow additional space for support equipment (4 feet on each side plus the space within the contour). These criteria provide a convenient means to estimate the number of RPVs the ship can carry or the number of RPVs that can replace a present aircraft

TABLE 8-1

SUMMARY OF RPV DATA

	LONG ENDURANCE	LOW ALTITUDE PENETRATOR				
	Conventional Configuration	Conventional	SLOROC*	Deflected Jet	Rotorwing	Tail Sitter
Characteristics						
Gross Weight - Pounds	7,890	2,252	2,729	2,992	3,088	2,881
Mission Payload - Pounds	750	150	150	150	150	150
Size: Length - Feet	31.7	19.83	21.17	22.46	25.0	18.5
Span - Feet	44.5 (27.6 folded)	10.95	12.5 (8.0 folded)	12.25	13.5 (15.0 dia)	10.67
Height - Feet	7.6	5.75	6.29	6.67	5.33	18.00 (12.33 folded)
Fuel Weight - Pounds	3,870	690	990	890	1,073	892
Approach Speed - Kts	62	97	60	--------	--------	---------
Touch-Down Speed - Kts	62	97	60	~0	~0	~0
Deck Space Requirements						
Flight Deck Spot Area - Length X Width - Feet**	36x49	15x24	27x25	16x26.5	19x29	12x15
Hangar Deck Spot Area - Length X Width - Feet	40x53	28x19	29x21	30x22	33x22	19x16 13 folded
Height Clearance - Feet	9	7	7	8	7	12
Door/Elevator Clearance - Feet	46 (29 folded)	12	13	13	16	

*Slow Rate of Closure

**Jet Blast and Launch Run Clearance Not Included

TABLE 8-2
SUMMARY OF SHIP DATA

	AIRCRAFT CARRIER	SEA CONTROL SHIP	DESTROYER
Class	Kitty Hawk(CVA-63)	SCS	Knox (DE-1052)
Characteristics			
Displacement - Tons Std.	60,100	14,100	3,011
Length - Feet	1062.5	630	438
Beam - Feet	130	103	46.75
Speed - Kts	35	24	27
Space Available			
Flight Deck Area - $\frac{\text{Length - Feet}}{\text{Width - Feet}}$	1062/249	548/105	25-32/54
Hangar Deck Area - $\frac{\text{Length - Feet}}{\text{Width - Feet}}$	700/95	288/50	27/34
Elevator or Door Width - Feet	68/52	35 x 49.3	17
Clearance Height - Feet	25	20	13
Catapults	4	0	0
Arresting Gear	Yes	No	No
Personnel Accommodation	2,150 (air grp.)	325 (air grp.)	17 (lamps)

aboard. The height clearances, door or elevator, are to assure clear passage for movement about the ship.

8.4 SHIP DATA

Along with the RPV data, ship data must be included to estimate ship compatibility and utilization. A summary of ship data is shown in Table 8-2. Besides the overall physical ship characteristics, personnel accomodations and availability of catapults and arresting gear are also included to facilitate estimating the judgement factors for evaluation.

Not all ships are amendable to all methods of launch and recovery. For instance, those without catapults and arresting gear would be severely penalized in cost and deck space for special installations to accommodate conventional RPVs. Also, the use of VTOL RPVs on aircraft carriers disregards the carrier's elaborate and expensive launch and recovery support equipment. If the vehicle penalty to accomplish VTOL is accepted, the evaluation of VTOL on aircraft carriers will add little to this study over what is accomplished in the study of VTOL operations on the sea control ship and the destroyer. Table 8-3 shows the launch and recovery matrix for missions, air vehicles, and ships considered in this study.

Table 8-4 lists the factors that were assigned qualitative ratings in the evaluation process. Summaries of these evaluations and the conclusions drawn from these data are presented in the appropriate ship study section, i.e., Paragraph 9.5 for the carrier, Paragraph 10.5 for the sea control ship and Paragraph 11.5 for the destroyer.

TABLE 8-3

AIR VEHICLE, SHIP, MISSION, LAUNCH AND RECOVERY MATRIX

	DESTROYER	SEA CONTROL SHIP	AIRCRAFT CARRIER
Low Altitude Penetrator Mission Air Vehicle Type			
Conventional		RATO/Arrest. Gear	Cata./Arrest.Gear
SLOROC	RATO/Net	RATO/Arrest. Gear	
SLOROC	RATO/Aerial Track		
Vectored Thrust	VTOL	VTOL	
Rotor/Wing	VTOL	VTOL	
Tail Sitter	VTOL	VTOL	
Long Endurance Mission			
Conventional			Cata./Arrest.Gear

TABLE 8-4
EVALUATION PARAMETERS

SHIP CONSTRAINTS

Ship Weight and Balance
Ship Maneuverability
Ship Motion due to Sea State

SHIP/RPV COMPATIBILITY

No. of Equiv. RPV's per manned aircraft
Flight Deck Spot
Hangar Deck Spot
Flight Deck Space
Hangar Deck Space
Storage Space
Personnel Space
Ship Command and Control Systems
Launch Systems
Recovery Systems
Maintenance Methods
RPV Test and Check-out
Handling Equipment
Ship Power Outlets
Ship Fuel Outlets

COMPATIBILITY WITH SHIP WEAPONS SYSTEM

Manned Aircraft
Other Weapons Systems (Guns, Missiles, etc.)

TECHNICAL RISKS

Air Vehicle Development
Launch Systems Development
Recovery Systems Development
Command and Control Systems Development

SAFETY

Deck Handling
Launch Operation
Recovery Operation
Jet Blast

COST

Air Vehicle Relative Costs
(100 Quantity, Less Payload)
Ship Modification Costs

9.0 AIRCRAFT CARRIER STUDIES

9.1 AIRCRAFT CARRIER OPERATIONS SUPPORT CONCEPTS

The aircraft carrier (CVA) has two areas that are used for handling/operations of aircraft: the flight deck and the hangar deck. The flight deck is used for the flight support tasks of launching, flying, recovering and servicing aircraft. The hangar deck is used for storage of flight ready aircraft when the flight deck is full, and for repair and periodic maintenance of aircraft. Inter-deck transport and intra-deck handling of aircraft must be controlled due to space, support resource and ship dynamics limitations.

These factors indicate that in the most desirable integration of the RPV system into the CVA environment, the RPV flight support functions would all be capable of being carried out on the flight deck while the repair and periodic maintenance functions would be carried out on the hangar deck (Table 9-1). In this concept, RPVs would not have to be moved to the hangar deck after flight just to be prepared for the next flight, but need only be struck below when repair is required. The major implication for RPV design is that all between-flight turnaround support of serviceable RPVs (i.e., RPVs which have no known malfunctioning equipment) must be capable of being accomplished in the unprotected flight deck environment.

9.1.1 RPV TURNAROUND

9.1.1.1 Power-On Check Functions

The operational readiness/prelaunch check functions require electrical power on the RPV through a hardwire link from a ship board mounted RPV control system. This RPV control system can be a fixed installation on-board the CVA consisting of a central RPV control station interconnected by hardwire link to a number of vehicle tiedown facilities. As shown in Figure 9-1, the RPV control center is located in a controlled environment room below deck and is connected to three types of vehicle tiedown facilities through trunk lines: check and prelaunch spots located on the flight deck, and RPV systems test facilites located on the hangar deck. The check spots are used for operational readiness checks of "up" RPVs. The prelaunch spots are used to initialize RPVs for launch. The systems test facilities are used for below deck periodic and corrective

TABLE 9-1
RPV FUNCTIONAL ENVIRONMENT

FUNCTION	RPV LOCATION	TASKS	AGE REQUIREMENTS
Refuel	Flight Deck	Refuel Replenish Oil	JP-5 Supply, Oil Supply Flight Deck Tie-Down
Service Mission Equipment	Flight Deck	Configure PME Replenish Flight Expendables	Flight Deck Tie-Down
Launch	Flight Deck	Initialize Systems Start Engine Launch	Electrical Power, Start Power, Holdback, Remote Control Link, RPV Control System
Flight	In-Flight	Operate RPV Operate PME	Remote Control Link
Recover	Flight Deck	Recover RPV Shut Down Systems Shut Down Engine	Remote Control Link Landing Cable
Conduct Minor Maintenance	Flight Deck	Replace Defective WRA's Perform ORR on Replaced WRA's	Flight Deck Tie-Down RPV Control System
Maintenance Cycle	Hangar Deck	Intermediate Maintenance Organizational Inspection and Repair HRA and IPRA Repair	Hangar Deck Tie-Down
	Flight Deck	Engine Run	RPV Control System Holdback

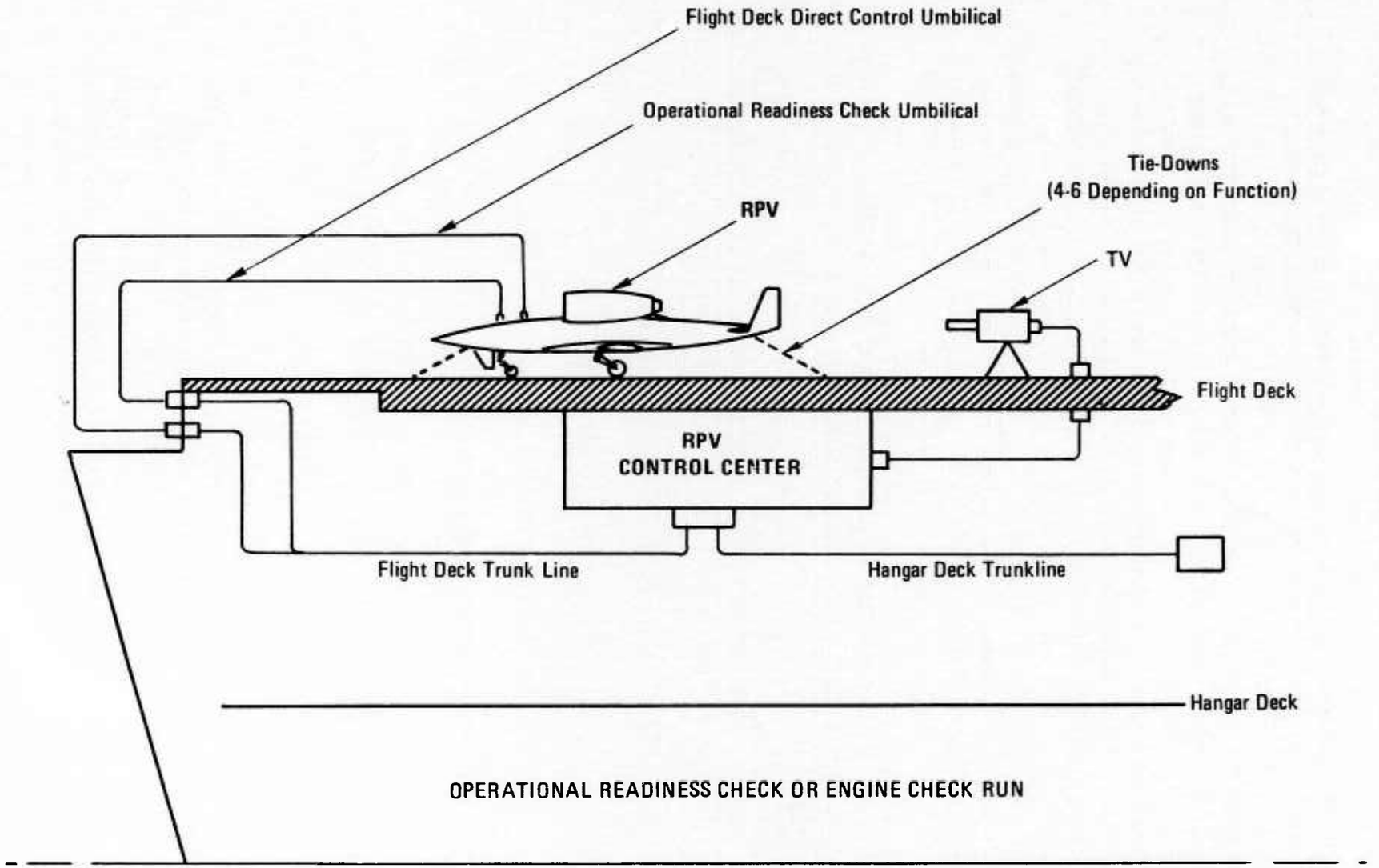


Figure 9-1. Block Diagram Carrier Flight Deck Check Spot

maintenance testing. The control center consists of a computer aided test, checkout and flight programming system capable of being connected to multiple RPVs simultaneously through hardwire links. The central computer in the control station is used to synthesize test stimuli and measure test responses to limit the amount of test equipment required at the RPV check and test spots. The RPV is secured at the check and test spots with aircraft tie-down deck fittings. The operational readiness check spots on the flight deck (Figure 9-1) are equipped with electrical cabling interface, but no test equipment. The systems test facilities on the hangar deck are equipped with electrical cabling interface, hydraulics/pneumatics tester, altitude/air speed pressures simulator, and other RPV test equipment. Communications between the control station operators and the vehicle tie-down facilities handlers is provided via intercom and closed circuit television.

For test and launch of the RPV, this control station is connected to the RPV through hardwire umbilicals. During flight the control station is connected to the RPV via an rf link. The RPV control center is thus used for control of:

a. Operational readiness check of RPVs on the flight deck prior to flight.

b. Initialization of RPV systems for launch.

c. Test of RPV systems following repair.

d. Periodic inspection test for preventive maintenance.

e. Flight deck check run of RPV engines.

f. Remote control of the RPV via rf link after the hardwire umbilical cable has been disconnected for launch, flight and recovery.

9.1.1.2 Servicing

The servicing functions do not require electrical power on the RPV. They do require an RPV servicing station to be located on the carrier flight deck. The servicing station will consist of RPV tie-down spots which are provided with access to flight and mission consumables servicing facilities and minor maintenance. The fuel and oil service interface points on the RPV must be designed for compatibility with the existing CVA facilities. Mission consumables include fluids for RPV air conditioning systems,

pressurized gases for prime mission equipment compartment integrity and moisture purge systems. Mission consumables could be provided from a mobile service cart specifically designed for RPV service or, the fluids/gasses could be provided from fixed servicing facilities colocated with existing aircraft servicing facilities aboard the carrier. Use of fixed facilities will preclude any requirement for mobile servicing support equipment to be deployed on the flight deck. Minor maintenance support will be provided from standard tool and spares transport carts.

9.1.2 MAINTENANCE CYCLE, CVA

Facilities available on the CVA hangar deck are sufficient to support most organizational and intermediate level maintenance of RPVs.

Organizational maintenance will consist of RPV peculiar preventive and corrective maintenance that can be accomplished on-vehicle using hand tools and minimum skills. RPV on-vehicle test using the central RPV control station would also be an organizational maintenance function. During testing, the central control station would be operated by a highly skilled RPV systems analyst. The analyst would conduct the test and would be assisted by a technician on-site at the RPV test spot. The control station equipment can be RPV squadron asset equipment which is installed in the CVA during deployment preparations. CVA provided facilities for the control station must include space and power for the control station and test spot facilities and connecting cable runs.

Intermediate maintenance consists of general on-vehicle aircraft preventive and corrective maintenance functions and off-vehicle component repair and bench test. The RPV squadron will provide personnel augmentation to the resident CVA aircraft maintenance department to support the increase of task. Intermediate maintenance support equipment will be CVA assets and should include structural, mechanical, engine, electrical and avionic repair, inspection and test equipment which is common to manned aircraft. Avionics bench test can be accomplished on a standard VAST concept facility equipped with unique RPV component test interfaces.

The RPV is removed from the operations cycle and placed in the maintenance cycle during maintenance for administrative purposes.

9.1.3 RPV HANDLING

The movement of RPVs aboard ship may be carried out under difficult and hazardous conditions. The wind over the deck and ship movement will impart varying forces to the RPV and these must be considered as potentially hazardous to an unsecured RPV. RPV handling procedures must therefore be designed to reduce the possibility of equipment damage or personnel injury as a result of ship movement or equipment operation. Whenever they are not being moved, RPVs should be tied down to the ship structure as with other aircraft. For respotting, the RPV should be connected to a tow vehicle with a rigid towbar prior to removal of tie-downs, and tied down in the new location prior to disconnection of the towbar. During launch and recovery, RPV movement relative to the ship must be coordinated with ship pitch, roll and heave.

Although RPV operations sequences differ from manned aircraft sequences the actual tasks are similar, and no special RPV related skills are required for RPV handling on the flight deck. Existing flight deck crews can therefore handle RPV operations. All RPV tasks requiring special skills will be accomplished prior to or after the handling sequences to minimize the impact of RPV operations on the carrier flight deck operational environment. Thus, RPV related skills required on the flight deck during RPV operations should be limited to an "RPV captain" whose function will parallel that of a plane captain and pilot during aircraft handling. The RPV captain will be assigned from the RPV squadron and will be responsible for the conditions of the RPV during the operations sequence.

During respotting, the RPV captain will assume responsibility of the RPV at its parked location prior to respot. He removes all securing equipment except for the required three tie-downs and wheel chocks. The RPV captain then transfers control of the RPV over to a plane director and his flight deck crew for the respot task. He will then accompany the RPV as it is moved to its new location by the flight deck crew. After the flight deck crew has secured the RPV at its new location, the RPV captain would again assume control of the RPV from the plane director. This procedure would be followed whenever an RPV is moved.

9.1.4 LAUNCH OPERATIONS

In support of RPV operations, it will be the function of the carrier Air Department to supervise and conduct the launching and recovery of RPVs and to control the conduct of airborne operations. The Air Department should also provide the logistic support and facilities for the maintenance and servicing of RPV s in order that supported RPV squadrons can

effectively accomplish their assigned mission. This assignment of responsibility puts the control and integration of RPV operation activity within the carrier assigned department while the responsibility for the maintenance and operation of RPVs is placed in the hands of the embarked RPV squadrons. Within this framework, RPV operations can be implemented aboard carriers using standard carrier aircraft support procedures.

The carrier Air Operations Officer will define the RPV mission requirements and prepare a daily air plan listing pertinent flight planning data. The embarked RPV squadron will then prepare the required number of RPVs for flight. All flight ready (up) RPVs will normally be maintained in a fully fueled state for safety and readiness. On receipt of the air plan, the flight designated RPVs will be given final mission-peculiar preparation, including removal of storage covers, operational readiness check, loading of mission consumables and removal of storage safety tie-downs.

As launch time approaches, the designated RPVs will be respotted to prelaunch positions by the flight deck crews using the previously noted procedures. The prelaunch position is defined as an interim transit position between flight deck storage and launch. At the prelaunch position, the RPV is tied down with a minimum of tie-downs to await its turn for launch. Thus, the prelaunch spots are planned by the aircraft handling officer to permit the most efficient "feed" of RPVs to the launch positions when Flight Quarters for RPV operations is announced.

On the direction of the launch control officer, the RPV is moved into the launch position to start the launch sequence. The launch position is defined as the location on the flight deck from which the RPV is launched. For deck run launch, it is the location from which the deck run is initiated. For rocket assisted launch, it is the location at which the rocket motor(s) is fired. For catapult launch, it is the battery position of the catapult. This definition is assumed, at least during the initial study of RPV-CVA operations, to obviate the need to address handling of RPV with engine running on the flight deck. Thus, the RPV will be secured into the launch position by the flight deck or catapult crew, where it will be prepared for launch. The launch evolution from respot to launch should take less than three minutes for all CVA launch methods, using the above described procedure.

9.1.4.1 Prelaunch Initialization

Prelaunch initialization is defined as the process by which the RPV onboard systems are setup (or initialized) for launch. This process includes:

a. Applying external power to the RPV from the CVA power sources.

b. Starting the RPV engine.

c. Placing the RPV systems in the launch mode (i.e., setting engine rpm, flight control surface position; system control logic, etc.).

d. Programming navigation and mission control systems.

Verifying remote control and track data links.

f. Switching to internal RPV power sources.

g. Reviewing on-board equipment operation monitors for indication of abort conditions.

Prelaunch initialization will be conducted at high speed by the computer in the RPV Control Station (RPVCS) operating with the computer onboard the RPV according to a predetermined launch countdown program. When all conditions for launch have been satisfactorily established, the RPVCS computer will provide a "launch ready" indication to the shipboard RPV Control Officer (SRCO). When the SRCO is satisfied with the setup of launch conditions, he will enable the launch electrically by providing a signal to the launch control officer on the flight deck. The launch control officer (or catapult officer) will then launch the RPV when flight deck conditions are appropriate for launch.

9.2 LAUNCH SYSTEMS FOR AIRCRAFT CARRIER

Due to the take-off distances required for the conventional RPV configurations considered in this study unassisted deck run takeoffs are not achievable. As discussed in Paragraph 5.3.1, some form of acceleration device must be adopted to achieve safe flight speeds in the limited distance available to launch the RPVs. It is not practical to consider the entire flight deck as being available for launch of RPVs due to the spotting of manned aircraft and other RPVs on deck. Therefore, the methods considered for launching RPVs from the carrier class ship are RATO assisted deck run, zero length RATO launch, and utilization of the existing manned aircraft catapult systems.

9.2.1 RATO ASSISTED DECK RUN

For launch using a RATO assisted deck run the rocket motor(s) would be attached to the RPV prior to moving the RPV to the pre-launch position. The RPV would be secured at the prelaunch position with three tie-down lines. These would secure the RPV while a thrust holdback link, rocket motor ignition umbilical and electrical umbilicals are installed by the flight deck crew. The thrust holdback link would be designed to hold the RPV captive to the deck against the thrust of the RPV engine, the wind over the deck and the motion of the ship. The thrust holdback link is released by an electrical signal from a launch panel operated locally at the prelaunch spot by the deck launch officer. The tie-downs would be manually operated safety devices controlled locally by the plane director, and disconnected after the holdback link and umbilicals are installed. After the RPV is secured into the prelaunch position, the RPV captain, on signal from the deck launch officer would contact the RPV Control Station, and standby for launch initialization. Final prepower-on preparations would include arming of the rocket motor by ordnance personnel. When directed by the Carrier Air Traffic Control Center (CATCC), the SRCO officer would power-up the RPV, initialize on-board RPV systems for launch including starting the RPV engine, and direct the RPV captain to clear the launch area. When all preparations are complete and the engine RPM is adjusted to required launch setting the SRCO would issue a direct control signal to enable the launch and verbally clear the deck launch officer to launch the RPV. The launch officer, checking with the RPV captain on RPV condition and then checking to insure correct deck launch conditions, would launch the RPV using a local launch control panel located at the prelaunch control location. At the moment of launch, the holdback release assembly would be operated by the increase in forward directed force caused by rocket motor thrust.

RATO assisted deck runs could be conducted near and parallel to any of the catapult sites. To insure that the RPVs would not deviate from a safe takeoff path due to RATO misalignment or deviations induced by ship motions, it is recommended that the RPV be mechanically guided during the deck run. This could be accomplished by restraining the RPV to the deck with a retractable arm which engages a deck mounted track along the takeoff path. Once safe flight speed is achieved, the arm would be released from the track and the aircraft would rotate and climb out.

Among the disadvantages of this concept is the modifications to the ship to provide the guide track and the requirement for expendable RATO motors. The RATO motors require special handling and storage and add to the cost of each launch. For launches off the forward catapult area,

the RATO motor exhaust would form a noxious exhaust cloud which would be swept rearward along the length of the flight deck. This smoke cloud could be harmful to flight deck personnel.

9.2.2 ZERO LENGTH RATO LAUNCH

Zero length, or near zero length RATO assisted launch of RPVs from aircraft carriers has already been demonstrated with launches of the Teledyne Ryan Model 147SK from the forward deck of the USS BENNINGTON (CVS20), as well as from the aircraft elevator of the same ship.

RATO launch from carriers would be conducted using mobile launchers which could be used to launch and transport the RPV on deck. The RPV would be loaded onto the launcher in the hangar deck area where overhead lifts are available to handle the RPV. The Basic Low Altitude Configuration with its 44.5 foot wing span and at a takeoff gross weight of nearly 8,000 pounds would present handling problems and require a very large RATO motor. Again the problem of the cost per launch would be increased with expensive, expendable RATO motors required for every launch. Large RATO motors would occupy valuable storage space, would require special handling, and would require additional ground support equipment to load the RATO motor onto the RPV. The special ground support equipment could be a modified bomb trailer if the RATO motor was not exceptionally large. The RATO motors for this type of launch are inherently larger than the RATO motors which would be used to accelerate the RPVs for RATO assisted deck run takeoffs. The mobile launchers could present storage problems if several were required to provide the desired launch rate.

9.2.3 CATAPULT LAUNCH

For a catapult assisted launch, the RPV would be towed into the catapult battery position by the flight deck crew and released to the catapult crew. After the catapult crew had secured the RPV to the catapult and connected the pull-away electrical umbilicals, the catapult officer would direct the RPV captain to initialize the RPV for launch. The RPV captain would then contact the SRCO and work with him to set up the launch. The SRCO initializes the on-board RPV systems, enables launch when the RPV system status is set, and then monitors the system for possible abort conditions. On "launch enable" the RPV captain maintains a visual check on final condition of the RPV and signals the catapult officer "RPV ready for launch" with a hand signal. The catapult officer then launches the RPV.

Early in the study program the members of the study team anticipated difficulties in launching lightweight RPVs using steam catapults designed to launch much larger manned aircraft. However, discussions with Navy personnel at North Island Naval Air Station in San Diego indicated the launch of lightweight RPVs to the required end speed while not exceeding acceptable axial load factors was indeed practical. In fact, as standard procedure prior to manned aircraft launch the catapults are fired with "No Load Shots". This consists of accelerating shuttle and bridle, with a combined weight of about 80 pounds, to an end speed of 120 knots. This procedure is also used to test the bridle arresting gear. To accomplish this acceleration of such a lightweight to the proper end speed, the catapult is set for 35 to 50 psi rather than 300 to 500 psi normally used for launching manned aircraft. This example illustrates the great flexibility of the steam catapult to launch air vehicles with a wide range of gross weights.

With this capability of the steam catapults to be throttled down, the RPVs considered in this study can be catapult launched without modification to the shipboard launch equipment. Manned aircraft launch and RPV launch could therefore be launched in sequence with each other from the same catapult, with the only change being an increase or decrease in steam pressure. It is estimated by Navy personnel familiar with catapult operations that it would require from 3 to 4 minutes to reduce pressure from that pressure required for manned aircraft launch to that required for RPV launch. The reverse process would take an estimated 4 to 5 minutes.

The problem of RPV catapult launch then is reduced to the task of assuring that the RPV is dimensionally compatible with shipboard launch equipment designed for the much larger manned aircraft. This implies that features of the RPV landing gear system will probably be larger than if the RPV were designed strictly for conventional take-off and landing. For example, the nose gear tire size will probably be a larger diameter tire than required from a loads analysis in order to accommodate the size of deck ramps to position the RPV on the catapult. The landing gear must be designed to absorb the energy associated with high sink rates and tires must be sized to roll over the deck pendants during recovery.

Figure 9-2 and Figure 9-3 illustrate the two conventional RPVs in the prelaunch position on the steam catapult.

9.3 RECOVERY ABOARD AIRCRAFT CARRIERS

The large size of the aircraft carrier makes the problem of recovering RPV relatively simple. The three basic types of RPVs, conventional, SLOROC, and VTOL, considered in this study could be accommodated by

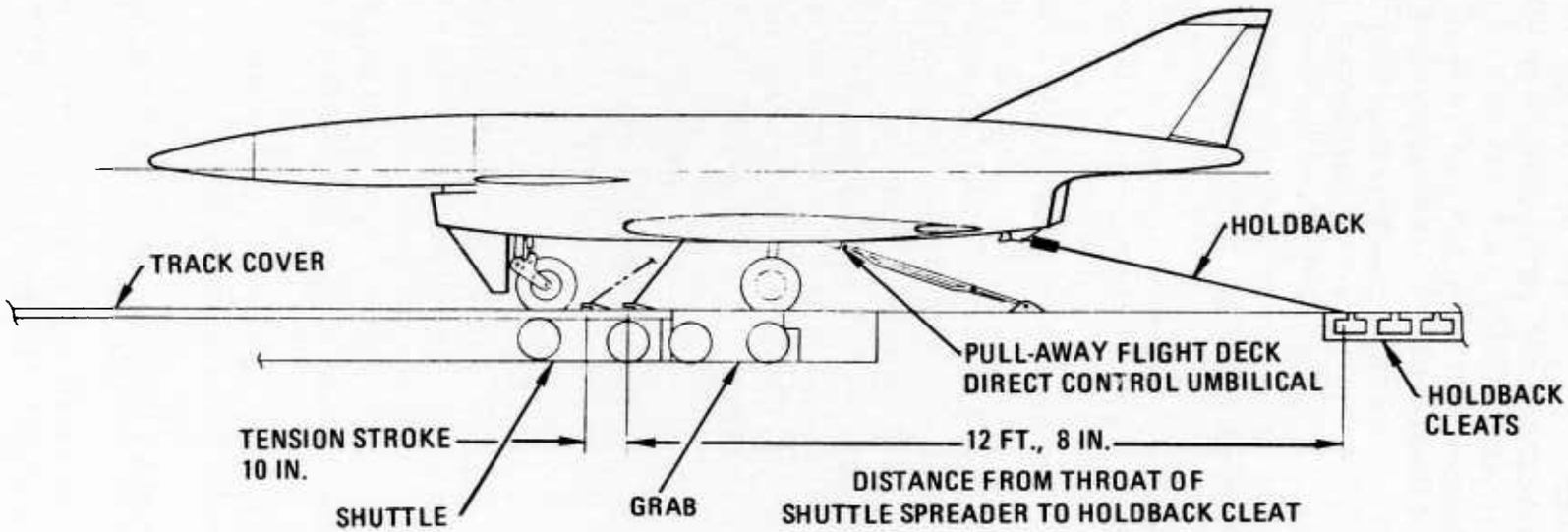


Figure 9-2. Low Altitude Penetrator Configuration Prepared for Catapult Launch

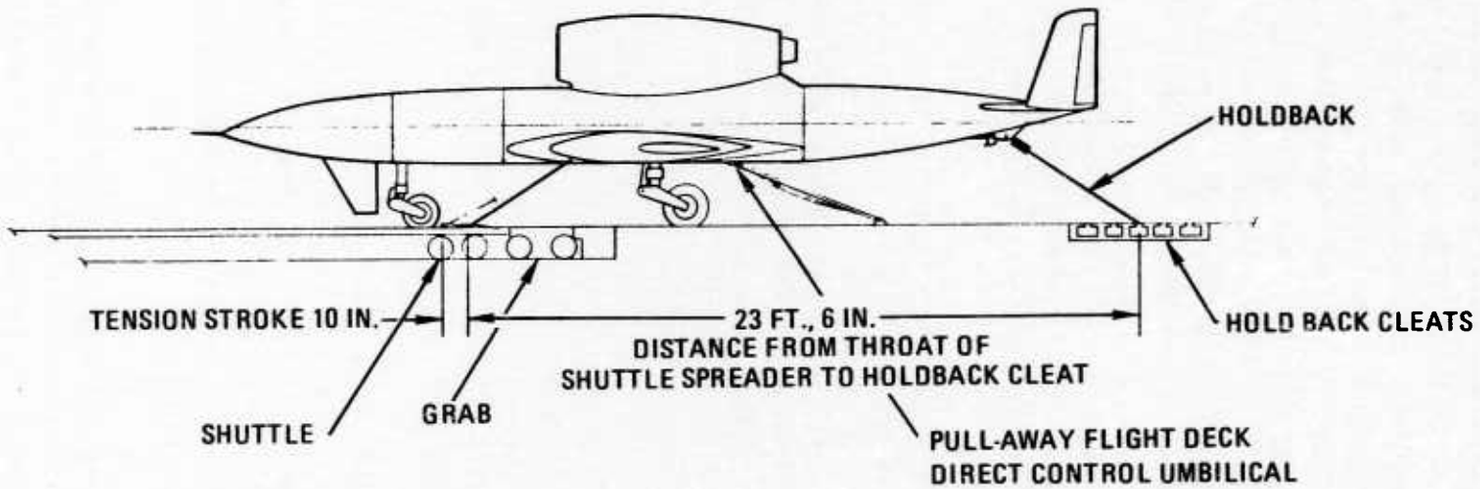


Figure 9-3. Long Endurance Configuration Prepared for Catapult Launch

the carrier. However, for the purposes of this study only the conventional RPVs will be considered for evaluation on aircraft carriers. The reasons for this are that the discussions, problem areas, solutions and decisions for the SLOROC and VTOL RPVs as they relate to the smaller ships can generally be applied to carrier class ships. In addition, since there is a tremendous investment already existing in launch and recovery equipment installed in the aircraft carrier, it would take very unusual circumstance to justify ignoring these facilities and accepting the additional costs associated with SLOROC or VTOL vehicles aboard the carrier. The SLOROC and VTOL concepts are justified only where space limitations or absence of launch and recovery equipment necessitates their application.

Concepts considered for recovery of the conventional RPVs aboard the carrier include the existing arresting engines, the existing emergency barrier, new arresting engines, or new barrier system and an airframe mounted arresting system.

9.3.1 MARK 7 ARRESTING ENGINE

The CVA class aircraft carriers are equipped with four arresting engines with deck pendants spaced approximately 40 feet apart along the center line of the canted deck. Typical of the aircraft recovery equipment is Mark 7 Mod 2 system. A brief description condensed from Reference 7 is included here for reference.

The Mark 7 Mod 2 Aircraft Recovery Equipment consists of arresting and barricade gear. This equipment is provided on an aircraft carrier to arrest incoming aircraft in a shorter landing distance than would normally be required. The majority of the arresting equipment is located below the flight deck.

The deck pendants are single wire rope cables, which span the flight deck from port to starboard and are spaced along the flight deck. They are numbered consecutively (P1, P2, etc.) from the aft end. The deck pendants are held above the flight deck by retractable wire support systems in a tensioned manner so that the incoming aircraft's arresting hook can engage one deck pendant.

The arresting system operates in the following manner. The arresting hook of an incoming aircraft engages a deck pendant. The engagement enables the force of the aircraft's forward motion to be transferred to a purchase cable. The purchase cable is a length of cable reeved to a set of movable and a set of fixed sheaves on the arresting engine and its ends coupled to the ends of a deck pendent. The fixed sheaves are attached to

a ram which forms a cylinder and ram assembly. As the purchase cable is pulled by the aircraft arresting hook on deck pendant engagement, the crosshead moves toward the fixed sheaves, and the fluid is forced, by the ram, from the cylinder. The flow of the moving fluid is metered through the control valve to the accumulator. The metered flow of the fluid through the control valve is a pre-determined factor which controls the pressure in the cylinder and thus provides a restraining force on the cable system, absorbing the force of the engaged aircraft.

At the completion of the arrestment, the aircraft's arresting hook is disengaged from the deck pendant and the deck pendant is returned to its normal ready position. The following is accomplished by operating the retracting valve. When the retracting valve opens the fluid flows from the accumulator (forced by compressed air) to the engine cylinder. The fluid flow to the engine cylinder forces the crosshead away from the fixed sheaves back to "BATTERY" position.

Arrestments using a deck pendant represent a normal aircraft landing. An emergency arrestment is provided when an aircraft cannot make a normal deck pendant arrestment. A barricade installation is provided to facilitate the emergency arrestment.

The Mark 7 Mod 2 Aircraft Recovery Equipment is designed to absorb theoretical maximum energy of 38,373,000 foot-pounds at peak fluid pressure and maximum cable run-out. This is equivalent to stopping a 50,000 pound aircraft at an engaging speed of 120 knots (with its engine thrust taken into account), in a distance of 310 feet. See Table 9-2 for the table of leading particulars of the Mark 7 Mod 2 Recovery Equipment.

The fundamental problem of utilizing the existing arresting equipment is the high inertia of the existing systems. While the system can be adjusted for various weight classes of aircraft, the system is not compatible with air vehicles as lightweight as the RPVs considered in this study. Even the heavier, long endurance RPV at a landing weight of about 5,300 pounds and at a landing speed of 65 knots represents a kinetic energy level of less than 1,000,000 foot-pounds. Compared to the maximum energy absorption capability of the carrier arresting equipment of over 38,000,000 foot-pounds, this RPV would utilize only 2.6 percent of the Mark 7 equipment's capacity. The smaller, low altitude RPV, landing at 95 knots and at a landing weight of 1,700 pounds represents only 1.8 percent of the arresting equipment's capability. The result is that the inertia of the arresting system, even with full open flow control valve, is so high that the RPV would be severely damaged when engaging the deck pendant with a fixed tail hook.

TABLE 9-2
TABLE OF LEADING PARTICULARS
MARK 7 MOD 2 RECOVERY EQUIPMENT

MAXIMUM ENERGY ABSORPTION	
Service Stroke	38,373,000 lb-ft
ENGINE DRIVE SYSTEM CABLES:	
Diameter	1-3/8 inches
Breaking Strength	
Deck Pendant (6 x 30 Flattened Strand)	188,000 lbs.
Purchase Cable (6 x 25 Round Strand)	175,000 lbs.
Reeving Ratio	18 to 1
ARRESTING ENGINE:	
Length	50 feet
Weight	37 tons
Engine Fluid	Hydraulic Fluid
Engine Fluid Capacity (Without Cooler)	320 gallons
Engine Fluid Capacity (With Cooler)	500 gallons
Ram Diameter	18.495 inches
Effective Ram Area	268.8 sq. inches
Length of Maximum Stroke	186.00 inches
Length of Service Stroke	171.00 inches
Grosshead Battery position (Distance from Stop)	1 to 7 inches
Accumulator Operating Medium	Hydraulic Fluid-Air
Maximum Pressure	650 psi
Initial Working Pressure	400 psi
Type of Coolant	Sea Water
Length of Runout	310 feet

9.3.2 MARK 14 ARRESTING ENGINE

A new arresting engine, the Mark 14, is currently under development by the Navy and promises to be more versatile in handling a wide range of aircraft weights.

The Mark 14 arresting engine is a new type of arresting device which is designed to replace the current type on new aircraft carriers. The existing engines are linear hydraulic systems, utilizing a very large piston connected through a series of pulleys and sheaves to the deck pendant as described above. These systems are heavy (approximately 37 tons) and require a great deal of ship volume. The Mark 14 arresting engine is a rotary hydraulic system where the aircraft landing energy is dissipated by a turbine rotating the displacing water. The Mark 14 is considerably more compact and lighter than its predecessors. The Mark 14 is being designed to accommodate minimum aircraft weights of 12,000 to 15,000 pounds. While the Mark 14 may be better than existing arresting engines for lightweight RPVs, the Mark 14 would still have too much inertia to handle the RPVs considered in this study.

9.3.3 EMERGENCY BARRIER

The existing emergency barrier was briefly considered as a recovery system for the RPVs. The following paragraphs, extracted from Reference 7, briefly describe the current barrier system.

The barricade installation provides for an emergency arrestment of an aircraft when a normal deck pendant arrestment cannot be made. During a barricade arrestment, the barricade webbing is engaged by the wings of the incoming aircraft. The tension created by the engagement breaks the release straps, which connect the webbing loops to the release assembly. The progressive failure of multiple straps produces a lower release load in the tensioning pendants and improves the barricade arrestment. The energy is then transmitted from the barricade webbing through the purchase cable to the arresting engine. A barricade installation is shown in Figure 9-4 reproduced from Reference 7.

The barricade installation is normally in a stowed condition and rigged only when its use is required. To rig a barricade, barricade triple webbing is removed from stowage, stretched across flight deck between stanchions, and secured to upper and lower tensioning pendants. Extension pendants are secured to purchase cable couplings. Deck ramps are clamped to the flight deck and the lower loading straps are tucked under U-shaped holddowns.

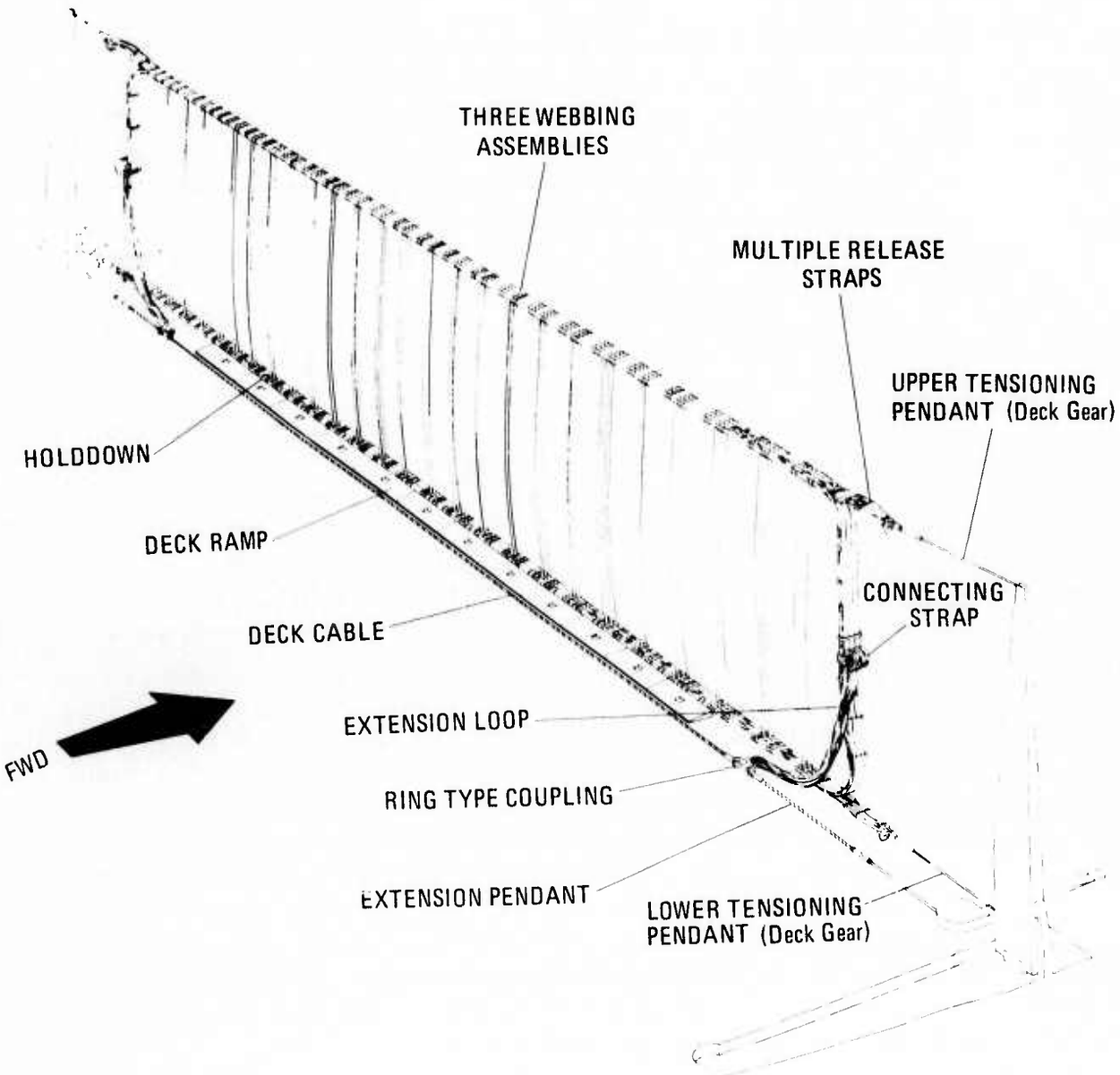


Figure 9-4. Barricade Installation

Barricade stanchions are raised to a vertical position by operation of controls at the deck-edge control station and by operation of barricade hydraulic control installation. The barricade triple webbing is centered and tensioned with the stanchion and deck winches to a height of 20 feet, measured at the center of the webbing. The barricade is now prepared for an emergency arrestment. Following a barricade arrestment, the barricade triple webbing and deck cables are discarded. Stanchions are lowered, by operation of barricade hydraulic control installation, to their stowed position (set in recessed slots in the flight deck).

Figure 9-5, from Reference 7 illustrates the deck activity and crew size to rig the existing barrier equipment.

The existing barricade system, as well as a reduced scale version for RPVs, were eliminated from further consideration as a candidate for aircraft carrier recovery or RPVs for the following reasons:

a. Deployment of the barricade would take too much time and manpower to use on a routine basis for recovery of every RPV on every flight.

b. The RPV would sustain unacceptable damage on each recovery.

c. The barricade webbing would have to be replaced at intervals that would cause serious supply problems.

d. Deployment of the barricade could interfere with manned aircraft operations.

9.3.4 SPECIAL RPV ARRESTING ENGINES INSTALLED ON CARRIER

One solution to the high inertia problem of the existing arresting engines is to design special arresting engines for recovery of RPVs. The special RPV ship-mounted equipment could be scaled down versions of either the Mark 7 linear actuator or the Mark 14 rotary actuator. However, in either case the cost and complexity of adding new systems to the carrier would have a serious impact on the integration of RPVs into carrier operations in an economical manner. In addition, there would be space limitations problems and there would be a deck pendant problem if the two recovery systems (manned aircraft and RPV systems) were colocated on the flight deck. An RPV during landing could accidentally engage the manned aircraft deck pendant and damage the RPV, or a manned aircraft could engage the RPV deck pendant which would be incapable of safely arresting the larger air vehicle. The time required to change deck pendants so

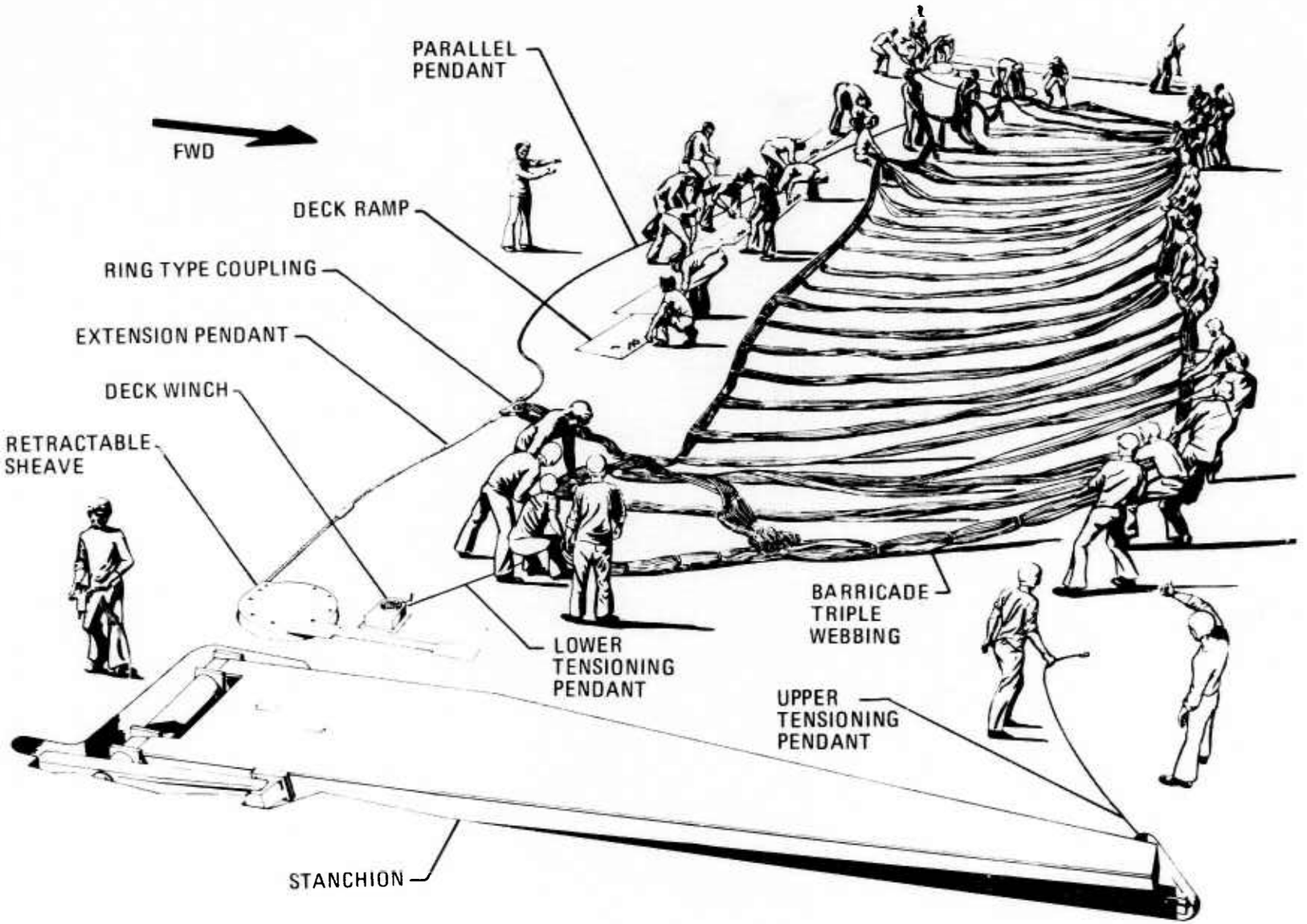


Figure 9-5. Rigging Barricade for Emergency Arrestment

that only RPV deck pendants were deployed during RPV recoveries, and only manned aircraft deck pendants deployed during manned aircraft recovery operations, would seriously degrade the capability of handling emergency recoveries of either RPVs or manned aircraft. Therefore, the parallel recovery system concept was discarded in favor of the proposed solution which follows.

9.3.5 RPV MOUNTED ARRESTING SYSTEM

A solution to the problem of using the existing deck pendants/arresting engine systems for RPVs would be to incorporate the energy absorption device onboard the RPV and to consider the deck pendants as having negligible deflections. This could be accomplished by designing a special arresting hook installation featuring a hook held by a shear pin at the end of a retractable hook support arm. The hook is attached to a steel cable or steel tape stored on a drum equipped with an automatic brake assembly. The basic elements of the system are illustrated in Figure 9-6. As the RPV approaches touchdown the hook support arm is extended and hook engages the deck pendant in exactly the same manner as a manned aircraft. As the deck pendant applies a resisting force, the shear pin is sheared and the hook is released from the RPV and held to the deck pendant by the tension force in the airframe mounted arresting cable or tape as illustrated in Figure 9-7 and Figure 9-8. As the cable or tape is payed out against the braking force of the brake assembly, the RPV is decelerated and brought to rest.

While it is not the intent of this study to include the detail design of such an energy absorbing device, it is however, appropriate to present here basic calculations to confirm the feasibility of such a system. The following discussion is intended to substantiate the basic concept and is based primarily on well established fundamentals of landing gear brake system design and use of conventional materials. The assumptions made are intentionally conservative to be consistent with the concept of a braking device which would have the attributes of repeatability of operation with minimal maintenance.

Assume for the purposes of this discussion that the RPV is landing at its minimum approach speed, but that the ship is stationary. This is conservative, since in normal operations, the ship would be underway and the resulting ship speed and wind over the deck would reduce the relative speed between the RPV and the ship and would therefore reduce the kinetic energy to be dissipated. Further assume that the landing weight will be the zero fuel weight plus an arbitrary fuel reserve of ten percent of total fuel capacity.

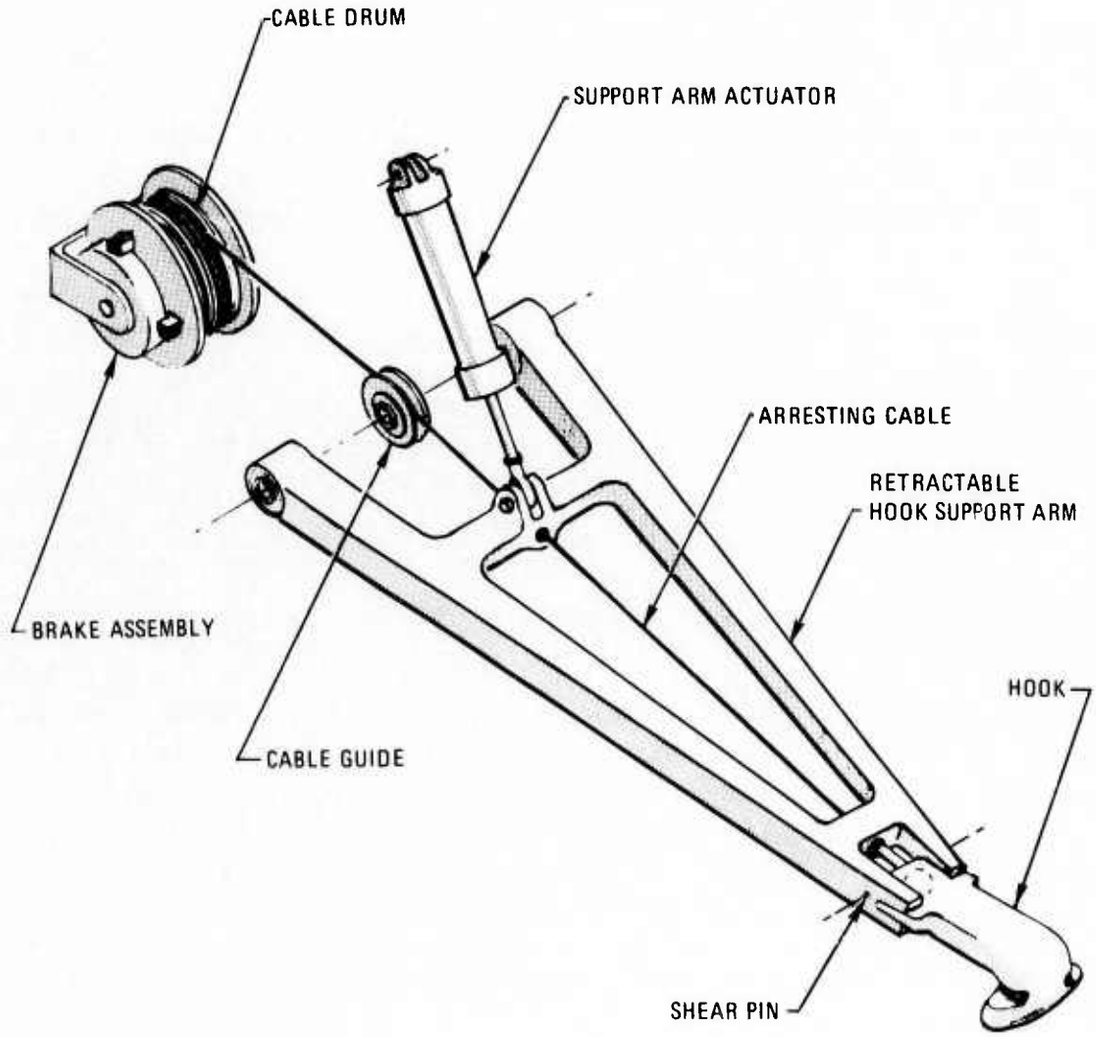


Figure 9-6. RPV Mounted Arresting System Hook Assembly

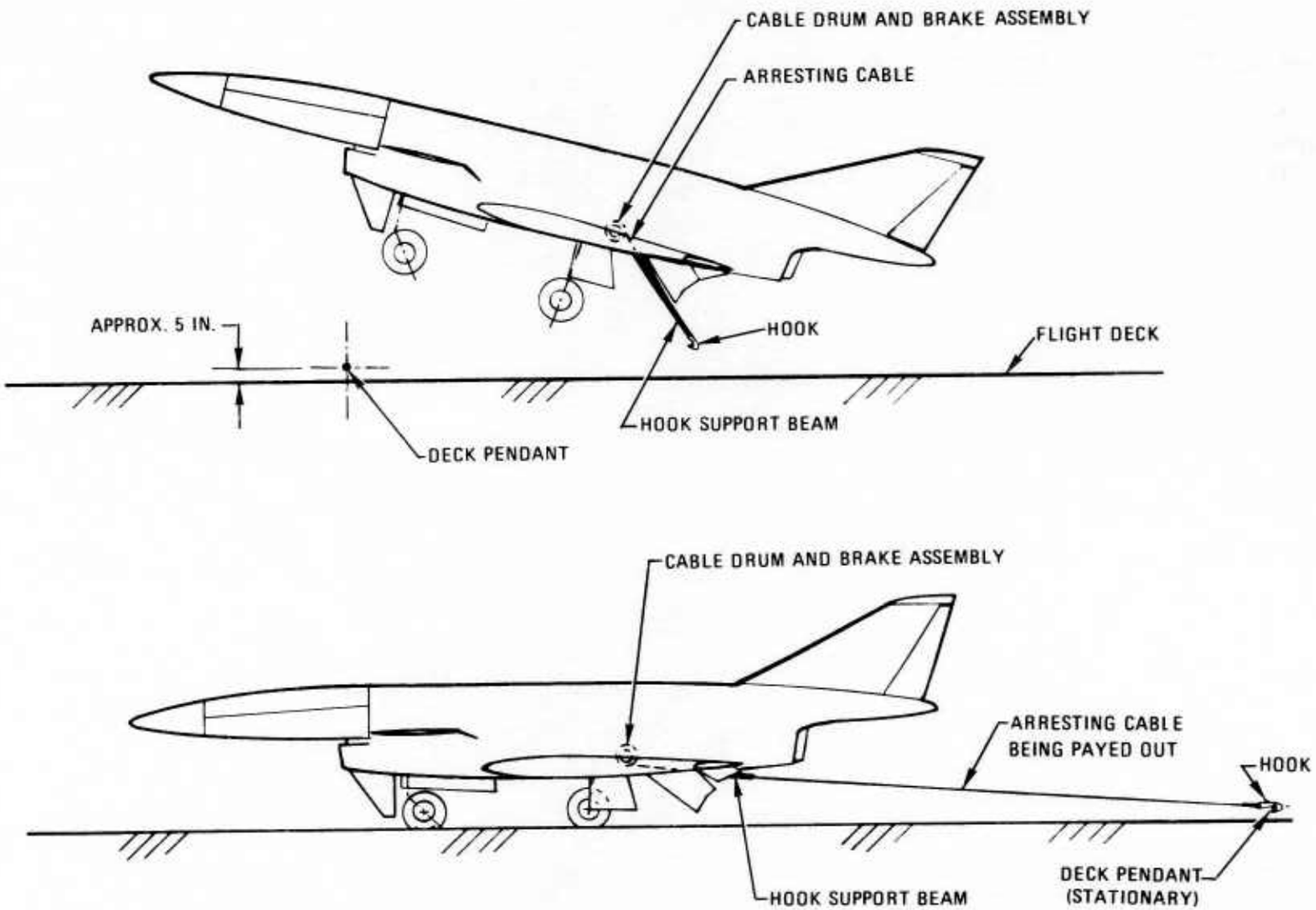


Figure 9-7. RPV Mounted Arresting System, Low Altitude Penetrator

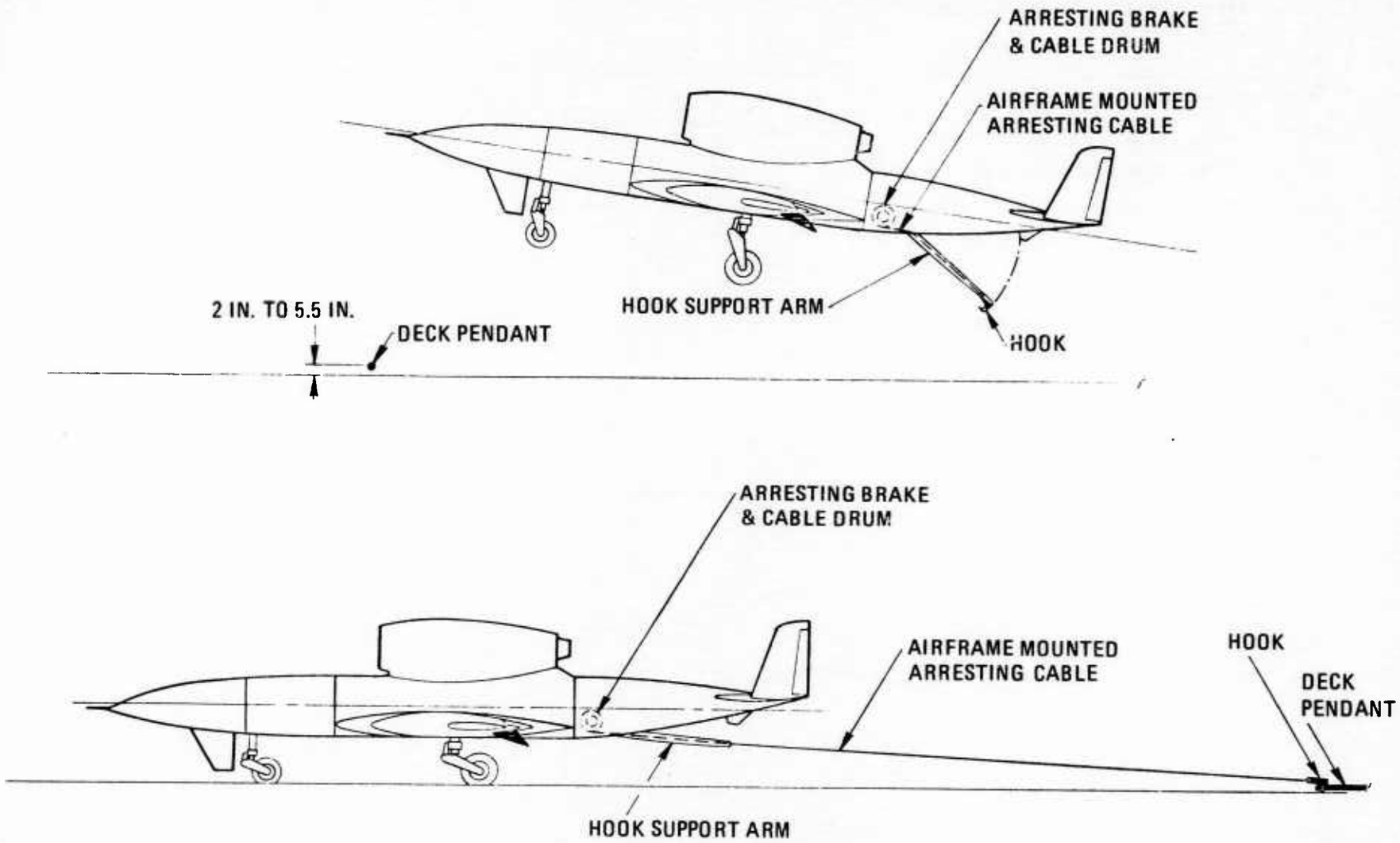


Figure 9-8. RPV Mounted Arresting System, Long Endurance Configuration

This discussion will be limited to the Conventional Long Endurance Configuration (SLR02), which is the heaviest RPV configuration considered in this study and represents the most severe conditions imposed on the proposed braking concept.

The landing weight for SLR02 would be 4,407 pounds (zero fuel weight of 4,020 plus 387 pounds fuel reserve). The landing speed would be 62 knots, which is equal to 105 fps. The kinetic energy at landing to be absorbed by the brake assembly, ignoring the energy which might be absorbed by the aircraft carrier's deck pendant, is found from:

$$KE = 1/2\ mV^2$$

$$KE = 1/2 \left(\frac{4407 \text{ lb sec}^2}{32.2 \text{ ft}} \right) \left| \frac{105 \text{ ft}}{\text{sec}} \right|^2 \qquad \text{eq. (1)}$$

$$KE = 750{,}412 \text{ ft. lb.}$$

The deceleration distance (d) for an assumed axial load factor (n) of 3.0 and an assumed overall system efficiency (E) of 0.70 is found from:

$$d = \frac{V^2}{2ngE}$$

$$d = \frac{\left| 105 \frac{\text{ft}}{\text{sec}} \right|^2}{2\ (3.0) \left(32.2 \frac{\text{ft}}{\text{sec}^2} \right) (0.70)} \qquad \text{eq. (2)}$$

$$d = 81.5 \text{ feet}$$

The force (F) required to decelerate the RPV in this distance is the RPV landing weight (W) times the load factor:

$$F = Wn \qquad \text{eq. (3)}$$

$$F = 4{,}407 \text{ lb } (3.0)$$

$$F = 13{,}221 \text{ lbs}$$

The time required to decelerate (t) at 3g in 81.5 feet is:

$$t = \left[\frac{2d}{3g} \right]^{1/2} \qquad \text{eq. (4)}$$

$$t = \left[\frac{(2)\ (81.5\ \text{ft})}{(3.0)\ (32.2\ \frac{\text{ft}}{\text{sec}^2})} \right]^{1/2}$$

$t = 1.7$ sec

To achieve acceptable lining wear on the brake assembly, it is desirable to limit the lining power loading, that is the horsepower absorbed per square inch of lining area, to a value of about 6 HP/square inch. Reference 10 indicates that for conventional aircraft wheel brakes, when lining power loadings go above 6 HP/square inch lining wear per stop increases rapidly. The total horsepower to be absorbed (HPA) is the kinetic energy to be absorbed divided by the time to absorb the energy:

$$\text{HPA} = \frac{750,\ 412\ \text{ft lb}}{1.7\ \text{sec}} \times \frac{\text{HP}}{550} \left(\frac{\text{sec}}{\text{ft lb}} \right)$$

HPA = 803 HP

For a lining power loading of 6.0 HP/square inch the brake lining area required is:

$$\text{Brake lining area} = \frac{80.3\ \text{HP}}{6.0\ \frac{\text{HP}}{\text{in.}^2}} = 134\ \text{in.}^2$$

The kinetic energy absorbed by the brake is converted into heat energy with negligible energy loss to the atmosphere during deceleration period.

The temperature rise (Δ T) of the disc or drum mass (M lb) is given by the equation from Reference 9 as follows:

$$\Delta T\ (°C) = \frac{KE}{M \times \text{specific heat} \times 1400} \qquad \text{eq. (5)}$$

A typical design value of ΔT for aircraft wheel brakes is 500°C (Reference 9).

The mean value of the specific heat normally assumed for steel, cast iron or copper alloy is 0.12 (the true value varies somewhat with temperature) (Reference 9).

For the application under discussion, the minimum weight of the disc or drum required to absorb the heat energy can be found by assuming a temperature rise of 500°C, a specific heat of 0.12 and by solving equation (5) for M is shown on the following page.

$$M = \frac{KE}{\Delta T\ (°C) \times \text{specific heat} \times 1400}$$

$$M = \frac{750,\ 412\ \text{ft lb}}{(500\ °C)\ (0.12)\ (1400)}$$

$$M = 8.9\ \text{lb}$$

Therefore the disc or drum weight required to absorb the heat energy would be less than 9 pounds and the brake lining area would be about 134 square inches. The airborne arresting cable or tape would have to be capable of exerting a force of at least 13,221 pounds before the application of an appropriate factor of safety. Steel cable would be an obvious solution, however, detail design may show that it would be more desirable from an installation standpoint to use a steel tape, which may be wound on a smaller radius, leading to a more compact design.

In conclusion, the calculations show that it would be feasible to design a brake assembly from conventional materials, using established design practices that would repeatedly decelerate the RPV in very short distance with minimal maintenance to the brake assembly.

The weight estimate for the airborne arresting equipment is 95 pounds for the SLR02 configuration using 1/2 inch diameter steel cable. Directional stability of the RPV during the short runout distance is not considered to be a problem.

The smaller, low altitude RPV (SLR01) would land at 95 knots and be decelerated in a runout distance of less than 96 feet while not exceeding an axial load factor of 6, assuming an overall efficiency of 70 percent for the system. The airborne recovery equipment is estimated to weigh about 60 pounds using 7/16 inch diameter steel cable for the SLR01 configuration.

The tail hook is similar in design to the tail hook designs currently being used on manned aircraft. Engagement is maintained by the tension force pulling the hook against the deck pendant, which is wrapped across the width of the hook in grooves provided for the deck pendant. If further studies indicate that a more positive engagement would be desirable, then the hook could be designed to incorporate an automatic latch mechanism which would trap the deck pendant in the hook at engagement.

9.4 RPV CONTROL STATION LOCATION

Considerations for location of the RPV control station include RPV operational and maintenance requirements and compatibility with other systems deployed on the ship.

Within the RPV system, the control station is the man-machine interface that controls the operation of all RPVs. At any time, the control station may be connected by hardwire link to multiple RPVs located on the catapult, at an operational readiness check spot on the flight deck, or at a test spot on the hangar deck. Telephone and television will provide communication links between personnel at the control station and at the RPV locations. The hardwire RPV control and communication link length and routing form one constraint on control station location. Excessively long line lengths will complicate the control system installation by requiring line drivers and remote switching components in the system design.

An additional constraint on location is the need for physical access between the control station and the carrier operations control centers, the Carrier Air Traffic Control Center and the Combat Information Center. Some physical access is required to effect coordination and eliminate duplication in mission planning and control facilities.

Compatibility with other systems depends in part on the unique ship cruise configuration. Ship outfitting for a particular cruise will change with mission, duty station location, etc.

Based on the foregoing requirements, a preferable location for the RPV control station would be in the forward port hangar area, on a mezzanine at the OZ level. This location would permit ready physical access to the operations control centers. Discussion with carrier aircraft handling personnel indicates that the port hangar deck area forward of the No. 1 elevator may be a good location for the RPV hangar test and maintenance spot. This location would minimize control line length to the control station. Minimal control lines would also be required for connection to an operational readiness check spot on the flight deck in the vicinity of the island. The longest communication link required is to the Landing Safety Officer pit at the aft port corner of the flight deck.

The RPV checkout and launch control line network is depicted in Figure 9-9. The interface schematic is depicted in Figure 9-10.

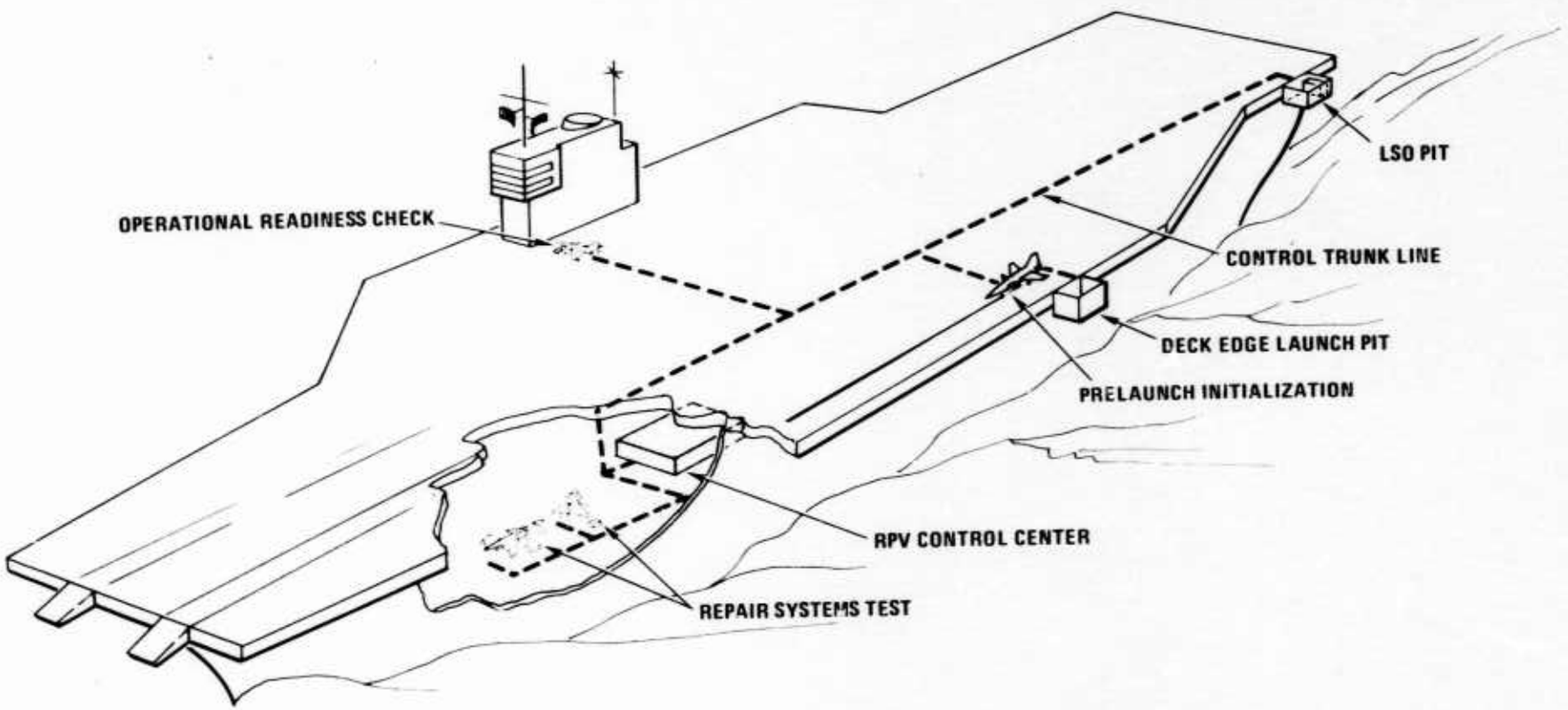


Figure 9-9. Remotely Piloted Vehicle Checkout and Launch Control Network

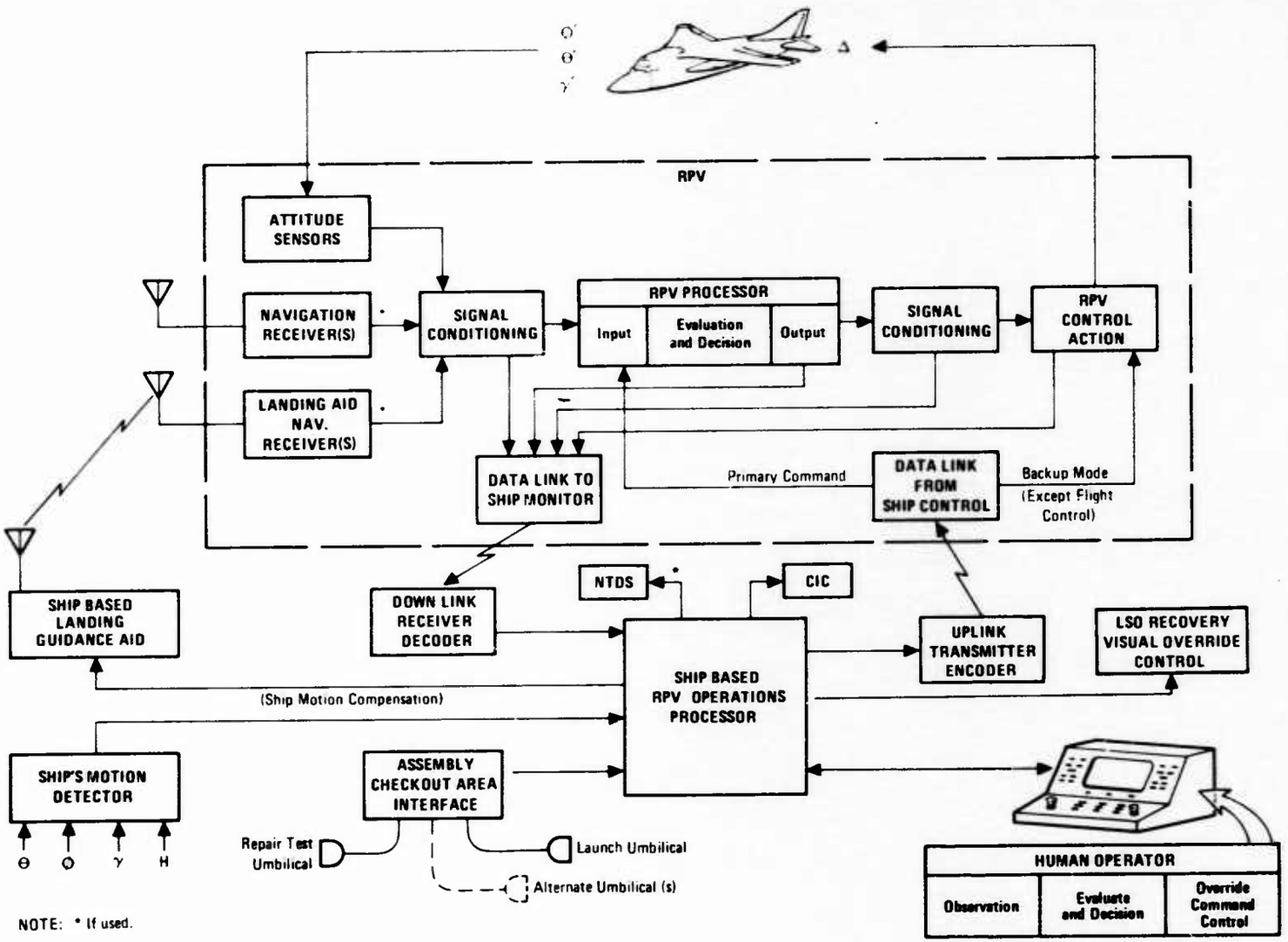


Figure 9-10. RPV Control Center Interface, Functional Diagram

The control, display and organizational support equipment complement for the Sea Control Ship can be augmented with additional consoles, memory, and interfacing elements to satisfy the operational RPV sortie rates associated with carrier operations. The essential considerations in the design of the Carrier RPV control station include:

- Minimum vessel modifications, yet providing an installation that can permit visual monitor of all operations;
- The control installation is to be the operations center from which all aspects of the maintenance test, launch control, mission control, and recovery control can be conducted;
- The installation should not hinder present manned aircraft operations or the conduct of normal vessel functions;
- The installation should be in keeping with the present manned vehicle operations, i.e., utilize the existing launch control, recovery, landing safety officer interfaces and mechanical functions.

In addition, the design should be compatible with carrier operations:

- The vehicle design should be compatible with existing landing aids AN/SPN-41 and AN/SPN-42.
- The RPV launch command should originate from the catapult control officer with interface to the control center.
- The RPV recovery in-sight monitor performs similar functions as the landing safety officer (LSO) in manned operations. A limited override control should therefore be provided, interfacing to the RPV operations processor.
- The RPV systems design should be compatible with the naval tactical data link interface.

In conventional aircraft operations, the launch order is given by the plane captain, and launch is executed by the deck-edge catapult control officer. With RPV operations, the launch function is similarly given by the RPV captain by voice or hand signal to the catapult control officer. The RPV captain monitors the RPV progress through the preflight readiness check and prelaunch initialization. The RPV engine will be started on the catapult and a 10-second final validation check will be conducted using the umbilical interface.

The launch instruction is simultaneously transmitted to the RPV control center whereby the RPV controller can monitor the launch using telemetered data. The visual RPV post launch monitor progress is followed by the RPV captain using a voice link to the control center.

A more detailed discussion of the command and control aspects of ship-based RPVs is provided in Section 6.0, "Command and Control Studies."

9.5 LAUNCH AND RECOVERY EVALUATION, AIRCRAFT CARRIER

Aircraft carrier launch and recovery evaluation is confined to catapult launch and arresting gear recovery for RPV operations. The two RPVs, one for each mission profile, are assigned evaluation judgements as discussed in the Evaluation Methodology Section, Paragraph 8.2. Table 9-3 provides a compilation of evaluation judgements grouped in operational interface, ship compatibility and utilization, safety implications, technical risks, and cost factors. For the long endurance mission, 1.6 RPVs can be carried for each replaced F-4 or three RPVs for each two F-4s based on the flight deck spot. However, for the low altitude penetrator mission, six RPVs can replace each F-4 based on hangar deck spot with folded wings. The cost factor, relative air vehicle cost, is normalized to the conventional configuration for low altitude penetrator as a reference. The unit cost comparisons are for 100 quantity, less mission payload cost.

9.6 AIRCRAFT CARRIER STUDY CONCLUSION

Both RPVs are acceptable for carrier launch and recovery operations although more effort must be put on developing optimum RPV operational techniques to minimize the impact of the RPV system on the manned aircraft operations. This is also under safety implication as accident potential. This impact can be reduced by requiring positive RPV control, developing traffic pattern consistent to vehicle performance and deck procedures consistent to the timing of events. On the whole, RPVs with catapult launch and RPV mounted arresting gear can be made compatible with aircraft carrier operations.

RPVs with VTOL capability are obviously feasible for aircraft carrier operations, but the acceptance of the increased costs and risks for this capability will depend on the importance of its mission.

TABLE 9-3

EVALUATION SUMMARY, AIRCRAFT CARRIER

EVALUATION CRITERIA	RPV CONFIGURATION	
	S1R01 CATAPULT LAUNCH, HOOK, ARREST GEAR RECOV.	S1R02 CATAPULT LAUNCH, HOOK, ARREST GEAR RECOV.
SHIP CONSTRAINTS		
Ship Weight and Balance	1	1
Ship Maneuverability	1	1
Ship Motion	2	2
SHIP/RPV COMPATIBILITY		
No. of Equiv. RPV's per replaced F-4,		
Flight Deck Spot (1)	7.9	1.6
Hangar Deck Spot (1)	6.2	1.7 (Folded)
Flight Deck Space	2	3
Hangar Deck Space	2	3
Storage Space	2	3
Personnel Space	2	2
Ship Command and Control Systems	3	3
Launch Systems	2	2
Recovery Systems	2	2
Maintenance Methods	2	2
RPV Test and Check-out	2	2
Handling Equipment	2	2
Ship Power Outlets	1	1
Ship Fuel Outlets	1	1
COMPATIBILITY WITH SHIP WEAPONS SYSTEMS		
Manned Aircraft	3	3
Other Weapons Systems (Guns, Missiles, etc.)	1	1
TECHNICAL RISKS		
Air Vehicle	2	2
Launch Systems	2	2
Recovery Systems	2	2
Command and Control Systems	2	2
SAFETY		
Deck Handling	2	2
Launch Operation	2	2
Recovery Operation	3	3
Jet Blast	2	2
COST		
Air Vehicle Relative Costs (100 Quantity, Less Payload)	1.0	1.94
Ship Modification Costs	small	small

Evaluation Scale:

1. Acceptable, no adverse impact or risk
2. Acceptable, little adverse impact or risk
3. Acceptable, moderate adverse impact or risk
4. Marginal
5. Unacceptable

(1) Actual no. of RPV's, not evaluation rating.

10.0 SEA CONTROL SHIP STUDIES

10.1 OPERATIONS SUPPORT CONCEPTS - SCS

The Sea Control Ship system design is based on a limited support concept for embarked aircraft, in which the manned aircraft to be used on the SCS will be designed for maximum independence from shipboard support facilities. Their design will include high reliability, self-monitoring and testing subsystems, a built-in self-start capability for the engine, and a built-in LOX generating system. In keeping with the concept of independence the design of RPVs for use on the SCS will stress high reliability, self-monitoring and self-test. These concepts are economically available as state-of-the-art technology.

10.1.1 LAUNCH SUPPORT

The primary launch spot selected for VTO RPVs on the SCS is on the aft starboard corner of the flight deck at frame 503. The launch spot is centered 15 feet from the starboard deck edge as shown in Figure 10-1. At this location, the RPV is visible from both the flight deck monitoring center, PRI-FLY, and from an RPV launch and recovery control center located under the SPN 35 radar dome mount. The location is clear of the aft CIWS mount and the aft King post and UNREP operations area, and it is readily accessible from the aft elevator. The aft starboard corner location would also leave the AV8 landing strip clear so that aircraft recovery would be interferred with only during RPV strike up from the hangar deck. Once the RPV is in place at the launch spot, AV-8 recovery operations could continue.

For vertical take-off RPVs, the positioning of the launch spot on the aft end of the flight deck will minimize the possibility of interference between the RPV at lift-off and on-deck operations or surrounding equipment; i.e., as the RPV rises from the deck with vertical velocity constant but forward velocity decreasing relative to the ship, the ship will move out from under the RPV. At the aft location, no deck equipment or ship structure will be aft of the RPV and the possibility of collision due to relative motion will be eliminated.

For RATO launched RPVs, the launcher is mounted off the aft starboard corner off the flight deck on the bulkhead above the hangar deck. For RATO launch to starboard from this location, the RATO exhaust plume

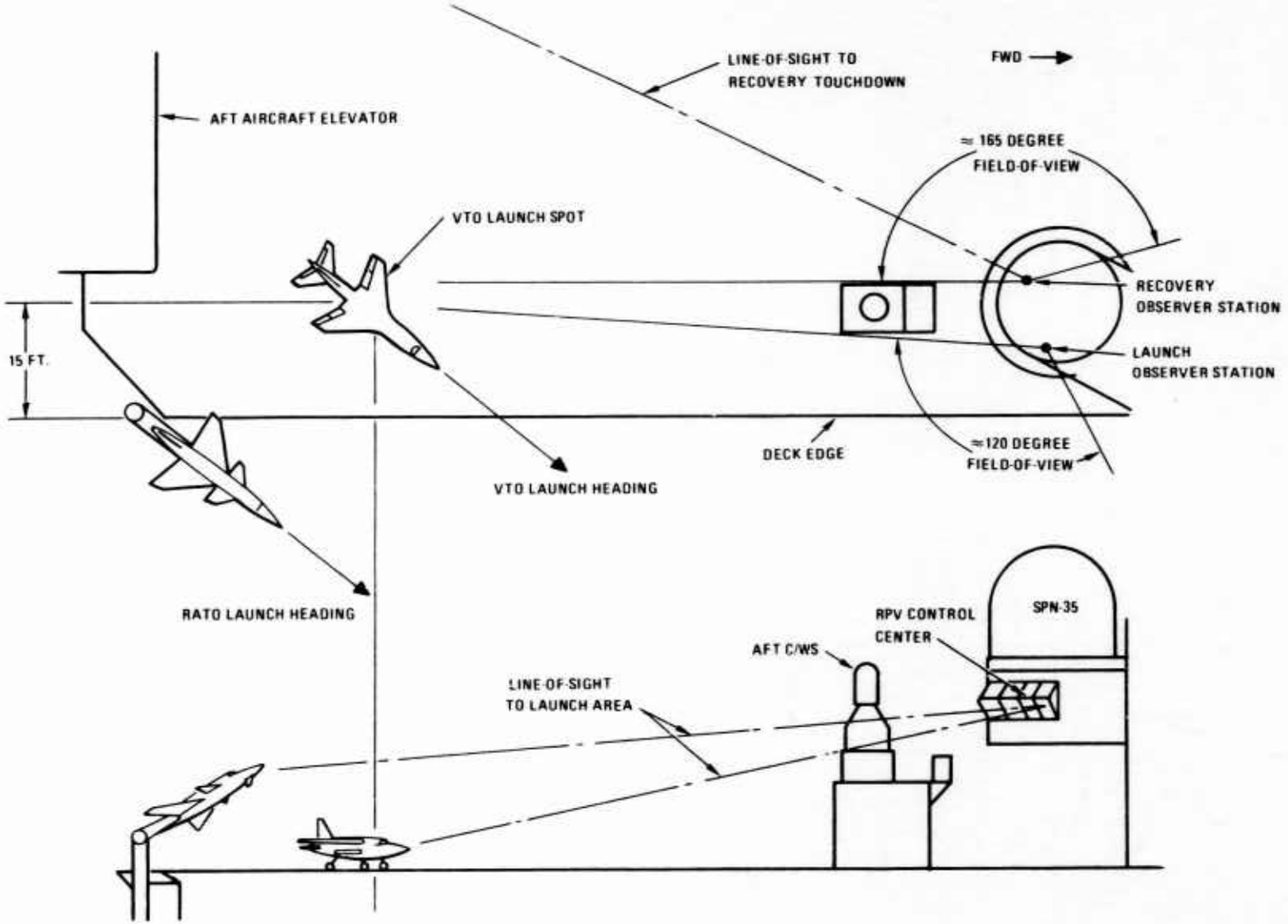


Figure 10-1. Remotely Piloted Vehicle Launch Spot Location, SCS

would be directed aft of the flight deck. The noxious RATO exhaust cloud would not interfere with an RPV remote controller's visibility in event of a need for contingency control action, or with flight deck visibility, and it would not present a health hazard to flight deck personnel. With the ship underway, the exhaust cloud would be quickly left astern without drifting over the flight deck. During RATO launch, the aft elevator would be placed in the lower position to clear the RATO exhaust plume.

RPV launch departure heading from the selected launch spot is to starboard 45-degree relative to ship's heading. This launch heading provides consideration for air traffic control cognizance, airspace and flight deck safety, and non-interference with manned aircraft operations. As depicted in Figure 10-2, this launch heading retains line-of-sight visibility to the departing RPV from an RPV launch control center located under the aft SPN-35 radar mount and from the starboard side of the island. As it departs from the ship on the 45-degree relative heading, the RPV would rapidly diverge from the ship's course, allowing RPV maneuvering space in event of post-launch erratic flight trajectory. The starboard side departure would also eliminate interference with manned aircraft launches emanating from the bow of the ship and maintain a clear AV-8 recovery approach corridor off the port stern of the ship.

The primary launch spot should be equipped with a built-in launch system with mechanical and electrical RPV interfaces permanently installed in the ship structure. This type of installation would reduce launch system damage due to handling, insure commonality between ships and permit operating crews to train to a high level of efficiency using standard launch techniques. The built-in launch system installation can be located in an RPV launch control center (LCC) deck house situated outboard of the aft CIWS installation with line-of-sight visibility to the RPV launch spot.

In the event of primary RPV launch system malfunction or loss, or requirement for an alternate launch spot, a secondary launch system should be provided. This system can be a transportable system for use anywhere on the flight deck. It would consist of a mechanical interface between the RPV and standard ship tiedown fittings and an electrical control and interface system possibly mounted on a trailer vehicle.

The launch control center (LCC) includes a launch operator-to-RPV hardwire power and communication system and a launch operator-to-ship operations control center communications system. The RPV communication system consists of a man-machine interface, a power and systems control relay box. and interconnecting cabling. The man-machine

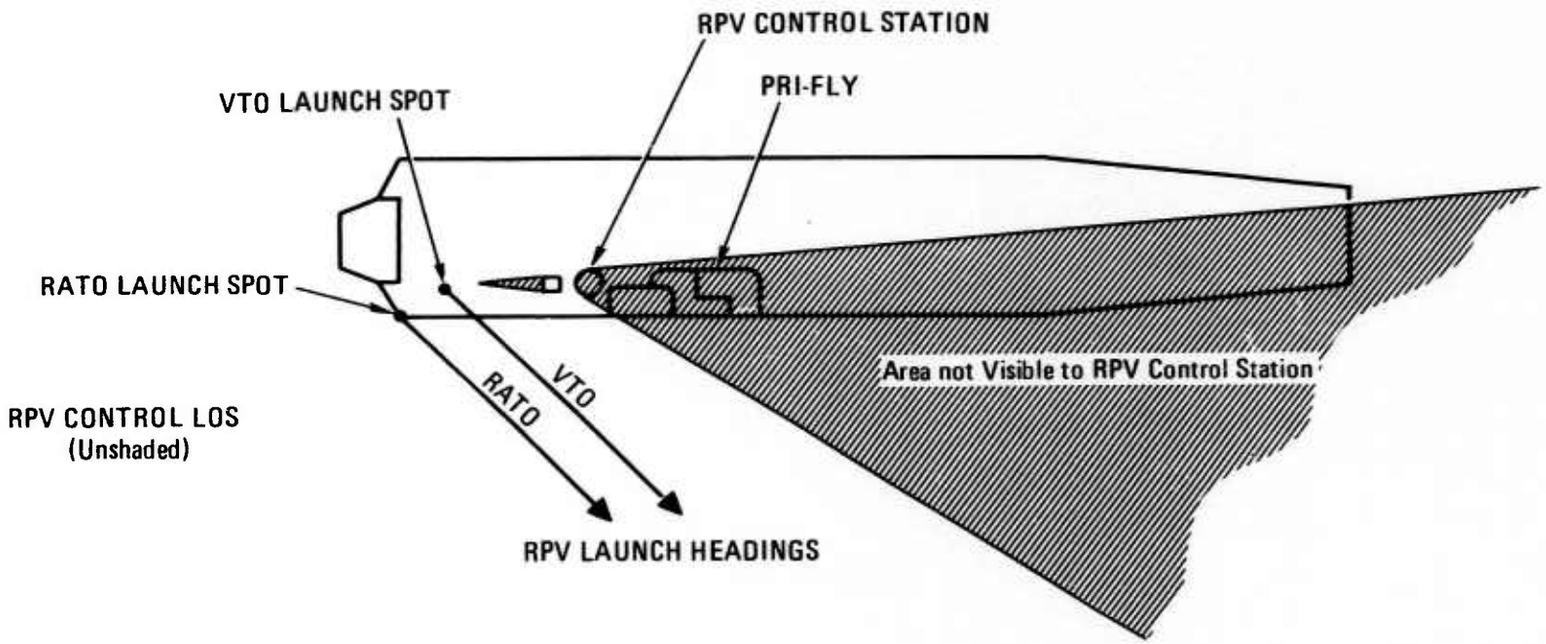


Figure 10-2. RPV Operations Visibility Areas, SCS

interface includes a control panel equipped with system and power control switches, status indicator lights and meters, and other input/output devices for communicating with the RPV on-board systems. Using the control system, the LCO will have the capability to control RPV systems power, to set initial launch conditions into RPV systems, to start and control the engine, and to control the RPV/ship mechanical and electrical interfaces.

10.1.1.1 Launch Procedure - SCS

When RPV launch condition is set on the SCS the air department crew trained for RPV operations will prepare the RPV launch spot on the flight deck. Preparations will include deploying RPV launch support equipment from stowage and insuring the designated RPV has access to the launch spot from its launch queue tie-down location.

The recommended primary launch spot for an RPV is on the aft starboard side of the flight deck with a launch heading of 40-50 degrees to starboard. For easy access, the RPV launch queue tie-down position may be on the aft end of either the flight or the hangar deck. If the RPV is spotted on the hangar deck, easy access is possible to the launch spot using the aft elevator.

Common launch support equipment to be deployed at the RPV location for all SCS RPV launch methods includes a holdback fixture, engine start auxiliary power unit (APU) and launch control center-to-RPV electrical interface. The holdback fixture is attached between the RPV and deck fittings to capture the RPV to the ship during engine start and launch countdown. The holdback fixture releases the RPV into flight after launch thrust is set and all pre-launch conditions have been set into the RPV systems.

The engine start auxiliary power unit (APU) is attached to the RPV through a power control relay box in the LCC to start the RPV turbojet engine on command from a launch control officer (LCO). A ground APU is used rather than an RPV installed start unit to minimize a RPV cost and performance degradation. The air department RPV launch crew moves the APU to a position aft of the aft CIWS installation and secures it into position. They then connect the APU power cable to a power relay control box connect on the external bulkhead of the LCC and start the APU.

The LCC-to-RPV electrical interface consists of two cables, an engine start power cable and a systems power and control cable. The launch

crew connects these two cables between the LCC and the RPV and secures them into place on the deck so that engine exhaust gas will not damage them. For the RATO boosted vehicle, an additional cable, the RATO ignition cable, must be connected between the LCC and the RATO unit.

When weather conditions permit, the RPV may be moved to the launch spot manually by the air department crew. In high sea states, a standard flight deck tow vehicle moves the RPV to the launch position. After the RPV is mechanically secured to the launch position with the holdback fixture, the tow vehicle is moved clear of the launch area. The flight deck crew then attaches the engine start and systems control cables, removes aircraft safety devices and signals the Launch Control Officer (LCO) in the Launch Control Center (LCC) that the launch preparations are complete.

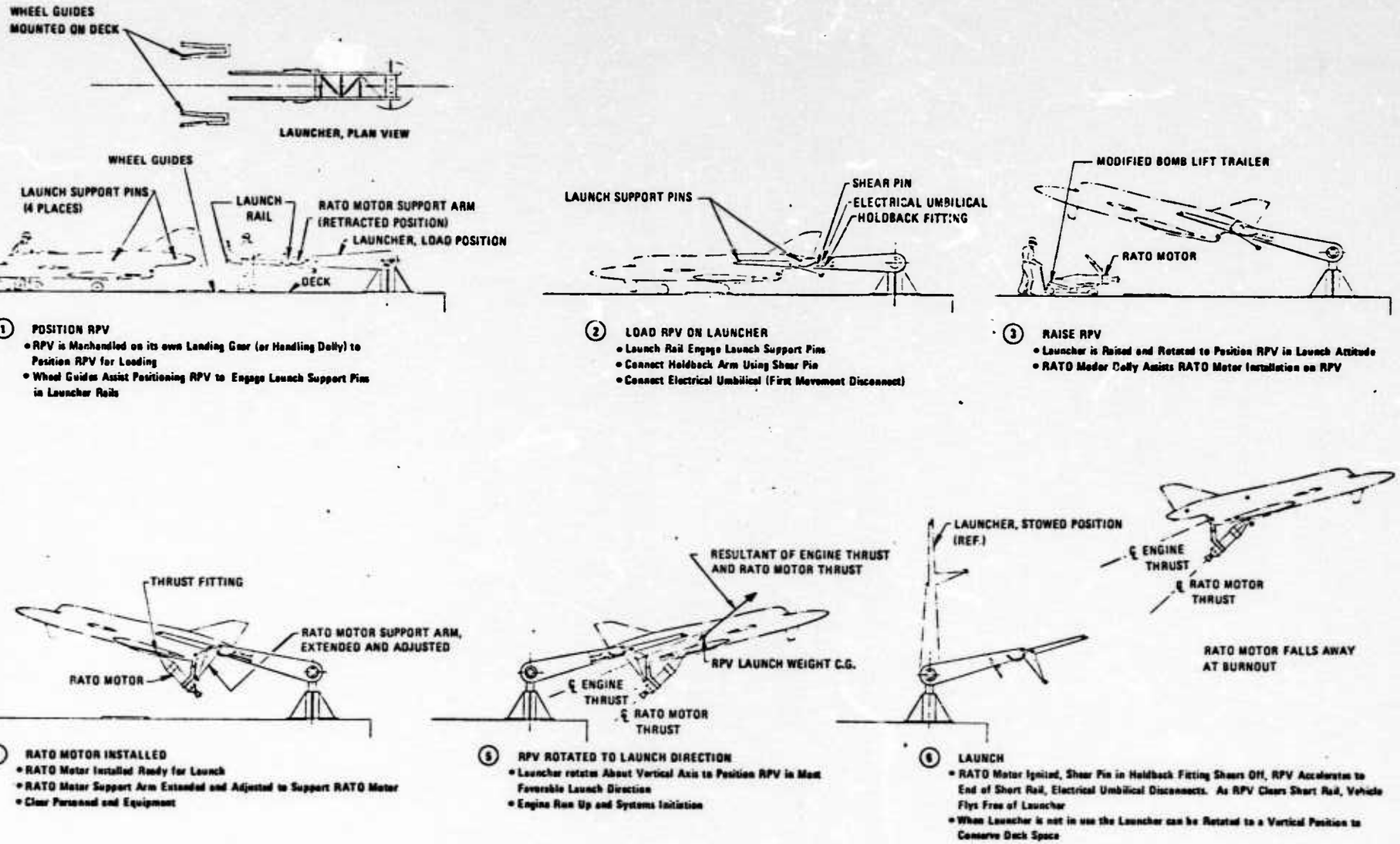
10.2 LAUNCH SYSTEMS

10.2.1 RATO LAUNCH SEQUENCE

The RATO launch sequence is depicted in Figure 10-3.

Sketch No. 1 - Position RPV

The SCS flight deck crew or the DE RPV operations crew manually moves the RPV to the launcher. The RPV will be supported on its own deployed wheeled undercarriage or, for the net and aerial track recovered vehicles, on a wheeled carriage trailer vehicle. During this task the wheeled RPV will weigh less than 2,800 pounds and the RPV-trailer combination will weigh approximately 3,000 pounds. The forward ventral side force fin on the RPV will be folded horizontally to the stowed position and the wings may be in either the folded or unfolded position. A combination tow and steering bar will be attached to the RPV nosewheel or the trailer for directional control. The towbar may be equipped with a manually operated brake to aid in control of RPV movement. At the indicated weights, the RPV can be easily manhandled in a calm sea state by a crew of 3. When sea conditions require, the crew can be augmented, and a tow vehicle can be used aboard the SCS or a winch and guide line aboard the DE.



① POSITION RPV
- RPV is Manhandled on its own Landing Gear (or Handling Dolly) to Position RPV for Loading
- Wheel Guides Assist Positioning RPV to Engage Launch Support Pins in Launcher Rails

② LOAD RPV ON LAUNCHER
- Launch Rail Engage Launch Support Pins
- Connect Holdback Arm Using Shear Pin
- Connect Electrical Umbilical (First Movement Disconnect)

③ RAISE RPV
- Launcher is Raised and Rotated to Position RPV in Launch Attitude
- RATO Moder Dolly Assists RATO Motor Installation on RPV

④ RATO MOTOR INSTALLED
- RATO Motor Installed Ready for Launch
- RATO Motor Support Arm Extended and Adjusted to Support RATO Motor
- Clear Personnel and Equipment

⑤ RPV ROTATED TO LAUNCH DIRECTION
- Launcher rotates About Vertical Axis to Position RPV in Most Favorable Launch Direction
- Engine Run Up and Systems Initiation

⑥ LAUNCH
- RATO Motor Ignited, Shear Pin in Holdback Fitting Shears Off, RPV Accelerates to End of Short Rail, Electrical Umbilical Disconnects. As RPV Clears Short Rail, Vehicle Flys Free of Launcher
- When Launcher is not in use the Launcher can be Rotated to a Vertical Position to Conserve Deck Space

Figure 10-3. RATO Launch Sequence

Wheel guide fences mounted on the deck assist in alignment of the RPV to the launcher and reduce the possibility of damage due to misalignment. Launch rail height is adjusted by elevating the launcher at the deck support fixture to align the rails with the launch support pins on either side of the RPV. The RATO motor support arm is in the retracted position to clear the underside of the launcher during loading.

Sketch No. 2 - Load RPV on Launcher

As the RPV is moved aft, the launch support pins engage the launch rails and are guided into the u-shaped capture sockets. A hold-back arm is connected between the launcher and the tail of the RPV. The hold-back arm is fitted with a calibrated shear pin to hold the RPV to the launcher against the combined thrust of the engine and the RATO igniter. This pin is sheared at launch by the thrust of the RATO main propellant, releasing the RPV from the launcher. After the mechanical interface is connected, the hold-back is adjusted to preset tension to control shock loading of the shear pin due to ship movement and launch forces. The shear pin is installed in the hold-back fitting prior to launcher loading to minimize cycling time. The mechanical interface can be made automatic to further reduce launcher cycle time.

Electrical power for systems control and engine start is supplied to the RPV through an umbilical cable connected between the launcher and the tail of the RPV. A separate shielded cable is provided for the RATO ignition circuit. The umbilical connectors are the first motion disconnect type, thus maintaining a completed circuit through RATO ignition, and in case of miss-fire, after ignition for emergency control. Control of RPV systems is thus maintained via the hardwire link until RPV motion due to RATO firing occurs.

While the hold-back and the umbilicals are being connected, the towbar can be removed from the wheeled RPV. The forward ventral side force fin is then deployed and thewings, if folded, are deployed. These parts are deployed manually and locked into position.

Sketch No. 3 - Raise RPV

The launcher raises the RPV off the landing gear or the RPV trailer to permit RATO installation. With the RPV raised and clear, the RPV

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trailer is removed from the launch area. At the RATO installation position, the launcher crew installs the RATO booster using a modified bomb lift trailer to raise the booster and position it for attachment to the RPV. The RATO-RPV interface consists of a forward thrust cone and an aft support fixture. The thrust cone directs RATO force into the thrust fitting on the RPV while the aft support fixture aligns the RATO booster to the vehicle center-of-gravity. The fixture alignment is calibrated off-vehicle to pre-determined settings for the particular vehicle configuration.

Sketch No. 4 - RATO Motor Installed

During installation, the RATO assembly is held to the RPV by a ball lock pin in the thrust cone for safety. A RATO motor support arm on the launcher is then extended down to the RATO, locked into position and adjusted to a pre-determined tension to hold the RATO assembly in position on the RPV. When installation is complete, all personnel clear the area and two ordnance men arm the RATO by installing an igniter in the forward end and removing the ball lock pin in the thrust cone.

Sketch No. 5 - RPV Rotated to Launch Direction

The launcher erects the RPV to launch pitch attitude and rotates about the deck mount vertical axis to position the RPV on the desired launch heading relative to the ship. The shipboard RPV control operator (SRCO) then applies ship electrical power to the ROV, starts the engine, and sets all RPV systems to launch condition on direction of the shipboard launch operations officer.

Sketch No. 6 - Launch

After coordinating with the safety and operations officers, the launch operations officer directs the SRCO to launch the RPV. At launch command, the RATO motor is ignited, shearing the holdback shear pin and boosting the RPV into free flight at desired airspeed, altitude and attitude. As the RPV moves away from the launcher, the electrical umbilicals disconnect, placing the RPV in the remote control flight mode.

When not in use the launcher can be elevated to a vertical position to conserve deck space. The rotation and elevation capabilities permit the launcher to be installed on the deck on close proximity to bulkheads or to the side of the ship, minimizing dedicated deck space requirements. With 1 foot clearance, the launcher occupies a 6.6 foot diameter deck space 22.1 feet high in the stowed vertical position. During launch operations, a clear area of 30 feet diameter and 10.8 feet in height will

be required around the launcher to swing the RPV to the launch heading and an access path 15 feet wide and 10.3 feet high will be required to move the RPV to the launcher, allowing 2 feet of clearance at wing-tips and around the loaded launcher. (See Figure 10-4.)

10.2.2 VTOL LAUNCH

The Vertical Take-Off (VTO) RPV is launched under its own power by rising vertically from a designated launch spot on the deck on the downward directed thrust of its own engine. The launch spot must be chosen to provide line-of-sight visibility for the Launch Control Officer (LCO) and the Shipboard Remote Control Officer (SRCO) for operations control and safety. The launch spot must also have rf line-of-sight visibility to the remote control system antennas to provide an unblocked remote control link during the transition from hardwire control umbilical disconnect to airborne free-flight. The launch spot is equipped with a mechanical and electrical ship-to-RPV interface to permit the SRCO to start the RPV engine, initialize RPV systems to launch conditions and launch the RPV into free-flight.

Since the VTO RPV is launched by adjusting its engine speed to provide a vertical thrust level which exceeds RPV weight, vehicle attitude and position during the thrust increase must be controlled to preclude premature movement. The RPV must be securely held to the ship during the pre-launch operation, then safely released into controlled free-flight at the proper time. The pre-launch capture and launch release function is provided by a holdback fixture which is connected between the RPV and an aircraft tiedown fitting on the deck of the ship. The holdback captures the RPV to the deck during engine start and launch initialization and prevents any movement of the RPV relative to the deck due to ship motion, wind or RPV engine thrust. The holdback insures a secure hardwire umbilical control link during pre-launch operations and provides a positive means of control over separation of the RPV from the ship at launch. With the holdback, the RPV can be held securely to the deck until engine thrust is adjusted to a pre-determined lift force value which exceeds RPV weight. The launch control officer (LCO) can then make the decision to release the RPV or abort the launch. If the decision to launch is made, the RPV is released with positive vertical lift force and accelerates upward clearing the deck and aft ship structure. If the launch is aborted, the RPV is not released and systems can be safely shut down. Thus, the holdback permits the SRCO to make final systems operational readiness checks safely up to the moment of launch.

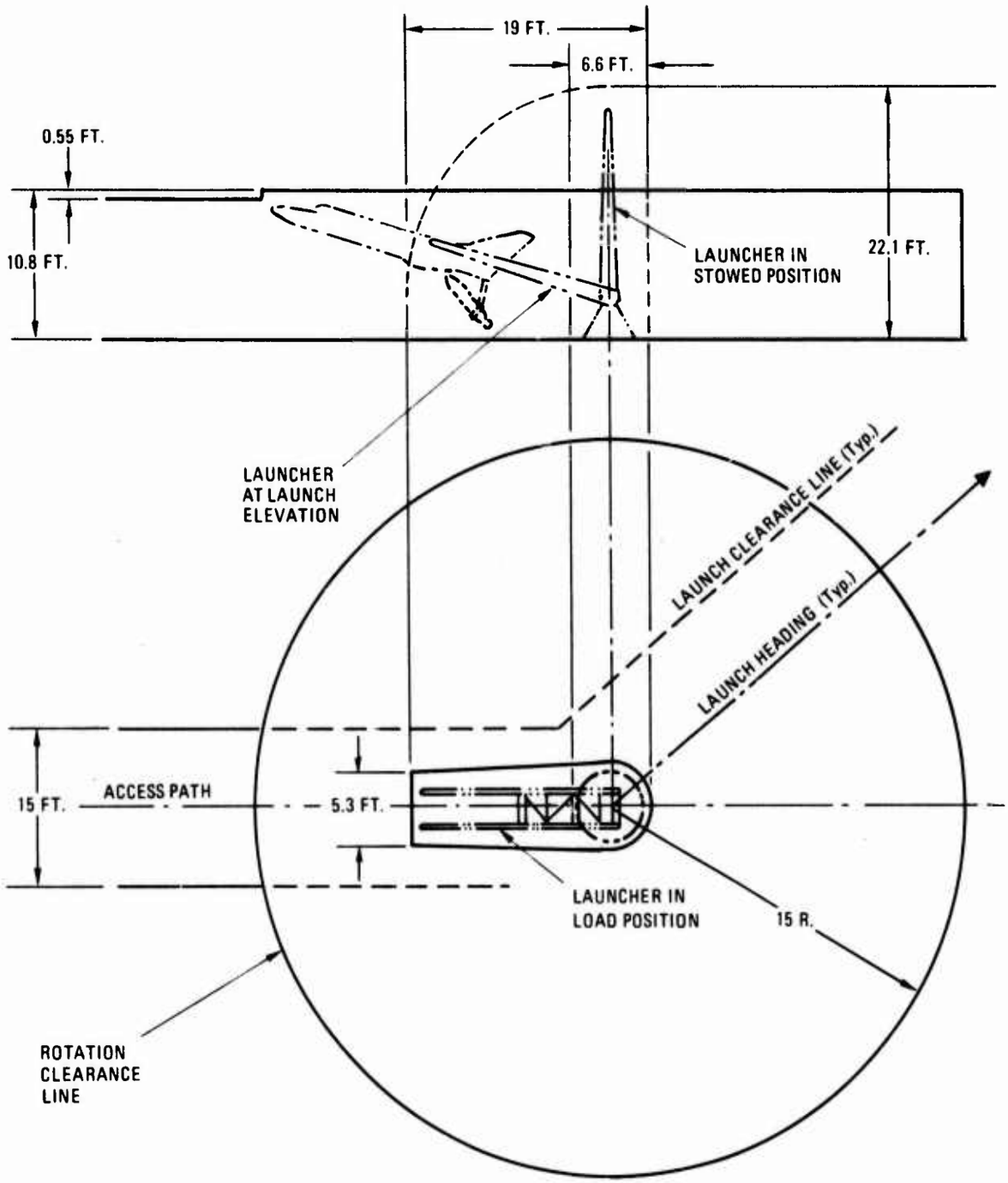


Figure 10-4. RATO Launcher Deck Space Requirements

The holdback also eliminates the need for a wheel brake system on the RPV during launch, allowing the design of a braking system to be driven by recovery and handling requirements. The holdback provides a feasible alternate restraint system to unanchored wheel chocks which are not desirable for use with VTOL vehicles due to engine blast effects and must be removed prior to engine start.

The holdback fixture can be a man-portable bar that connects between a standard deck mounted aircraft tiedown fitting and a fitting on the underside of the RPV. The holdback fixture must be adjustable to take up slack and apply tension against the landing gear shock struts. The tensioning device can be a level actuated locking cam which is hand operated after the holdback is securely attached at both ends. The upper end of the holdback which connects to the RPV is equipped with a remotely operated disconnect which separates the holdback from the RPV at the launch command. A standard pyro-technically actuated weapons release system can be used in the disconnect for standardization of logistics support. The release system is triggered by an electrical impulse from the SRCO launch control panel on command of the LCO.

10.3 RECOVERY SYSTEMS

10.3.1 RECOVERY SUPPORT

In an attempt to limit the impact on manned aircraft operations, RPV launch and recovery operations were confined to the aft part of the flight deck in this study with the intention of permitting manned aircraft operations to be carried on simultaneously on the forward area of the flight deck. With interference from RPV operations so limited, manned aircraft can be maintained in an alert status on deck, or can be launched and recovered for the surface attack, ASW and plane guard functions during RPV operations, and the offense-defense role of the SCS is not impaired.

Limitation to the aft flight deck also simplifies the RPV control station location problem. The location proposed for launch operations control, under the aft SPN-35 radar antenna mount, is also compatible with both vertical and arrested RPV landings on the aft deck, as it permits line-of-sight visibility to the RPV during approach, touchdown and contingency wave off.

Two types of RPV recovery were investigated for the SCS, arrested recovery and vertical descent to landing. In the arrested recovery, the RPV hooks a fixed cable deck pendant strung across a landing zone on the

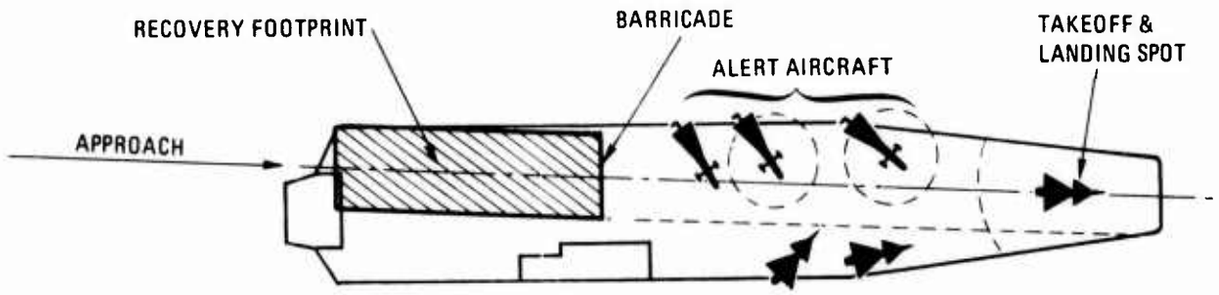
aft end of the ship. A friction brake system in the RPV absorbs recovery energy to bring the RPV to a stop. This method is discussed in greater detail in Paragraph 9.3.5. The arrested recovery will be used for landing the SLOROC and the standard low altitude penetrator RPV designs on the SCS. In vertical descent recovery, the RPV approaches the recovery spot on the ship with very low relative vertical and forward velocity and is guided to a mechanical linkup with a docking system which captures the RPV to the ship. The descent procedure and docking mechanism used depend on the type of RPV being recovered. The vertical descent recovery will be used to recover the tailsitter, rotary wing and deflected thrust RPV concepts on the SCS.

10.3.2 ARRESTED RECOVERY

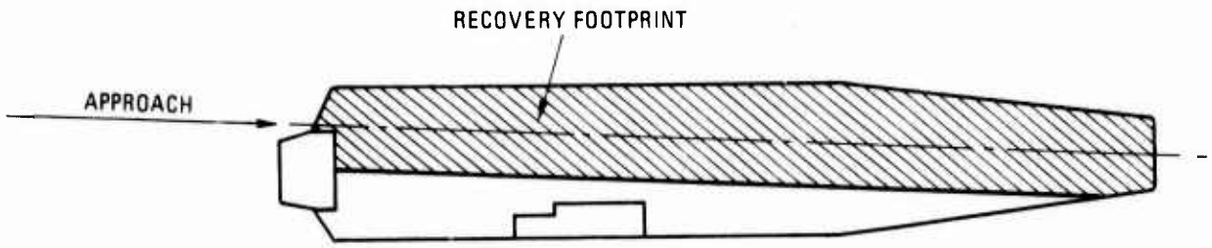
Recovery approach for arrested recovery can be in the standard aft-port to forward-starboard direction of the manned aircraft recovery pattern or an aft-starboard to forward-port recovery pattern as shown in Figure 10-5.

The standard SCS runway approach can be used for arrested recovery of the SLOROC RPV with a safety barricade erected across the flight deck at frame 357 (alternate No. 1, Figure 10-5) to provide contingency protection to the forward flight deck area in event of no hook up or failure of the hook to deploy. By moving the barricade forward, more deck space can be provided for arrested recovery of the low-altitude penetrator RPV concept. However, use of the barricade restricts movement of aircraft on the flight deck. This restriction and the hazards of landing aircraft longitudinally down the flight deck, which led to the development of the angled deck on carriers, may make arrested landings of RPVs on the standard SCS runway both unsafe and impractical. With this approach pattern, a go-around option in event of no hook up can be provided only by eliminating the barricade and clearing the forward deck area of manned aircraft to allow distance for the RPV to accelerate for touch-and-go takeoff (alternate No. 2, Figure 10-5). Also, forward visibility from the RPV control station is limited on the starboard side. A go-around option for the standard SCS runway approach, therefore, appears too restrictive on the ship's mission and hazardous, and thus is unattractive.

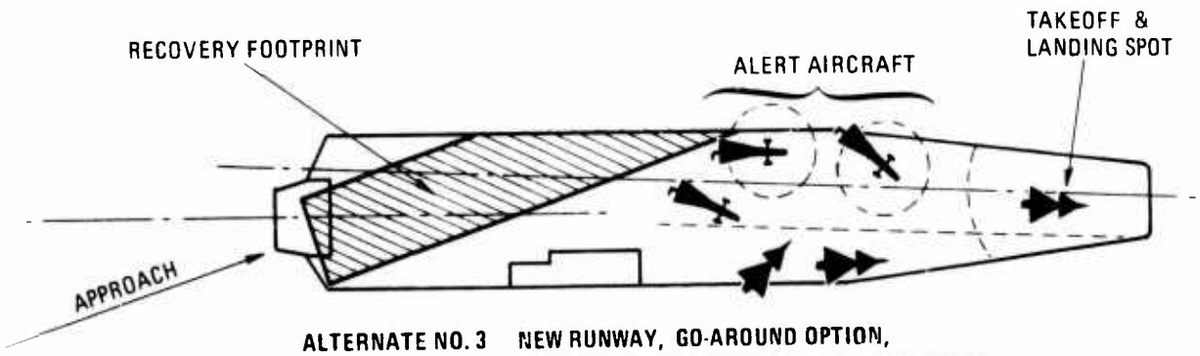
A third alternate landing runway for the arrested SLOROC RPV could be oriented from aft-starboard to forward-port on the aft end of the flight deck. The small landing footprint of the arrested SLOROC RPV, 54 feet by 164 feet, will fit within the presently proposed flight deck dimensions. No additional deck space is required. This alternate could not be used for the low-altitude penetrator RPV unless the flight deck is modified with an



ALTERNATE NO. 1 STANDARD RUNWAY, NO GO-AROUND OPTION
FORWARD FLIGHT DECK ACTIVITY PERMITTED



ALTERNATE NO. 2 STANDARD RUNWAY, GO-AROUND OPTION
NO FLIGHT DECK ACTIVITY



ALTERNATE NO. 3 NEW RUNWAY, GO-AROUND OPTION,
FORWARD FLIGHT DECK ACTIVITY PERMITTED

Figure 10-5. Arrested Recovery Footprint, SCS

extended runout area for the angled flight deck. A safety barricade may be added partway across the flight deck at frame 333 to provide additional protection for the forward flight deck area but operational experience may show this option to be unnecessary. The angled landing footprint will reduce the hazards of RPV landings to the superstructure and the forward flight deck area and also provide a clear route for the no-hookup go-around option. The go-around option has great value on the SCS due to the limitations on intermediate maintenance which may make on-ship repair of barricade recovered RPVs impractical.

The landing footprint angle relative to ship centerline should be selected as high as possible to maximize the usable forward deck space. The maximum angle of approximately 20 degrees, as depicted in alternate No. 3 of Figure 10-5 provides the most usable forward deck space and as the angle decreases, the clear forward deck space decreases. The selected deck angle will depend on a combination of desired forward deck space, headwind and cross wind constraints, air turbulence from the super-structure and the desirability of adjusting ship's heading to effect RPV recovery.

The arrested recovery landing zone on the ship is equipped with three fixed wire rope cables, each 48 feet long, strung laterally across the flight deck at 30 foot intervals as shown in Figure 10-6. The cables are held a minimum of 2 inches above the deck to facilitate hook up and still permit landing gear rollover. If a barricade is required, a scaled down version of the standard aircraft carrier barricade can be used. Deceleration distance in front of the barricade is required, reducing usable deck space forward of the RPV landing area. The arrestment pendants and/or the barricade can be designed for deployment only during RPV recovery operations to keep the deck clear at other times. Neither the pendants nor the barricade are equipped with arrestment engines, as the deceleration energy is dissipated in the RPV on-board braking system.

The recovery approach is controlled automatically by the computers in the RPV and the shipboard control center operating in a coordinated manner over an rf data link. The SRCO has a manual override capability for taking control in emergencies or special unprogrammed situations, e.g., RPV control problem due to battle damage, etc. The automated landing system guides the RPV to touchdown at an optimum point on the deck for pendant hook up. For the go-around capable systems, the on-board computer senses touchdown and initiates go-around in event of no hook up, or shuts down the engine after deceleration to a stop in event of successful arrestment. For no-go-around systems, the onboard computer shuts down the engine on touchdown. After successful arrestment, the flight deck crew secures the RPV to a tow vehicle, releases the tailhook from the RPV and moves the RPV off the recovery area.

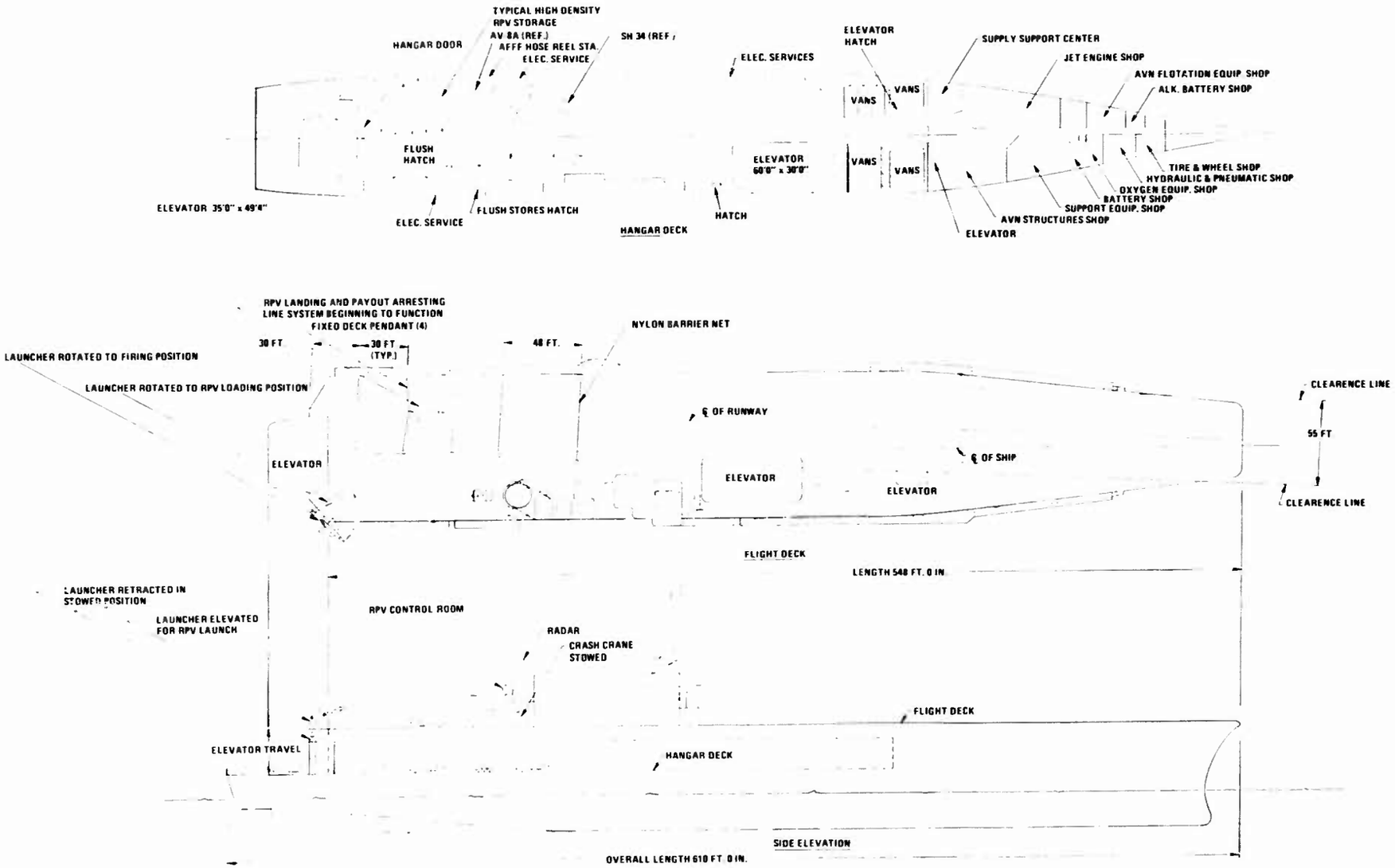


Figure 10-5. Slow-Rate-of-Closure RPV Operations Aboard Sea Control Ship

10.3.3 VERTICAL LANDING

Three RPV concepts were considered for vertical landing on the SCS; the tailsitter, the deflected jet and the rotor wing. The tailsitter RPV lands with fuselage in the vertical attitude while the other two vehicles land with fuselage in the horizontal attitude. All three vehicles are captured to the deck at the recovery spot by mechanical docking mechanisms to insure a positive recovery and preclude post-recovery movement due to ship's motion. The docking mechanisms consist of hardware installations in the RPV and at the recovery spot on the deck.

Approach to the SCS for recovery is from the aft starboard quarter similar to that depicted in Figure 10-5, alternate No. 3, for the arrested recovery. This path provides a clear area forward of the RPV for contingency waveoff with minimal hazard to aircraft resources spotted on the forward flight deck. The absence of ship structure on the aft flight deck also minimizes the hazards due to the forward velocity of the RPV decreasing below that of the ship in event of a missed approach or false docking. The heading provides clear line-of-sight visibility from the RPV control center during recovery approach, docking and contingency waveoff with acceleration of the RPV to the port side of the ship.

The aft starboard quarter approach has the disadvantage of operation in the air turbulence caused by the ship superstructure at the critical recovery phase where the RPV is in close proximity to the ship structure. The control problem can be reduced by decreasing ship's speed during VTOL recovery or adjusting ship's heading for favorable wind off the aft starboard quarter.

10.3.4 RECOVERY OF THE TAILSITTER VTOL CONFIGURATION

The tailsitter RPV transitions to the vertical attitude at some distance from the ship so that the recovery approach can be safely made at low speed in stabilized near-vertical attitude flight. The automated landing system guides the RPV to touchdown and engagement of the docking mechanism by continuously adjusting approach path to insure touchdown at preselected optimum ship roll, pitch and heave characteristics. The tailsitter drops vertically onto the recovery spot where it is captured by the docking mechanism. The docking mechanism recovery gear is described in Paragraph 11.3.3.3 under Tailsitter Recovery on the DE-1052.

10.3.5 RECOVERY OF THE ROTOR WING & DEFLECTED JET VTOL CONFIGURATIONS

Like the tailsitter RPV, the rotor wing and deflected jet RPVs transition to hover flight mode at some distance from the ship so that recovery approach can be safely made at low speed and stabilized horizontal fuselage attitude. The automatic landing system guides the RPV to engagement of the docking mechanism by adjusting the approach path to insure RPV arrival over the recovery spot at preselected altitude and approach angle for optimum ship roll, heave and pitch characteristics. Both the rotor wing and deflected thrust RPVs are docked by engagement of a suspended mooring line in a deck mounted clamping fixture as shown in Figure 11-8 and Figure 11-9.

VTO Docking Method

A guide and clamp fixture is installed on the flight deck in the recovery spot to capture the mooring line suspended from the RPV. The guide is a saw-tooth shaped fixture with the V-shaped notches oriented toward the approach path of the VTOL RPV. At the apex of each notch is a pressure operated clamp. The RPV approaches the guide with a weighted wire rope mooring line suspended under it at a fixed length. The automatic landing system adjusts vehicle flight path to bring the suspended weight into the sawtooth shaped guide. As the RPV moves forward, the suspended cable is guided to the apex of the notch and the clamp actuates, capturing the mooring cable. As tension on the mooring cable increases, the RPV enters a hauldown mode in which the vertical lift is kept constant and the mooring line winch in the RPV winches the vehicle down to the deck. The constant tension winch permits cable payout when the deck moves down or cable takeup when the deck moves up due to ship heave and pitch. When the wheels contact the deck, the engine is shut down and the ship RPV operations crew secures the RPV.

Deck Modifications

To protect the flight deck of the SCS from the direct impingement of the high temperature, high pressure turbojet exhaust of the tailsitter configuration, a raised landing platform similar to that described for the DE-1052 class ships (Paragraph 11.3.3.3) can be used. A square platform can be located aft of the aft king post hatch at Frame 490 and 520 and at the starboard deck edge. Access to and from the platform can be by a removable ramp to limit RPV dedicated deck space or a permanent ramp if deck space is not critical. The platform dimensions can be made compatible with helicopter landing gear footprint requirements so the spot can be

used to position a plane guard or alert helicopter when not in use for RPV launch or recovery. The platform must be located clear of the aft elevator access path, aft UNREP station and the fueling/power stations in the vicinity.

10.4 RPV COMMAND AND CONTROL - SCS OPERATIONS

The RPV control center installation for the sea control ship should be designed under the following ground rules:

- A minimum of modifications to the vessel yet providing an installation that can permit visual monitor of all operations.
- The control installation would be the central operations from which all aspects of the maintenance, launch, mission, and recovery could be made.
- The installation would not offer hindrance to present manned operations or in the conduct of normal vessel functions.
- The installation would be in keeping with the present planned manned vehicle operations, i.e., utilize the existing landing aids, if practical.
- The support functions would be in keeping with the planned concepts of stocked vans.

Accordingly, in this study the space below the AN/SPS 35 antenna was utilized. Reference is made to Figure 10-7, which shows a preliminary design for an enclosed, glass-lined observation control room fitted in this area. The ceiling height is stepped to provide more usable area in the frontal (bay window) section; from 7 feet in the after section (rack console area) to the 6-1/2 feet in the forward section. The platform is located between and supported by the structural members which support the AN/SPN 35 Antenna. In the console area, there is space for eight standard military 6-foot high relay racks which can contain all necessary electronics. The remaining area can be used for air conditioning equipment and sanitary facilities. The enclosure provides environmental shelter and yet permits a 225-degree scan of the operations, except for the locally obstructed view over the aft basic point defense weapon. The forward observation platform can easily fit 5 multi-mode consoles, with ample seating facilities and walkaround servicing areas.

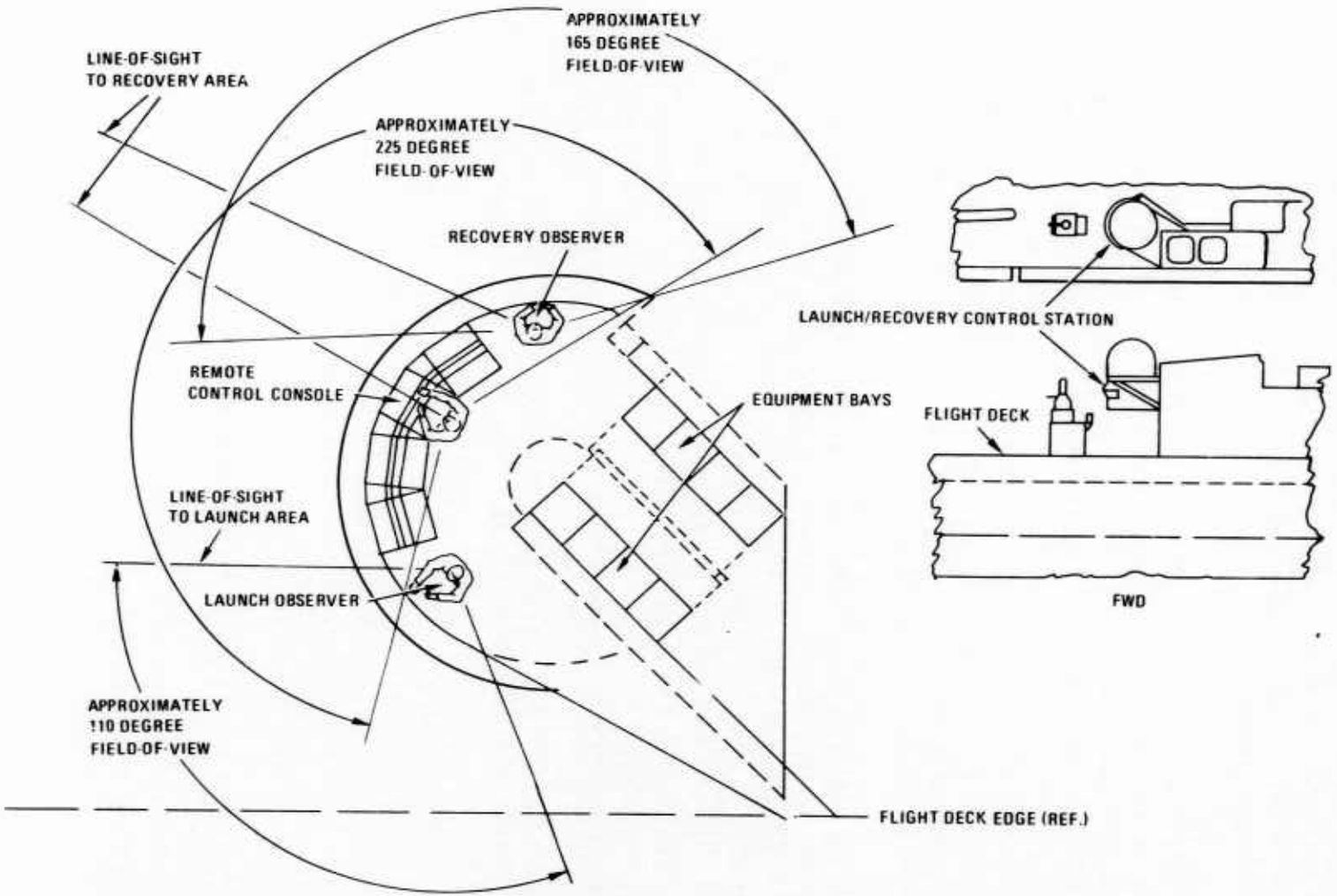


Figure 10-7. Recovery Control Center, SCS Launch

Access to the control room is by an added catwalk on the 0-5 level. The site permits good visibility of the RPV launch area by the RPV controller. This position also provides excellent visual coverage of incoming RPVs permitting visual as well as data link monitoring for override control during recovery. In addition, the missed approach path can be visually monitored from this station.

Communications and control to the below decks ready maintenance area uses the digital data bus and voice grade intercommunications. The organizational support specialized check out equipment is interfaced to the console complex for display and control. For large sortie rates and low turnaround times, a dedicated console located in the ready maintenance area would relieve the launch operations center of check out task during high rate operations. For normal low rate, i.e., less than 2/day, the combined checkout, launch, mission, and recovery control from the control center is considered acceptable.

Discussions with various competitors in the Sea Control Ship landing aid system competition determined that a modification to the commercial civil version of the scanning beam system is a preferred candidate. It is the Co-Scan system manufactured by AIL, the manufacturers of the AN/SPN-41 scanning beam system. The planned modification includes the extension of the elevation scan capability to 45 degrees. Primarily, this is to satisfy the helicopter approach patterns and should also satisfy the majority of the RPV approach profiles as well.

During tactical operations, however, only single approaches may be made during conditions of wave induced ship motion, i.e., only one incoming air vehicle at a time may use the ship motion compensated landing aid. Otherwise, large guidance errors will be transmitted to those vehicles in the approach path other than the one vehicle for which the close-in maneuver is being compensated for. The landing aids trade analysis, Section 6.3, clearly identifies significant benefits in applying the multilateration technique to RPV shipboard recovery.

The multi-lateration technique has particular advantages in individually addressing multiple vehicles in the approach patterns with landing steering commands in the presence of high ship motion and the simple installation requirements for this system.

10.5 LAUNCH AND RECOVERY EVALUATION, SEA CONTROL SHIP

The sea control ship launch and recovery operations evaluation covers five air vehicle configurations - two using RATO launch and arresting gear recovery and three using different methods for VTOL. All configurations were sized to perform the 500 nautical mile range mission for the high-low-high altitude penetration mission. Table 10-1 presents a compilation of evaluation judgements on a qualitative scale as discussed in the Evaluation Methodology Section, Paragraph 8.2. For each factor, a horizontal sweep across the table provides the relative variations between RPV configurations used for various launch-recovery methods. For instance, the impact of the operational interface factors, such as the ship's weight and balance, maneuvering constraint, weather and sea state constraints, and personnel are essentially the same for all configurations.

One of the two factors that show quantitative data is the number of RPVs per replaced SH-3 helicopter. Since a sea control ship fully loaded with RPVs (at this time) is unrealistic, the relative measure per replaced aircraft is appropriate.

10.6 SEA CONTROL SHIP STUDY CONCLUSIONS

An assessment based on the considerations listed in Table 10-1 and on engineering analysis has led to the following conclusions regarding the candidate air vehicle concept studies for SCS based operations:

a. RPV operations are feasible and practical from the sea control ship (SCS).

b. The conventional landing RPV (Configuration SLR01) can conceivably be adapted to the SCS, but the relatively high landing speeds and higher energy levels of this vehicle increase the accident potential above that of the other candidates.

c. The three VTOL concepts are all highly adaptable to the SCS but at much greater cost relative to the other configurations.

d. A high technical risk is associated with the rotor wing concept at this time due to the early stage of development of the rotor and power train.

e. The slow rate of closure (SLOROC) concept offers a substantially lower landing speed than can be attained with the conventional design and with relatively little increase in vehicle cost.

   Approach speed is 35.8 percent lower resulting in a 41.3 percent reduction in vehicle kinetic energy at touchdown. For these reasons, the SLOROC air vehicle concept was selected as the most practical low-altitude penetrator for operation from the sea control ship.

f. A simplified ship mounted arresting cable system without the usual energy absorbing devices will be required for the SLOROC RPVs. Energy absorption will be obtained with a vehicle mounted drum brake and cable system as discussed in Paragraph 9.3.5.

g. The launch system selected is zero-length RATO launch (see Paragraph 10.1.1.2).

TABLE 10-1

EVALUATION SUMMARY, SEA CONTROL SHIP

EVALUATION CRITERIA	RPV CONFIGURATION				
	SLR01 RATO LAUNCH, HOOK, ARREST GEAR RECOV.	SLR03 STOPPABLE ROTOR, VTOL	SLR04 VECTORED THRUST, VTOL	SLR05 TAIL SITTER, VTOL	SLR06 RATO LAUNCH, HOOK, ARREST GEAR RECOV.
SHIP CONSTRAINTS					
Ship Weight and Balance	1	1	1	1	1
Ship Maneuverability	1	1	1	1	1
Ship Motion	3	3	3	3	3
SHIP/RPV COMPATIBILITY					
No. of Equiv. RPV's per Replaced SH-3					
Flight Deck Spot (1)	5.9	3.8	5.0	11.7	4.9
Hangar Deck Spot (1)	3.3	2.3	2.9	5.7	2.8
Flight Deck Space	2	3	2	2	2
Hangar Deck Space	3	3	3	2	3
Storage Space	3	3	3	3	3
Personnel Space	2	2	2	2	2
Ship Command and Control Systems	3	3	3	3	3
Launch Systems	2	2	2	2	2
Recovery Systems	4	2	2	2	3
Maintenance Methods	1	1	1	2	1
RPV Test and Check-out	3	3	3	3	3
Handling Equipment	2	2	2	3	2
Ship Power Outlets	1	1	1	1	1
Ship Fuel Outlets	1	1	1	1	1
COMPATIBILITY WITH SHIP WEAPONS SYSTEMS					
Manned Aircraft	4	3	3	3	3
Other Weapons Systems (Guns, Missiles, etc.)	2	2	2	2	2
TECHNICAL RISKS					
Air Vehicle	2	4	3	3	2
Launch Systems	2	2	2	2	2
Recovery Systems	2	2	2	2	2
Command and Control Systems	2	2	2	2	2
SAFETY					
Deck Handling	2	2	2	2	2
Launch Operation	2	2	2	2	2
Recovery Operation	4	2	2	2	3
Jet Blast	2	3	3	3	3
COST					
Air Vehicle Relative Costs (100 Quantity, Less Payload)	1	1.85	1.48	1.46	1.26
Ship Modification Costs	low	low	low	low	low

Judgment Scale:

1. Acceptable, no adverse impact or risk.
2. Acceptable, little adverse impact or risk.
3. Acceptable, moderate adverse impact or risk.
4. Marginal.
5. Unacceptable

(1) Actual no. of RPV's not evaluation rating.

11.0 DESTROYER STUDIES

11.1 DESTROYER OPERATIONS SUPPORT CONCEPTS

Aboard destroyer type vessels, RPVs will encounter a harsh physical environment and severely limited support resources. These factors will combine to limit the amount of maintenance that can be done at sea. The maintenance concept will therefore be constrained to operational support activities aboard the destroyer, with complete organizational and intermediate maintenance support provided at facilities aboard destroyer tenders or at stations ashore.

11.1.1 OPERATIONAL SUPPORT

Operational support is defined as that on-vehicle servicing, inspection and repair performed on-board the destroyer to retain the RPV in an operationally ready, or "up", status. It does not include any vehicle teardown, repair or calibration requiring RPV peculiar support equipment, or any testing requiring RPV peculiar stimulus generating or response measuring test equipment external to the RPV. The operational support functions will include the following tasks:

- Servicing
  - Fuel and Oil Replenishment
  - Cleaning
  - Lubricating
  - Corrosion Prevention
  - Battery Servicing

- Inspection
  - Periodic Inspections not Requiring Disassembly
  - Pre-Flight Power-On Confidence Check of On-Board Systems

- Repair
  - Replacement of Avionic Light Replaceable Assemblies (LRAs)
  - Repair of RPV Structure Using Shipboard Shop Facilities and Tools.

Servicing

The servicing tasks do not require any additional support equipment to be placed on-board the destroyer. The RPVs will be refueled using the existing JP-5 fueling facilities. Oil will be provided in quart cans. Cleaning, lubricating and corrosion prevention are all manual tasks not requiring support equipment. Battery servicing, if required, will be provided using shipboard facilities. Of all these servicing tasks, only refueling need be conducted outside of the hangar on the flight deck. The ship - RPV fueling interface should therefore be designed for all-weather, night and day operation within the RPV operational sea state conditions.

Inspection

Corrosion control in the destroyer environment will be a major consideration in prolonging life of a reusable RPV. Inspections to detect corrosion will be necessary. Periodic inspections will be done either in the aircraft hangar or on the flight deck of the destroyer. Design considerations for visual inspections will include access panels located to provide direct observation of qualitative built-in test equipment (BITE) status indicators and critical RPV equipment installations.

Checkout

Equipment operational status will be determined by exercising the complete system in an end-to-end RPV Operational Readiness Check prior to flight. This check will be conducted using a ship mounted RPV control system consisting of a power and function control panel, external power source, and power and data distribution box connected to the RPV through a quick disconnect hardwire umbilical. The RPV control system is essentially a man-machine interface, which permits a human operator to control RPV power and operate on-board systems to check RPV status. To minimize test equipment required on the ship, the RPV will be designed with a Built-In-Test Equipment (BITE) concept. Under the BITE concept, the operational status of RPV avionic equipment will be determined internally by using a computer on-board the RPV to operate test equipment built into the avionic components in accordance with USN Versatile Avionic Ship Test (VAST) system requirements as defined in specfications AR-8, AR-9, and AR-10. For components without Built-In Test Equipment (BITE), the computer will be programmed to synthesize test stimuli and measure component response to determine operational readiness. Where the on-board computer can be used to sequence the operational readiness check, synthesize test stimuli and measure test responses, external test equipment will be eliminated, minimizing the requirement for RPV dedicated equipment and space on-board the destroyer.

Besides controlling the Operational Readiness Check, the RPV Control Station will be used as an aircraft "cockpit" to initialize RPV systems for launch. During launch initialization and subsequently during RPV flight, the on-board computer will be programmed to monitor systems operation and identify failures.

Repair

Some replacement of faulty RPV components will be accomplished on-board the destroyer. This will be limited to components which may be removed and replaced without using special tools and when replacement does not result in a requirement to conduct a special test or calibration of the system involving use of external test equipment. Spares will be provided from a limited stock of flight critical items stored on-board the destroyer, or they will be transferred to the destroyer from the parent RPV activity located aboard a destroyer tender or shore facility. For repair or test beyond this limited on-board capability, the faulty RPV will be returned to the parent RPV organization.

Handling

A restraint system is used aboard DE-1052's to prevent inadvertent RPV movement on deck due to ship's motion. The design of the system gives consideration to operation in adverse weather conditions such as high winds and deck icing. The restraint system is used to:

a. Hold the RPV in place at the launch spot prior to and during attachment of the launch holdback fitting.

b. Hold the RPV in place at the recovery spot after recovery and during preparations for movement into the hangar.

c. Restrain the RPV movement during transport between the launch/recovery spot(s) and the hangar.

d. Hold the RPV in place in the hangar during maintenance.

For functions a, b, and d, above, the RPV must be moored in one spot for a period of time with no movement required. For these functions, personnel will be working on the RPV, connecting mechanical and/or electrical interfaces between the RPV and the ship, and RPV movement must be completely restrained to preclude hazards to personnel, especially during adverse weather conditions. Therefore, for these functions, the RPV is tied down to the ship using the standard deck tie-down fittings,

adjustable tie-down cables and tie-down fittings on the RPV airframe. The number of tie-downs used depends on the immobility required and weather conditions.

During point to point transport, the RPV must be restrained to the movement route, which in the case of recovery, may vary due to the probability of landing at any point on the recovery area. Since different restraint systems for launch and recovery are not advisable, a tracked system which restrains the RPV to a fixed path on the deck cannot be used.

Also to minimize interference with other ship operations and permanent dedication of facilities or space to RPVs, the restraint system should consist of readily removable equipment which can be deployed only when needed. The RPV restraint system could then be stowed to clear the flight deck during UNREP or other activities. A deployable wire rope restraint system meets these requirements. The system can be composed of the following:

a. Hand operated winch in the hangar with cable for attachment the RPV to tow the RPV forward relative to the ship or restrain movement aft.

b. A second hand operated winch on the aft end of the flight deck to tow the RPV aft or restrain movement forward.

c. Deck cables running fore and aft on the flight deck and in the hangar, attached to the deck at various points along their length. The RPV is connected to these cables by secondary guys to prevent excessive lateral movement during transport. Length of the guys is adjusted to provide for recovery spot offset. The guys are connected to the main fore and aft guide cables with quick disconnect couplings to permit stepover at the guide cable tie-downs.

For RPV movement, the RPV is connected to the guide cable system prior to disconnection from the tie-down system. At the destination spot, the vehicle is tied down prior to removal of the transport restraint system. Obviously, the transport restraint system can be optional when circumstances do not require its use for RPV transport.

Hangar Storage

The importance of protecting the RPV from the harsh environment of the open sea must be emphasized. Environmental tests were conducted using two Teledyne Ryan BQM-34A RPVs aboard the USS RICHARD B.

ANDERSON (DD-786) in 1971 to test the corrosive-resistant ability of the RPVs during sea trials. One of the RPVs was protected with a radome bubble and the other was left unprotected. While the protected vehicle displayed no evidence of corrosion, the unprotected vehicle had noticeable corrosion in magnesium components of the wing and empennage. Most of the problem of corrosion could be avoided by eliminating the use of magnesium components. However, corrosion is only one aspect of the need for a protective shelter. Other factors to be considered are sea water in electrical connections, rain and sea water entrapped in the vehicle and subsequent freeze up, wave damage and sea spray damage, weathering under hot sun of rubber seals and evaporation of fuel. Therefore, an important criteria in evaluating the various RPV configurations in this study is the number of RPVs that can be accommodated in the hangar of the DE-1052 class ocean escort.

11.2 LAUNCH

11.2.1 RATO LAUNCH

The two SLOROC configurations considered for the DE-1052 class destroyer are SLR06-2 and SLR06-3 which would be recovered using the Net Recovery System (Paragraph 11.3.1), and the Aerial Track Recovery System (Paragraph 11.3.2), respectively. In both cases, the method of launch would be RATO launch from a short-rail launcher.

The RATO launcher on the DE-1052 class ocean escort would be mounted the port side of the ship immediately aft of the flight deck. The rotating launcher would be supported on a telescoping column which permits lowering the entire launcher just below the flight deck level for storage.

Figure 11-1 illustrates the launcher installation on-board the DE-1052 class ship.

To prepare for RATO launch the launcher is raised from its stowed position below the flight deck level and rotated to the RPV loading position on the flight deck. The RPV is transported from the hangar area using a special handling dolly and backed into the launch support rails. Positioning of the RPV on the launcher is assisted by the deck mounted wheel guides for the RPV handling dolly. The RPV is then secured to the launcher with a thrust holdback fitting and the electrical umbilical is connected. The launcher is then elevated, raising the RPV off the flight deck and off the handling dolly. The dolly is returned to the hangar area and the RATO motor is delivered from the magazine (located just forward of the hangar with direct access from the hangar area) to the launcher for installation on the RPV. Once the RATO motor is installed, the RPV can be rotated to the desired launch heading. Normally this

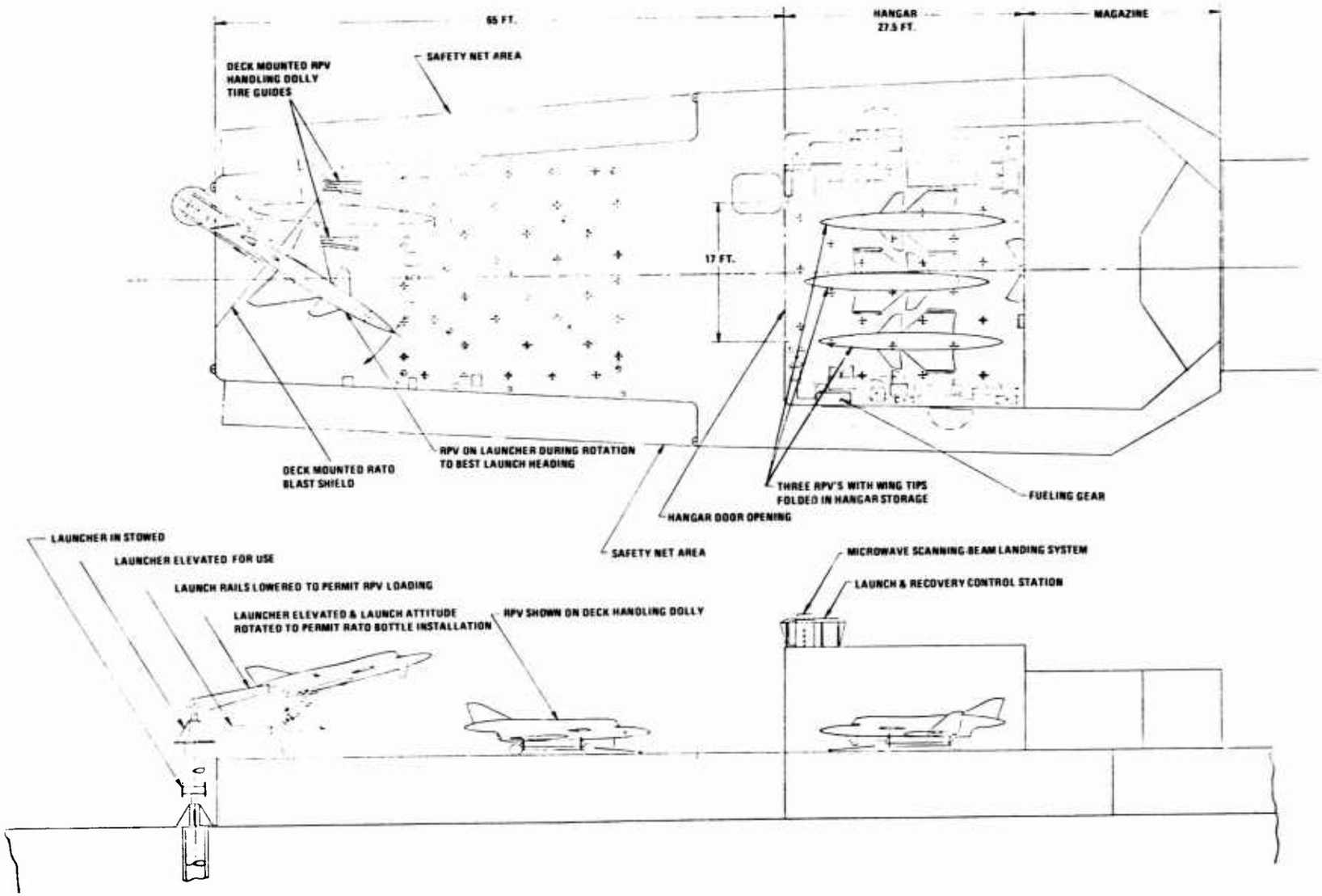


Figure 11-1. RATO Launch Provisions, DE-1052 Class Ocean Escort

would be diagonally across the flight deck. A sheet steel deck covering protects the aluminum plate flight deck from adverse RATO motor exhaust effects.

For RATO launch from this location, the RATO exhaust plume would be directed aft of the flight deck. The noxious RATO exhaust cloud would not interfere with an RPV remote controller's visibility in event of a need for contingency control action, or with flight deck visibility, and it would not present a health hazard to flight deck personnel. With the ship underway, the exhaust cloud would be quickly left astern without drifting over the flight deck.

The launch sequence for RATO launch is discussed in greater detail in Paragraph 10.1.1.2 and illustrated in Figure 10-3.

11.2.2 VTO LAUNCH

All three vertical take off (VTO) RPV concepts are considered for launch from the DE-1052. Launch support is minimized for the VTO RPV since it is launched under its own power by rising vertically from a designated launch spot on the deck on the downward directed thrust of its own engine. The launch spot on the flight deck provides line-of-sight visibility for the Shipboard Remote Control Officer (SRCO) in the DE RPV control station for operations control and safety. The launch spot also has rf line-of-sight visibility to the remote control system antennas to provide an unblocked remote control link during the transition from hardwire control umbilical disconnect to airborne free-flight. The launch spot is equipped with mechanical and electrical ship-to-RPV interfaces to facilitate transfer of the RPV to the launch spot and initialization of RPV to launch condition for launch into free-flight. The interfaces include:

a. A transport restraint system to hold the RPV securely to the ship during transport to the launch spot.

b. A holdback fixture to hold the RPV securely to the ship during prelaunch engine run.

c. Electrical umbilicals, power sources and control systems to permit the SRCO to start the RPV engine, initialize on-board systems to launch condition and release the RPV holdback at launch.

The holdback fixture requirements and VTO launch procedure are described further in Paragraph 10.1.1.3 under VTOL launch from SCS. The destroyer (DE) RPV control station is described in Paragraph 11.4.

Launch Heading

The preferred launch heading for VTO RPVs is to port to provide unobstructed visibility for the SRCO during the critical post-launch phase of flight. Since the VTO RPV rises vertically when released by the launch holdback fixture, the area aft of the launch spot should be clear of high structure which would sweep forward with the motion of the ship to collide with an RPV that is rising slower than normal. The area under the launch path should also be cleared of equipment that is susceptible to damage from the downward directed exhaust gases expelled from the VTO engines at high temperature and high velocity. This restriction will include painted surfaces, light fixtures, personnel nets, etc.

Launch Procedure

When the launch condition is set aboard the DE, the RPV operations crew opens the hangar door and deploys the launch support equipment, including transport restraint system, control umbilicals and prelaunch holdback fixture. The RPV is connected to the restraint system and the maintenance tiedowns are removed. The vehicle is then moved to the launch spot using the transport restraint system, if conditions require. During this function, the Tailsitter RPV is stopped outside the hangar and the nose module is erected and secured. The RPV is then tied down at the launch spot and the holdback fixture and umbilicals are connected and secured.

An umbilical interface power check can then be conducted to verify connection integrity, The RPV operations crew then removes and stows the transport restraint system and other loose gear, closes the hangar door to protect hangar contents from jet blast effects and clears the flight deck area.

At the predetermined countdown start time, the SRCO applies electrical power to the RPV to initialize onboard systems for launch. The engine is started, power is switched to internal RPV power sources and the engine is brought up to launch thrust setting. With all systems in the GO condition and launch clearance verified with ship operations control, the holdback is released to launch the RPV into flight.

During initialization for launch of the VTO RPV concept using thrust vectoring for launch, the engine is started with thrust nozzles directed aft to preclude deck heating and heat damage to landing gear. After all systems are properly initialized for launch, the nozzles are directed downward and the holdback fixture is actuated, releasing the RPV into vertical flight.

Ship Modifications

Ship modifications to support launch of VTO RPVs vary with each concept of RPV. The Tailsitter and Vectored Thrust vehicles both require deck protection from the high temperature, high velocity exhaust gases.

For the Tailsitter, the exhaust gas impinges on the deck throughout prelaunch engine run, from engine start to launch or abort shutdown. The gas flow is also concentrated in one location under the exhaust pipe of the vehicle, and strikes the deck at a vertical angle. The design of deck modifications for the Tailsitter is also driven by recovery requirements in which the deck must be protected from engine exhaust while providing a means of securely capturing the RPV to the ship at touchdown.

A combination deck protection and RPV capture system for recovery of the Tailsitter is discussed in Paragraph 11.3.3.3. This installation can be used with a prelaunch holdback fixture to support Tailsitter RPV launch. The raised platform protects the deck from direct impingement of exhaust gas. Since, for launch, the exhaust gas impingement is concentrated for long duration, the raised platform can be augmented with additional protective plates or scoops to direct exhaust gas away from the deck. This alternate is not possible at recovery since the actual touchdown spot may vary.

For launch of the vectored thrust RPV concept, the impingement of exhaust gas on the deck will occur for only a short time as the thrust nozzles are directed downward only during the final moments before holdback release. In this case, deck protection can consist only of high temperature alloy plating in the area under the RPV.

For the Stopped Rotor RPV concept, no additional mechanical interface is required over the holdback fixture.

11.3 RECOVERY

11.3.1 NET RECOVERY SYSTEM

A net recovery system has been evaluated for the DE-1052 class destroyer for the recovery of modified version of the SLOROC configuration (see

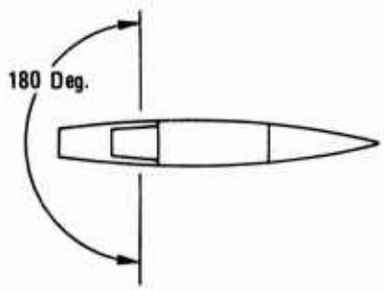
Figure 11-2). The basic concept utilizes a large net which forms a large landing area at the ship's stern as illustrated in Figure 11-3.

11.3.1.1 Approach Path for Net Recovery System

The selection of the most desirable approach path during recovery of the RPV using the Net Recovery System should consider such factors as minimizing relative closing speed between the RPV and the ship, taking into account natural wind direction and speed, ship speed and RPV flight characteristics. Other considerations for approach path selection should include the effects on the relative ease of predicting ship motion, the availability of suitable shipboard locations for recovery equipment and the effects of air turbulence caused by ship superstructure. Of course, the driving consideration for all aspects of both launch and recovery techniques is the concern for ship and crew safety.

The most logical location for recovery net equipment on the DE-1052 is in the general vicinity of the existing helicopter flight deck area. This area provides the least obstructed location for the installation of the net recovery systems. In addition, it is in close proximity to storage and maintenance facilities.

Since it is the intent of this study to assume a cooperative ship, it follows that the ship will be oriented to the natural wind in such a way as to allow the RPV to approach the ship into a head wind and thereby reduce the relative approach speed. By minimizing the approach speed, the kinetic energy to be dissipated during recovery will be greatly reduced. Under these conditions, an approach from the bow, or bow quarters, is not anticipated. This limits the potential approach paths to a circular segment approximately 180 degrees as shown in the sketch below:



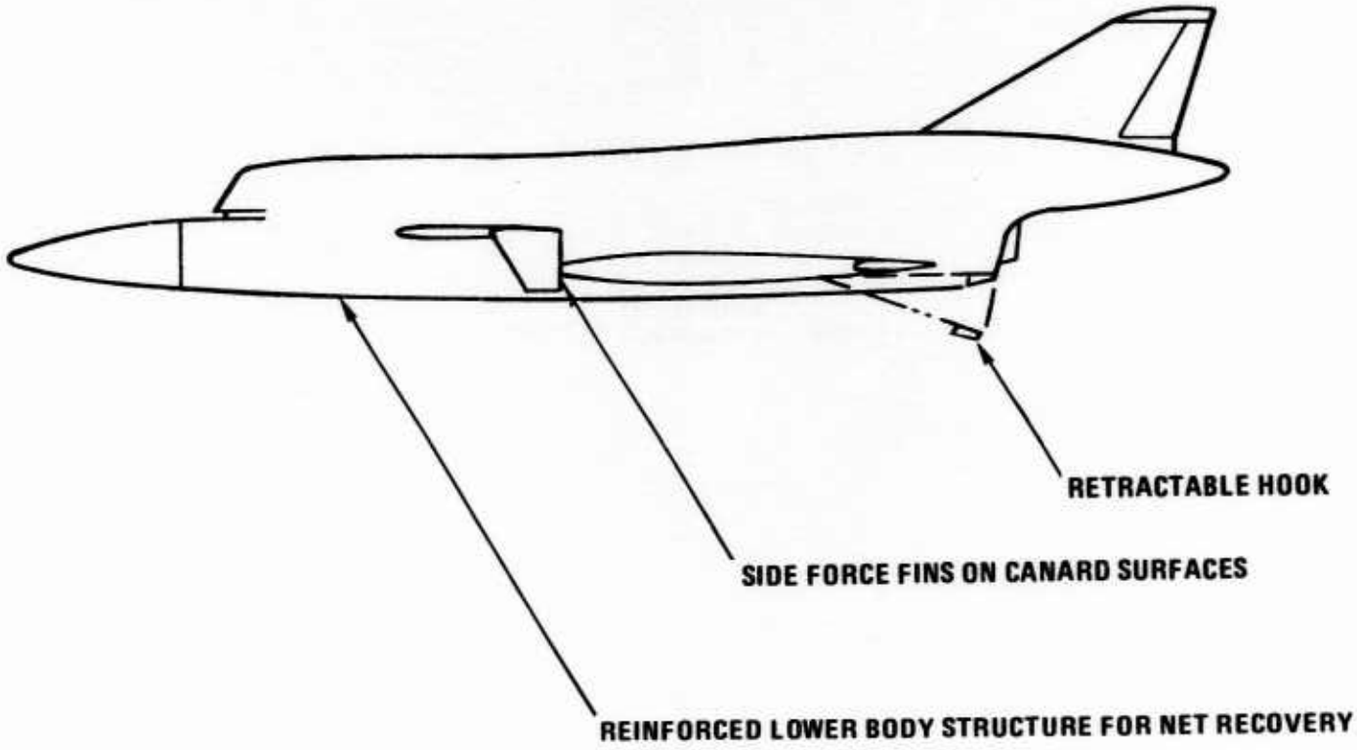


Figure 11-2. Slow-Rate-of-Closure Configuration, SLR06-2 for Net Recovery

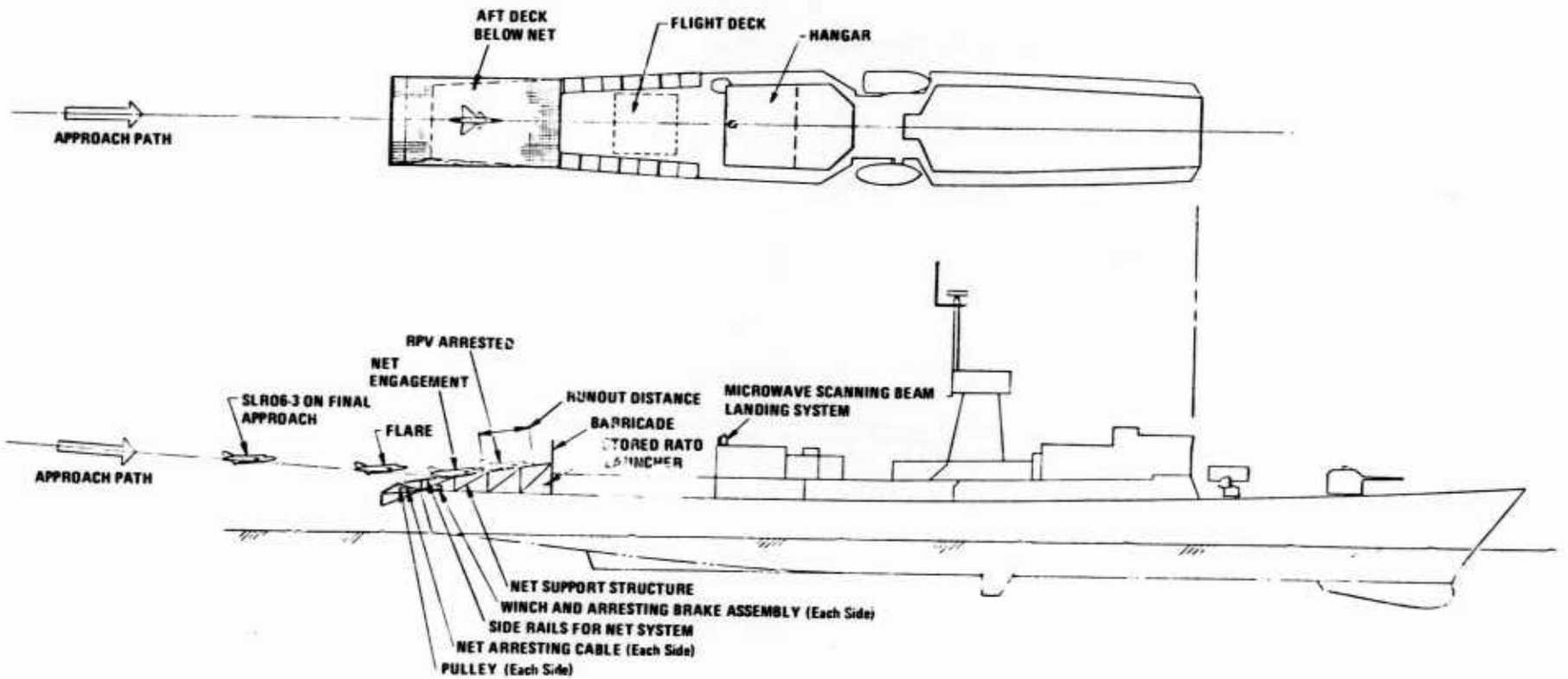
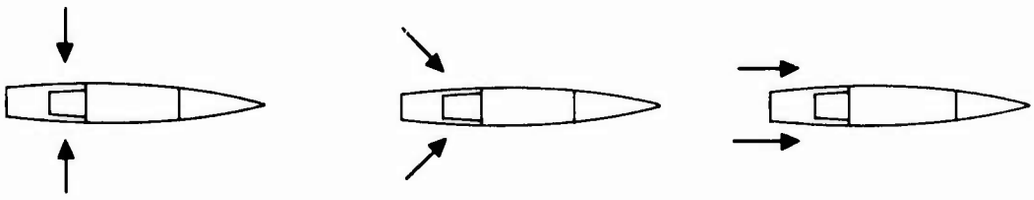


Figure 11-3. Net Recovery System for DE-1052 Class Ocean Escort

Depending on the type and location of the recovery equipment, the total approach segment can be divided into three basic types of approach to the ship as shown below:



(A) Approach from Beam (B) Approach from Aft Quarters (C) Approach from Stern

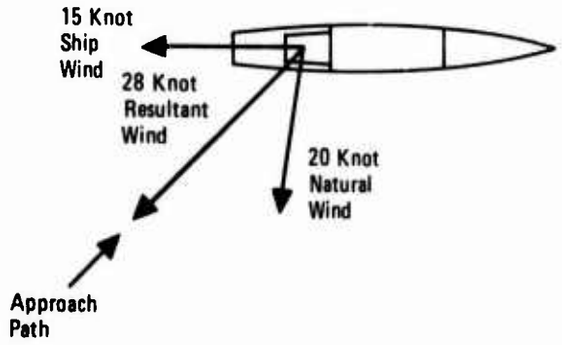
11.3.1.2 Approach from Beam

A disadvantage of this location is the relative difficulty in providing a recovery system which would provide an adequate deceleration distance to keep the load factor on the RPV within acceptable limits during recovery.

One aspect of ship motion prediction is complicated by the beam approach path, that of ship speed. An approach from the beam requires the RPV to lead the ship to compensate for the ships speed and direction. If the RPV leads the recovery target area too much, there is the danger of the RPV impacting the forward area of the ship or may cause the RPV to climb at steep angles to avoid hitting antenna masts during a waveoff. A low approach would also require steep climb angles anywhere along the length of the ship during a beam approach.

Finally a beam approach would not allow the RPV to take full advantage of both ship speed and natural wind conditions to reduce relative approach speed. Considering the extremes, if the ship were to cruise into the wind, a beam recovery approach would result in a cross-wind landing. If the natural wind were a beam of the ship, then the RPV could land directly into the natural wind, but would not be taking advantage of the ship speed. By combining ship direction and speed, with natural wind direction and speed, a resultant wind vector can be obtained which is positioned directly abeam of the ship and in a direction opposite to the recovery approach path. Obviously, the resultant wind vector will always be less than the ship headed directly into the wind if a beam approach is assumed. The

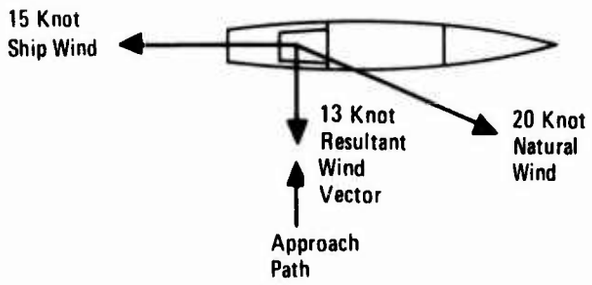
sketch below illustrates the resultant wind vector with the ship traveling at 15 knots and a 20-knot natural wind.



BEAM APPROACH WIND VECTOR DIAGRAM

11.3.1.3 Approach from the Aft Quarter

By approaching from angles in the area of the aft quarter, the recovery system is provided greater flexibility in the selection of combining natural wind conditions and direction of ship travel. By positioning the ship to account for ship speed and natural wind direction a resultant wind vector can be achieved which would allow the RPV to land directly into a headwind and thereby reduce closing speed between the RPV and the ship. This case would require heading the ship across the flow of the natural wind, the relative angle determined by the magnitude and direction of the ship speed and the natural wind. An example of a wind vector diagram for an approach from the aft quarter is illustrated in the sketch below for a ship speed of 15 knots and a natural wind of 20 knots.



AFT QUARTER APPROACH WIND VECTOR DIAGRAM

As in the case of the beam approach, the ship can not be directed to take full advantage of both ship speed and natural wind to reduce RPV closing speeds. The RPV would require an approach path that included prediction of ship position at contact with the recovery equipment. The aft quarter approach increases the safety to the ship by providing greater opportunity to clear the ship superstructure in the event of a wave-off than in the case of a direct beam approach.

11.3.1.4 Approach from the Stern

An advantage of an approach from the stern is the possibility of combining ship speed and natural wind conditions to minimize closing speed by heading the ship into the wind. By flying the RPV on a parallel course to the ship, the RPV can approach from behind the ship, headed into the wind. Relative closing speed can be varied by changing ship speed or RPV flight speed without requiring a change of ship or RPV heading. The problem of predicting ship position (lead) at recovery contact is eliminated or greatly simplified. The kinetic energy of the RPV during recovery would be dissipated by allowing the RPV to decelerate the required distance along the length of the ship, rather than across the width of the ship as in the other approach paths discussed above. In the event of a wave-off the RPV would be required to perform relatively simple turn maneuvers without steep climb angles.

Other considerations involved in this type of approach include the fact that the recovery target area will experience more motion due to ship roll due to being located off the ship's roll axis. Depending on the distance from the roll axis, these motions could be considerable for heavy sea states. These motions include both vertical and lateral displacements

due to roll. Vertical displacements due to pitch is dependent on the distance from the ship's pitch axis and therefore not necessarily different from the vertical displacements associated with the other approach paths. The effects of air turbulence created by the ship superstructure would be minimized by the location off to the side of the ship of the recovery equipment. If the turbulent area behind the ship is shifted to either port or starboard due to relative wind vectors, recovery on the less turbulent side would greatly ease recovery. This is possible under the assumption of a cooperative ship.

However, the location off to the side of the ship for the net system was not considered practical for this application for the following reasons. The large size of the net would require heavy support structure to position the net off to the side of the ship and would contribute an unsymetrical top-side weight which could seriously affect the roll stability of the ship. The side net system would be difficult to deploy and retract during adverse sea state conditions. Once the RPV was recovered in this net, it would be difficult to attach recovery gear to the RPV to bring the vehicle onboard the ship. The side net location was not considered as safe as the centerline location for protection of the ship. The following section describes a centerline net installation.

11.3.1.5 Net Recovery System

The overall net size would be approximately 65 feet long and 36 feet wide. The net would extend from the aft edge of the flight deck to approximately 12 feet behind the stern of the ship. A protective barrier is located at the aft end of the net to protect the ship. At the forward end of the net, a barrier arrangement, which is similar to the emergency barrier system aboard aircraft carriers, is installed. This barrier is a series of vertical webs attached to the arresting brake system. This barrier protects the flight deck area in the event of a missed engagement of the net.

The net is mounted between, and supported by, rail tracks installed at the outboard edges of the ship. Reinforced nylon webs run across the deck at approximately 1 foot intervals. Additional webs running lengthwise are tied to the transverse webs to form a grid of webs with one foot square openings. Each transverse web is attached to a sliding cleat mounted in the rail track at each side of the ship. Each end of the transverse webs is also mounted to a cable running along each rail track to two cable drums mounted on the deck of the ship. Each cable drum is equipped with an arresting brake which serves as the means to dissipate the kinetic energy of the RPV during recovery. The RPV approaches the ship from the rear following the glide path slope provided by the

microwave scanning-beam landing system described in Section 6. The SLOROC vehicle approaches the recovery area in the slow flight mode and in this configuration, the vehicle is capable of flight speeds as low as 60 knots in still air, limited by aerodynamic control surface effectiveness. By approaching from the rear of the ship, the relative speed can be reduced significantly by combining ship speed and heading the ship into the natural wind. The recovery net is inclined at about 9 degrees up from the stern of the ship to facilitate landing at high angles of attack and to insure positive engagement of the hook. A horizontal net would require a longer landing area to provide an equal probability of landing in the specified recovery area. The inclined net also eliminates the possibility of the recovery net being inclined downward toward the bow of the ship at the instant of recovery. As the RPV lands on the net, a tail hook engages one of the transverse webs and pulls against the braking force applied through the cables mounted at the sides of the net. As the cable is payed out against the braking force, the RPV is brought to rest, supported by the net. The RPV is removed from the net by attaching lines to lift fittings on the vehicle's upper surface and lifting it from the net with a crane. The crane would be mounted aft of the flight deck area and would be capable of being rotated and extending over all parts of the recovery net to permit lifting the RPV from any position on the net.

The net recovery system has the advantage of reducing RPV weight by eliminating nearly all recovery system weight from the air vehicle. The SLOROC system is much simpler than the VTOL systems considered and would therefore be a less expensive RPV than the VTOL vehicles.

However, the net system has many drawbacks for RPVs as large as the low altitude penetrator vehicle considered in this study. One major disadvantage is the safety of this concept. Even at low speeds, the 1,800 pound recovery weight represents a considerable amount of kinetic energy and the size of the net which can be mounted on the DE-1052 class ship is not large compared to the size of the air vehicle. While the net and barrier system described provides protection for the rear of the ship, it would not be practical to install a net tall enough to protect all of the forward superstructure. In the event of a high approach and wave-off, the RPV would be required to veer off to one side to avoid hitting the ship. In the event the RPV landed in the vertical barrier, the ship would be protected but the RPV would probably sustain some damage to wing leading edges and to the canard surfaces. On many of the DE-1052 class destroyers, the aft deck has been fitted with a missile launcher. On those ships fitted with the launcher, the ability to install the net system would be seriously hampered. The net when deployed would negate the defensive capability of the missile launcher. There would be physical

interference with the missile launcher if the net were installed as shown in Figure 11-3. For those ships with the missile launcher, the net would have to be installed at higher, more awkward locations above the deck.

Deck handling of the RPV is compromised in the version of the SLOROC configuration as the landing gear has been eliminated. This requires a special deck handling dolly to move the RPV about the deck and hangar area. A special crane installation is also required for this concept.

11.3.2 AERIAL TRACK RECOVERY SYSTEM

11.3.2.1 System Description

The Aerial Track Recovery System concept envisions recovering RPVs by replacing airfields and long flight decks with a cable track system. The basic aerial track recovery system consists of a cable suspended between two supports with a trolley that rides along the track cable. Attached to the trolley is an engagement sling which consists of a series of cable loops. These loops are the target for the RPV mounted hook to engage during landing. Also attached to the trolley is the arresting cable which is mounted through a series of pulleys to a cable drum fitted with an arresting brake. The RPV approaches the recovery site with a retractable arm extended several feet above the upper surface of the fuselage as shown in Figure 11-4. At the extended end of this support arm is mounted the engagement hook. The RPV is flown into position so that it is flying parallel to the destroyer approaching from the stern to minimize relative approach speed. The RPV is guided to the target sling and engages a cable loop with the hook. Following engagement, the RPV continues down the track pulling the arresting cable against the force applied by the friction brake. As the arresting cable is payed out against this braking force, the RPV is gradually decelerated. As the vehicle decelerates, the RPV weight is supported by the track cable through the sling and trolley. At the end of the runout, the RPV is suspended below the aerial track near the forward end of the track. To position the RPV on the flight deck at the stern of the ship, the arresting cable is winched in, pulling the RPV back along the track cable to the flight deck area. The track cable support arms are designed to be rotated about a vertical axis which permits the track cable to translate from the recovery position off the side of the ship to a position over the flight deck area. Once the cable track supporting the RPV has been brought in over the ship, the track cable is gradually slackened, lowering the RPV to the flight deck where it is secured to a deck handling dolly.

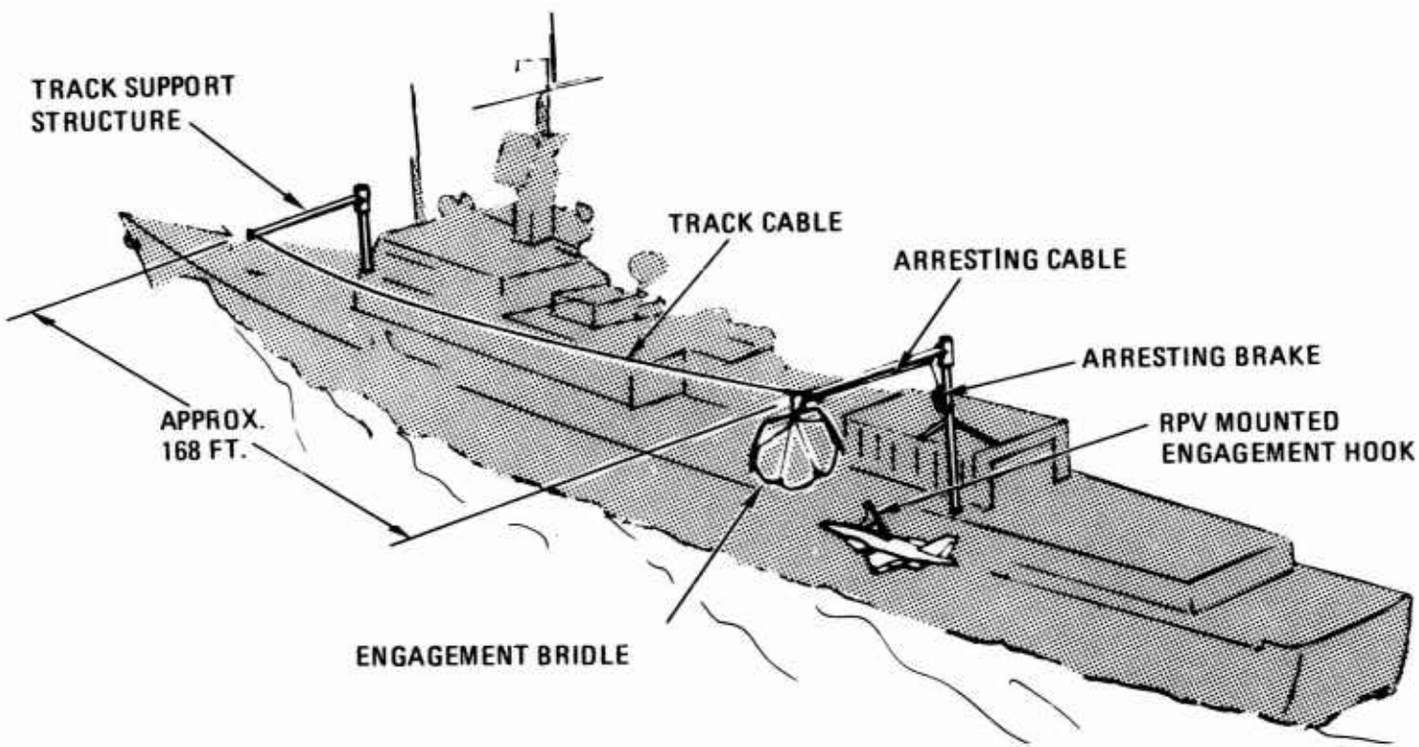


Figure 11-4. Aerial Track Recovery System

The track cable support structure is designed to position the engagement sling well above the water level and to the side of the ship. This requires two masts approximately 38 feet tall and cross arms at the top of each mast approximately 35 feet long at each end of the aerial track as shown in Figure 11-5.

The RPV mounted portion of the recovery system consists of a retractable arm which supports the engagement hook as shown in Figure 11-6. The engagement arm and hook are mounted on the centerline of the upper surface of the RPV fuselage. The length of the hook support arm determines the tolerance available to contact the engagement sling. The longer the hook support arm, the easier it is to engage the moving target. However, as the braking force is applied to decelerate the RPV, the force is reacted by the hook which is offset from the center of gravity of the RPV. This creates a couple which tends to rotate the RPV in a nose-up direction. The longer the hook support arm the greater the pitching moment during deceleration. It is therefore obvious that there is conflict between the desire for a long arm to increase the probability of hitting the engagement sling with the hook, and the desire to reduce the length of the arm to minimize the pitching moment tending to rotate the RPV during deceleration. There is also the practical problem of stowing the hook in the RPV which imposes physical limitations on the length of the hook support arm.

11.3.2.2 Ship Motion Effects

The effects of ship motion on the Aerial Track Recovery System are more significant than they are for other recovery systems considered in this study. Based on the location of the recovery equipment shown in Figure 11-5, the possible displacements due to ship motion were determined. The effects of roll, pitch and heave were examined independently and the results were then combined to determine the total effects of ship motion on displacement of the recovery sling.

The following values were used to evaluate the ship motion:

- Maximum roll angle of ±7 degrees
- Maximum pitch angle of ±5.5 degrees
- Maximum displacement due to ship heave of 5 feet

Due to the location of the engagement sling relative to the ship's roll axis, it is estimated that a reference target point in the engagement sling

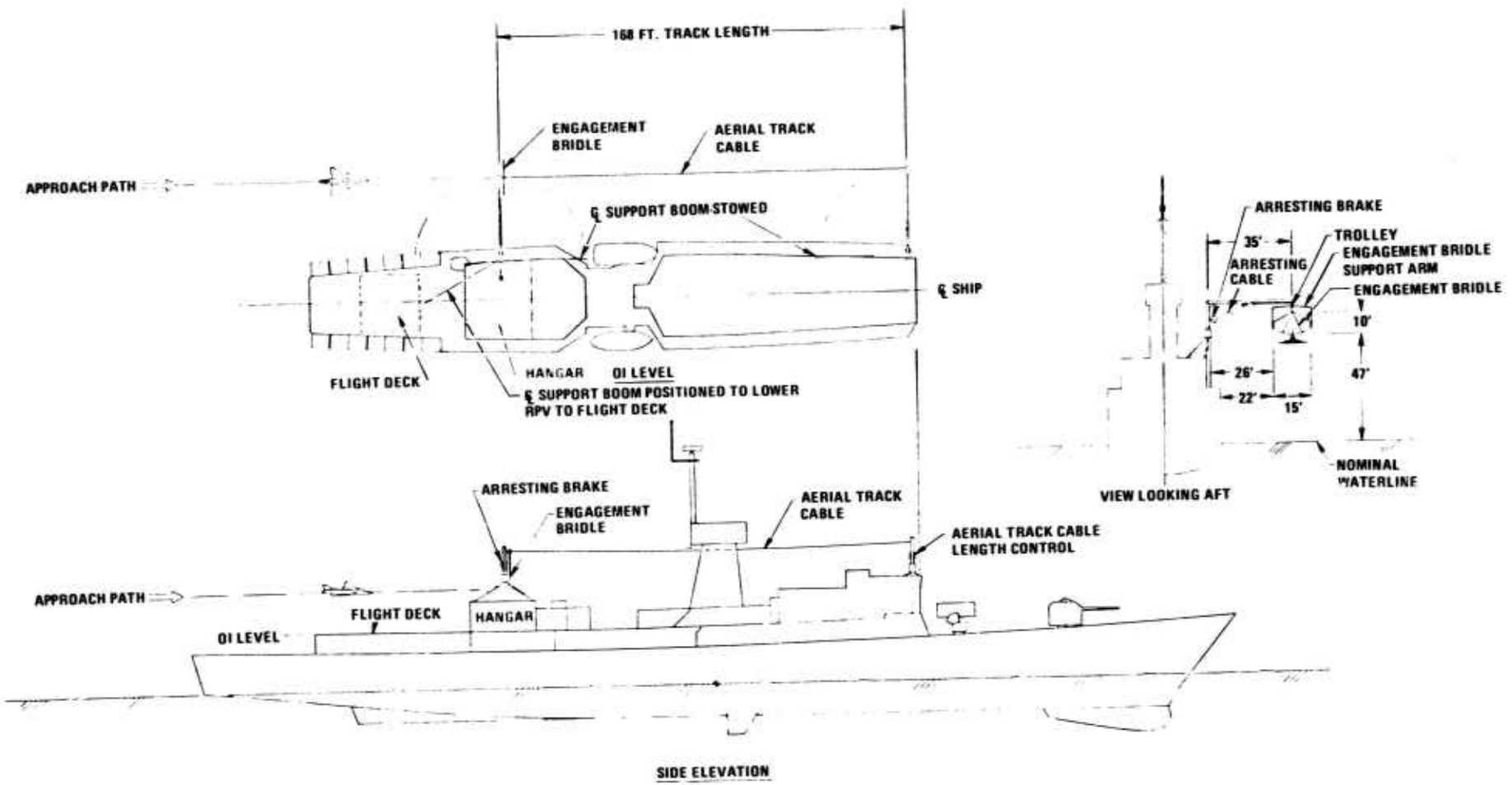


Figure 11-5. Aerial Track Recovery System, General Arrangement

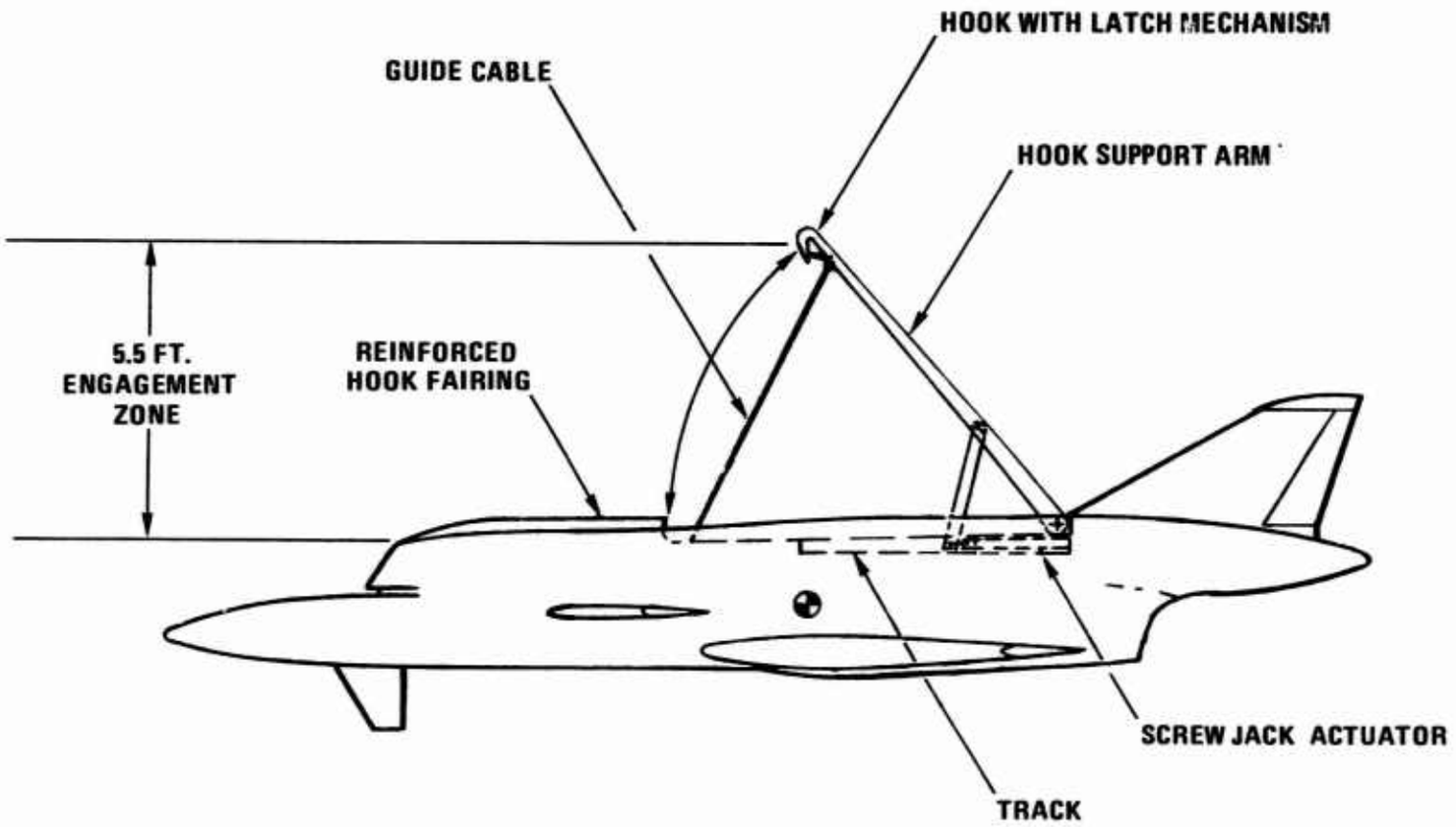


Figure 11-3. Slow-Rate-of-Closure Configuration, SLR06-3 for Aerial Track Recovery

would be displaced vertically a total of 12.9 feet corresponding to a total roll of 7° each side of vertical. Similarily it is estimated that the reference target point would translate a total of 12.2 feet laterally due to rolling a total of 7 degrees each side of vertical. The effects of ship roll are illustrated in Figure 11-7. In addition to the vertical motion due to ship roll, the sling would be displaced 5 feet due to ship heave. Another contributing factor to vertical motion of the engagement sling is ship pitching motions. Based on a pitch rotation of ±5.5 degrees and the location of the engagement sling relative to the point of rotation for ship pitching motions, the sling can be expected to have a maximum total vertical travel of 14 feet due to ship pitch. Under Sea State 4 conditions, the probability that each of these three phases of ship motion, namely; roll, heave and pitch, would occur simultaneously is possible, but would occur less than 5 percent of the time (Reference 8). Accordingly, it was decided to assume that the maximum vertical travel would correspond to the sum of the two conditions contributing most to vertical travel occuring simultaneously. These conditions are maximum roll combined with maximum pitch, which combined give a total vertical displacement of 25.1 feet. The maximum condition for lateral sling displacement is 12.2 feet caused by ship roll.

With a total vertical displacement of over 25 feet, the probability of positioning the RPVs 5.5 feet engagement zone to safely engage the 10 foot high engagement sling becomes questionable. Terminal guidance and RPV control characteristics would have to be extremely precise. It is doubtful that the RPV approaching at flight speeds which border on the lower limits of aerodynamic control effectiveness could generate sufficient control response to provide the required maneuverability to consistently engage the recovery equipment. However, dynamic simulation, taking into account RPV flight characteristics and ship motion effects, would be required to fully evaluate the feasibility of this recovery system. If the RPV proved to be out of position for safe recovery, a safe wave-off could be achieved by climbing away from the ship.

To make the problem of engaging the sling with the hook even more difficult, the motions due to pitch, heave and roll can occur in random combinations. This implies that the motion of any point if the recovery target area would be traversing a random curvilinear path making it very difficult to predict, even over a short time interval, the location of the engagement sling at the instant of engagement. This problem would be greatly reduced if the engagement sling were gyro-stabilized about the roll axis. This however, would add considerable cost to the system and would not eliminate the effect of pitch and heave. To stabilize the recovery gear for roll, pitch and heave could prove to be prohibitively expensive.

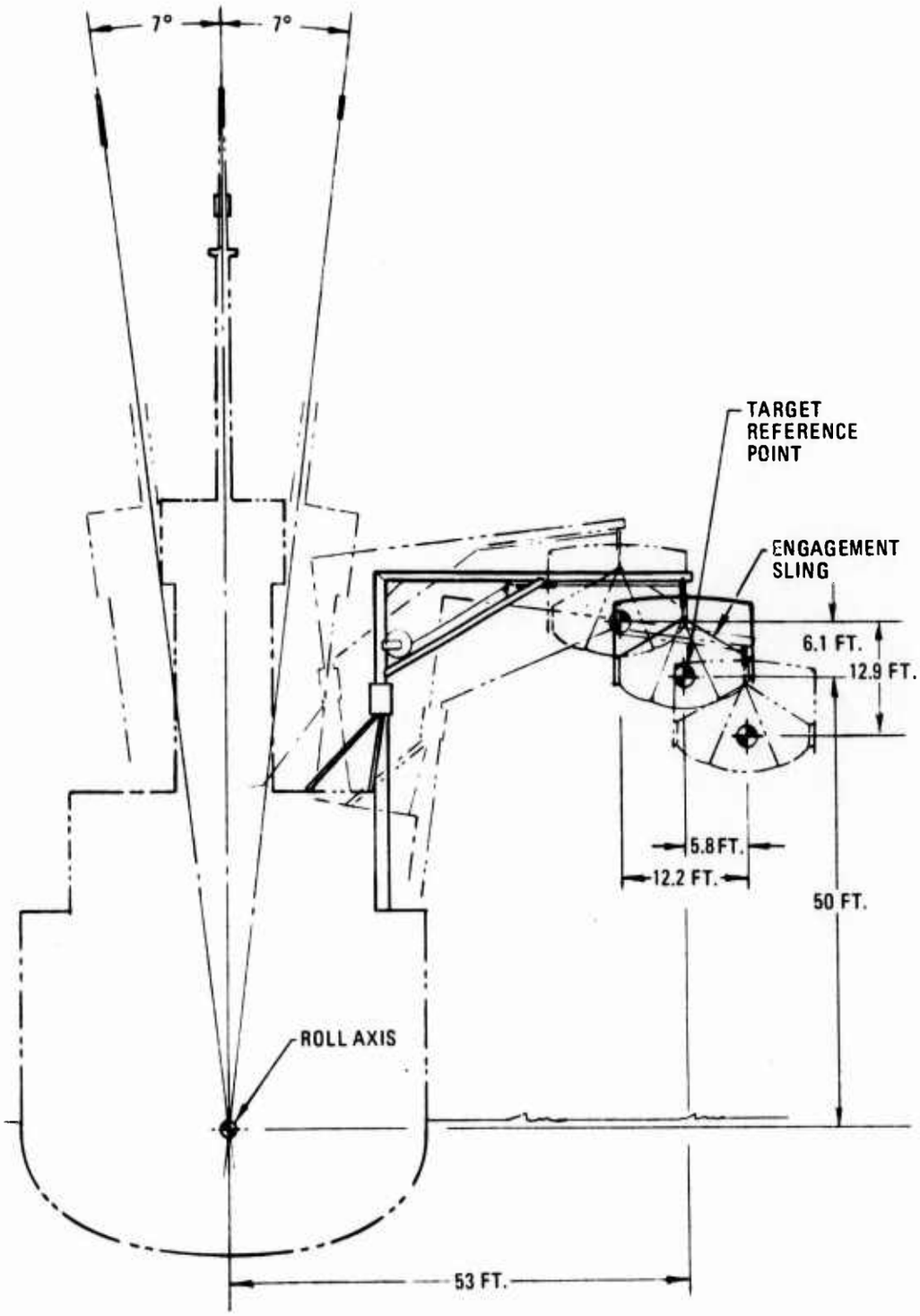


Figure 11-7. Recovery Gear Displacement due to Ship Roll

11.3.2.3 Other Considerations

Other disadvantages of the Aerial Track Recovery System include the additional topside weight added to the ship. Weight added above the center of gravity of any ship is of vital concern to the roll stability of the ship. For destroyer class ships added topside weight can be critical. The aerial track support masts, arms and cable system would weigh approximately 10,000 pounds. To aggravate the problem, this additional weight would be displaced from the ship's centerline 35 to 40 feet on the port side of the ship only. The unsymmetrical loading of the additional recovery system weight may cause serious roll instability during high sea states. An attempt to quantify the effects on roll stability of the DE-1052 class ocean escort was outside the scope of this concept evaluation study.

Deck handling and storage is compromised by requiring a handling dolly to transport and store the RPV, rather than having conventional landing gear in the RPV.

Among the advantages of the Aerial Track Recovery System is the minimal effect that incorporating this system would have on other ship operations. In particular, even when the aerial track system is deployed, there is no degradation to the ship's defense systems. The recovery system would be very simple to deploy and would require minimal manpower. Another advantage of the concept is the weight savings in the RPV by eliminating conventional landing gear. The estimate of 50 pounds for the airborne recovery gear for aerial track recovery of the SLR06-3 version represents only 1.9 percent of the vehicle gross weight. The conventional landing gear and special recovery hoop system for another version of the same vehicle (SLR06-1) accounts for 6.0 percent of vehicle gross weight.

The location off to the side of the ship permits a safer approach than the direct stern approach required for the net recovery system described in Paragraph 11.3.1. With the length of track available the RPV could be decelerated at very low load factors. For example, at a recovery speed of 60 knots, the RPV could be decelerated at load factors less than 2. The average force applied by the arresting cable and brake assembly would be less than 5,000 pounds for this condition.

Based on the above considerations, the disadvantages associated with the Aerial Track Recovery System far outweigh the advantages offered, and consequently this concept is not considered as a practical recovery system

for the size of the RPVs considered in this study. The rejection of this concept in this study should be tempered with the suggestion that for the recovery of much smaller RPVs, designed to perform less demanding missions, the effects of dramatically reducing the scale of the recovery gear and utilizing a large net in place of the engagement sling located closer to the ship's axis of rotation could permit the development of a very competitive candidate recovery system.

11.3.3 VTOL RECOVERY

Among the advantages of all VTOL concepts is the fact that the landing speed can be near zero due to the hover capability of these concepts. This dramatically reduces the energy dissipation requirements of the recovery system. The low landing speeds therefore greatly increases the degree of safety to the ship and crew. Greater operational flexibility is inherent in these designs since the VTOL concepts are not dependent on restrictive ship speed and directions to achieve the desired wind vectors to reduce landing speeds. The VTOL concepts also offer the advantage of being able to hover over the flight deck waiting for the deck of the ship to be in a level attitude at the moment of touchdown. This hover ability makes it much easier to exploit lulls in sea condition to achieve recovery under the most advantageous conditions.

11.3.3.1 Stopped Rotor VTOL Recovery

Recovery of the Stopped Rotor VTOL concept is more like the recovery of manned helicopters than any of the other concepts considered in this study. The stopped rotor concept has good hover capability, and has low temperature, low velocity downwash characteristics. The recovery system has, in addition to the command and control system discussed in Section 6, the shipboard mounted docking mechanism and the airborne mooring winch and cable.

Following transition from high speed conventional flight, where the wing is fixed and forms a modified delta wing, the RPV approaches the ship in the hover mode with the rotor/wing extended above the fuselage acting as a rotary wing with characteristics similar to that of a helicopter. The RPV approaches the ship from the aft quarter from either the port or starboard side.

Approach from the aft quarter was selected based on the experience of manned helicopter landings aboard this class of ship. This approach path minimizes the effect of air turbulence shedding off the forward superstructure of the ship on the stability of the slow flying RPV.

This approach also avoids the RPV hovering over the aft portion of the ship and provides an unobstructed path to touchdown on the flight deck. Guidance of the RPV for a precise landing is provided by the multilateration guidance system as discussed in Paragraph 6.3.1. The multi-lateration transponder units are located as shown in Figure 11-8.

On command from the RPV flight controller, a cable with a swaged ball at its end is lowered from a winch mounted in the RPV directly below the center of gravity of the vehicle. The winch is located in the landing gear bay and is completely covered when the landing gear doors are closed. The ball serves as a weight to keep the line stable and serves as the means to fix the cable to the deck. As the RPV hovers over the deck the ball is trailed across the flight deck toward the mooring line engagement fixture located in the center of the flight deck area as shown in Figure 11-8. As the RPV passes over the mooring fixture the cable is channeled by the sides of one of the several "sawtooth" guides, forcing the ball and cable toward the apex of the "V" shaped slot. The end of the slot is a latch mechanism designed to trap the ball and secure the cable. Once secured the RPV mounted winch is commanded to apply a constant tension force which is greater than the lift force being produced by the RPV propulsion system. The net result is a constant force pulling the RPV toward the deck. As the sea causes the ship to move up and down, a mechanism in the winch senses any change in the desired tension force and commands either greater or lesser torque from the winch motor as required to maintain the constant tension force. As the ship moves up to meet the hovering RPV, the cable is shortened to prevent slack in the mooring line, and as the ship falls away from the RPV, the line is allowed to be payed out to prevent over-loading the line. The basic concept has been successfully used by manned helicopters aboard ships for many years and needs only to be scaled to RPV applications. Due to the net downward acting tension force in the cable, the RPV is pulled to the deck and is held secure by the cable.

The mooring line engagement fixture is designed to be high enough off the deck to assure engagement of the ball at the end of the mooring line and at the same time be compatible with the landing gear design.

The deck handling crew may remove the RPV from the docking mechanism by turning off power to the mooring winch and manually releasing the latch mechanism which trapped the ball at the end of the mooring line. The RPV may then be rolled into the hangar on its own landing gear.

The Stopped Rotor VTOL configuration is readily accommodated on the flight deck of the destroyer. With the RPV in the center of the designated

Figure 11-8. Stopped Rotor VTOL Concept, SLR03 Aboard DE-1052 Class Ocean Escort

recovery area the 15-foot diameter rotor presents no clearance problem to any ship structure, as there is approximately 25 feet clearance to the nearest ship structure.

Among the disadvantages of this concept is the relatively large size of the RPV caused primarily by the propulsion system layout and the inability to readily fold the wings for storage due to mechanical complexity of the rotor tips. As can be seen in Figure 11-8, the hangar on the DE-1052 destroyer can accommodate only two RPV's.

Another disadvantage of this concept is the inherent mechanical complexity of the propulsion system. The requirement for diverter valves, additional power turbines, mechanical drive trains, rotor retraction/extension mechanism, cyclic pitch mechanism, and inflight rotor indexing and braking device, add to the maintenance tasks and increase the probability of mechanical failure.

Probably the major drawback to this concept, at this time, is the fact that this concept is in the earliest stages of development. While there has been some research conducted to develop the concept there still remains serious technical problems to be solved.

Much of the technical risk is associated with the rotor/wing geometry and its flight characteristics. A number of stopped rotor wing plan forms have been suggested in recent years and the following discussion briefly summarizes the current status of development, and the reasons for selection of the modified delta for the SLR03 Configuration.

At the onset of this study, it was necessary to select a rotor-wing configuration amendable to the design mission. This involves considerations of a low altitude high subsonic data requirement at Mach No. 0.85 as well as a high altitude cruise requirement. Based on the preliminary data available, it was felt that the three-bladed delta configuration would provide a better match in terms of propulsive requirements due to the adaptability of the Delta type configuration for high speed (good low profile drag and drag divergence characteristics) and aerodynamic wing area for cruise with the low drag (delta) center body. It was concluded from rotor theory that a minimum number of rotor blades would provide a figure of merit for hover somewhat higher than that of the four bladed configuration. The cross configuration with the unswept wing panels would require extremely thin airfoil sections to avoid drag divergence. The blades aligned with the body would cause high drag. These blades (aligned with the body) could cause adverse effects on drag due to lift at the relatively high required cruise lift coefficients.

In the stopped rotor concept the propulsion system size tends to vary inversely with rotor size. As rotor size increases the impact of disc loading on transition speed and maximum speed can result in large disparities if not properly matched. In addition, the impact of rotor configuration on control system complexity and weight must be considered. According to the available technical literature cyclic loads tend to be less of a problem with a four bladed system, than a two or three bladed rotor. The out-of-trim moments in pitch and roll during transition seem to favor a four bladed system. Teledyne Ryan has recently received information from the Naval Ship Research and Development Center that suggests a possible solution with the four bladed system stopped at a 45-degree azimuth angle. This system is similar to NASA's oblique wing development and would have far less drag due to lower wing-body interference and improved drag divergence characteristics due to increased sweep. However, a problem area relating to aerolastic load structural divergence would have to be addressed for the forward swept blades using this concept.

Since this study was directed primarily at identifying the most practical concepts for launch and recovery, the Stopped Rotor was heavily penalized in the evaluation for technical risk.

As stated earlier, the main advantages of the Stopped Rotor VTOL concept are its good hover capability, low downwash velocity, low downwash temperature, and minimal ship modifications required to accept the RPV. This concept would take on added importance if a new mission were defined which required longer hover time because of the Stopped Rotor concept's inherent hover efficiency when compared to other methods to achieve hover flight.

11.3.3.2 Vectored Thrust VTOL Recovery

The Vectored Thrust VTOL configuration, SLR04, utilizes the thrust of the cruise engine vectored to the vertical position to support the RPV in hover flight. The approach to the ship, docking procedure, and winch down to landing is the same as for the stopped rotor VTOL concept discussed in Paragraph 11.3.3.1.

The Vectored Thrust VTOL differs from the stopped rotor concept in that the turbojet efflux is high velocity, high temperature gas rather than the low velocity, low temperature rotor downwash. Exhaust gas temperatures at the nozzle exit are 237°F for the front forward nozzles (turbofan exhaust) and 1280°F for the rear nozzles (turbojet exhaust).

These temperatures are rapidly diminished as the exhaust gases mix with ambient air. To protect the aluminum plate deck, it is proposed to cover the landing area with a protective shield of steel sheet. The shield would be cutout to provide access for the tiedown fittings and the king post installation fittings. Further studies which would consider effects of exhaust gas/ambient air mixing in detail and exposure time to the jet exhaust may prove that the shield is not required. In any case, the ship modifications would be relatively minor.

Advantages of the Vectored Thrust include the ease of transition from one flight mode to another which increases mission reliability. The horizontal fuselage attitude and low center of gravity increases stability of the RPV while resting on the deck or in the hangar area. The reaction jets and vectorable engine thrust makes the RPV easy to control with precision. The concept has been highly developed in manned aircraft (AV-8A) and application of this manned aircraft technology can be applied directly to the development of this RPV concept.

The major disadvantage of the Vectored Thrust is the limited number of vehicles that can be accommodated in the DE-1052 hangar area. As illustrated in Figure 11-9, only two RPVs will be positioned inside.

The wing was not assumed to have wing fold provisions due to the presence of the ducting for the roll reaction control located in the wing tips. If the added complexity of a wing fold mechanism which would account for the ducting were accepted, it is possible to add one more RPV to the storage area for a total of three RPVs.

11.3.3.3 Recovery of Tail Sitter VTOL Configuration, SLR05

The Tail Sitter VTOL concept (SLR05) is shown in Figure 11-10 aboard the DE-1052 class ocean escort ship. Shipboard provisions for recovery of the RPV include command and control provisions discussed in Section 6.6, and deck modifications to accommodate the RPV recovery gear.

Deck Modifications

To protect the aluminum plate flight deck of the DE-1052 class ship from direct impingement of the high temperature, high pressure turbojet exhaust of the Tail Sitter configuration, a raised landing platform is proposed. The raised deck is a perforated steel sheet platform supported approximately one foot above the existing flight deck. The perforations

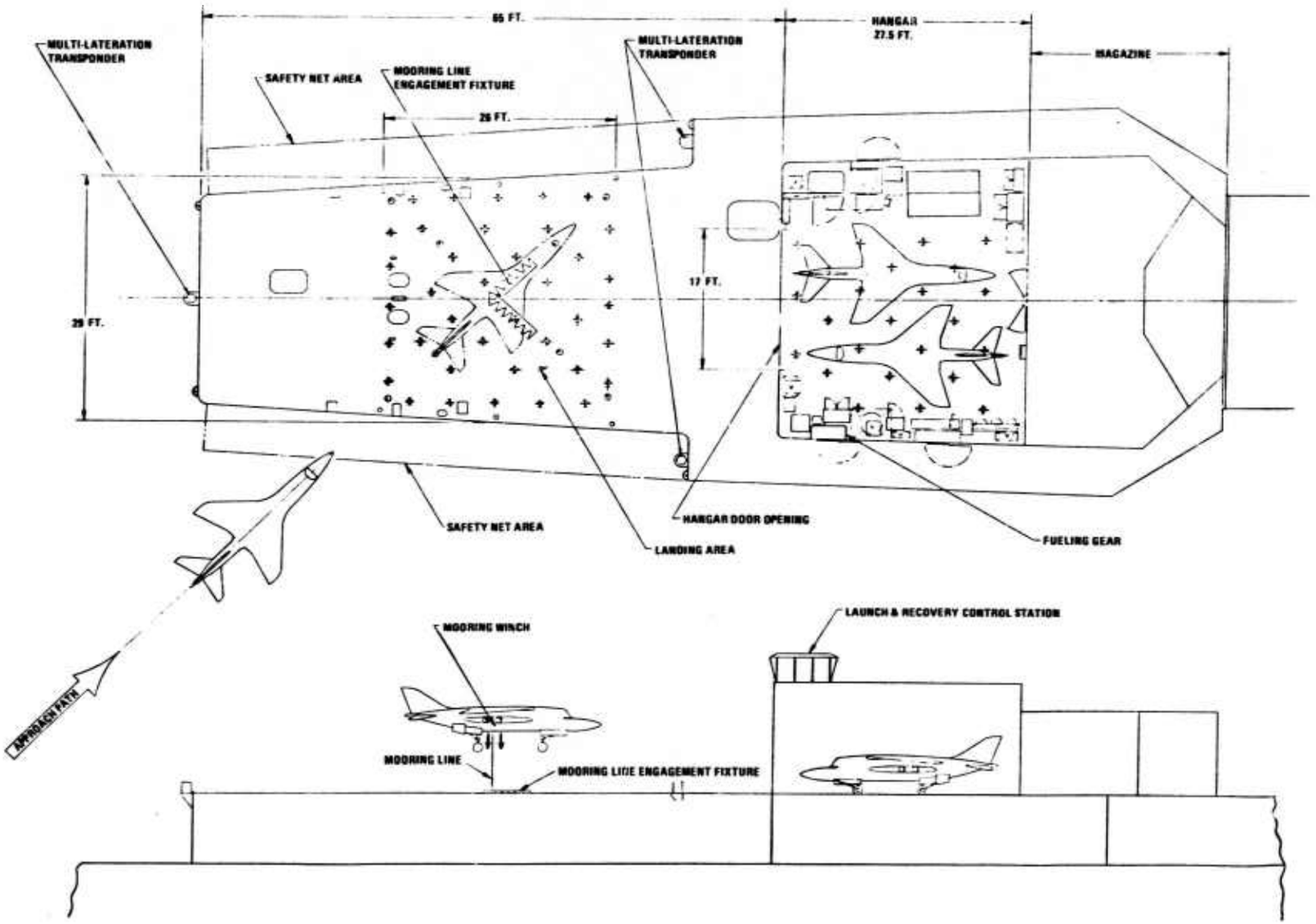


Figure 11-9. Vectored Thrust VTOL Concept, SLR04 Aboard DE-1052 Class Ocean Escort

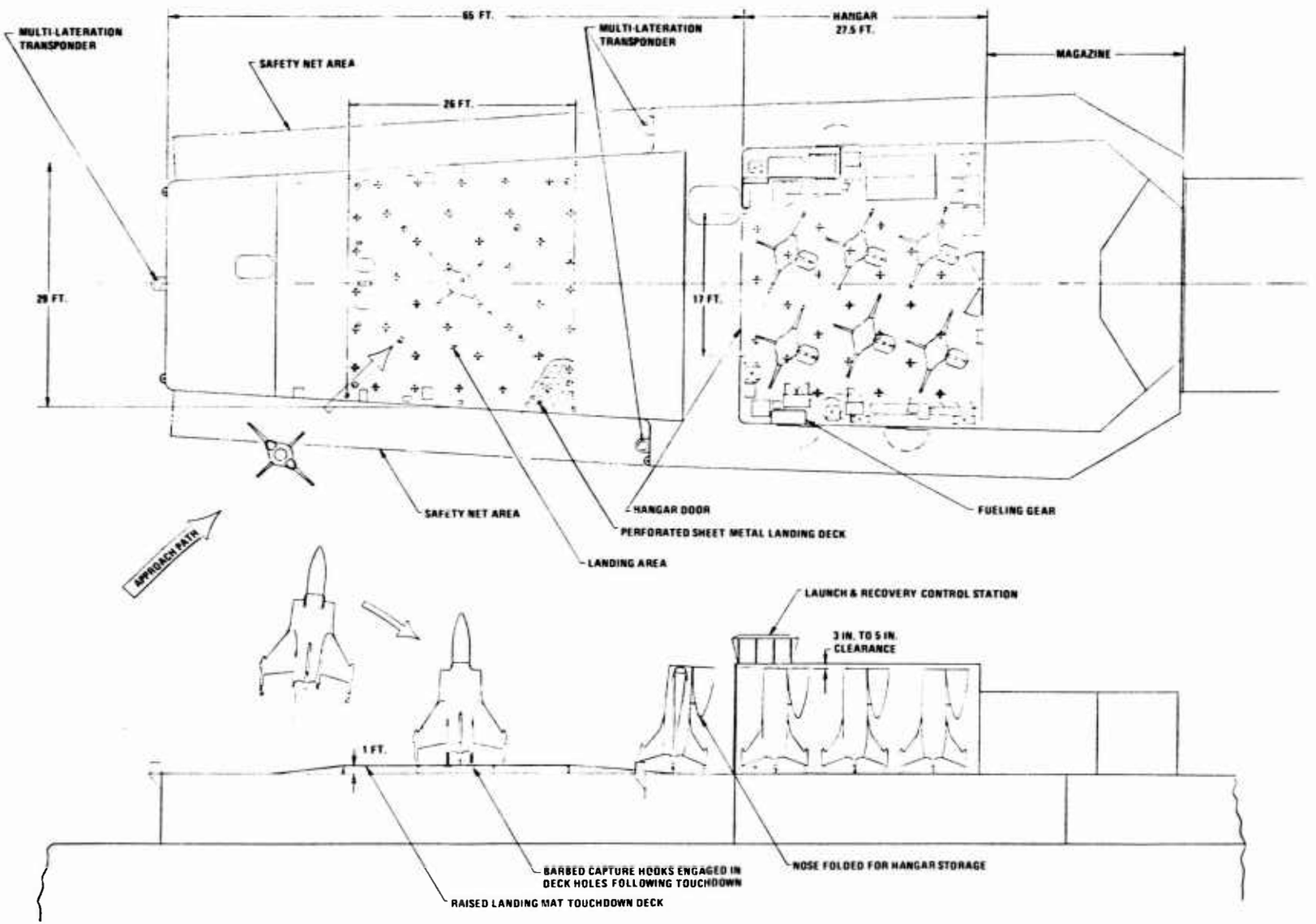


Figure 11-10. Tailsitter VTOL Concept SLR05 Aboard DE-1052 Class Ocean Escort

are machine stamped circular holes which forms a grating of tapered holes. To provide an ample landing area, the full width of the current flight deck is covered by the landing grating as shown in Figure 11-10. The grating also provides the means to secure the RPV to the deck at the moment of recovery.

RPV Recovery Gear

The SLR05 configuration features a cruciform landing gear arrangement with small, non-retractable wheels at the tips of each wing panel and each vertical tail. Shock struts on each landing gear member are designed for maximum vertical velocity of approximately 15 feet per second. Wheels are sized as a compromise between providing minimum drag during cruise flight and ease of deck handling. An RPV landing aboard the deck of a destroyer would be subject to deck motions, especially in higher sea states, which could cause the RPV to shift on the deck. An ice covered deck would present problems of keeping the RPV from sliding off the deck or into ship structure. To prevent the RPV from moving, once on the deck, the RPV should be secured to the deck at all times except when transporting from one deck location to another. Securing to the deck during landing operations is accomplished on the tail sitter RPV by incorporating a pair of automatic securing hooks. These hooks are located at the rear of the fuselage in an extension of the wing root fairing. The hooks have multiple retractable arms which are normally in the retracted position and form a smooth aerodynamic shape. During landing, the action of the shock absorbers being compressed actuates the extension mechanism for the hook struts. As the hook struts extend downward the hooks penetrate the openings in the grating of the landing platform. The fuselage mounted end of the hook struts are articulated to permit limited rotation. This feature and the tapered design of the grating holes permit penetration of the grating even if the hook hits the grating before deflecting through one of the openings. When the hook has extended to a predetermined length which assures penetration of the grating, a release mechanism automatically opens the multiple arms forming a barb-like anchor. The landing gear shock struts returning to a static position applies a tension load on the hooks, firmly securing the RPV to the landing platform. The flight deck crew can remove the RPV by manually releasing the anchor hooks when preparing to move the RPV into the hangar area.

Moving the Tail Sitter RPV into the hangar requires folding the nose section downward and securing it to the side of the fuselage. This reduces the height of the RPV to clear the hangar door opening. A shallow ramp facilitates removing the RPV from the raised landing platform.

The vertical attitude of the Tail Sitter permits a much higher storage density than the other configurations examined for use aboard the destroyer class ship. A total of six tail sitters can be accommodated in the DE-1052 hangar. Other configurations considered for the destroyer are limited to two SLR03 and SLR 04 vehicles or three SLR06 vehicles stored in the hangar.

Among the disadvantages of installing the landing platform over the existing flight deck area is the covering of the deck provisions for installation of the aft king post. The king post is utilized to rig lines from the destroyer to another ship for resupply at sea. This problem could be circumvented by reducing the size of the landing platform, if this should prove practical. Another solution would be to make the portion of the platform covering the king post fitting removable or retractable and accept this added complexity. A third alternative would be to limit all resupply activities to the forward king post installation.

11.4 RPV COMMAND AND CONTROL - DESTROYER OPERATIONS

The control display and organizational support equipment complement for the sea control ship can be tailored to satisfy the relatively low operational rates postulated for the destroyer class vessels. The control room installation is shown in Figure 11-11. The essential considerations in this design are:

- Minimum vessel modifications, yet providing an installation that can permit visual monitor of all operations.

- The control room will be the center of operations from which all aspects of the checkout tests, launch, mission, and recovery control can be conducted.

Observation Control Tower - Many of the DE-1052 class ships are equipped with the LAMPS control tower which is used for both launch and recovery of manned helicopters. The available space in this enclosure does not permit installation of another major item of equipment such as the RPV control console. It was considered essential to reserve the existing LAMPS control tower for helicopters operations when RPVs are not deployed on the destroyer. Accordingly, an alternate observation control tower is added to the hangar. This is shown in Figures 11-11. The placement of this enclosure was selected to provide a combination of benefits:

- Visual observation of deck for launch and recovery

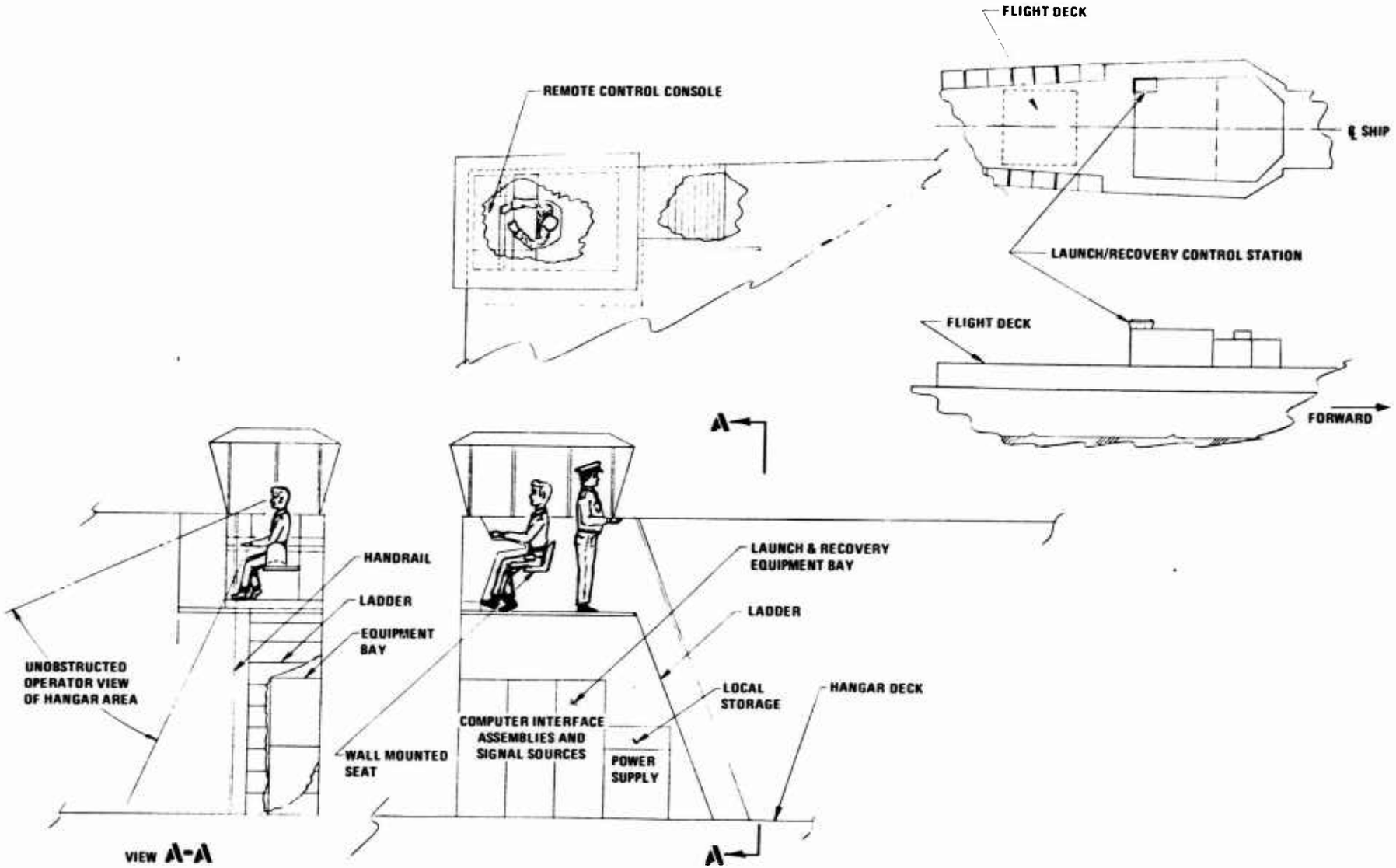


Figure 11-11. DE-1052 Ocean Escort Launch-Recovery Control Station

- Visual observation of approach and missed-approach maneuvers
- Visual observations during repair test, and prelaunch checkout
- Physical space for control console, operator and supporting electronics component.

Landing Aids - The multilateration system appears to be the most effective landing aid for destroyer use. It provides close-in guidance, and is capable of simultaneous control of several RPV's. The small space required for the installation makes the multilateration system particularly adaptable to destroyers. The location of the multilateration transponders is shown in Figures 11-8, 11-9 and 11-10. However, should the Navy develop the Co-Scan System, its use with destroyers is limited to single RPV approaches and would be subject to several operational restrictions identified in the trade studies presented in Paragraph 6.3.2.

A more detailed discussion of the command and control aspects of ship-based RPV's is provided in Section 6.0, "Command and Control Studies".

11.5 LAUNCH AND RECOVERY EVALUATION, DESTROYER

The destroyer launch and recovery evaluations cover five RPV concepts-two slow rate-of-closure (SLOROC) designs and three VTOL configurations. One of the SLOROC designs is configured for net recovery, the other for recovery by aerial track system. Each of the three VTOL designs represent a different concept, i.e., deflected jet, rotor wing, and tailsitter. All were sized to perform the 500 nautical mile high-low-high altitude, penetration mission. This mission requirement results in very small aircraft by normal standards (wing spans under 15 feet), but even this size RPV appears large and even close to maximum size when considered in terms of the small deck area and storage space available on destroyers.

Table 11-1 presents a compilation of evaluation judgements on a qualitative scale as discussed in the Evaluation Methodology Section, Paragraph 8.2. The relative judgements are obtained horizontally across, and the assessment of the RPVs by the vertical columns.

The ship constraint in terms of numbers of RPVs for the destroyer is not indicated relative to another vehicle that it must replace, but is based on the number that can be housed in the hangar. In all cases, except for the tailsitter, two to three RPVs can be stored in the hangar depending

TABLE 11-1

EVALUATION SUMMARY, DESTROYER

EVALUATION CRITERIA	RPV CONFIGURATIONS				
	SLR03 STOPPABLE ROTOR, VTOL	SLR04 VECTORED THRUST, VTOL	SLR05 TAIL SITTER, VTOL	SLR06-2 SLOW RATE OF CLOSURE, NET RECOVERY	SLR06-3 SLOW RATE OF CLOSURE, AERIAL TRACK RECOV.
SHIP CONSTRAINTS					
Ship Weight and Balance	2	2	2	3	4
Ship Maneuverability	3	3	3	3	4
Ship Motion	3	3	3	4	5
SHIP/RPV COMPATIBILITY					
Max. No. of RPV's accommodated in hangar (1)	2	2	6	3	3
Flight Deck Space (One RPV)	3	3	3	3	3
Hangar Deck Space	3	3	3	3	3
Storage Space	4	3	3	3	3
Personnel Space	3	3	3	3	3
Ship Command and Control Systems	3	3	3	3	3
Launch Systems	3	3	3	3	3
Recovery Systems	3	3	3	5	5
Maintenance Methods	2	2	4	2	2
RPV Test and Check-out	2	2	3	2	2
Handling Equipment	2	2	3	4	4
Ship Power Outlets	2	2	3	2	2
Ship Fuel Outlets	1	1	1	1	1
COMPATIBILITY WITH SHIP WEAPONS SYSTEMS					
Manned Aircraft	5	5	5	5	5
Other Weapons Systems (Guns, Missiles, etc.)	3	3	3	5	4
TECHNICAL RISKS					
Air Vehicle	4	3	3	2	2
Launch Systems	2	2	2	2	2
Recovery Systems	2	2	2	5	5
Command and Control Systems	2	2	2	2	2
SAFETY					
Deck Handling	2	2	3	4	4
Launch Operation	2	2	2	2	2
Recovery Operation	3	3	3	5	5
Jet Blast	3	3	3	2	2
COST					
Air Vehicle Relative Costs (100 Quantity, Less Payload)	1.85	1.48	1.46	1.26	1.26
Ship Modification Costs	low	low	low	moderate	high

Judgment Scale:

1. Acceptable, no adverse impact or risk.
2. Acceptable, small adverse impact or risk.
3. Acceptable, moderate adverse impact or risk.
4. Marginal.
5. Unacceptable.

(1) Actual no. of RPV's not evaluation rating.

on the amount of crowding which is acceptable. On the other hand, the tailsitter requires a much smaller area due to its vertical storage attitude and up to six of these vehicles can be accommodated in the destroyer hangar. By limiting the number of RPVs to those that fit in the hangar, the flight deck can be freed for other applications such as logistic transfer of supplies and personnel.

11.6 DESTROYER STUDY CONCLUSIONS

An assessment based on the considerations listed in Table 11-1 and on engineering analysis has led to the following conclusions regarding the candidate air vehicle concepts studied for destroyer based operations.

1. The conventional landing low altitude penetrator (Configuration SLR-1) is not adaptable to destroyer basing due primarily to the limited flight deck area available which is totally inadequate to handle the high landing speeds and high energy levels associated with conventional aircraft of the weight and size of configuration SLR01.

2. The slow rate of closure (SLOROC) concept provides substantially lower landing speeds, but speeds are still high enough to preclude direct deck landings on destroyers. Both net and aerial track recovery systems were investigated for SLOROC recovery, but the accident potential with these systems are considered too high, especially in rough seas and high ship motion conditions, and neither of these systems can be recommended for air vehicles in the SLOROC weight and speed range.

3. The three VTOL concepts studies are adaptable to the destroyer operations, but the rotor wing vehicle was dropped from consideration at this time because of insufficient development of the rotor, engine and power drive train.

4. The vectored thrust configuration has many advantages particularly in its superior transition characteristics. However these vehicles are large considering space available on destroyers and only two will fit within the available hangar.

5. The tailsitter VTOL can be designed to provide adequate launch, transition, and recovery characteristics. In addition, because of the vertical attitude of the parked airframe, as many as six can be stored within the destroyer's hangar (See Figure 11-10). It thus appears that the tailsitter represents the best

compromise between performance and storage requirements, and for these reasons, the tailsitter VTOL concept was selected as the most practical solution for the destroyer based, low altitude penetrator air vehicle.

The study concludes that destroyer-based RPVs in the 3,000-pound class are feasible. However, the system requires the development of expensive VTOL air vehicles and the system would be restricted to operations in low to moderate sea states.

Unless there is a unique and critical mission requirement for this class of RPV, it appears that the high cost and operational risks for this system outweigh other considerations for its employment in destroyer operations.

Other Teledyne Ryan studies have shown that smaller, lighter RPVs with reduced mission capability appear to be practical for operation from destroyers (Reference 11). The smaller vehicles, because of their light weight and low landing speeds, are suitable for launch from small catapult launchers and recovery using systems such as the net recovery system discussed in Reference 11.

12.0 RECOMMENDED STATEMENT OF WORK FOR PHASE II OF THE RPV SHIPBOARD LAUNCH AND RECOVERY OPERATIONS STUDY

12.1 PURPOSE AND SCOPE

The purpose of this Statement of Work is to identify and define work recommended for Phase II of the RPV Shipboard Launch and Recovery Operations study. The Phase II studies will analyze the launch and recovery systems selected during Phase I in sufficient depth to permit the estimation of preliminary total-system life cycle costs. Man/machine interfaces will be identified and manpower requirements to man and maintain the complete weapons system will be defined. Operations analysis will be conducted to investigate problems associated with integrating the RPV operation into the air operations of the carrier and the sea control ship and into the destroyer (DE or DD) sea operations. Command and control studies will be continued to further develop approach-path control techniques, and computer simulation will be performed to evaluate launch characteristics and to evaluate the ability of the selected approach control systems to keep the RPVs within the allowable approach cones.

12.2 TASK DESCRIPTION

12.2.1 COST ESTIMATES

The contractor shall provide preliminary estimates of total system life-cycle costs inclusive of systems development, acquisition, operation, and maintenance costs for the point designs and systems selected as a result of Phase II. Additionally, cost sensitivities will be provided for system parameters such as attrition rates, vehicle monthly utilization, number of squadrons deployed, and other primary contributors to cost.

12.2.2 MAN/MACHINE INTERFACE

The contractor shall identify the types (skills) and numbers of people required to maintain the airframe, airborne systems, and shipborne systems.

The types (skills) and numbers of people required to operate the weapons systems throughout the mission will be identified.

The contractor shall study aspects of the RPV launch and recovery operation which could pose safety hazards to either personnel or equipment and shall recommend safe procedures.

A summary of train requirements will be provided including the training requirements for flight control operations, technicians, maintenance and handling personnel.

12.2.3 AIR VEHICLE DESIGN

The contractor shall develop a "Blended Controls Concept" (coordinated use of canard, wing, and tail controls) to provide "tight" control of landing approach path.

Stability and control derivatives and coefficients shall be calculated to support a computer simulation of the launch and recovery phases of the mission.

The contractor shall refine the Phase I air vehicle designs and shall conduct analyses to verify and improve RPV launch characteristics and reduce landing speeds.

Analysis shall be conducted to define the direct-thrust-control requirements for the VTOL configurations.

12.2.4 OPERATIONAL PROCEDURES

The contractor shall develop a preliminary storage plan for the RPVs and their support equipment.

Pre-launch procedures shall be identified and flow charts and drawings shall be prepared to illustrate the sequence of events and movements of the RPVs and supporting equipment from the storage area to the launch-ready position.

The contractor shall identify launch procedures and shall identify methods and equipment required to command guide the RPV, throughout its mission profile including approach and landing.

The contractor shall describe the handling procedures and shall identify the equipment involved in recovering the RPVs from the deck or net, and for moving the RPV to the storage area.

12.2.5 COMMAND AND CONTROL

The contractor shall develop approach path control techniques including control laws and representative mechanizations, and shall perform computer simulation for evaluation and validation.

A system error analysis shall be conducted to estimate touchdown dispersion distributions.

12.3 REPORTS

A final technical report covering all work accomplished in Phase II shall be prepared and submitted to ONR.

13.0 REFERENCES

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5. Miller, F. L., Ultrareliable Automatic Flight Control System Investigation, Report No. LJ-1201-0657 (AD489834), Sperry Phoenix Company, Phoenix, Arizona, July 1966.

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9. Conway, H. G., Landing Gear Design, Chapman & Hall Ltd., London, 1958.

10. WADC TR 58-118, Georgia Tech, Subject: Aircraft Landing Gear Break Lining Tests.

11. Teledyne Ryan Aeronautical, U.S. Navy Ship-Deployable Tactical RPV System, Volume 1, Technical Proposal For a Feasibility Demonstration, TRA Report No. 29308-15, 19 February 1974.