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SYSTEM CONFIGURATION TRADEOFF ANALYSIS FOR ARMY MINI-RPV PROGRAM

January 1977

Prepared for

U.S. ARMY AVIATION SYSTEMS COMMAND
St. Louis, Missouri

Under Contract F33657-75-D-0329-0011

ARINC RESEARCH CORPORATION

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FOREWORD

The tradeoff analysis conducted by ARINC Research Corporation for the Army Mini-RPV Program is reported in an unclassified text and a CONFIDENTIAL attachment. The attachment contains five data tables, as referenced in the text. Publication numbers are:

a. Unclassified report: 1282-01-1-1576

b. Classified attachment: 1282-01-1-1576A, outgoing classified log number SNA/C/77-12, CONFIDENTIAL

ABSTRACT

A tradeoff analysis of equipment applicable to the U.S. Army Mini-RPV Program is described. Candidate equipments are evaluated and ranked for each subsystem of the remotely piloted vehicle, from which alternative complete systems ("baseline" and "variants") are synthesized.

SUMMARY

A tradeoff analysis of configuration and equipment candidates for the Army miniature remotely piloted vehicle (mini-RPV) considered the parameters of equipment performance, physical characteristics, availability, and cost. Performance criteria were based on sets of increasingly severe Minimum System Characteristics (MSCs) that the mini-RPV must satisfy over the present-to-1980 and 1980-1985 time periods.

Equipment candidates were evaluated and ranked for each subsystem of the RPV and then combined to form complete sets of candidate systems. Results of the subsystem analysis and system synthesis are summarized below.*

SUBSYSTEM ANALYSIS

Payload

From the examination of candidate payload equipments, the following observations were made:

a. Panoramic photographic cameras are applicable to MSCs 1.0 and 2.0. Several candidate cameras can satisfy the detection, recognition, and identification functions of these MSCs.

b. Stabilized television cameras are applicable to MSCs 1.0 and 2.0, and several available equipment types have the necessary performance characteristics. The use of a continuous zoom lens system is desirable, as it would allow an operator to maximize the time a target is within the field of view while maintaining an adequate level of resolution.

c. The laser rangefinder/designator is applicable to MSCs 2.0, 2.5, and 3.0. Several available equipments satisfy these requirements.

d. Video autotrackers are applicable to MSCs 2.0, 2.5 and 3.0. Several available equipments satisfy the requirements.

e. Stabilized FLIR systems are applicable to MSCs 2.5 and 3.0, although their applicability is limited by their rather low adverse-weather capability. None of the candidate FLIR systems examined had resolution and field-of-view combinations that would meet the mission requirements. The candidates are ranked relative to how closely they approached the requirements.

*A review of the MSC definitions in Section 3 would aid the reader unacquainted with mini-RPV mission requirements.

f. LLLTV systems have limited applicability to MSCs 2.5 and 3.0. They have no adverse weather capability and require at least some ambient light (starlight, moonlight). The resolution capability of the single candidate identified met the requirements of MSC 2.5 but not of MSC 3.0.

g. Millimeter radar is applicable to MSC 3.0. However, the one candidate in this category, which is in the early stages of development and not expected to be available until the early 1980s, does not have projected performance characteristics that meet the resolution and maximum range requirements of MSC 3.0.

Data Link

No available data link system will meet the combined requirements of anti-jam resistance, baseband frequency, and wideband data rate for the mini-RPV. Since there is an effort to develop a suitable system (the Integrated Communication and Navigation System, ICNS) at Harris Corporation, that system would be ranked as the preferred candidate.

Navigation System

The ICNS is also the first-ranked candidate for the navigation subsystem for MSCs 1.0 through 3.0 because of its potentially low weight and cost, and high anti-jam margin.

Autopilot

For MSC 1.0, an autopilot utilizing a tilted rate sensor was selected over an electrostatic autopilot because of lower operational and developmental risks.

For MSCs 2.0, 2.5 and 3.0:

a. The vertical gyro autopilot is ranked first for operations requiring limited duration turns. Its primary advantage is its lower weight relative to the other viable candidate, the dual displacement gyro autopilot.

b. The dual displacement gyro system is ranked first for flight operations requiring long-duration turns or nonlevel flights.

c. The rate gyro/precision pendulum ranks third in either case.

Launch and Recovery

For launch and recovery of the mini-RPV, the top-ranked subsystem combination is a longitudinal loading (catapult) method for launch, coupled with a capture (net) approach for recovery. This combination's advantages are least design impact on the air vehicle and minimal development risk.

Airframe

The top-ranked airframe configuration for the mini-RPV, for MSCs 1.0 through 2.5, is a fixed-wing type. No significant overall advantage could be determined between the delta and cruciform types of fixed-wing airframe.

Although the fixed-wing airframe would also seem to be the preferred candidate for MSC 3.0, technical progress in the development of other candidates, particularly the VTOL ducted fan, should be monitored for future consideration.

Propulsion

The preferred engine type for the mini-RPV is a two-cycle, air-cooled, reciprocating engine with spark ignition. A limited number of engines of this type are available in the applicable 5 to 25 horsepower range. However, those engines are either designed for other applications, require some modification for use in a mini-RPV, or are prototype models not currently available in quantity.

An Army program now in the proposal stage has the objective of demonstrating the propulsion technology base for future Army and other DoD agency requirements for mini-RPVs. This program addresses engines of the 15 to 25 horsepower class, and should provide 1) a technology base of demonstrated performance capabilities for a mini-RPV engine designed to make maximum use of current high-production components, and 2) potential development/manufacturing sources for subsequent small RPV engines.

The most suitable of the available engines are identified in this report. The above-mentioned Army study should have considerable influence on the types of mini-RPV engines available in the future.

SYSTEM SYNTHESIS

The top-ranked subsystems were combined to form a number of mini-RPV system candidates for each MSC. No system so synthesized was found to satisfy the full range of MSCs, since no available sensor types combine the required resolution capability with the ability to operate satisfactorily at night and under adverse weather conditions. For specific MSCs, the number of candidate system configurations that will meet or closely approach the associated requirements were identified as follows:

	Number of Candidate Systems:	
MSC	Meeting Requirements	Approaching Requirements
1.0	3	–
2.0	2	–
2.5	–	2
3.0	–	3

The baseline candidates for each MSC vary only in payload configuration, the other subsystems being constant. The final selection process therefore involved payload considerations only, and the results are as follows:

a. The baseline configurations for MSCs 1.0 and 2.0 involve options of real-time or hard-copy imagery, or both, to be produced by the payload equipments. The decision in this instance is one of operational policy, and is not within the scope of this study.

b. The low-light-level television (LLLTV) payload is recommended for MSC 2.5 because of both lower life cycle cost and better resolution capabilities relative to the other candidates.

c. The forward-looking infrared radar (FLIR) payload is recommended for MSC 3.0 as a best "technical risk" candidate for approaching the day/night/limited adverse weather requirement by 1985. LLLTV is not recommended for MSC 3.0 because of inherent shortcomings in adverse weather performance and its requirement for ambient light. The radar candidate was eliminated because of its low range and resolution capabilities.

The final recommended configurations for each MSC are summarized in Table A.

TABLE A. FINAL RANKING OF MINI-RPV SYSTEM CONFIGURATIONS

MSC	Payload	Data Link/ Navigation	Autopilot	Launch and Recovery	Airframe	Engine
1.0	A. Panoramic Camera • KS-129 (Perkin-Elmer) B. Panoramic Camera/TV Sensor • KS-129/Praeire II C. TV Sensor • Praeire II	Integrated Comm. and Navigation System	Rate Gyro ↓ Rate Gyro	Catapult/Net	Fixed Wing	McCulloch MC101-M/C
2.0	A. TV Target Acquisition and Designation System • Praeire II B. TV Target Acquisition and Designation System/Photo Camera • Praeire II/KS-129	↓	Vertical Gyro	↓	↓	McCulloch MC101-M/C DH Enterprises Undesignated 20 HP
2.5	LLLTV Target Acquisition and Designation System • LLLTV Version of Blue-Spot (Westinghouse)	↓	↓	↓	↓	↓
3.0	FLIR Laser • Mini-FLIR (Aeronutronic)	Integrated Comm. and Navigation System	Vertical Gyro	Catapult/Net	Fixed Wing	McCulloch MC101-M/C

GLOSSARY

AJ	Anti-jam
ARPA	Advanced Research Project Agency
ASARC	Army System Acquisition Review Committee
AVSCOM	Army Aviation Systems Command
BTA	Best Technical Approach
CEP	Circular error of probability
CFP	Concept Formulation Package
COEA	Cost and Operational Effectiveness Analysis
DSARC	Defense System Acquisition Review Council
EW	Electronic warfare
FLIR	Forward looking infrared radar
GCS	Ground control station
GSE	Ground support equipment
ICNS	Integrated Communication and Navigation System
IRIS	Infrared Imaging Seeker
LC	Line of contact
LCIGS	Low Cost Inertial Guidance System
LLLTV	Low-light-level television
LO-CATE	LORAN - Ground Processing
MCS	Mission Control Station
MOS	Military occupation speciality
MSC	Minimum System Characteristics
O&O	Operational and Organization
PLRS	Position Location Reporting System
POISE	Pointing and Stabilization Element
RCS	Radar cross-section
RPV	Remoted piloted vehicle
RSTA	Reconnaissance, surveillance, and target acquisition

SFC	Specific fuel consumption
TGPSG	Tactical Global Positioning System Guidance
TM	Telemetry
TMDE	Test, measurement, and diagnostic equipment
TOA	Tradeoff Analysis
TOD	Tradeoff Determination
USAFAS	U.S. Army Field Artillery School
VTOL	Vertical takeoff and landing

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ILLUSTRATIONS

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1
INTRODUCTION

1.1 BACKGROUND

The Army has undertaken a development program leading to the deployment of a miniature, remotely piloted vehicle (mini-RPV) system in the 1980-85 time frame. The capabilities postulated for the mini-RPV include reconnaissance, limited surveillance, target acquisition and designation, artillery fire adjustment, and limited electronic warfare (EW) functions. The system will provide support organic to specific combat elements of Army divisions.

The mini-RPV system will be developed incrementally to provide all of the capabilities listed above, under all conditions of day/night and adverse weather and as far as 50 kilometers forward of the Line of Contact (LC). Operational capabilities will be increased stepwise until they are fully achieved in 1985, commencing with minimum system characteristics (MSC) of basic day reconnaissance/surveillance missions 20 kilometers forward of the LC in the present-to-1980 time frame and progressing through several levels of MSC to the full capability.

As one of the initial steps in the mini-RPV program, the system developer (the Army Aviation Systems Command, AVSCOM) and the user (Army Field Artillery School, USAFAS) are required to generate a Concept Formulation Package (CFP). The purpose of the CFP is to present evidence of the economic, operational, and technical feasibility of mini-RPV in support of its progression into the engineering development phase of the program. The CFP will be used in presentations to the Army System Acquisition Review Committee (ASARC) and for the Defense System Acquisition Review Council (DSARC) if the program qualifies later as a major procurement.

The CFP is divided into four major sections:

a. The Tradeoff Determination (TOD), which outlines technical approaches and catalogs equipments that may satisfy mini-RPV system requirements.

b. The Tradeoff Analysis (TOA), which is to present a detailed assessment of the TOD based on the required operational capability and mission performance envelopes.

c. The Best Technical Approach (BTA), which will recommend a technical approach for the effort. The BTA will present evidence that primarily engineering rather than experimental effort is required to achieve the desired capability.

d. The Cost and Operational Effectiveness Analysis (COEA), which presents a cost and operational effectiveness comparison of the recommended approach with various reconnaissance, surveillance and target acquisition systems.

After TOD was completed in preliminary form by AVSCOM, ARINC Research Corporation was contracted to perform the TOA. The COEA will be completed by the USAFAS when the TOA and BTA have been completed.

Production of the TOA was the primary objective of this study by ARINC Research. The effort culminated in the identification of the system configuration(s) that represent the best balance among technical options, cost, schedule and operational and support effectiveness. The alternatives were ranked, and the top-ranked alternative may represent the Best Technical Approach.

As a secondary objective, ARINC Research was to recommend any indicated revisions to the TOD previously generated in preliminary form by AVSCOM. These recommended revisions included the elimination of descriptions of subsystems not considered to be viable candidates by virtue of performance or design maturity; the ranking of the remainder of the subsystems described therein; and the addition of new systems identified as a result of this study.

1.2 OVERALL TECHNICAL APPROACH

The overall technical approach to this study, and the organization of this report, are illustrated in the block diagram of Figure 1-1. For each subsystem evaluated, a brief description of the associated approach and study results appear in the following sections.

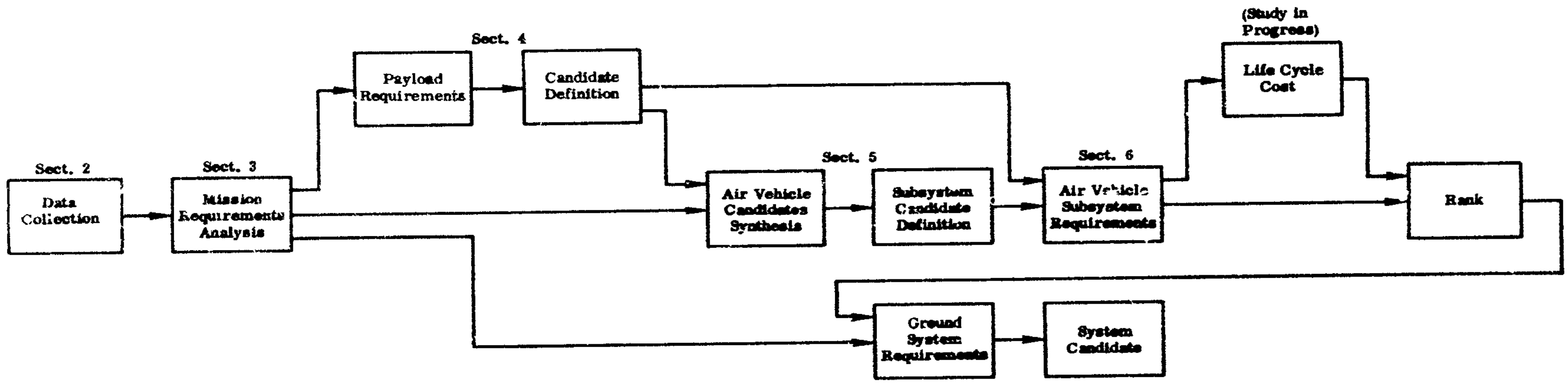


Figure 1-1. Simplified TOA Process

2
DATA COLLECTION

The primary source of data relative to candidate equipments for mini-RPV subsystems was the TOD. It is recognized that numerous developmental programs and equipments having potential applicability to the mini-RPV are not included in the mid-1976 version of the TOD. As much data as possible on such programs and equipments were obtained from discussions with equipment manufacturers and supplementary information provided by the Army.

A literature search was conducted utilizing the services of the Defense Documentation Center, the library of the University of California at Irvine, and the technical library of ARINC Research. A bibliography containing the results of that search, and constituting the technical and data baseline for this study, appears in Appendix A.

Recommendations for improvements and additions to the TOD are presented in Appendix D.

MISSION REQUIREMENTS DETERMINATION

Information on Project Seeker mission requirements was obtained from two primary sources: the system's Concept Formulation Package and Operational and Organization Concepts document. The CFP defines a set of increasingly stringent missions in the form of minimum system characteristics, as follows:*

a. MSC 1.0: Capable of performing daytime reconnaissance and surveillance missions at an operational range of 20 kilometers forward of the line of contact in the present-to-1985 time frame.

b. MSC 2.0: Capable of performing daytime reconnaissance, surveillance, target acquisition, and designation missions at an operational range of 20 kilometers forward of the LC in the present-to-1985 period.

c. MSC 2.5: Capable of performing reconnaissance, surveillance, target acquisition, designation, and EW jamming missions** at an operational range of 20 kilometers forward of the LC during the day, at night, and in adverse weather, in the present-to-1980 interval.

d. MSC 3.0: Capable of performing reconnaissance, surveillance, target acquisition, designation, and EW jamming missions during the day, at night, and in adverse weather at an operational range of 50 kilometers forward of the LC, in the 1980-1985 time frame.

Detailed information describing specific tasks to be performed during the missions is also contained in the O&O Concepts document and CFP. These requirements are:

a. Fifty percent probability of detection of a moving or stationary tank-size target on a road at a slant range from the RPV of 5,000 meters; and, off road, in light clutter at a slant range of 2,500 meters.

b. Fifty percent probability of recognition of a moving or stationary, tank-size target on a road or in light clutter at a slant range from the RPV of 2,200 meters.

c. Fifty percent probability of identification of a moving or nonmoving tank-size target on a road or in light clutter at a slant range from the RPV of 1,100 meters.

d. Automatic tracking and stabilization to permit the laser beam spot to remain on a 2.3 square-meter, high-contrast target 95 percent of the designation or lock-on time, at a slant range of 2,500 meters under normal flying conditions.

*Underlining added to emphasize further requirement(s) beyond previous MSC.

**EW jamming equipment will not be carried concurrently with sensor payloads.

e. Target location of 100 meters CEP and to 75 meters in altitude, with a confidence of 50 percent at a slant range of 2,000 meters and a range from the ground control station (GCS) of 30 kilometers.

f. Target location of 200 meters CEP and to 75 meters in altitude at a slant range from the RPV of 2,000 meters and a range from the GCS of 50 kilometers.

Further requirements given in the CFP are that, by 1985, the system will possess a 75 percent probability of:

a. Detection of a moving or nonmoving target of one-quarter ton truck size on a road at a slant range from the RPV of 4,000 meters, and in a field environment at a slant range of 3,000 meters.

b. Recognition of targets of one-quarter ton truck size at a slant range of 3,000 meters on a road or in a field environment.

c. Identification of a target of one-quarter ton truck size target at a slant range of 1,500 meters on a road or in a field environment.

In addition to mission requirements, these two documents also define and describe other characteristics and capabilities relative to:

a. Mobility

b. Emplacement/displacement

c. Electronic protective measures

d. Wind constraints (launch and recovery)

e. Vertical clearance (launch and recovery)

f. Aural signature

g. Visual signature

h. RPV location

i. Ground control station aural and visual signature

j. GCS record imagery

k. RPV control

4
PAYLOAD ANALYSIS

Analysis of candidate equipments for the mini-RPV payload involved the sequential determination of:

a. Payload requirements for all MSCs.

b. Feasible payload configurations.

c. Values of the primary parameter (imaging sensor resolution) that candidate equipments must satisfy.

d. Available equipments that, used in the various payload configurations, would meet performance criteria. This listing would span the range of high to low performance, cost, and weight, providing a base for subsequent tradeoff analyses.

e. Recommended equipments for each payload configuration, based on a performance/physical characteristic/cost tradeoff of items on the initial equipment listing.

4.1 MISSION REQUIREMENTS

The sensor requirements and MSC definitions from the CFP and O&O Concepts document were combined to form the total mission requirements for the mini-RPV payload. These requirements are summarized in Table 4-1.

4.2 GENERIC PAYLOAD CONFIGURATIONS

Based on the RPV payload requirements, payload configurations can be derived in general terms by designating generic equipments having the required capabilities and suitable to the mini-RPV application. Generic payload configurations applicable to the requirements summarized in Table 4-1 are diagrammed in Figures 4-1 through 4-4 for various MSCs. The generic equipments shown in these diagrams are those identified in the payload section of the TOD, and are shown in their relationship to other interfacing onboard avionics.

TABLE 4-1. MINI-RPV PAYLOAD REQUIREMENTS

MSC	Target			Mission		Visibility		RPV Range Fwd of LC (km)	Time Frame for Technology
	Type	Background	Slant Rng (m)	Task	Prob. (%)	Day	Night, Adverse Weather		
1.0 and 2.0	Tank	No clutter	5000	Detect	50	X		20	Present to 1980
		In clutter	2500	Detect	50	X			
		In clutter	2200	Recognize	50	X			
		In clutter	1100	Identify	50	X			
2.5	Tank	No clutter	5000	Detect	50	X	X	20	Present to 1980
		In clutter	2500	Detect	50	X	X		
		In clutter	2200	Recognize	50	X	X		
		In clutter	1100	Identify	50	X	X		
3.0	1/4-Ton Truck	No clutter	4000	Detect	75	X	X	50	1980 to 1985
		In clutter	3000	Detect	75	X	X		
		In clutter	3000	Recognize	75	X	X		
		In clutter	1500	Identify	75	X	X		
2.0 and 2.5	2.3 x 2.3 meters	High contrast	2500	Designate	95	—	—	30	Present to 1980
	Any	Any	2000	Target Location	50	X	X (MSC 2.5 only)		
3.0	2.3 x 2.3 meters	High contrast	3000	Designate	95	X	X	50	1980-1985
	Any	All	2000	Target Location	50	X	X		

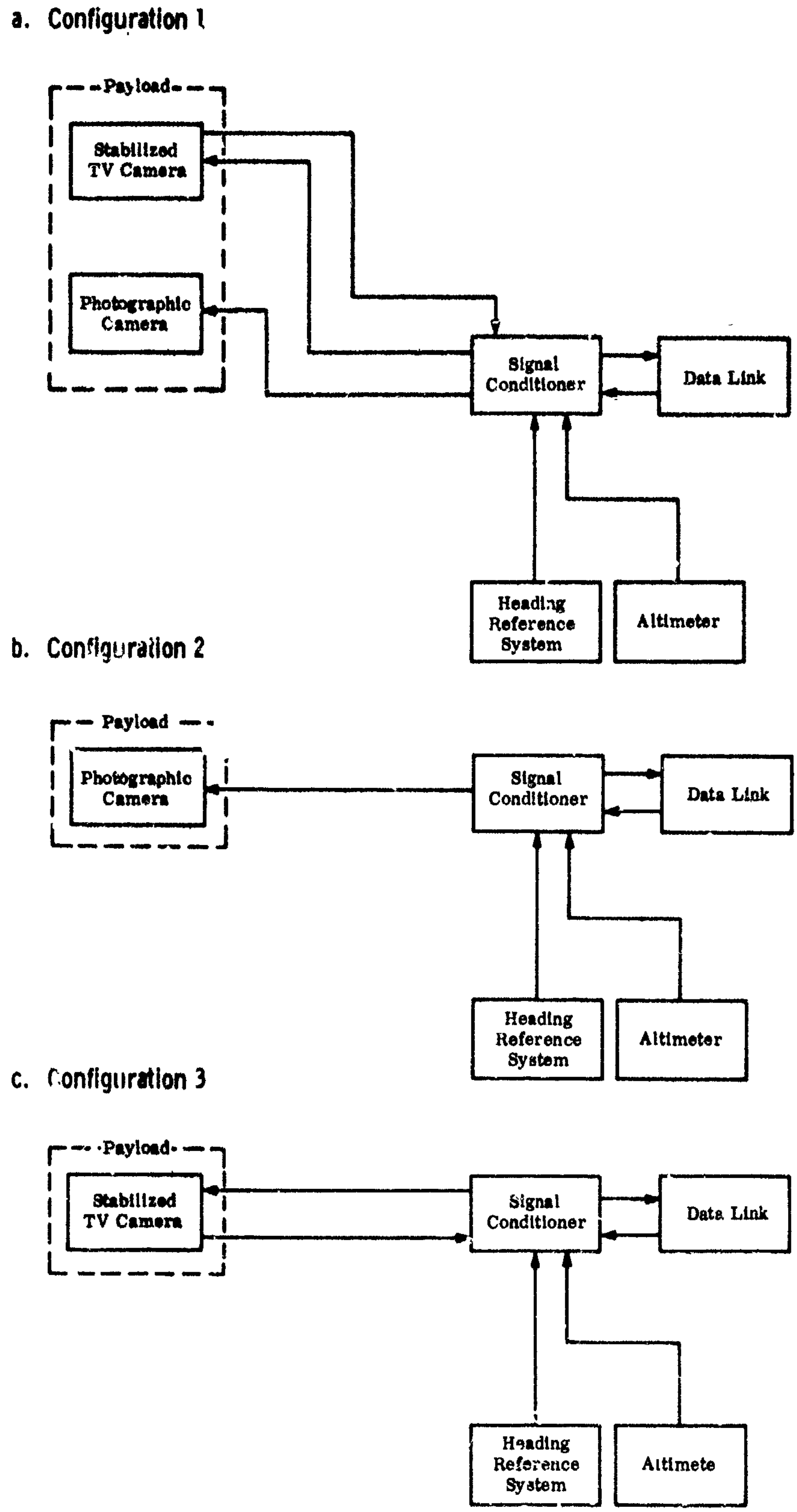
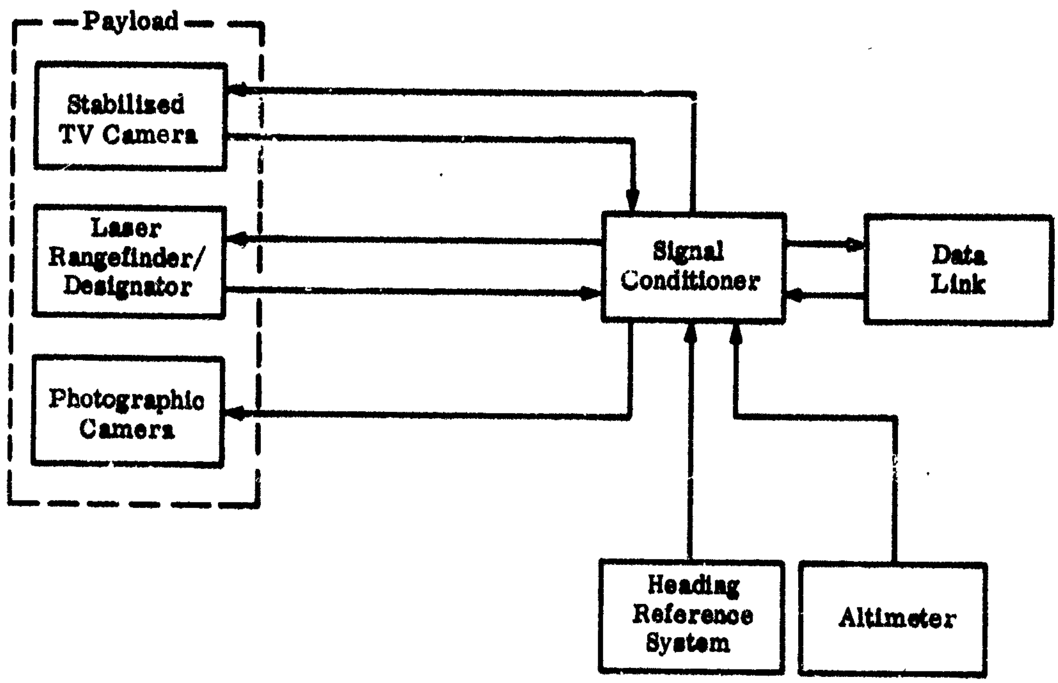


Figure 4-1. Generic Payload Configurations, MSC 1.0

a. Configuration 1



b. Configuration 2

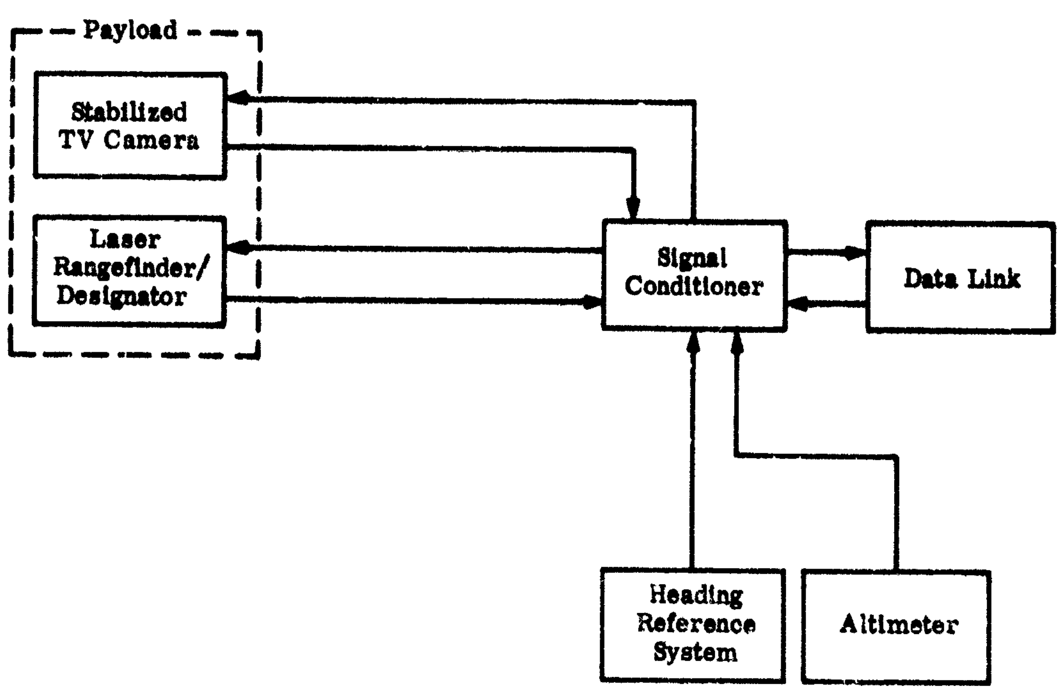


Figure 4-2. Generic Payload Configurations, MSC 2.0

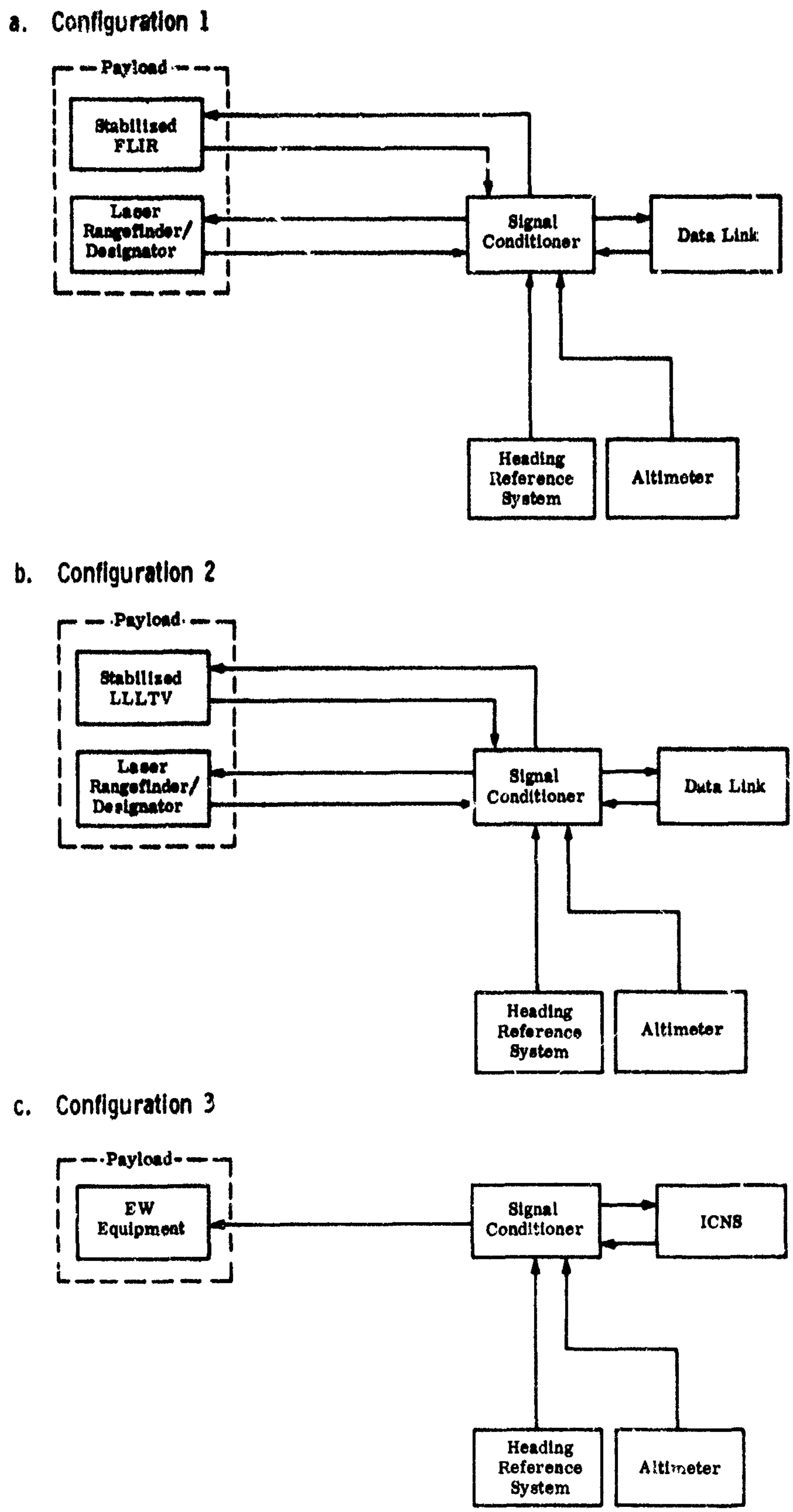


Figure 4-3. Generic Payload Configurations, MSC 2.5 and 3.0

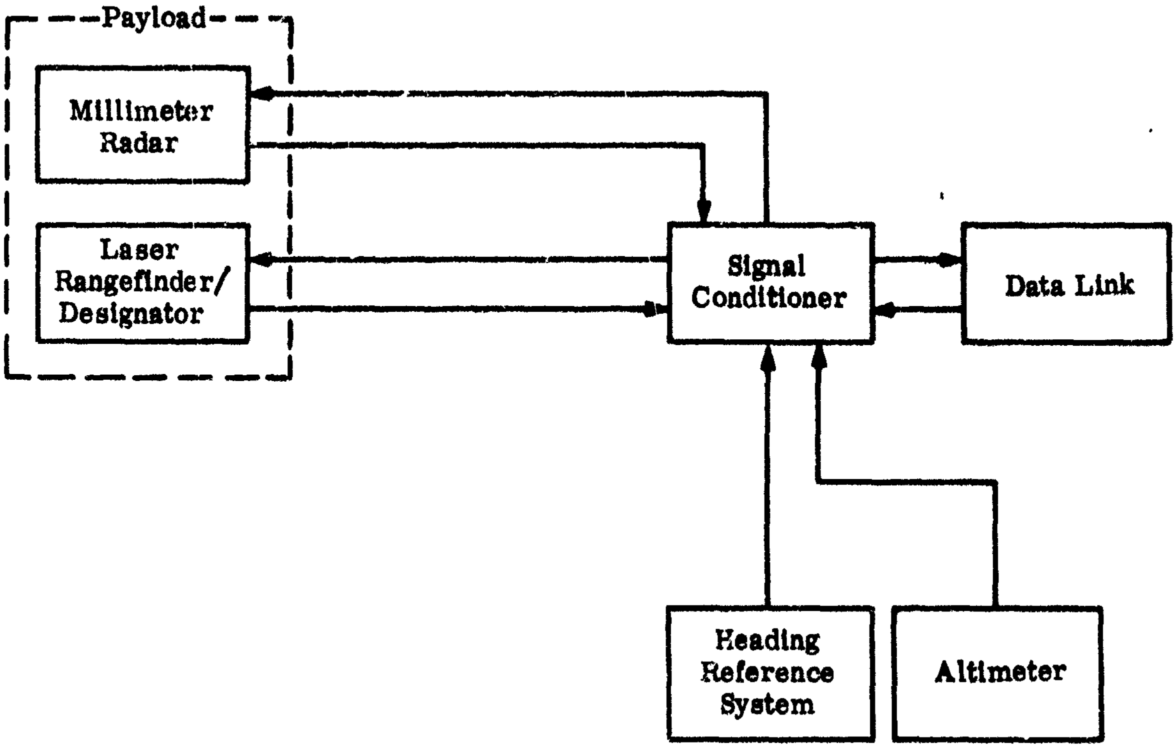


Figure 4-4. Generic Payload Configuration, MSC 3.0

4.3 SENSOR RESOLUTION VALUES

The imaging sensor parameter of primary importance to the performance of the defined RPV missions is resolution. This parameter can be expressed in a number of ways, among them:

a. TV lines per picture height (TVL/PH), or the number of effective lines in the vertical field of view; termed R_{TV} in this report.

b. Line pairs per milliradian (lp/mr), or the number of resolvable line pairs per milliradian of the vertical field of view; termed R_{lp}.

c. Lines per millimeter (l/mm), or the number of resolvable test-pattern bars and adjacent spaces per millimeter of the exposed frame size at the firm plane; termed R_{mm}.

d. Milliradians (mr), or the vertical angle subtended by smallest resolvable target; termed R_{Θ}.

The following equations derived as shown in Appendix B-2, express the relationship between these various forms of resolution and the mission-related factors of slant range, target size, vertical field of view, and required number of line pairs or cycles of spatial frequency necessary to perform the desired resolution task.

$$R_{TV} = 0.0209 \frac{ND}{X_T} FOV \qquad \text{(TVL/PH)} \qquad (4\text{-}1)$$

$$R_{lp} = \frac{ND}{1000(X_T)} \qquad \text{(lp/mr)} \qquad (4\text{-}2)$$

$$R_{mm} = \frac{ND}{X_T f} \qquad \text{(l/mm)} \qquad (4\text{-}3)$$

$$R_{\Theta} = \frac{1000(X_T)}{ND} \qquad \text{(mr)} \qquad (4\text{-}4)$$

where

N = Required cycles of spatial frequency for resolution. (Means of determining applicable values of N are discussed in Appendix B-1.)

D = Slant range in meters.

X_T = Minimum target dimension in meters

FOV = Field of view in degrees

f = Camera focal length in millimeters (assumed to be 50 mm)

The above equations were exercised for the conditions dictated by MSC requirements, and the results are given in Table 4-2. These data were used in the payload tradeoff evaluation (Section 4.4).

TABLE 4-2. IMAGING SENSOR RESOLUTION REQUIREMENTS

Conditions				Resolution			
N	D	X_T	FOV	R_{TV}	R_{lp}	R_{mm}	R_θ
1	5000	2.9	12	432	1.72	34	0.58
1.2	4000	2	12	602	2.40	48	0.42
2	2500	2.9	12	432	1.72	34	0.58
2.4	3000	2	12	903	3.60	72	0.28
3	2200	2.9	4.5	214	2.28	46	0.44
3.6	3000	2	4.5	508	5.40	108	0.19
6	1100	2.9	4.5	214	2.28	46	0.44
7.2	1500	2	4.5	508	5.40	108	0.19

N = Required cycles of spatial frequency for resolution

D = Slant range in meters

X_T = Minimum target dimension in meters

FOV = Field of view in degrees

R_{TV} = Resolution in TV lines per picture height

R_{lp} = Resolution in line pairs per milliradians of vertical field of view

R_{mm} = Resolution in lines per millimeter of exposed frame at film plane

R_θ = Resolution in milliradians required

The minimum trackable target size of an autotracker determines the maximum range at which the tracker can operate with a given field of view. The percentage of the FOV occupied by a target at range is expressed by:

$$\text{Pct. FOV} = \frac{X_T}{(\text{FOV})(\text{D})} \times 100 \qquad (4\text{-}5)$$

where

FOV = Field of view in radians

D = Maximum tracking range in meters

The requirement to track a 2.3 x 2.3 meter target in a FOV of 4.5 degrees at 2000 meters can be expressed as 1.5% FOV, and at 3000 meters as 1.0% FOV.

4.4 PERFORMANCE EVALUATION OF PAYLOAD COMPONENTS

Having identified and quantified the critical performance parameters for the payload components, we will now examine the candidate hardware items applicable to these parameters. An initial listing of payload equipment candidates was generated from information in the TOD; from other documents compiled by ARINC Research during the data collection task (see Section 2 and the Bibliography, Appendix A); and from discussions with manufacturers. These equipments are listed in Table 4-3.

4.4.1 Photographic Cameras (Panoramic)

As previously stated, the critical performance parameter for photographic cameras is resolution. Table 4-4 lists resolution requirements (from Table 4-2) for specified MSCs and mission tasks, together with the resolution capabilities, weight, and approximate cost of candidate cameras. Examination of these data reveal that:

a. All candidates meet the requirements for present-to-1980 time frame (MSCs 1.0 and 2.0).

b. None of the candidates can meet the requirement for 75% probability of recognition at a slant range of 3000 meters.

c. None of the candidates can meet the night and adverse weather requirements of MSCs 2.5 and 3.0. It would seem, therefore, that they should be selected primarily on the basis of performing per MSCs 1.0 and 2.0.

Other ranking factors are the weight and cost associated with each candidate. From this viewpoint, four equipment types (the KA-60C, CA-167B, KA-85A, and Itek 3" Optical Bar Panoramic) can be eliminated on the basis of high weight and/or cost, with no performance advantage over the other candidates.

TABLE 4-3. INITIAL LISTING (ALPHABETICAL) OF PAYLOAD EQUIPMENT CANDIDATES (Sheet 1 of 2)

Panoramic Photographic Cameras

Manufacturer	Model
Actron	HP-462X
Actron	KA-85A
Bourns/CAI	CA-167B
Bourns/CAI	CA-168 (modified)
Fairchild	KA-60C
Itek	3-inch bar panoramic
Itek	3-inch panoramic
Perkin-Elmer	KS-129A

Stabilized Television Systems

Manufacturer	Model
Aeronutronic	Praeire II
Honeywell	POISE
Westinghouse	Blue-Spot

Laser Rangefinder/Designator

Manufacturer	Model
Aeronutronic	Praeire II
Honeywell	POISE
Hughes	Mini-MULE
RCA	AN/GVS-5
Westinghouse	Blue-Spot

Video Autotracker

Manufacturer	Model
DBA Systems	(Undesignated)
Honeywell	POISE
Southern Research Institute	Maverick

Low Light Level Television

Manufacturer	Model
Westinghouse	Blue-Spot (with image intensifier)

TABLE 4-3. (Sheet 2 of 2)

Forward Looking Infrared (FLIR)

Manufacturer	Model
Aeronutronic	Mini-FLIR
Hughes	IRIS
Texas Instruments	Mini-FLIR

Millimeter Radar

Manufacturer	Model
Norden	Developmental

Electronic Warfare (EW)

Manufacturer	Model
RCA	Communications jammer
RCA	Radar jammer
U.S. Army EW Laboratory	Expendable communications jammer
U.S. Army EW Laboratory	Unattended/expendable radar jammer
Undesignated (from off-shelf components)	VHF/UHF intercept/repeater
Undesignated (from off-shelf components)	Precision intercept/direction finder

TABLE 4-4. REQUIREMENTS AND CAPABILITIES, PHOTOGRAPHIC CAMERAS (PANORAMIC)

A. Requirements

MSC	Mission			Required Resolution (l/mm)
	Range (m)	Task	Prob. (%)	
1.0, 2.0, and 2.5	5000	Detect, no clutter	50	34
	2500	Detect, in clutter	50	34
	2200	Recognize	50	46
	1100	Identify	50	46
3.0	4000	Detect, no clutter	75	48
	3000	Detect, in clutter	75	72
	3000	Recognize	75	108
	1500	Identify	75	108

B. Characteristics and Capabilities

Model	Manufacturer	Wt. with Film (lb)	Cost Est. ($K)	Resolution (l/mm)
KS-129A	Perkin-Elmer	15.0	3.4	80
CA-167B	Bourns/CAI	15.0	10.0	60
Modified CA-168*	Bourns/CAI	8.5	3.0	100
KA-85A	Actron	22.0	16.7	60
HP-462X*	Actron	10.0	.3.0	70
3" Pan.*	Itek	4.8	N/A	70
3" Bar-Pan.*	Itek	17.0	N/A	52
KA-60C	Fairchild	48.0	14.5	60

*Not in TOD

While resolution is the primary performance parameter, other parameters, as listed in Table 4-5, also enter the candidate screening process. Examination of the data in this table for the four remaining candidates reveals that significant difference exists in coverage, number of frames, and availability. These factors can be considered as shown below for the four equipment candidates now remaining in the evaluation. Each candidate is rated as either high (3), medium (2), or low(1) relative to the degree to which it satisfies the operational characteristics listed in the left column.

In the candidate evaluation, availability was given a greater weighting than the other two parameters. This resulted in ranking the KS-129A over the CA-168 (Mod) despite advantages of the latter in performance, weight, and cost. Availability also was the basis of rating the CA-168 (Mod) over the HP-462X.

Parameter	CA-168 (Mod)	KS-129A	Itek 3" Pan	HP-462X
Coverage	1	3	2	2
Max. Frames	3	2	1	3
Availability	2	3	2	1
Total	6	8	5	5

Based on the foregoing considerations, the panoramic photographic camera candidates for the mini-RPV payload are ranked as follows:

1. KS-129A, Perkin-Elmer
2. CA-168 (Mod), Bourns/CAI
3. HP-462X, Actron
4. 3" Panoramic, Itek

TABLE 4-5. SECONDARY PARAMETERS OF PHOTOGRAPHIC CAMERA

Parameter	CA-168 (Mod.)	KS-129A	Itek 3" Pan	HP-462X
Optics	35mm, f2.0	50mm, f2.3	80mm, f2.8	55mm, f1.8
Coverage	35° x 90°	34° x 180°	18° x 143°	120°
Film size	35mm	35mm	35mm	35mm
Max. no. frames	1000	450	200	1100
Frame rate	4/sec	4/sec	1/1.35 sec	1/sec
Exposure	Manual	Manual	Manual	Auto
Data annotation?	NA	NA	No	Yes
Iris range	f2.0 to f22	f2.3 to f22	f2.8 to f22	NA
Shutter speeds	$\frac{1}{500}, \frac{1}{1000}, \frac{1}{2000}, \frac{1}{4000}$	$\frac{1}{500}, \frac{1}{750}, \frac{1}{1000}, \frac{1}{1500}, \frac{1}{2000}, \frac{1}{3000}, \frac{1}{4000}$	1/500	NA
Power required	28W	30W	40W	NA
Availability	Proposed modification	In production	In limited production	Proposed development

NOTE: NA = Not available.

4.4.2 Stabilized TV Cameras

As for photographic cameras, the critical performance parameter for TV cameras is resolution. Table 4-6 lists resolution requirements for the planned MSCs and mission tasks, derived as discussed in Section 4.3; and lists candidate TV cameras and their dynamic resolution capabilities at FOVs of 4.5 and 12 degrees.

The data of Table 4-6 reveal that none of the cameras meet the near-time-frame (MSCs 1.0 through 2.5) 12-degree FOV resolution requirement for detection; or any of the resolution requirements for MSC 3.0. Improved resolution can be obtained by two methods; narrowing the FOV (i.e., optically zooming in) or increasing the TV scan rate. By narrowing the FOV below 12 degrees, the resolution requirement can also be lowered to an extent that available cameras can satisfy, as can be seen in Figure 4-5. The penalty paid for reducing the field of view, however, is a reduction of the time that a target is within the FOV (target presentation time). The relationship between FOV and target presentation time is shown in Figure 4-6. For each candidate system, target presentation time is found by first determining the maximum FOV corresponding to the dynamic limiting resolution (Figure 4-5), and then entering Figure 4-6 at this maximum FOV to determine a resulting target presentation time.

The interim report (ref. 41, Appendix A) on RPV tests conducted with Blue-Spot equipment in 1975 concludes that area scan and reaction could be satisfactorily accomplished within 10 seconds. As shown in Figure 4-6, it can be seen that detection tasks for MSCs 1.0 through 2.5 can be accomplished with FOVs that allow target presentation times of 10 seconds or greater.

As shown in Table 4-6, resolution requirements for MSC 3.0 exceed the capabilities of all candidate cameras. Narrowing the FOV to meet these requirements would cause reduction of target presentation times below the necessary 10 seconds. To meet the required resolution requirements, the use of cameras with higher scan rates seem necessary. Higher scan rates would in turn require data-link input analog bandwidths of greater than the presently planned 4.5 MHz. If, however, the faster scan rates were used in conjunction with a lower frame rate, the bandwidth increase could be minimized.

The lower-frame-rate approach would require that the TV image data be stored in memory onboard the mini-RPV and transmitted at a slower rate than it is generated. One of the problems associated with slow frame presentation is flickering, or, in the case of extremely slow frame rates, "jumping" from one still picture to another. Hughes Aircraft Company has sought to resolve this problem by generating at the GCS synthesized frames based on known airframe-dynamics data operating on the last image data. These synthesized images are used to fill in between frames of actual images to create a smoothed or flicker/jump-free presentation.

TABLE 4-6. REQUIREMENTS AND CAPABILITIES, STABILIZED TV CAMERA SYSTEMS

A. Requirements

MSC	Target			Mission		Req. Res. (TVL/PH)	At FOV (deg.)
	Type	Background	Range (m)	Task	Prob. (%)		
1.0, 2.0 and 2.5	Tank	No clutter	5000	Detect	50	432	12.0
	Tank	Clutter	2500	Detect	50	432	12.0
	Tank	Clutter	2200	Recognize	50	214	4.5
	Tank	Clutter	1100	Identify	50	214	4.5
3.0	1/4-T Trk	No clutter	4000	Detect	75	602	12.0
	1/4-T Trk	Clutter	3000	Detect	75	903	12.0
	1/4-T Trk	Clutter	3000	Recognize	75	508	4.5
	1/4-T Trk	Clutter	1500	Identify	75	508	4.5

B. Capabilities

Data Source	System	Resolution (TVL/PH)	At FOV (deg.)
Aeronutronic, "Little r" proposal (Ref. 16)	Praeire II	390 330	12.0 4.5
Lockheed, Statement of Work No. LMSC/6577023	POISE	300	12.0
TOD*		252	4.5
TOD**	Blue-Spot	306 254	12.0 4.5

*Estimated to be 12° resolution less 16%.

**Converted from angular resolution and adjusted to 12° and 4.5° by linear interpolation.

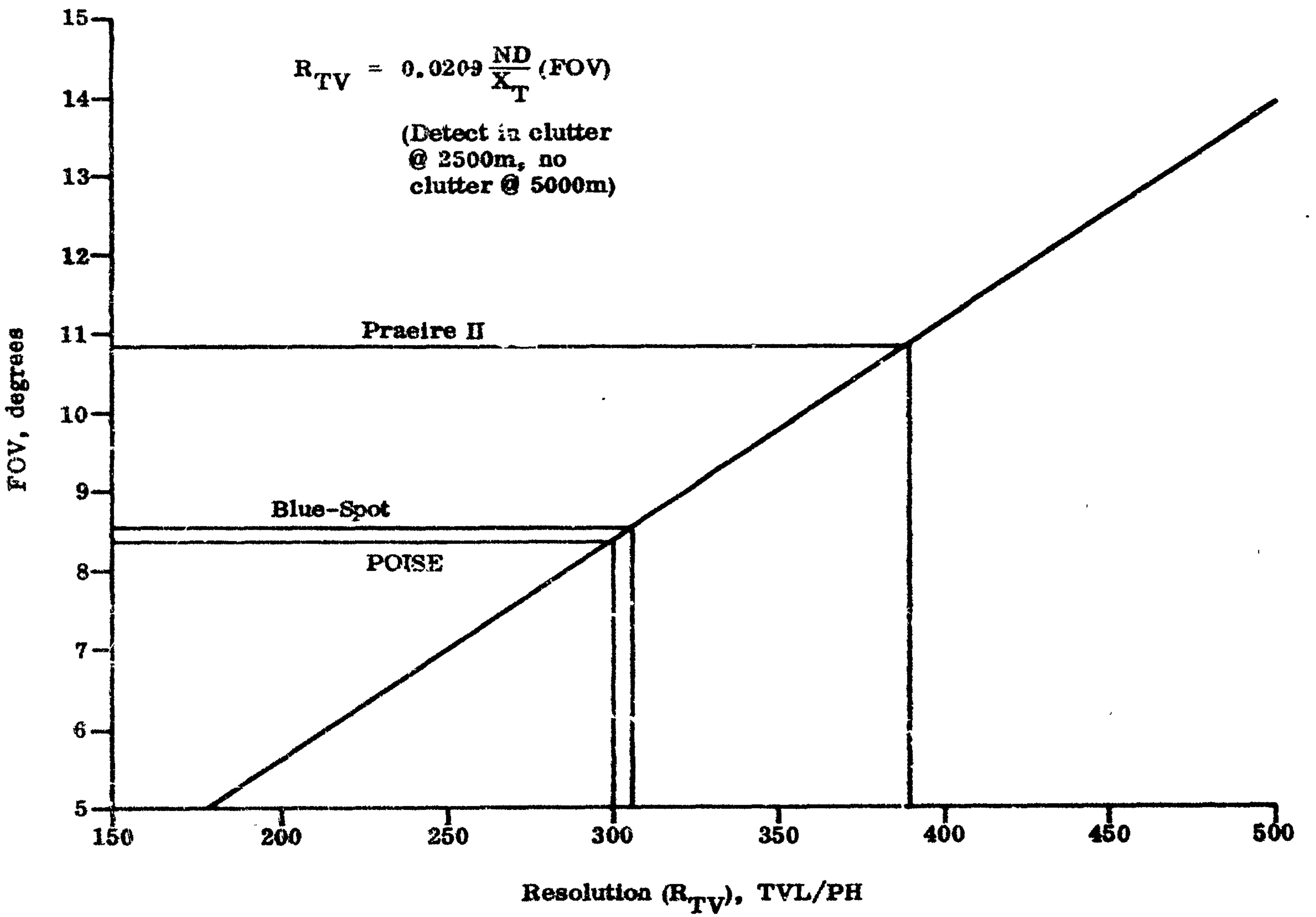


Figure 4-5. Required TV Resolution Vs. FOV

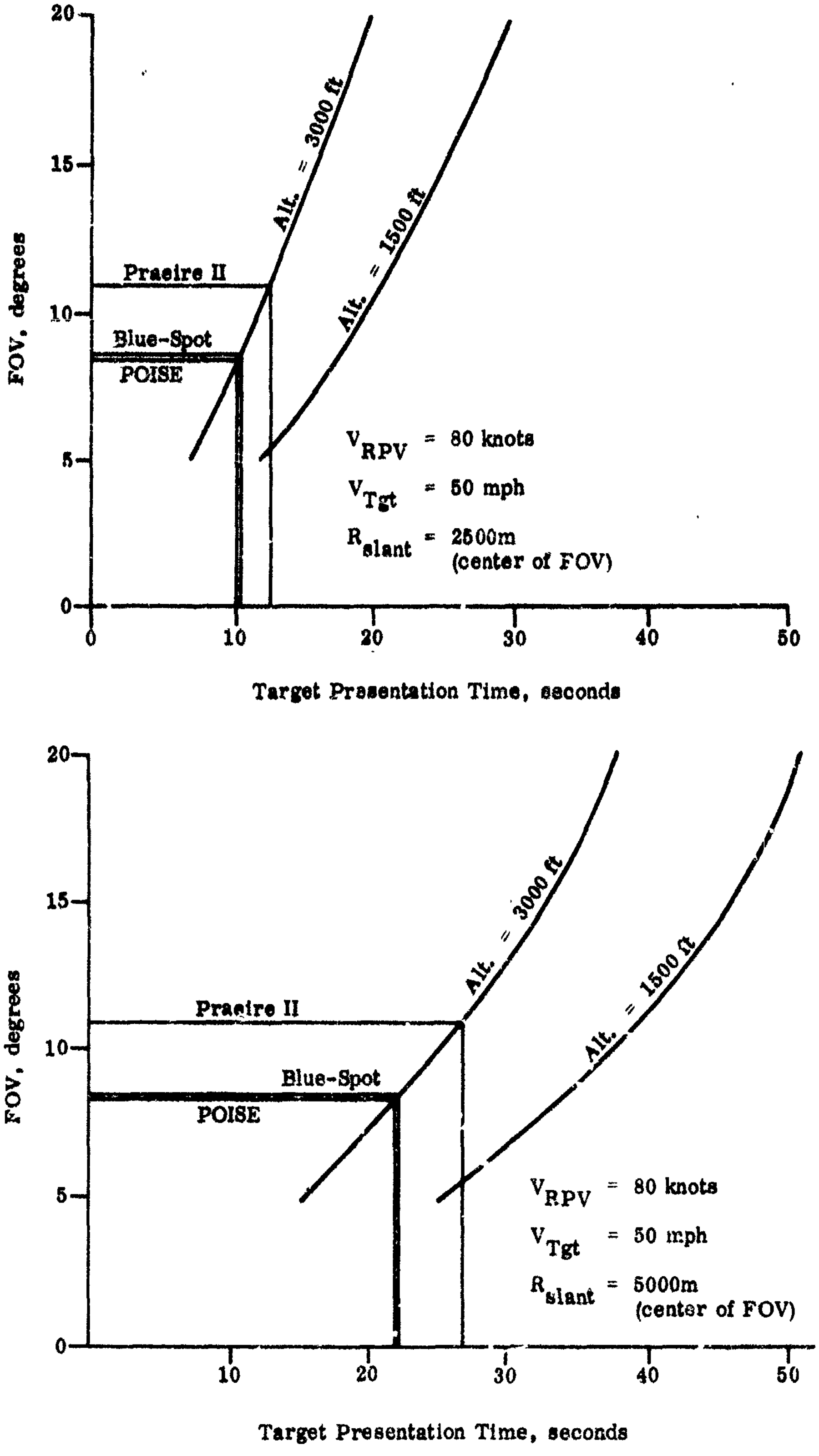


Figure 4-6. Target Presentation Time Vs. Field of View

Ranked in the order of their resolution capabilities, the candidate stabilized TV systems that meet the present-to-1980 time frame mission requirements are:

	Weight (lb)	Cost ($K)	Required Pwr (W)
1. Praeire II, Aeronutronic	18	15	100
2. Blue-Spot, Westinghouse	31	20	266
3. POISE, Honeywell	31	20	200

Note that cost, weight, and power factors also clearly favor the Praeire camera. The remaining two systems would rank approximately equal, with a slight advantage going to the Blue-Spot for somewhat better resolution.

For the 1980-1985 mission requirements, no stabilized TV camera systems suited to mini-RPV applications and having sufficient resolution capabilities were identified.

4.4.3 Laser Rangefinder/Designators

The critical performance parameters for the laser rangefinder/designator are accuracy for the rangefinder and beam divergence for the designator. Table 4-7 lists performance requirements for the laser, together with equipment candidates and their performance capabilities. Four of the candidates have performance capabilities that meet or exceed the required values. These are, in order of overall performance:

1. Mini-MULE (proposed), Hughes

2. Praeire system laser, Aeronutronic (ILS-100PR)

3. POISE system laser, Honeywell

4. Blue-Spot system laser, Westinghouse

Because of the technical risk associated with the development of the Hughes laser, for a gain in performance in excess of the minimum requirement for the mini-RPV application, it is lowered in the candidate ranking. The final ranking of laser designator/rangefinders is as follows:

1. Praeire II laser (ILS-100PR), Aeronutronic

2. POISE system laser, Honeywell

3. Blue-Spot laser, Westinghouse

4. Mini-MULE, Hughes

TABLE 4-7. REQUIREMENTS AND CAPABILITIES, LASER RANGEFINDER/DESIGNATOR

A. Requirements

MSC	Target			Pct. Time on Target	Pct. Beam on Target	Maximum Req. Beam Divergence* (mr)	Req. Beam Energy (mj)	Req. Range Accuracy (m)
	Range (m)	Size (m)	Contrast					
1.0, 2.0, and 2.5	2000	2.3 x 2.3	High	95	90	Manual tracking, 0.2 Autotrack, 0.5	75	±5 (90% conf)
3.0	3000	2.3 x 2.3	High	95	90	Autotrack, 0.5	75	±5 (90% conf)

B. Capabilities

System	Beam Divergence (mr)	Beam Energy (mj)	Range Accuracy (m)
POISE	0.5	80	±5
Blue-Spot	0.5	75	±5
Praeire (ILS-100PR)	0.2	80	±5 (90% conf)
ED** AN/GVS-5	1.0	Not avail.	±10
Hughes Mini-Mule	0.25	100	±5

*Total beam pointing error required is 0.23 mr for manual tracking and 0.12 mr for autotrack.
**Rangefinder only.

Since the first three of the above laser rangefinder/designators are part of integral systems, any of them would be the preferred choice if its overall system is selected for use in the mini-RPV payload.

4.4.4 Video Autotracker

The critical performance parameter for the video autotracker is minimum trackable target size, expressable as a percentage of FOV. Table 4-8 lists mission requirements for this parameter, together with candidate autotrackers and their capabilities.

The two candidates meeting minimum performance requirements, ranked in the order of minimum trackable target size are:

1. DBA Systems, Inc., autotracker

2. Honeywell autotracker (POISE system)

The POISE system autotracker has a 1-pound weight advantage, not considered significant.

TABLE 4-8. REQUIREMENTS AND CAPABILITIES, VIDEO AUTOTRACKER

A. Requirements

MSC	Target Range, (m)	Target Size (m)	Target Contrast	Task	Min. Req. Target Size (Pct. FOV)*
2.0 & 2.5	2,500	2.3 x 2.3	High	Designate	1.2
3.0	3,000	2.3 x 2.3	High	Designate	1.0

B. Capability

Source (System or Manufacturer)	Target Size (Pct. FOV)*
POISE	1.0
SRI, Inc.	2.0
DBA Systems, Inc.	0.3

*For FOV = 4.5°

It is implicit in the TOD descriptions that the Praeire and Blue-Spot systems also contain autotrackers, but no specifications for their performance are given. Discussions with Aeronutronic indicated that no specific autotracker has been selected for its Praeire system.

Thus, based on available information, the preferred autotracker for all systems except POISE would be the DBA unit. The POISE autotracker would be preferred if that system is incorporated into the payload to provide another function.

4.4.5 Stabilized FLIR Systems

Forward looking infrared radar (FLIR) sensors have the capability of operating during the day, at night, and under limited adverse weather conditions. Operational FLIR systems exist, but those that meet the size and weight requirements of the mini-RPV application are either prototype or technology demonstration models.

The TOD contains data on two mini-FLIR models in the technology demonstrator category. Additional information was obtained from the two companies involved, Texas Instruments and Aeronutronic. Characteristics of their FLIR systems are presented in Table 4-9. These values, representing predictions based on engineering calculations of the two contractors, are believed to reflect the state of the art of mini-FLIR systems.

Information was obtained from Hughes on a mini-FLIR sensor designated IRIS (Infrared Imaging Seeker). The existence of this equipment indicates that Hughes has in-house FLIR technology capable of developing equipment that could meet the mini-RPV requirement. The IRIS itself cannot meet the requirement since it has only a fixed, small FOV of 2.25 degrees.

At the writing of this report, it was learned that Honeywell is developing a mini-FLIR sensor intended to be adaptable to the POISE system, replacing the TV sensor. Since the mini-FLIR performance characteristics were not available in sufficient time, the data were not included in this analysis. It is recommended that the progress of this program be monitored, since it would seem to have potential as a strong candidate in the future.

The parameter of primary interest for this system is resolution, with minimum resolvable temperature (MRT) and noise equivalent temperature (NET) being of secondary interest for purposes of preliminary comparison. NET is the temperature difference required to give a signal-to-noise ratio of 1 for a large-area target. MRT is defined as the minimum temperature difference for which the bar pattern used in the tests is just visible.

For evaluating these mini-FLIR systems, the characteristic values in the two right-hand columns of Table 4-9 were considered to represent the capabilities of equipment from the respective developers (T.I. and Aeronutronic). Cost and weight data from the TOD were taken as the best available estimates for these parameters.

Table 4-10 lists FLIR resolution requirements for the MSCs, and the resolution capabilities of the two candidate systems. The data show that both systems can meet only the recognition and identification requirements of MSC 2.5. Although neither of the systems will meet the mission performance requirements for MSC 2.5 or 3.0, the Aeronutronic mini-FLIR is ranked slightly higher than the Texas Instruments version because of better resolution in the wide field of view, and estimated lower weight.

TABLE 4-9. CHARACTERISTICS OF STABILIZED FLIR SYSTEM

(See Attachment 1, CONFIDENTIAL)

TABLE 4-10. REQUIREMENTS AND CAPABILITIES, STABILIZED FLIR SYSTEMS

(See Attachment 1, CONFIDENTIAL)

4.4.6 Electronic Warfare

Electronic warfare missions could include 1) jamming of enemy communications or radar, and 2) interception and/or location of enemy emitters. Equipments applicable to these missions, together with their characteristics, are listed in Table 4-11. Since no performance requirements for EW missions are specified for the mini-RPV, no evaluation of the EW candidates can be made.

4.4.7 Stabilized Low Light Level Television (LLLTV)

The critical performance parameter for LLLTV systems is resolution at low light levels. Equipments presently available in the LLLTV category are conventional TV systems employing highly sensitive camera tubes. Typical of this class of equipment is the Westinghouse Blue-Spot system, which uses a camera tube with an image intensifier. The resolution of this system is reported to be comparable to that of the conventional (i.e., larger) Blue-Spot system; its production cost is estimated to be $28,000 each.

4.4.8 Radar

No millimeter radar systems are available for mini-RPV applications. A system in development at the Norden Division of United Technologies, Inc., is forecast to be available in the 1980-1985 interval. This radar is expected to have a production cost of $40,000 and a weight of 35 pounds. Its projected performance is not adequate for mini-RPV MSC 3.0 in two critical areas: 1) maximum range: 3 kilometers, versus the required 5 kilometers, and 2) azimuth resolution: 22.5 meters, versus the required 2 meters (1/4-ton truck).

TABLE 4-11. ELECTRONIC WARFARE EQUIPMENT CHARACTERISTICS

(See Attachment 1, CONFIDENTIAL)

4.5 PAYLOAD CANDIDATE RANKING

For each generic equipment type listed in Table 4-3, a critical performance parameter was identified. A minimum value for each such parameter was determined relative to mission requirements. Equipments were then ranked for the payload application on the basis of a two-step screening process.

a. An initial screening that related only to the ability of the equipments to meet the initial performance parameters.

b. A final screening that considered the tradeoffs between critical performance parameters and other equipment characteristics such as cost, weight, size, power consumption, technical risk, and secondary performance capabilities.

Based on this screening process, the final ranking of candidates for the payload configurations is shown in Table 4-12 for MSC 1.0, Table 4-13 for MSC 2.0, and Table 4-14 for MSCs 2.5 and 3.0.

4.6 CONCLUSIONS, PAYLOAD CANDIDATES

During the examination of candidate payload equipments relative to their capability of performing the specified tasks, the following observations were made.

a. Panoramic photographic cameras are applicable to MSCs 1.0 and 2.0. Several candidate cameras can satisfy the detection, recognition, and identification functions of these MSCs.

b. Stabilized television cameras are applicable to MSCs 1.0 and 2.0, and several available equipment types have the necessary performance characteristics. The use of a continuous zoom lens system is desirable, as it would allow an operator to maximize the time a target is within the field of view while maintaining an adequate level of resolution.

c. The laser rangefinder/designator is applicable to MSCs 2.0, 2.5, and 3.0. Several available equipments satisfy these requirements.

d. Video autotrackers are applicable to MSCs 2.0, 2.5, and 3.0, and several available equipments can satisfy the requirements.

e. Stabilized FLIR systems are applicable to MSCs 2.5 and 3.0, although their applicability is limited by their rather low adverse-weather capability. None of the candidate FLIR systems examined had resolution and field-of-view combinations that would meet the mission requirements. These candidates are ranked relative to how closely they approached the requirements.

f. LLLTV systems have limited applicability to MSCs 2.5 and 3.0. They have no adverse weather capability and require at least some ambient light (starlight, moonlight). The resolution of the single candidate identified met the requirements of MSC 2.5 but not of MSC 3.0.

g. Millimeter radar is applicable to MSC 3.0. However, the one noted candidate in this category – Which is in the early stages of development, and which will not be available until the early 1980s – does not have projected performance characteristics that meet the MSC 3.0 resolution and maximum range requirements.

TABLE 4-12. PAYLOAD RANKING, MSC 1.0 (Sheet 1 of 2)

a. Payload A

Photographic Camera

Rank	Camera	Weight (lb)	Cost ($K)	Power (W)
1	KS-129	15	3.4	30
2	CA-168 (Mod)	8.5	3.0	28
3	Itek 3" Panoramic	4.8	NA	40
4	HP-462X	10	3.0	NA

NA = Not available

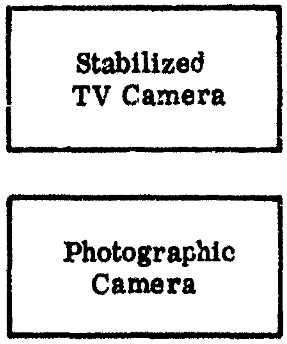
b. Payload B

Stabilized TV Camera

Rank	Camera	Weight (lb)	Cost ($K)	Power (W)
1	Praeire II	18	15	200
2	Blue-Spot	31	20	266
3	POISE	31	20	200

TABLE 4-12. (Sheet 2 of 2)

c. Payload C



Payload Combination

Rank	TV Cam.	Photo Cam.	Weight (lb)	Cost ($K)	Power (W)
1	Praeire II	KS-129	33.0	18.4	230
2	Praeire II	CA-168 (Mod)	26.5	18.0	228
3	Praeire II	Itek 3" Panoramic	22.8	NA	240
4	Praeire II	HP-462X	28.0	18.0	NA
5	Blue-Spot	KS-129	46.0	23.4	296
6	Blue-Spot	CA-168 (Mod)	39.5	23.0	294
7	Blue-Spot	Itek 3" Panoramic	35.8	NA	306
8	Blue-Spot	HP-462X	41.0	23.0	NA
9	POISE	KS-129	46.0	23.4	230
10	POISE	CA-168 (Mod)	39.5	23.0	228
11	POISE	Itek 3" Panoramic	35.8	NA	240
12	POISE	HP-462X	41.0	23.0	NA

NA = Not available

TABLE 4-13. PAYLOAD RANKING, MSC 2.0

a. Payload A

Stabilized TV Camera

Laser Designator/ Rangefinder

Rank	TV/Laser System	Weight (lb)	Cost ($K)	Power (W)
1	Praeire II	26	30	222
2	Blue-Spot	39	35	266
3	POISE	39	35	250

NA = Not available

b. Payload B - Above plus Photo Camera

Rank	TV/Laser System	+	Photo Camera	Weight (lb)	Cost ($K)	Power (W)
1	Praeire II		KS-129	41	33.4	252
2	Praeire II		CA-168 (Mod)	34.5	33	250
3	Praeire II		Itek 3" Panoramic	29.5	NA	262
4	Praeire II		HP-462X	36	33	NA
5	Blue-Spot		KS-129	54	38.4	296
6	Blue-Spot		CA-168 (Mod)	47.5	38	294
7	Blue-Spot		Itek 3" Panoramic	43.8	NA	306
8	Blue-Spot		HP-462X	49	38	NA
9	POISE		KS-129	54	38.4	280
10	POISE		CA-168 (Mod)	47.5	38	278
11	POISE		Itek 3" Panoramic	43.8	NA	290
12	POISE		HP-462X	49	38	NA

TABLE 4-14. PAYLOAD RANKING, MSC 2.5 AND 3.0
(Sheet 1 of 2)

a. Payload A

Stabilized FLIR

Laser Designator/ Rangefinder

Rank	Equipment Combination: FLIR	Equipment Combination: Laser	Weight (lb)	Cost ($K)	Power (W)
1	Aeronutronic	Praeire II	32.6	66 (est.)	120
2	Aeronutronic	POISE	31	66	NA
3	Aeronutronic	Blue-Spot	31	66	NA
4	Aeronutronic	Hughes	31	NA	NA
5	Texas Instr.	Praeire II	42.6	66 (est.)	NA
6	Texas Instr.	POISE	41	66	NA
7	Texas Instr.	Blue-Spot	41	66	NA
8	Texas Instr.	Hughes	41	NA	NA

NA - Not available

b. Payload B

Stabilized LLLTV

Laser Rangefinder/ Designator

Rank	LLLTV Type	Weight (lb)	Cost ($K)	Power (W)
1	Blue-Spot	44	43	296

TABLE 4-14. (Sheet 2 of 2)

c. Payload C (MSC 3.0 only)

Radar

Rank	Weight (lb)	Cost ($K)	Power (W)
1	35	40	NA

NA = Not available

d. Payload D

EW Equipment

Mission/Equipment Type	Cost ($)	Weight (lb)	Power (W)
Communications Jammer	500 (10K qty)	0.5	10
Radar Jammer	600 (10K qty)	0.7	10
Expendable Comm. Jammer	50 (10K qty)	5	10 (battery)
Unattended/Expendable Radar Jammer	2,000 (1K qty)	10	5 to 10
VHF/UHF Intercepter Repeater	500 (small qty)	2	10
Precision Intercepter/ Direction Finder	1,000 (small qty)	6	10

5 DATA LINK ANALYSIS

The operation of an RPV in a reconnaissance, surveillance, and target acquisition (RSTA) mission requires the employment of three data links between the RPV and ground control station. These are:

a. The command uplink, which provides communications from the GCS to the RPV in the form of commands for the control of the RPV and the onboard payload.

b. The status downlink, which provides communications from the RPV to the GCS in the form of information on the status of the aircraft, such as attitude, altitude, airspeed, etc.

c. The sensor information downlink, which provides wideband communications from the RPV to the GCS. The information conveyed by this link would primarily be the data from an imaging sensor such as a television camera, FLIR, or radar.

5.1 REQUIREMENTS

Required characteristics of the data links, as presented in the TOD, are summarized in Table 5-1.

5.2 CANDIDATE SYSTEMS

The data link requirements for a mini-RPV performing RSTA missions cannot be met with any existing operational equipment.

In 1972, the Defense Advanced Research Project Agency (ARPA) undertook the investigation and development of a miniaturized Integrated Communication and Navigation System (ICNS) for mini-RPVs. This program involved three contractors – Harris Corporation, Northrop Corportion, and Hughes Aircraft Company. Each contractor investigated different spread-spectrum modulation techniques. Upon completion of these studies, Harris was selected to continue with its development approach, based upon a combination of chirp and pseudo-random noise.

Harris has completed laboratory demonstrations of the approach and is currently engaged in a program expected to result in the miniaturization of a complete integrated anti-jam data link for a mini-RPV.

The TOD contains design goals and requirements for the Harris data link system. This system is specified to have high anti-jam (AJ) margins on all links and is designated in the TOD as a Level 3 system. By substituting non-AJ components for certain AJ types (to reduce cost or weight), lower levels of AJ protection can be postulated (Levels 1 and 2). These levels are representative of other AJ data link systems presently being investigated by industry, but to date little or no flight demonstrable hardware are available. Characteristics of these configurations are summarized in Table 5-2.

The characteristics denoted under Level 0 are typical of data link systems in current use with mini-RPV investigative programs, such as Lockheed's Aquila. These data link systems have no anti-jam features and operate at frequencies not in accordance with international frequency allocations for a mini-RPV.

5.2.1 Baseline Data Link Systems

As stated previously, no available data link systems will meet the combined requirements of anti-jam resistance, baseband frequency, and wideband data rate set forth for the mini-RPV. Since the only known effort to develop a suitable system is at Harris Corporation (the ICNS), that system would be ranked as the preferred candidate.

5.2.2 Alternative Systems

For interim use until the ICNS becomes available, a system made up of off-the-shelf components such as the Lockheed Aquila system could be employed. This step would involve some system adaptation to allow operation in a frequency band for which international allocations can be obtained.

The Government Electronics Division of Motorola is in the preliminary stages of developing a data link system that will contain a secure wideband downlink accommodating 525-line video. That system is reported to incorporate bandwidth compression and onboard frame storage techniques. Although the system could not be counted on for application in the present-to-1980 time frame, it is recommended that Motorola progress be monitored with a view toward application in the 1980-to-1985 period.

TABLE 5-1. MINI-RPV DATA LINK REQUIREMENTS

(See Attachment 1, CONFIDENTIAL)

TABLE 5-2. MINI-RPV DATA LINK CHARACTERISTICS FROM TOD

(See Attachment 1, CONFIDENTIAL)

6 NAVIGATION ANALYSIS

6.1 REQUIREMENTS

Required navigational accuracies for the mini-RPV are dependent on the mission, with the target acquisition and location mission being the most demanding. To locate a target with a CEP of 100 meters at a slant range between RPV and target of 2,000 meters and a range from the ground control station of 30 kilometers, the RPV must be accurately located within ±55 meters relative to the ground station. This value is based on 1) the demonstrated performance of available navigational systems, and 2) a target acquisition error analysis performed as part of this study. Procedures and results of the error analysis are presented in Appendix C.

For the surveillance and reconnaissance mission (MSC 1.0), navigational requirements are much less stringent. These requirements are estimated by determining the navigational accuracies required to place a reconnaissance target of known location with the field of view of the RPV sensor. A navigational accuracy of 200 meters is sufficient for performance of this mission.

For operation ranges beyond 30 kilometers (MSC 3.0), the optimum reconnaissance altitude (~2000 feet) is below the line-of-sight back to the ground control station. Operations at these extended ranges would require elevating the tracking antenna, elevating the RPV mission altitude, or providing a data link relay.

Table 6-1 summarizes the above navigational requirements.

TABLE 6-1. NAVIGATIONAL REQUIREMENTS FOR VARIOUS MSCs

Parameter	Value	MSC			
		1.0	2.0	2.5	3.0
Range	30 km	X	X	X	
	50 km				X
Accuracy	±55m		X	X	X
	±200m	X			
Below line-of-sight	–				?
Lightweight	–	X	X	X	X

6.2 CANDIDATE CONFIGURATIONS

A large number of navigational candidates can be postulated for the mini-RPV. For this tradeoff analysis, available and developmental systems will be discussed in terms of their applicability and potential. As will be demonstrated, the Integrated Communication and Navigation System is the most obvious choice for the 1980 to 1985 time frame, simply because it is also the recommended data link system (see Section 5.2.1). Aside from that, it offers accurate navigation together with a significant anti-jam capability.

Other systems are briefly discussed relative to their applicability to the less demanding navigational requirements of MSC 1.0, and as backup systems in the event that ICNS development is not sufficiently successful or timely.

6.2.1 Integrated Communication and Navigation System (ICNS)

The ICNS is briefly described in Section 5 relative to its applicability to the data link. The discussion here will be limited to the navigation portion of its airborne components.

Airborne components of the ICNS weigh approximately 8 pounds. This weight includes the modem and adaptive null steering antenna, and assumes extensive use of LSI chips in the production configuration. The navigational function of the onboard system is to act as a transponder for the gound control station. With the GCS in a rho-theta tracking configuration, location accuracies of 20 meters in range and 0.1 degree in azimuth are obtainable and within the navigational accuracies required. In a roh-rho navigational configuration employing two or three ground antennas, these accuracies can be improved. The degree of improvement is dependent on the base distance between the antennas and on other factors such as accuracies in locating and orienting the ground antennas.

The major disadvantage of the ICNS, whether used as a data link or navigational system, is its requirement for line-of-sight between the ground station and RPV. The operational range and altitude of the RPV is dependent on the elevation of the GCS antennas or relay antennas, and the elevation of the terrain between the antennas and RPV.

6.2.2 Global Positioning System (GPS)

The GPS is a satellite-based system that radiates navigational signals for use by air, land, or sea located receivers. As envisioned for mini-RPV applications, the GPS receiver would be onboard the RPV, with the navigational processing components located at the ground control station. In this configuration, the airborne components are expected to weigh less than 3 pounds. An accurate weight estimate is difficult to make at this time, since no GPS element is being developed specifically for this application. The estimate of 3 pounds is based on the projected weight of a receiver intended for use on the GB4-15 glide bomb.

The GPS is expected to be operational in the mid-1980's. The accuracies projected are only those for development goals. A longitude and latitude accuracy of 50 meters appears obtainable. A program is also underway to provide GPS with some anti-jam capability.

6.2.3 Position Location Reporting System (PLRS)

The Position Location Reporting System is a time-ordered, multiple-access system under development for the Army and Navy by Hughes Aircraft Company. The PLRS will employ multilateration techniques to locate and track positions of all cooperating users in a combat area. This capability will permit battlefield commanders to monitor the position of units under their command, and will allow users to ascertain their own position as well as exchange a limited amount of data.

The PLRS comprises two types of units: a master unit (MU) controlling a network of several hundred user units and providing a central display of their location; and a user unit (UU) designed for manpack operations. Functionally identical units can be utilized in RPVs, aircraft, helicopters, or ground vehicles. The MU, designed to be housed in an S-280 shelter, consists of an AN/UYK-7 and two AN/UYK-20 computers, a graphic display, a system master clock, and transmitting/receiving equipment for communication with the user net.

For position locating, multiple time-of-arrivals (TOAs) are assigned to be measured by each user unit in a PLRS network, and are transferred to the MU in single UU burst messages. At the MU, these TOAs are used to calculate the position of every unit in the network. No matter how large the network, as long as a user unit is in contact by line-of-sight with three or more other UUs, the MU can find the user's position directly or by utilizing the other user units as relays. The contact link is by a spread spectrum signal with an anti-jam margin of 22 dB.

For application to RPVs, the manpack can be reduced in weight from its projected 16 pounds by eliminating the battery, display, and some controls. As long as the RPV is in line-of-sight contact with three user units, whether on the ground or in other RPVs acting as relays, the location of the RPV can be known with accuracies better than 30 meters. The MU must be connected to the RPV control van probably by another UU to provide the location of each RPV.

6.2.4 Other Candidates

A number of other navigational systems have potential application to mini-RPVs. These systems have accuracies sufficient to meet the requirements of MSC 1.0, or in some cases, to extend the operational envelope of the RPV to non-line-of-sight navigation. The systems are discussed below in order of their potential.

6.2.4.1 Loran – Ground Processing (LO-CATE)

The LO-CATE system receives and retransmits navigational aid signals such as loran or omega. The retransmitted signal can be received at a ground station for processing and tracking of an RPV. For loran, the LO-CATE system has an unsurveyed accuracy of 200 to 250 meters. Advantages of this system are its light weight and relatively low cost. Disadvantages are its susceptibility to jamming and the requirement for deploying loran ground stations.

If used in conjunction with a more accurate navigation system, LO-CATE would have an accuracy of 20 to 30 meters relative to the last accurate position update. This accuracy would degrade as a function of the distance covered since the last accurate update.

6.2.4.2 Low Cost Inertial Guidance System (LCIGS)

The Low Cost Inertial Guidance System, being developed by the Air Force Armament Laboratory, is intended for use on tactical weapons such as glide bombs. The LCIGS will provide primary navigational guidance, with GPS or some other sensor/correlation system such as a radiometric area correlation network providing accurate navigational updates. LCIGS specifications in terms of accuracy are not known at this time, but are expected to be less accurate than for the other inertial systems listed in Table 6-2.

6.2.4.3 Omega Navigation Receivers

Various omega-type navigational systems have been designed for RPV and expendable RPV applications. These systems are lightweight and relatively inexpensive, and have accuracies of 1,852 meters (one nautical mile) in daytime and 3,704 meters (two nautical miles) at night.

The mini-RPV application would primarily be to provide guidance in conjunction with a more accurate system. The differential accuracy of the omega receiver relative to the last accurate position known is a function of receiver sensitivity and the RPV location relative to the omega ground stations. The time between accurate position updates and changes in RPV location would not be significant enough to affect accuracy.

Present omega receivers have a sensitivity of one centilane, or 1/100 of a lane determined by the omega wavelength. When the RPV is directly between two omega stations, the lane is roughly seven miles wide, yielding an omega navigational accuracy of 7/100 mile or approximately 114 meters. This accuracy deteriorates as the RPV moves away from a location directly between the omega ground stations.

6.2.4.4 Loran – Onboard Processing

A number of loran receivers are available for processing loran signals onboard an RPV. The receivers are considerably heavier and more expensive than LO-CATE receivers; and since they offer no advantage over the LO-CATE ground processing systems, they will not be considered in this study.

6.2.4.5 Doppler Navigational Systems

The representative doppler system in the TOD is the AN/ASN-128. This unit weighs 30 pounds (including display and controls), costs more than $25,000, and has an accuracy of 600 meters for a 30-kilometer mission. At this weight, cost, and accuracy level, a doppler system is not applicable as a primary system for MSC 1.0 or as a backup system for GPS. Therefore, doppler systems were not considered further in this study.

6.2.4.6 Inertial Navigational Systems

Representative inertial navigational systems, except the LCIGS mentioned in Section 6.2.4.2, weigh from 20 to 30 pounds and cost more than $50,000 each. Their accuracy at the end of a 90-minute flight is in the order of 2,500 meters. These systems are obviously not suitable for mini-RPV applications.

6.3 CANDIDATE ASSESSMENT

The performance and physical data discussed above, together with other relevant information, is summarized for the navigation subsystems in Table 6-2. The applicability of these systems to each MCS is discussed in the following paragraphs.

6.3.1 Mission 1.0

The Integrated Communication and Navigation System is the obvious choice for MSC 1.0, since it also serves as the data link system. Two other candidates listed in Table 6-2, omega and loran, are not considered serious contenders. However, in the event ICNS is not successfully developed, either of these alternatives could be coupled with another data link system to provide navigational guidance.

The navigational accuracies of the omega and loran systems are somewhere between their absolute and differential accuracies. At launch, the system can be calibrated to the known launch location, which will provide initial navigational accuracies of 100 to 200 meters for omega and 30 to 50 meters for loran. As the RPV moves away from the calibrated location and as time advances, the navigational accuracies deteriorate toward the absolute accuracies of 1800 to 4000 meters for omega and 200 to 250 meters for loran. However, RPV operational ranges and mission durations are not large enough to deteriorate significantly the calibrated accuracies.

A third alternative to ICNS is the Position Location Reporting System. If deployed for battlefield command and control, PLRS would offer an available, accurate navigational system with modest anti-jam protection, reporting real-time RPV locations to the RPV control van and to the PLRS master unit for battlefield control.

A summary ranking of navigation systems for MSC 1.0 appears in Table 6-3.

6.3.2 MSCs 2.0 and 2.5

For MSCs 2.0 and 2.5, the target location objectives require a much more accurate navigational system than for MSC 1.0. Two systems will be available for 1980 to meet these requirements; the Integrated Communication and Navigation System and the Position Location Reporting System. These candidates are compared and ranked in Table 6-3 relative to the mini-RPV application. As for MSC 1.0, ICNS is ranked first, mainly because of its availability as the data link.

No significant weight or cost savings would be realized by removing the navigational function from ICNS in favor of a second system such as PLRS. PLRS can be coupled with a data link system to back up ICNS in the event that its development is delayed or proves unsuccessful.

6.3.3 MSC 3.0

MSC 3.0, with its 50-kilometer range, imposes the most severe navigational problems for the mini-RPV. While there are a number of possible solutions, none of them is simple. The primary systems for each candidate are the Integrated Communication and Navigation System, the Tactical Global Positioning System Guidance, and the Position Location Reporting System. These candidates are discussed below and ranked in Table 6-3.

TABLE 6-2. CHARACTERISTICS OF NAVIGATIONAL SYSTEMS

System	Weight (lb)	Accuracy (meters)			Special Ground Station Support	Cost ($K)	Year Avail.	Devel. Risk
		30 km, 1.5 hr	50 km, 2.0 hr	Rel. (Diff.)				
Integrated Communication and Navigation System (ICNS)	<10	20 range 52 az.	20 range 87 az.	-- --	Part of data link system	10-20	1980	Low
Tactical Global Positioning System Guidance (TGPSG)	3	50	50	--	Ground processing of GPS data	5-7	1985	Med.
Position Location Reporting System (PLRS)	<12	<30	<30	Not applic.	PLRS master station	11	1980	Low
Other								
LORAN - Ground Processing (LO-CATE)	~3	200-250	200-250	30-50	LORAN ground stations	1	1980	Low
Low Cost Inertial Guidance System (LCIGS)	15-20	Unk.	Unk.	Unk.	None	10-15	1985	Med.
OMEGA Systems	3.25	1800-4000	1800-4000	>114	None	3	1980	Low
LORAN - Onboard Processing	8-10	200-250	200-250	30-50	LORAN ground stations	>4	1980	Low
Doppler Systems	<30	600	1000	2%	None	>25	1980	Low
Inertial Systems	20-30	2700	3000	Not applic.	None	>50	1980	Low

TABLE 6-3. RANKING OF NAVIGATION SUBSYSTEM CANDIDATES

Candidate	Weight	Range	Accur.	Oper. Flex.	Surviv-ability	Devel. Risk	Cost*	Overall
MSC 1.0								
Integrated Communication and Navigation System (ICNS)	1	3	2	2	1	2	1	1
OMEGA Navigational Receivers	2	1	4	1	3	1	2	2
LORAN - Ground Processing (LO-CATE)	3	2	3	3	3	1	3	4
Position Location Reporting System (PLRS)	4	4	1	1	2	2	4	3
MSC 2.0-2.5								
ICNS	1	2	2	2	1	1	1	1
PLRS	2	1	1	1	2	1	2	2
MSC 3.0								
ICNS								
Ground Based Antenna	1	2	3	3	1	1	1	1
Airborne Tracking Antenna	1	1	4	2	2	3	3	3
Augmented - Airborne Relay	2	1	5	1	4	2	2	5
Tactical Global Positioning System Guidance (TGPSG) with Airborne Data Link Relay	2	1	2	1	2	3	3	2
PLRS with Airborne Data Link Relay	3	2	1	2	3	3	4	4

*Cost ranking is based on use of ICNS as the data link system, and the additional cost of the loran system for ground equipment.

6.3.3.1 Candidate 3.1 – ICNS

The ICNS can be extended in range for this mission in one of three ways:

a. Mission altitude can be raised to maintain line-of-sight.

b. Airborne tracking antennas can be deployed to extend the line-of-sight to 50 kilometers.

c. ICNS can be augmented by an onboard system to report the RPV's location through the data link system via an airborne relay.

Each of these approaches is discussed below.

6.3.3.1.1 Candidate 3.1.1 – Ground Based Antenna – The least expensive approach to solving the navigational requirements of MSC 3.0 would be simply to maintain line-of-sight between the GCS and RPV, and then increase the transmitted power to whatever value is needed for the additional range. The disadvantage is obvious: at 50 kilometers, line-of-sight would require an RPV operational altitude of 5,000 feet. Operation at this altitude would require payload sensors of greatly improved resolution. The utility of this candidate must be resolved at the RPV system level, and final assessment is deferred until then. All other candidates presented here assume a 2,000-foot operational altitude.

6.3.3.1.2 Candidate 3.1.2 – Airborne Tracking Antenna – By deploying one or more relay RPVs, a navigational relay can be created between the GCS and the mission RPVs. Two approaches are possible in this regard. First, a single tracking RPV can be deployed with an antenna to track mission RPVs using a rho-theta (range-azimuth) approach. Second, two or more RPVs can be deployed with antennas to track RPVs using a rho-rho (trilateration or multilateration) approach. In each case, the tracking RPVs must themselves be accurately tracked by the GCS. These RPVs would also serve as data link relays between the mission RPVs and the GCS.

The rho-theta approach is technically the most difficult to implement. A tracking antenna must be installed on a mini-RPV, and the RPV altitude and heading must be known accurately to orient the tracking antenna. Both feats are difficult. The advantage over the multilateration approach is the use of a single RPV as a navigational relay.

Although technically less difficult, the multilateration approach requires that two or more navigational relays be continuously maintained airborne during operation of RPVs at extended ranges. It may be possible to deploy the RPVs in much the same manner as the PLRS user units. Each ICNS airborne set would then act as a navigational relay, thereby establishing a network. This concept is described in more detail under the PLRS candidate (Section 6.3.3.3).

6.3.3.1.3 Candidate 3.1.3 – Augmented-Airborne Relay – The augmented airborne relay candidate is based on normal ICNS ground tracking to the limits of line-of-sight, and then switching to an onboard position reporting system and an airborne data link relay to extend the range to 50 kilometers. The onboard system could be either an omega receiver, loran receiver (LO-CATE), or the Low Cost Inertial Navigation

System. Each system has its advantages and disadvantages. Omega is the cheapest but offers the least accuracy; LO-CATE offers the best accuracy but requires that special loran stations be deployed; LCINS is jam-proof but is by far the heaviest and is expected to have poor accuracy.

6.3.3.2 Candidate 3.2 – TGPSG with Airborne Data Link Relay

The Tactical Global Positioning System Guidance is the simplest solution to providing navigation during non-line-of-sight operations.

The TGPSG operates by receiving time and ephemeral data from at least three satellites. The ephemeral data can be received at the ground control station, which would reduce the onboard TGPSG receiver workload to that of receiving the timing signals and presenting them in proper format to the data link modem for transmission to the airborne relay.

The timing and emphemeral data must be correlated with each other at the ground station. If the ground TGPSG receiver and airborne receivers are tuned to the same satellites, synchronization of the timing data received at the ground station with that from the RPV would provide the necessary correlation.

6.3.3.3 Candidate 3.3 – PLRS with Airborne Data Link Relay

For MSC 3.0, the Position Location Reporting System is especially desirable if a large number of mini-RPVs are airborne simultaneously. As long as an RPV is in line-of-sight with three or more PLRS user units, whether on air vehicles such as RPVs and helicopters or on the ground, the position of the RPV can be computed at the PLRS master unit. This situation would probably exist if a number of RPVs are airborne simultaneously and spread out between the MU and the 50-kilometer maximum range requirement. If not, special PLRS RPVs would have to be deployed. Naturally, the data-link relay RPV could be counted as one of these PLRS RPVs.

The primary advantages of this system are its superior accuracy and its commonality and cooperation with a battlefield position-reporting system. The major disadvantages are the necessary deployment of airborne PLRS user units, and an airborne weight and cost penalty (worse than the TGPSG system).

6.3.3.4 MSC 3.0 Ranking

MSC 3.0 navigation candidates are ranked in Table 6-3. Underlying assumptions are that:

a. Deployment of a large number of RPVs simultaneously in a PLRS network is more the exception than the rule; and

b. Payload sensor resolution capabilities will be sufficiently advanced by 1985 to permit normal figiht operations at 5,000 feet or higher.

Based on these assumptions, the ground-based ICNS (alternative 3.1.1) is ranked first, primarily because of its low cost, low risk, low weight, and high anti-jam margin. However, if operation of the RPV at higher mission altitudes than now envisioned as optimal for target acquisitions (assumption b, above) does not prove to be the case because of weather limitations or inadequate sensors, the ground-based ICNS candidate would be eliminated. The TGPSG system would then be ranked first because of its operational flexibility and potential for cost and weight reduction.

7
AUTOPILOT ANALYSIS

An autopilot is made up of sensors, such as transducers, gyroscopes, and magnetometers, together with a processor in a specific combination determined by the functional requirements and accuracies needed to perform a mission. In this section, mini-RPV mission requirements as affect the autopilot are stated, and then the combinations of autopilot components that will meet those requirements are derived. Some of these combinations are already in use, in such systems as the Aquila and Praeire mini-RPVs. Others have been postulated in various reported studies. To aid the selection of the best candidate autopilot, the candidates are ranked with respect to the degree to which they satisfy mission and other program requirements.

7.1 AUTOPILOT REQUIREMENTS

Autopilot requirements for the mini-RPV are listed in Table 7-1, with their applicability to each MSC indicated. These requirements are divided into two categories: flight stabilization and control, and attitude reporting or control.

Critical parameters relative to flight stabilization and control of mini-RPVs are airspeed, altitude, and direction. Attitude reporting or control is necessary for the accurate determination of target position. This function is accomplished by continuously reporting the attitude and heading of the RPV, or by momentarily stabilizing the vehicle in a known attitude during the target location task. The following paragraphs discuss the origin of each parameter value listed in Table 7-1.

7.1.1 Flight Stabilization

Parameters considered in flight stabilization are directional stability, altitude accuracy, and airspeed, as discussed individually in the following subsections.

7.1.1.1 Directional Stability

Flight-path guidance of an RPV is usually by a system that detects and tracks the aircraft's flight path. The heading reference is used to stabilize the aircraft between guidance updates. Assuming a reasonable update rate (one per second), the heading detection and hold accuracies are not very stringent for normal mission operations of an RPV.

If the guidance system is dependent on ground processing, failure of that system or a loss of carrier would cause the RPV to revert to free-flight or dead-reckoning state. In the case of carrier loss, a relatively simple onboard routine can direct the RPV back toward the ground control station or through an area jammed by the enemy. This routine would include a prelaunch-selectable heading, altitude, and time delay, the latter preventing initiation of the loss-of-carrier routine in the event of momentary data loss. The selectable heading would be compared with the heading detected and thereby generate a heading error from which the aircraft can be guided until the command link is regained.

TABLE 7-1. AUTOPILOT REQUIREMENTS

Parameter	Value	MSC			
		1.0	2.0	2.5	3.0
Flight Stabilization and Control					
Directional Stability	±5°	X	X	X	X
Altitude Accuracy					
Normal	±100 ft	X	X	X	X
Accurate Recovery	±2 ft	X	X	X	X
Airspeed					
Accuracy	±4 ft/sec	X	X	X	X
Envelope - Max.	216 ft/sec	X	X	X	X
Attitude Reporting or Control					
Pitch Accuracy	±1.0°		X	X	X
Roll Accuracy	±1.0°		X	X	X
Heading Accuracy	±2.0°		X	X	X
Altitude Accuracy	±50 ft		X	X	X
Other					
Light Weight		X	X	X	X
All Weather				X	X
Loss of Carrier Routine		X	X	X	X

7.1.1.2 Altitude Accuracy

No stringent altitude control accuracies are specified for the mini-RPV missions. The requirement noted in Table 7-1 is within the obtainable accuracies of available barometric altimeters. However, the altitude accuracy required for some vehicle-recovery methods can be quite demanding, so these methods usually call for augmentation of the altitude control system with ground approach instrumentation.

During recovery, the basic RPV system must be sufficiently stable to allow some delays in the response of the recovery approach control. Stability of this nature usually requires damping of the short-term pitch and phugoid modes. The smallest recovery window for an RPV is that required by the present Aquila wire-and-impact platform system, which is 5 feet high. A variation in altitude control of ±2 feet can be tolerated for this system.

7.1.1.3 Airspeed

The maximum airspeed specified by the TOD is 240 kilometers per hour (216 feet per second). The primary requirement for airspeed control accuracy is during recovery, when the RPV is closest to stall speed and when excess speed is converted into additional inertia to be arrested. An accuracy of ±4 feet per second is within the capability of available airspeed transducers, and meets these recovery requirements.

7.1.2 Attitude Reporting

Attitude and altitude reporting or control accuracies are established for the target acquisition mission. The mission requirement is to locate targets at a slant range from the RPV of 2,000 meters and:

a. With a CEP of 100 meters at an RPV distance from the GCS of 30 kilometers.

b. With a CEP of 200 meters at an RPV distance from the GCS of 50 kilometers.

To meet this requirement, attitude and location accuracies have been allocated to the various contributing components based on the capabilities of available hardware. Table C-2 of Appendix C lists the accuracies needed to meet the mission requirement.

7.1.3 Other Requirements

7.1.3.1 Light Weight

The maximum allowable weight of the RPV is an important consideration in selecting the type of autopilot and allocating functions between the aircraft and ground station. The more functions that can be assigned to the ground station, the less equipment is required for the airborne system and hence the less vehicle weight and recurring cost. However, the more functions assigned to the ground station, the more critical the data link becomes. The allocation of these functions is determined by identifying the aircraft functions that must be retained in the event of a loss of the data link.

7.1.3.2 All-Weather Capability

During all-weather missions, aircraft are subject to electromagnetic interference and loss of visual flight aids. In addition, the recovery mode of the autopilot must be compatible with whatever special recovery guidance system is required for night or adverse weather operations.

7.1.3.3 Loss of Carrier Routine

There are three causes of loss of carrier: data link component failure, terrain masking, and receiver jamming. If the data link fails, the aircraft can be assumed to be lost. The effect of component failure may be reduced by adding redundancy. In the event of terrain masking the carrier can be regained, usually by the RPV's gaining altitude. In a jamming environment, the carrier may be regained by directing the aircraft toward the ground control station or toward an area known to be free of jamming.

Combining these requirements, the loss-of-carrier routine in conjunction with the autopilot should turn the aircraft toward a preset heading and make it climb to a preset altitude. To avoid initiating the loss-of-carrier routine due to short term masking or jamming and to avoid prematurely breaking off target track and designation, a time delay should be added.

The loss-of-carrier routine can also serve as a preprogrammed means of overflying known areas of jamming. This is envisioned as a dead-reckoning guidance scheme with a time delay set to initiate the loss-of-carrier routine after the target is overflown. Use of the loss-of-carrier routine in this manner requires a certain degree of onboard directional stability. Assuming that the payload video information can still be received by the ground control stations, reconnaissance flights would be possible even in the event of jamming. Assuming further that the RPV is detected and jammed 4,000 feet from the target, a flight heading accuracy of ±5 degrees is acceptable to place the target in a 20-degree field of view of the video sensor flying at 2,000 feet.

7.2 COMMON FEATURES AMONG CANDIDATES

Autopilots perform four basic functions: airspeed sensing and control, altitude control, heading control, and attitude stabilization.

7.2.1 Airspeed Control

Airspeed can be sensed by an airspeed transducer. An angle-of-attack wind vane could also be used for indirectly determining airspeed, but wind vanes are susceptible to breakage or bending in field operations.

Airspeed can be controlled by varying the pitch of the aircraft, an approach that provides the necessary responsiveness to prevent stalls. During recovery operations, however, when an accurate glide slope angle or rate of descent may be required, airspeed can be controlled by the throttle, and altitude control can utilize the more responsive pitch actuators for maintaining accurate glide slope angles.

During normal flight operations, pitch control signals are dampened to prevent unstable oscillations. Either a rate gyro can be used for this purpose, sensing pitch rate directly; or a displacement gyro, by differentiating pitch displacement signals.

7.2.2 Altitude Control

For altitude control, the altitude is normally sensed by a barometric or radar altimeter and controlled with pitch or throttle actuators. The high accuracies of relatively heavy radar altimeters are not required for this application, and such equipments will not be included in the candidates.

For normal flight operations, altitude is usually controlled through the throttle. For recovery flights into small recovery windows, altitude control is switched to the pitch actuators to provide quicker response and a more controllable glide slope. For many airframes, normal accelerometers are added to dampen pitch oscillations and correct for downdrafts during recovery operations. Normal accelerometers provide the quick response for accurate flight-path control that altimeters or ground-based landing systems lack.

7.2.3 Heading Control

Heading control is the most difficult of the autopilot functions. This function includes maintaining directional control, performing banking or skid turns, and supplying a certain degree of attitude control. A number of control schemes are feasible. Common to each scheme is a magnetometer either coupled with a directional gyro, corrected by a vertical gyro, or operated alone to supply a directional reference to the autopilot.

Corrections for directional errors are made by banking (roll), skid (yaw), or coordinated turns (roll and yaw), depending on the type and stability of the airframe. In any case, the turn is controlled by either a displacement gyro or a rate sensor.

7.2.4 Attitude Stabilization

For attitude stabilization, all of the autopilot candidates selected in this study for the mini-RPV use environmental sensors for primary control, with attitude sensors such as inertial or electrostatic system for dampening or turn control. Attitude-oriented autopilots are not considered for the mini-RPV, since studies have shown that autopilots using attitude as their primary control are more apt to experience stalls. When a small aircraft (such as an RPV) flies at low speed in a gust environment, it experiences greater angle-of-attack disturbances than larger or faster aircraft. Employment of an attitude system would tend to aggravate the situation and might cause a susceptibility to stalling.

7.2.5 Processor

The last major component of the autopilot is the processor. The processor information utilized in this study are representative of analog processors currently being used on mini-RPVs. Data were not available on digital autopilots. The one digital autopilot investigated was the GBU-15 Weapon Control Unit under development by Hughes for the Air Force Armament Laboratory. Development of that processor has not proceeded sufficiently to produce useful data for this study. However, this type of processor offers a substantial increase in autopilot capability and should be investigated when data are available.

7.3 DESCRIPTION OF AUTOPILOT CANDIDATES

The mini-RPV autopilot will provide flight path control and onboard processing to execute loss-of-carrier maneuvers and permit quick response for approach control into small recovery windows. Accurate attitude or heading control/reporting is not required for MSC 1.0, but is required for the subsequent MSCs.

As discussed below, there are two autopilot-configuration candidates for MSC 1.0, and three for MSCs 2.0, 2.5, and 3.0 (collectively).

7.3.1 Candidates for MSC 1.0

The two candidate autopilot configurations for MSC 1.0 have the same airspeed and altitude control capabilities; variations in the configurations are in the methods of heading control and roll, yaw, and pitch dampening.

7.3.1.1 Candidate 1.1

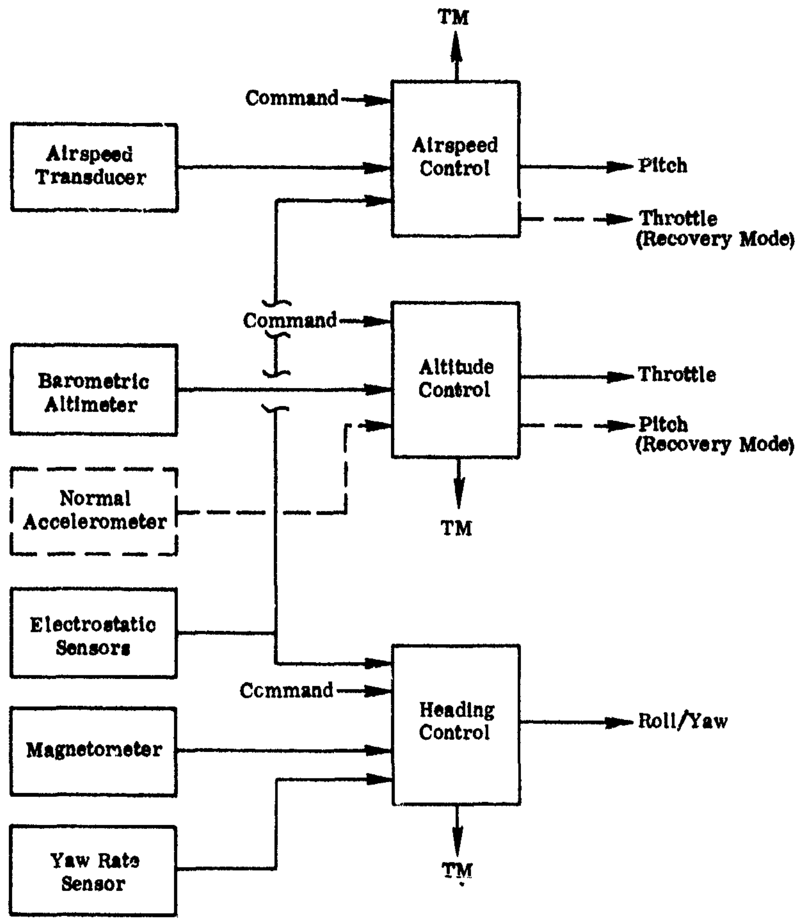
For autopilot candidate 1.1, Figure 7-1 shows the interrelationship of functions and generic equipment, and lists representative available equipment types having the required capabilities for performing the functions. This candidate features an electrostatic sensor system to provide roll and pitch attitude. The attitude signal is differentiated to provide roll and pitch damping. There are two possible modes for turn control, as follows:

a. Mode 1.1.1 - Using the yaw rate, roll rate, or both, turn control can be accomplished by commanding a rate error. Recovery to level flight is achieved by removing the command and driving the rate errors to zero; heading control by maintaining zero roll and yaw rate; and flight path control by tracking the vehicle from the ground and commanding rate errors to correct flight path direction. A two-axis magnetometer provides 1) telemetry data to aid in orienting television monitors, and 2) an initial reference to compute a heading error for the loss-of-carrier routine. In the event the carrier signal is lost, the aircraft would return to level flight for an accurate comparison of true heading to the preset loss-of-carrier heading. Then the autopilot would execute a standard rate turn and recover to level flight when the integral of the yaw rate equals the heading error.

b. Mode 1.1.2 - Using the attitude output from the electrostatic sensors, a three-axis magnetometer can be corrected to give fairly accurate heading information in a turn. Then heading control is accomplished by commanding a desired heading, comparing the commanded with the actual heading, and turning the aircraft to eliminate the error. For loss of carrier, a preset heading is automatically inserted as a command and maintained until the carrier is regained.

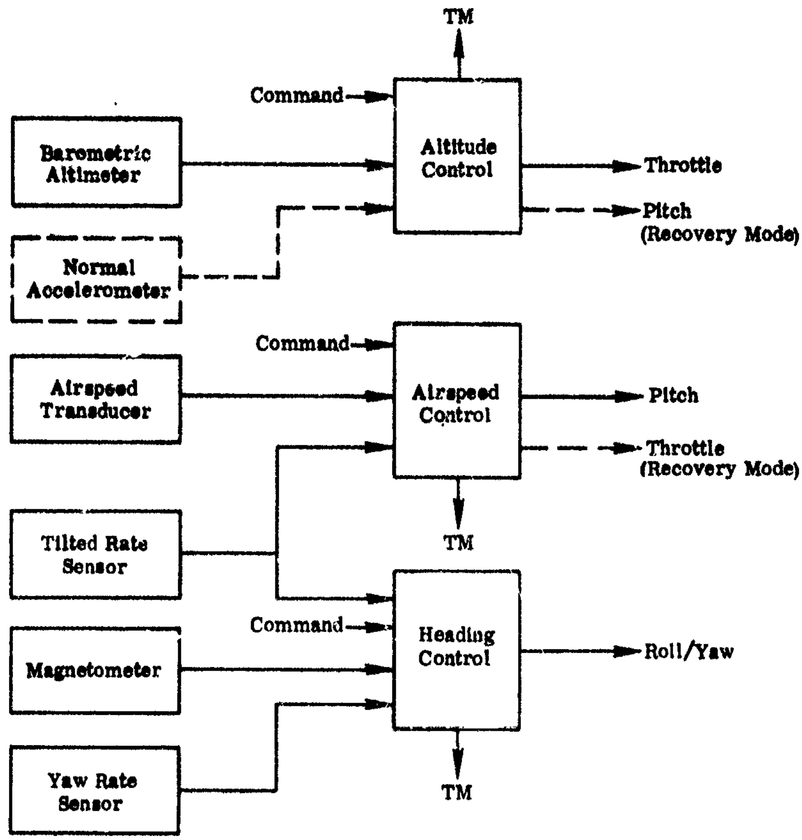
7.3.1.2 Candidate 1.2

Autopilot candidate 1.2 is described in Figure 7-2 in terms of function/generic equipment interfaces and specific available equipments for performing the functions. This candidate features a tilted rate gyro to provide roll and pitch rate. Electro-fluidic rate sensors were investigated for this application, but were found (relative to the gyro) to be less accurate, about twice as expensive, and more susceptible to temperature variations.



Parameter	Representative Equipment	Weight (lb)	1000-Unit Cost Each ($)	Max Pwr Consump. (W)	Accuracy			
					Equip.	Install.	Other	Total (RSS)
Altitude	Rosemount Model 1241M Altitude Transducer	0.38	560	0.38	2.15m	0	15.23m	15.38m
Airspeed	Rosemount Model 1221D Airspeed Transducer	0.38	575	0.38	1.286 m/s	0	0	1.286 m/s
Pitch/Roll Angle	Electrostatic Sensors	0.45	Low	Low	2°	0	Unk.	>2°
Heading	Schonstedt Sam-72C 2-Axis Magnetometer	0.16	500	0.68	1.5°	0.5°	0.5°	1.66°
Yaw Rate	Humphrey R651 Rate Gyro	0.69	300	0.5	1 deg/s	Insig.	0	1 deg/s
Normal Acceleration	Humphrey Model No. LA67 Accelerometer	0.25	100	–	0.05	Insig.	–	0.05
–	Processor	~3.5	~1000	~3.0	–	–	–	–
–	Servos	~0.7	~250	~3.0	–	–	–	–
Total		6.51	>3285	>7.94				

Figure 7-1. Functional Diagram and Component Characteristics of Electrostatic Autopilot (Candidate 1.1)



Parameter	Representative Equipment	Weight (lb)	1000-Unit Cost-Each ($)	Max Pwr Consump. (W)	Accuracy			
					Equip.	Install.	Other	Total (RSS)
Altitude	Rosemount Model 1241M Altitude Transducer	0.38	560	0.375	2.15m	0	15.23m	15.38m
Airspeed	Rosemount Model 1221D Airspeed Transducer	0.38	575	0.375	1.286 m/s	0	0	1.286 m/s
Heading	Schonstedt Sam-72C 2-Axis Magnetometer	0.16	500	0.68	1.5°	0.5°	0.5°	1.66°
Pitch/Roll Rate	Humphrey Model RG51 Rate Gyro	0.69	300	0.5	1 deg/s	0	0	1 deg/s
Yaw Rate	Humphrey Model RG51 Rate Gyro	0.69	300	0.5	1 deg/s	0	0	1 deg/s
Normal Acceleration	Humphrey Model LA67 Accelerometer	0.25	100	–				
–	Processor	~3.5	~1000	~3.0	–	–	–	–
–	Servos	~0.7	~250	~3.0	–	–	–	–
Total		6.75	3585	8.43				

Figure 7-2. Functional Diagram and Component Characteristics of Rate Gyro Autopilot (Candidate 1.2)

Directional stability is maintained by driving the roll and yaw rates to zero; and flight path control by tracking the path from the ground control station and commanding yaw rate errors. The tilted rate gyro provides damping for both the pitch and roll motion.

A two-axis magnetometer provides heading telemetry to orient the television monitor, and a reference to perform loss-of-carrier maneuvers. During loss of carrier, the aircraft is leveled for an accurate magnetometer reading, the heading error between the actual and preset loss of carrier heading is determined; and the aircraft is then turned until the integral of the yaw rate equals the heading error.

7.3.2 Candidates for MSCs 2.0-3.0

For MSCs 2.0, 2.5, and 3.0, the mini-RPV autopilot must provide more accurate attitude and heading reporting or control than for MSC 1.0. Thus the electrostatic sensors postulated for MSC 1.0 will not be applicable to the more stringent missions since the 2-degree variation in roll/pitch accuracy will not allow the target's altitude to be determined within the required 75 meters.

All of the following candidates have the same airspeed and altitude control system. As the target location analysis shows, barometric altimeters have adequate accuracy for meeting the target location requirements. The variation in the configurations are in the methods of heading control, roll/pitch dampening, and vehicle attitude determination.

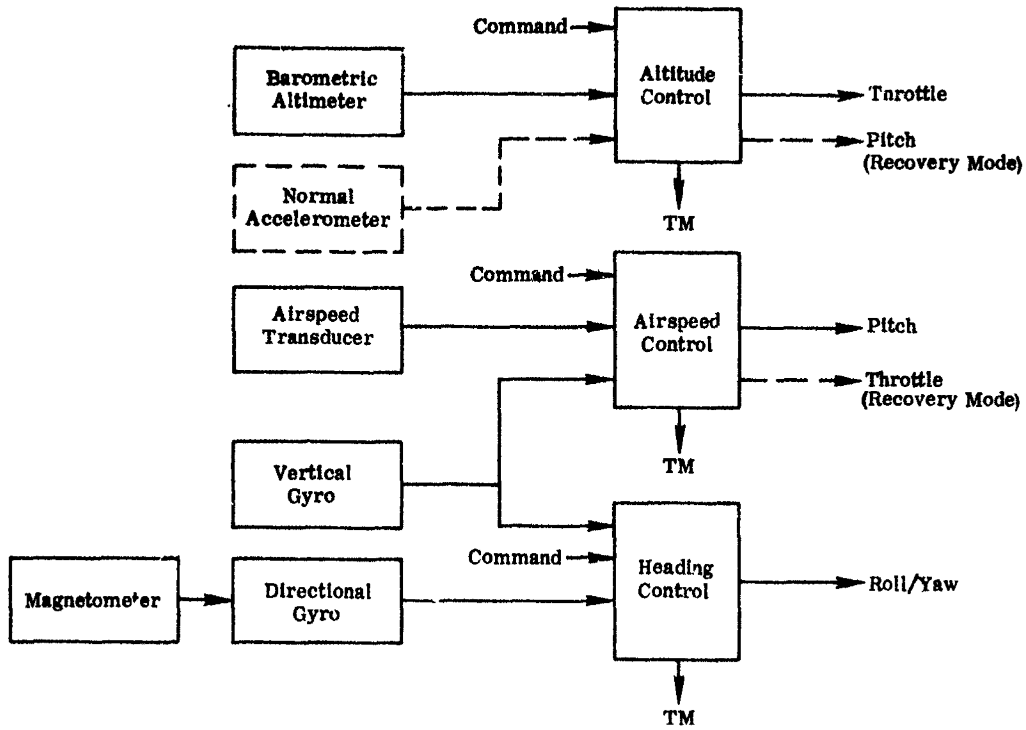
7.3.2.1 Candidate 2.1

Autopilot candidate 2.1 (see Figure 7-3) is the heaviest of the three candidates for MSCs 2.0 through 3.0, employing both a vertical and directional gyro. The vertical gyro provides roll and pitch signals that are differentiated to provide damping of roll and pitch motion. The directional gyro is slaved to a two-axis magnetometer when the aircraft is level to provide a heading signal and heading reference for any position in the attitude envelope. Turn or heading control is then effected by comparing the actual and commanded heading and then turning the aircraft to eliminate the error.

Yaw damping for turning is based on the derivative of the directional gyro signal. The loss-of-carrier mode is initiated by insertion of the preset heading as a command heading.

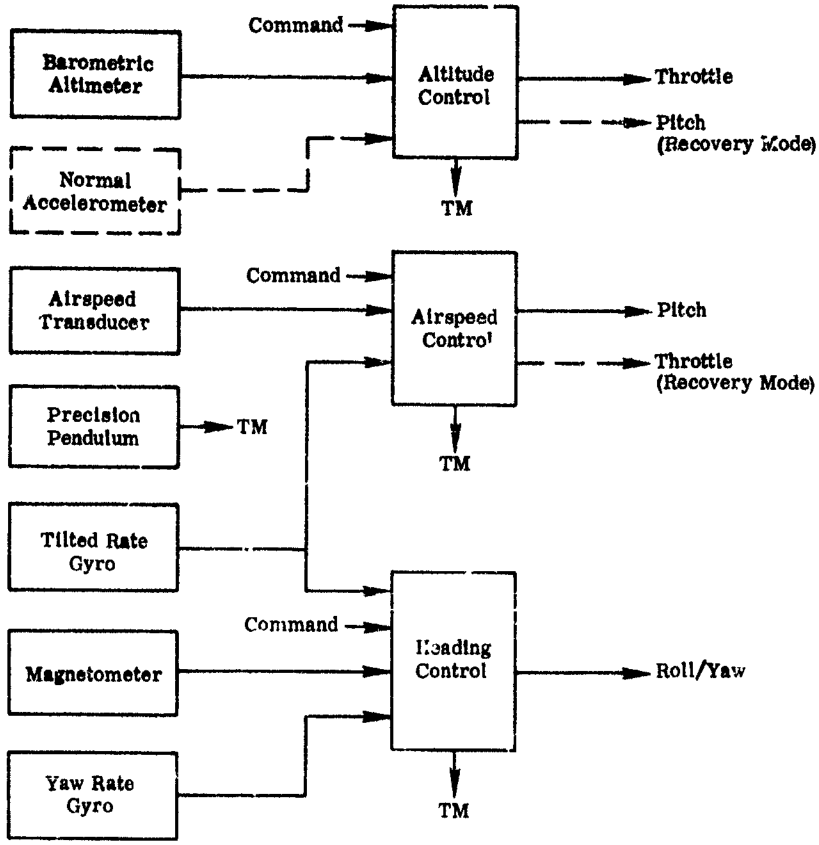
7.3.2.2 Candidate 2.2

Autopilot candidate 2.2 (see Figure 7-4) is the lightweight alternative, employing no displacement gyros. It is similar to candidate 1.2 for MSC 1.0 in that it employs only rate gyros which provide damping for all three axis motions. Directional stability is maintained through driving the yaw and roll rate to zero. Turns are accomplished by inserting a yaw rate error. The flight path is controlled by tracking the RPV from the ground and commanding yaw rates for flight path correction.



Parameter	Representative Equipment	Weight (lb)	1000-Unit Cost Each ($)	Max Pwr Consump. (W)	Accuracy			
					Equip.	Install.	Other	Total (RSS)
Altitude	Rosemount Model 1241M Altitude Transducer	0.38	560	0.38	2.15m	0	15.23m	15.38m
Airspeed	Rosemount Model 1221D Airspeed Transducer	0.38	575	0.38	1.286 m/s	0	0	1.286 m/s
Pitch/Roll Angle	Humphrey V624 Vertical Gyro	2.85	600	9.00	0.5°	0.5°	0	0.707°
Heading	Humphrey DG11 Directional Gyro with Remote Flux Gate Detector	3.3	1300	7.5	2.0°	0.707°	0.5°	2.179
Normal Acceleration	Humphrey Model LA67 Accelerometer	0.25	100	–	0.05	Insig.	–	0.05
–	Processor	~4.5	~2000	~4.0	–	–	–	–
–	Servos	~1.5	~500	~4.0	–	–	–	–
Total		13.16	5335	25.26				

Figure 7-3. Functional Diagram and Component Characteristics of Dual Displacement Gyro (Candidate 2.1)



Parameter	Representative Equipment	Weight (lb)	1000-Unit Cost Each ($)	Max Pwr Consump. (W)	Accuracy			
					Equip.	Install.	Other	Total (RSS)
Altitude	Rosemount Model 1241M Altitude Transducer	0.38	560	0.38	2.15m	0	15.23m	15.38m
Airspeed	Rosemount Model 1221D Airspeed Transducer	0.38	575	0.38	1.286 m/s	0	0	1.286 m/s
Pitch Angle	Humphrey CP17-0601-1 Precision Pendulum	0.31	55	0.5	0.2°	0.5°	0.5°	0.735°
Pitch/Roll Rate	Humphrey RG51 Rate Gyro	0.69	300	0.5	0.3 deg/s	0	0	0.3 deg/s
Yaw Rate	Humphrey RG51 Rate Gyro	0.69	300	0.5	0.3 deg/s	0	0	0.3 deg/s
Heading	Schonstedt Sam-72C 2-Axis Magnetometer	0.313	500	0.68	1.5°	0.5°	0.5°	1.66°
Normal Acceleration	Humphrey Model LA67 Accelerometer	0.25	100	–	0.05g	Insig.	–	0.05g
–	Processor	~4.5	~2000	~4.0	–	–	–	–
–	Servos	~1.5	~500	~4.0	–	–	–	–
Total		9.01	4690	10.94				

Figure 7-4. Functional Diagram and Component Characteristics of Rate Gyro/Precision Pendulum (Candidate 2.2)

During the loss-of-carrier mode, the autopilot first levels the aircraft for an accurate reading of magnetic heading using a two-axis magnetometer. Then a standard rate turn is executed until the difference between the initial heading and the preset loss-of-carrier heading equals the integral of the yaw rate during the turn.

The differences between this alternative and candidate 1.2 for target location are as follows:

a. When the RPV is leveled by driving the yaw and roll rate gyros to zero, the two-axis magnetometer will accurately report its heading.

b. The requirement to report accurately the roll attitude is alleviated by holding the roll angle at zero.

c. Pitch angle is determined through use of a precision pendulum. When the pitch rate is low, normal acceleration above zero, and longitudinal and lateral acceleration close to zero, as indicated by effects on other sensors, then the pitch angle can be read from the precision pendulum.

7.3.2.3 Candidate 2.3

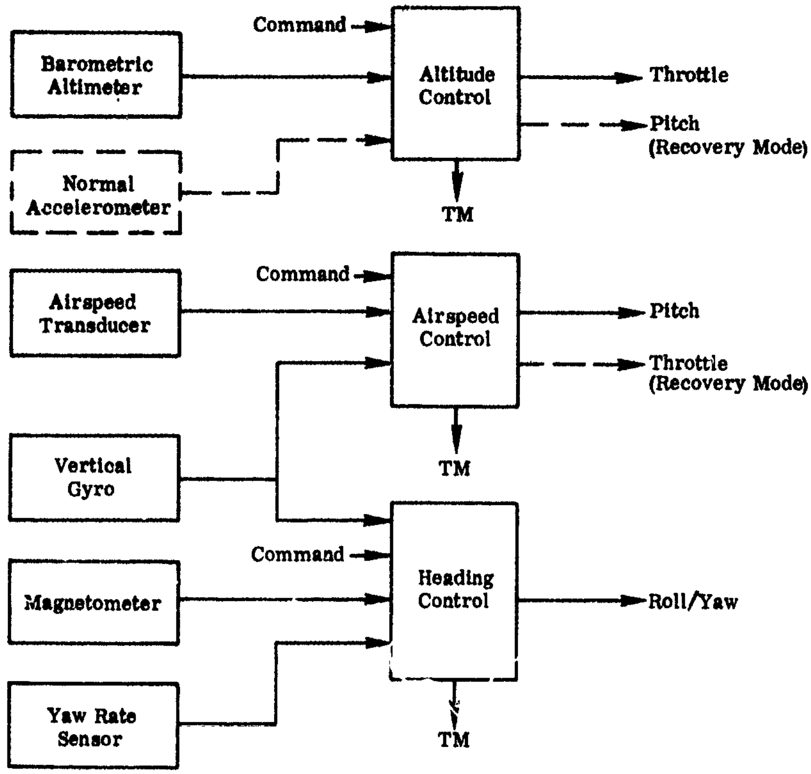
Candidate 2.3 (see Figure 7-5) features a vertical gyro to provide roll and pitch attitude signals. For heading control, the difference between the commanded and actual heading is used as a control error to turn the aircraft. The three-axis magnetometer is corrected by the vertical gyro to provide a heading signal for turn control and to downlink for use in target location computation. Turn dampening and rate are provided by the yaw rate sensor or by the derivative of the heading signal. Derivatives of the vertical gyro signal provide damping for pitch and roll motion.

7.4 CANDIDATE ASSESSMENT

Each of the autopilot candidates meets the requirements listed in Table 7-1. The difference between the candidates is primarily in the degree to which they satisfy these requirements, together with certain qualitative considerations. The final ranking of these candidates was established as discussed below and summarized in Table 7-2.

7.4.1 MSC 1.0

The two candidates for MSC 1.0 are identical except for the source and application of pitch/roll attitudes and rates. The electrostatic autopilot of candidate 1.1 provides roll and pitch attitudes within roughly ±2 degrees when the earth's electrostatic field is undisturbed. The other candidate employs a tilted rate sensor as a source of pitch and roll rate signals. Both systems can stabilize the aircraft for level flight. The electrostatic system has the advantage of slightly lighter weight, and can provide roll and pitch attitude angles to correct a three-axis magnetometer during a banking turn. The tilted rate sensor provides a direct pitch rate signal to dampen pitch motions, which the electrostatic system does not. The weight of the tilted-rate gyro and electrostatic sensor is roughly 0.7 and 0.5 pound, respectively.



Parameter	Representative Equipment	Weight (lb)	1000-Unit Cost Each ($)	Max Pwr Consump. (W)	Accuracy			
					Equip.	Install.	Other	Total (RSS)
Altitude	Rosemount Model 1241M Altitude Transducer	0.385	560	0.38	2.15m	0	15.23m	15.38m
Airspeed	Rosemount Model 1221D Airspeed Transducer	0.38	575	0.38	1.286 m/s	0	0	1.286 m/s
Pitch/Roll Angle	Humphrey VG24 Vertical Gyro	2.83	600	9.00	0.5°	0.5°	0	0.707°
Heading	Schonstedt Sam-73C 3-Axis Magnetometer	0.31	650	1.19	1.5	0.5°	0.5°	1.66°
Yaw Rate	Humphrey Model RG61 Rate Gyro	0.69	300	0.5	1 deg/s	0	0	1 deg/s
Normal Acceleration	Humphrey Model LA67 Accelerometer	0.25	100	–	0.05g	Insig.	–	0.05g
–	Processor	~4.5	~2000	~4.0	–	–	–	–
–	Servos	~1.5	~500	~4.0	–	–	–	–
Total		10.84	5285	19.45				

Figure 7-5. Functional Diagram and Component Characteristics of Vertical Gyro Autopilot (Candidate 2, 3)

TABLE 7-2. RANKING OF AUTOPILOT CANDIDATES

Criteria	Candidate Ranking				
	MSC 1.0		MSC 2.0-3.0		
	1.1	1.2	2.1	2.2	2.3
Flight Stabilization and Control					
Turn Control					
Rate Control	1	1	1	1	1
Stability	1	1	1	1	1
Directional Stability	1	1	1	1	1
Altitude Control Accuracy					
Normal	1	1	1	1	1
Accurate Recovery	1	1	1	1	1
Airspeed Control					
Stability	1	1	1	1	1
Envelope	1	1	1	1	1
Attitude Reporting (Level Flight)					
Pitch Accuracy	N/A	N/A	1	2	1
Roll Accuracy	N/A	N/A	1	2	1
Heading Accuracy	N/A	N/A	2	1	1
Altitude Accuracy	N/A	N/A	1	1	1
Other					
Weight	1	2	3	1	2
All Weather - Terrain	2	1	1	1	1
Mission Flexibility	2	1	1	2	1
Loss of Carrier	1	2	1	1	1
Development Risk	2	1	1	2	1
Overall Ranking	2	1	2	3	1

The critical difference between the two systems is the developmental and operational risk associated with the electrostatic system. The system must be operated free of electrostatic disturbances such as clouds. Development work must still be done to determine the effects of mountains on the electrostatic field and hence the electrostatic autopilot. At this point, the tilted rate sensor system, candidate 1.2, is rated ahead of the electrostatic system, candidate 1.1, based on these environmental risk factors.

7.4.2 MSCs 2.0, 2.5, 3.0

Three candidates meet the requirements of MSCs 2.0, 2.5, and 3.0. These are the dual displacement gyro system, candidate 2.1; the rate gyro/precision pendulum system, candidate 2.2; and the vertical gyro system, candidate 2.3.

The three candidates offer about the same degree of performance for flight stabilization and control. However, their attitude-reporting capability is quite different. Figure 7-6 is a plot of expected target-location accuracy vs. time for the two candidates that can operate in nonlevel flight.

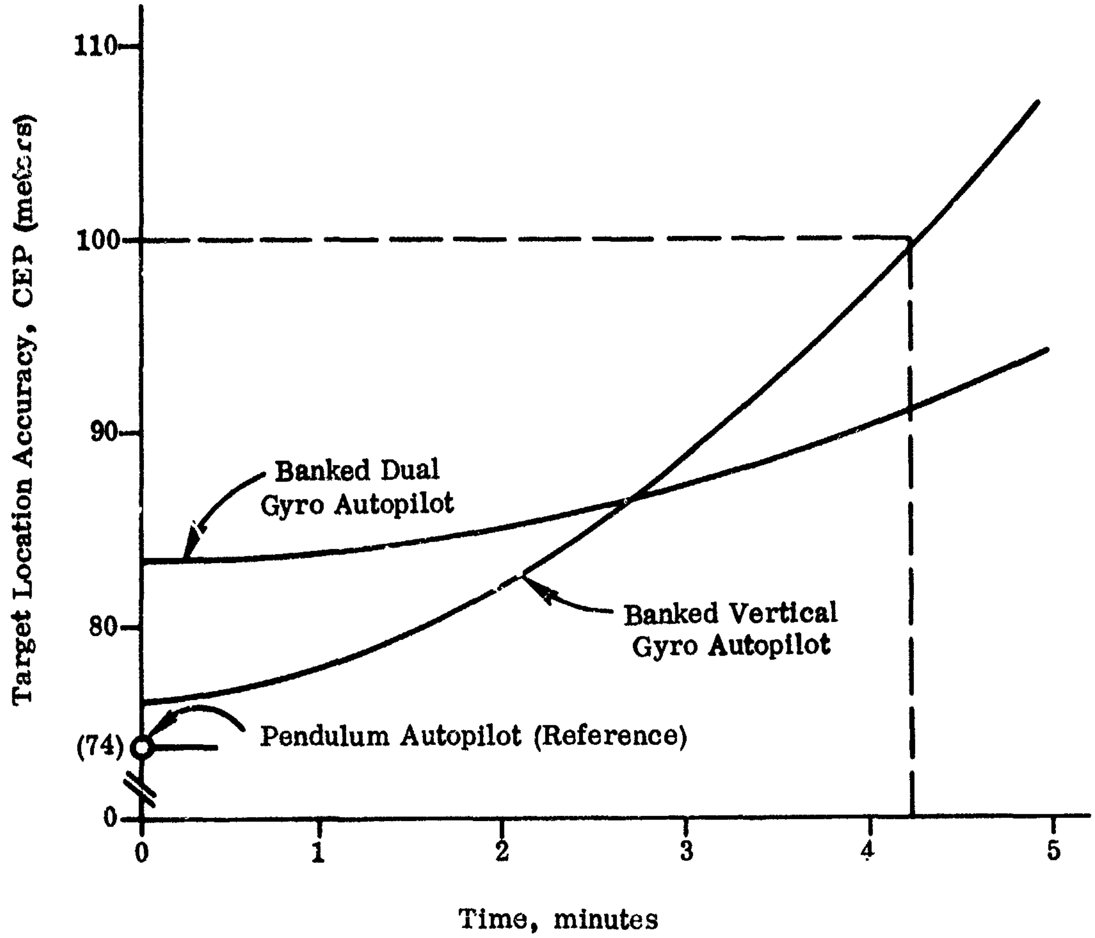


Figure 7-6. Target Location Accuracy Vs. Time
(Steady State Condition, Missions 2.0 and 2.5)

The rate gyro/precision pendulum autopilot provides the most accurate target location. Unfortunately, this system is usable only in level flight and with small pitch rates, zero longitudinal acceleration, small lateral accelerations, and positive vertical accelerations. Variations from these conditions induce errors in the reported pitch attitude that increase as the various disturbing forces couple with each other.

Figure 7-6 shows the other two candidates to be less accurate for target location in level flight, and to degrade further in accuracy when the vehicle is banked. The vertical gyro autopilot tends to be more accurate than the directional gyro in level flight, but degrades faster because of a higher gyro drift rate when it turns. The drift rates used for Figure 7-6 are for static conditions; during actual flight, the slope of these curves would be steeper as dynamic forces not considered here aggrevate the drift rate.

From a weight standpoint, the precision pendulum/rate gyro autopilot and the vertical gyro configuration both have a 4-pound advantage over the dual displacement gyro autopilot. The advantage favoring the precision pendulum version is offset, however, by its limited target-location attitude envelope and the high risk involved with developing a pendulum autopilot.

8
ONBOARD LAUNCH AND RECOVERY EQUIPMENT

This section addresses the launch and recovery subsystem of the mini-RPV, including landing aids. Supporting ground equipment is addressed in Section 12.

Concurrent with this study, Teledyne Ryan Aeronautical is performing an Army-funded investigation of recovery systems for mini-RPVs. While not intending to extend to the detail of the Ryan investigation, this study will be in sufficient depth to establish the relative impact of launch/recovery candidate equipment on the mini-RPV design and life cycle cost; and the study results will be presented in such a manner as to readily incorporate the findings of the Ryan investigation.

8.1 REQUIREMENTS

The requirements given in the Concept Formulation Package for mini-RPV launch and recovery address three constraints: wind, weather, and operating space. In addition, the acceleration limits imposed on the Ryan study are also adopted for this analysis. Table 8-1 summarizes these requirements for each MSC.

8.2 ONBOARD LAUNCH EQUIPMENT

The mini-RPV will be launched by being accelerated to flight speed through application of an internal or external force along the thrust or longitudinal axis. During launch, acceleration loads will be longitudinal; and for some launch modes, loads may be imposed along the other two principal axes. Since structural loading has the greatest influence on the air vehicle, it served as the criterion for categorizing launch-equipment candidates.

The impact of these candidate systems on the air vehicle is summarized in Table 8-2 and discussed below.

8.2.1 Candidate L1 – Longitudinal Loading

A catapult is typical of a launch system that induces primarily longitudinal loading on an air vehicle. For a 200-pound vehicle accelerated at 12g, the longitudinal load is 2400 pounds. This load is exerted through attachment points on the fuselage. Additional attachment points may be needed on the wing to constrain the vehicle in a takeoff attitude.

The constant-attitude launch of a catapult usually does not impose any special requirements on airborne avionics. For example, displacement gyros can withstand 15g or more in longitudinal acceleration without being caged. Using uncaged vertical gyros reduces their weight and cost.

8.2.2 Candidate L2 – Lateral Loading

A rotating horizontal launch device conceived by NASA is the only known system that imposes primary lateral loads on an air vehicle. The vehicle is attached to an arm mounted at its center to a vertical tower. A counterbalance is attached to the opposite end of the arm to reduce the structural loads on the tower and mounting hub. The arm is then rotated, usually using the RPV engine for power. When a safe flight speed is reached, both the RPV and counterbalance are released.

For an air vehicle weighing 200 pounds, a 6g maximum lateral acceleration limit would require a radius of 30 feet to provide a launch velocity of 52 mph (40 mph stall speed x 1.3 safety factor).

TABLE 8-1. ONBOARD LAUNCH AND RECOVERY SYSTEM REQUIREMENTS FOR VARIOUS MISSIONS

Requirement	MSC			
	1.0	2.0	2.5	3.0
Wind				
Horizontal component: 10 meters/second, gusting to 16 meters/second	X	X	X	X
Vertical component: 2 meters/second	X	X	X	X
Weather				
Daytime	X	X	X	X
Adverse			X	X
Launch/Recovery Field				
Horizontal distance: 150 meters	X	X	X	X
Vertical obstacle: 15 meters	X	X	X	X
Acceleration Limit				
Longitudinal: ±12g	X	X	X	X
Lateral: ±6g	X	X	X	X
Vertical: ±12g	X	X	X	X
Directional flexibility: Rotate system 90° in 5 minutes	X	X	X	X

8.2.3 Candidate L3 – Vertical Loading

A rotating swing devised by Developmental Sciences, Inc., is the only known system that imposes primarily vertical loads on an air vehicle. The air vehicle is attached upside down to the bottom of a vertical arm with a counterbalance at the top end. The arm is attached at its center to an axis. Then using the vehicle engine as power, the arm is rotated until a safe flight speed is reached. When the vehicle is at the top of the swing, both it and counterbalance are released.

For an air vehicle weighing 200 pounds, a maximum vertical acceleration limit of 12g would require a rotating arm radius of at least 15 feet to provide a launch velocity of 52 mph (40 mph stall speed x 1.3 safety factor).

This launch method imposes special design considerations for the air vehicle in the areas of wing structure, avionics, and fuel systems. The structural loads on the wing during launch are proportional to the normal flight wing loading. For high-wing-loaded vehicles, structural loading becomes severe during launch. The unusual attitude and vertical forces can affect the displacement gyros and fuel delivery system. Gyros would have to be caged during launch and uncaged immediately afterward. The fuel delivery system would require positive-pressure feed as opposed to gravity feed.

8.3 ONBOARD RECOVERY EQUIPMENT

Recovery is the most difficult phase of RPV flight operations. Many recovery techniques have been postulated, each attempting to dissipate the dynamic energy of the RPV by either friction, aerodynamic drag, or mechanical energy absorption.

Friction/drag techniques include parachutes, landing gear, and skids. Because of the rough terrain and short setup time anticipated for the Army Mini-RPV, the latter two techniques are not considered suitable.

In the mechanical restraint category are systems that restrain the RPV by an attached cable, usually engaging a hook; or that capture the RPV, usually by means of a net.

For this discussion, the parachute approach will be designated as candidate R1, the hook method as candidate R2, and the capture approach as candidate R3. Table 8-2 summarizes the estimated impact of each of these approaches on the mini-RPV, in terms of weight, cost, autopilot augmentation, unusual structural loads, and instrumentation considerations; and whether or not they can satisfy an all-weather requirement. The following subsections amplify the information in Table 8-2 where considered appropriate.

8.3.1 Candidate R1 – Parachute

Parachute recovery systems can be either guided or unguided. For purposes of this analysis, the two types were considered as a single recovery candidate. If that candidate proves desirable, the guided/unguided parachutes will be considered separately in greater detail.

TABLE 8-2. IMPACT OF CANDIDATE EQUIPMENTS ON AIR VEHICLE

Candidate	Impact on Air Vehicle							
	Subsystem Weight Incr. (lb)	Cost Increase ($)	Autopilot Augmentation	Unusual Structural Loads	Instrum. Consid.	Power Consump. (W)	Data Link Req'd?	All-Weather?
a. Launch Equipment								
L1 - Longitudinal Loading (Catapult)	Small	Small	None	Long. inertial loads	None	–	–	Yes
L2 - Lateral Loading (Horizontal Rotation)	Small	Small	None	Lat. inertial loads	Cage gyros	–	–	Yes
L3 - Vertical Loading (Rotating Swing)	Small	Small	None	Vert. inertial loads	Cage gyros			Yes
b. Onboard Recovery Equipment								
R1 - Parachute	4-20	100-500	None (unless guided)	Long. inertial load and vert. shock	None (auto. parachute release req'd)	–	–	No
R2 - Hook								
R2.1 - Deployed Hook	2	Small	Phugoid mode and short-pitch mode dampening; increased altitude control response	Long. inertial load	None	–	–	Yes, with landing aid
R2.2 - Wing Mounted Hook	Small	Small	Increased yaw control response	Wing spar shear stress, long. and lat. inertial loads	None	–	–	Yes, with landing aid
R3 - Capture (Net)	None	None	? (depends on size of net)	Long. inertial load	None	–	–	Yes, with landing aid
c. Landing Aid Equipment								
A1 - Cooperative Systems								
A1.1 - Payload Equipment	None	None	–	–	–	None	Yes	Yes, (depends on payload sensor)
A1.2 - Special Augmentation								
A1.21 - Microwave System	4	?	–	–	–	?	–	Yes
A1.22 - Electro-Optical System	2	?	–	–	–	Small	No	No
A2 - Non-Cooperative Systems	None (passive tracking aid may be req'd)	None	–	–	–	None	Yes	Yes, (depends on ground sensor)

To meet the wind and space requirements of Table 8-1, either type of parachute system would have to be deployed at low altitude. If an unguided parachute is deployed within the recovery space, the deployment altitude should not exceed 180 feet to prevent the air vehicle from drifting past the recovery area where there is a 13 meter/second wind and the vehicle is descending at a rate of 15 feet per second. The guided parachute could be deployed at a higher altitude depending on its glide capability. In either case, its use is limited to daylight operations. During nighttime or adverse-weather operations, location and recovery of the vehicle after ground impact would be impractical.

The weight and cost of a simple unguided parachute system is demonstrated in Figure 8-1, which shows the variations in these quantities as a function of vehicle gross takeoff weight.

8.3.2 Candidate R2 – Hook

Hooks can be used to arrest the motion of an RPV by snagging a restraining cable. The cable is rigged to slow the vehicle at an acceptable deceleration rate. The hook is either deployed at the end of a cable or rod (solid, linked, or extendable), or attached to the wing. The way the hook is deployed depends on the stowage capacity of the RPV and the rigidity requirement for the hook. Cables and linked rods are most easily stowed. Solid rods are the most rigid, and hold the hook in a predetermined attitude without rotation. Extendable rods tend to be less rigid than solid rods, and linked rods lack the pitch rigidity of a solid rod. Generally, the greater the rigidity of the deployed equipment, the greater the probability of snagging the cable. Of course, hooks that are attached as an integral part of the wing are quite rigid and do not require stowing.

Arresting hooks impact the air vehicle design in three areas; weight, structural loading, and flight stability. A hook and its deployment device are lightweight, usually not more than 2 pounds.

The structural loads upon engagement of the arresting cable can vary considerably. In the case of a wing-mounted hook, a vertical cable is engaged which transfers the inertial energy of the RPV into rotational energy as it spins around the cable. The loads on the wing during the transition are primarily due to bending moments and shear stresses along the wing spars or equivalent structure. The magnitude of the loads is proportional to the vehicle weight, speed, distance from the contact point to the attachment points, and elasticity of the cable recovery system. After the transition to a rotational motion, the loads on the vehicle are composed of tension loads through the wing spars and lateral inertial loads resulting from centrifugal force.

The loads imposed by the deployable hook system are much simpler. After engaging the arresting cable, a tension load through the deployed cable or rod decelerates the air vehicle and creates longitudinal inertial loads on the vehicle.

Probably the most significant impact of the use of hooks is upon the autopilot, since hook recovery systems require narrow recovery windows. The Aquila recovery window, for example, is less than 6 feet high and 25 feet wide. Any wing-mounted hook system has a recovery window no wider than the distance between the hook and fuselage. These small recovery windows place a limiting stability requirement on the autopilot.

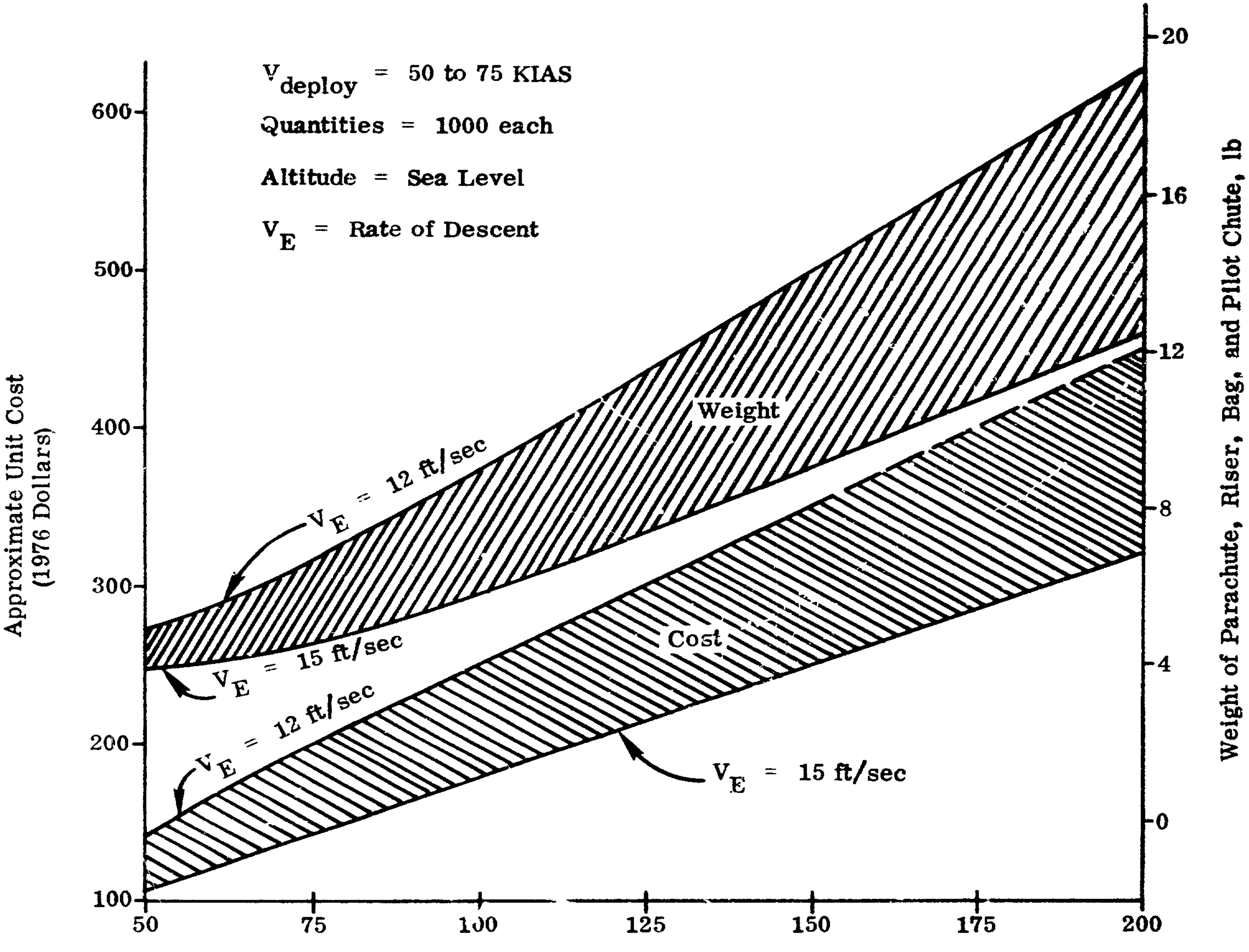


Figure 8-1. Weight and Cost for Simple Parachute Systems

For a short and wide recovery window, stabilization circuitry must be added to compensate for the phugoid and short-term pitch modes, and a control mode switching is added to increase altitude control responsiveness. For a tall and narrow window, yaw stability should be enhanced by employing rudder control instead of roll control to mtaintain directional stability. Further considerations of small recovery windows are addressed in the autopilot discussion, Section 7.

8.3.3 Candidate R3 – Capture

The capture or net technique for recovery requires no special airborne hardware, but does influence the air vehicle design. Net recovery imposes longitudinal inertial forces on the vehicle during deceleration, which vary with the energy absorbtion system associated with the ground net. The longitudinal loading can be assumed to be distributed over the leading edge of the wing, with the inboard load decreasing as the forward protrusion and loading of the fuselage nose increases.

The recovery window associated with the capture method of RPV recovery (20 feet wide x 10 feet high) is larger than for the hook method, and thus the capture approach has less severe influence on the autopilot design. One drawback of the capture candidate is in the removal of the vehicle from the net. Protruding antennas and sensors, and sharp corners of the air vehicle, can snare the net and cause delayed removal and lengthened recovery time.

8.4 LANDING AIDS

Landing aids encompass the equipment and methods used to guide an RPV into the recovery window. Such aids are considered necessary for the mini-RPV because of the skill level of the ground controllers and the weather and combat conditions expected for tactical mini-RPV operations. The Army RPV controllers will not be trained to a level required to recover mini-RPVs successfully without landing aids in the wind, visual, and stress conditions anticipated during combat operations.

This section addresses types and methods of applicable landing aids. For purposes of analysis, they are divided into two groups: cooperative systems (candidate A1), or those that use onboard equipment for tracking; and noncooperative systems (candidate A2), or those that passively track the air vehicle.

8.4.1 Candidate A1 – Cooperative Systems

Cooperative systems are those that employ onboard equipment as part of the landing aid system. To be viable for a mini-RPV, the equipment must be lightweight and inexpensive, and require little airframe surface area. For this reason, the more sophisticated landing aids are not addressed here. The cooperative equipment is further categorized and discussed as "payload equipment" and "special augmentation".

8.4.1.1 Candidate A1.1 – Payload Equipment

The simplest and least expensive approach to providing landing aids is to use equipment already available. Gimballed payload sensors, such as television cameras, FLIRS, and millimeter radar, can be employed to determine the azimuth and depression angle of the recovery site. Distance can be determined using the target laser range finder. Azimuth, depression angle, range and air vehicle flight data can then be downlinked for ground processing. The ground computer determines the error in the approach flight path and commands the RPV to correct the error.

8.4.1.2 Candidate A1.2 – Special Augmentation

Of possible applicability to the mini-RPV are two landing aids being developed for naval shipboard applications – a microwave and an electro-optical system.

The microwave system, being developed by Cutler-Hammer, employs a "CO-SCAN" transmitter and two coordinated antennas on the ground, and a modified AN/ARA-63 receiver, decoder, and antenna on the RPV. The onboard demonstration system weighs 4 to 5 pounds and occupies 125 cubic inches. In operation, the receiver on the approaching RPV detects coded pulse pairs during the instant the ground scanning antenna sweeps across the air vehicle position. The decoder then measures the spacing between pulse pairs and identifies them as either glide slope or localizer information. The results can be either input to the autopilot or downlinked for the contoller's display.

The electro-optical system is under development by Hughes Aircraft Company for the Office of Naval Research. The system uses an optical beam spatially coded for glide slope or localizer information, and modulated to supply commands to the air vehicle. The beam is steered to the RPV location and then can steeer the RPV onto the approach path by being gradually swept until aligned with the desired glide path. Once on the beam, the onboard electro-optical sensor receives the spatial codes and inputs headings and altitude errors into the autopilot. Commands can also be sent via the beam to bias the autopilot inputs and command any other vehicle function.

The onboard system is estimated to weigh 2 pounds. This system has the advantage of replacing the normal data link during recovery and freeing it for other operations. Details of the system were not available to ARINC Research for this study.

8.4.2 Candidate A2 – Noncooperative Systems

A noncooperative system is one that operates without utilizing onboard equipment. The Aquila television recovery system is an example of this type. Infrared sensors and millimeter radar could also be used to locate the RPV. All such systems would operate essentially the same. The sensor is placed behind the recovery window but boresighted with the glide path. The sensor image is displayed at a console, usually at the control van. A controller places a cursor on the RPV image and a ground-based computer processes the display data and issues commands to the RPV to correct the flight path. Ranging data are not required.

Some augmentation, such as lights or reflectors, could be added to the air vehicle to increase the recovery system's tracking capability and widen its operation tc include night and adverse weather conditions.

8.5 CANDIDATE ASSESSMENT

The ranking of onboard launch and recovery equipment candidates is based on the extent to which they meet the mini-RPV requirements stated in Table 8-1, and other qualitative factors that determine their effectiveness. Although these candidates are restricted to airborne components of the launch and recovery system, ground components are considered during this assessment to aid in the ranking process.

The onboard launch and recovery equipment candidates are first ranked for each MSC, and then compatible top-ranked candidates are combined and ranked for the full range of MSCs. Compatible candidates are those launch equipments having similar impact on the air vehicle. This approach reduces the design requirements of the launch and recovery equipment on the air vehicle. A summary of the ranking is presented in Table 8-3 for launch and recovery systems, and in Table 8-4 for landing aids.

8.5.1 Launch Equipment Ranking

The following is the rational for the ranking of the launch equipment candidates as presented in Table 8-3.

8.5.1.1 Impact on Air Vehicle

As can be seen from Table 8-2, the impact on the air vehicle of each launch candidate is small. For missions not requiring a displacement gyro, such as MSC 1.0, the candidates are ranked equally. However, the vertical loading device is limited to air vehicles with low wing loading. For missions requiring displacement gyros, candidate L1 (longitudinal loading, catapult), has the advantage of not requiring that the gyros be caged during launch. For this reason this candidate is ranked ahead of the other two for MSCS 2.0, 2.5 and 3.0.

8.5.1.2 Cost

The onboard cost for each launch candidate is small and approximately the same. The bulk of the cost for the system is in the ground launcher. Candidate L1, the catapult, requires its own energy source and is considered the most complex. The other two candidates are relatively simple, comprising a rotating arm, a supporting frame, and a release mechanism; and employ the RPV engine as their energy source. Therefore, from the point of view of complexity, the catapult is the most expensive of the ground portion of the launcher.

8.5.1.3 Survivability

Survivability is defined as the susceptibility of the launch system to detection and recognition. Some catapult systems, such as the pneumatic power types, have a characteristic aural signature, but that signature usually cannot be heard over the RPV engine noises. The rotating arms and supporting structures of the other two candidates would be more difficult to camouflage from visual recognition. However, the small cross-sectional area of the structure makes them more difficult to detect. The candidates would have to be judged equally susceptible to detection and recognition.

TABLE 8-3. CANDIDATE RANKING, ONBOARD LAUNCH AND RECOVERY EQUIPMENT

Candidate	Impact on Air Vehicle by MSC		Ground Component and System Considerations						Overall Ranking, by MSCs		
	1.0	2.0-3.0	System Cost	Surviv.	Deploy.	Transp.	Rel.	Devel. Risk	1.0	2.0	2.5-3.0
Launch Equipment											
L1 - Longitudinal Loading (Catapult)	1	1	2	1	1	1	3	1	1	1	1
L2 - Lateral Loading (Horizontal Rotation Device)	1	2	1	1	2	1	2	3	2	3	3
L3 - Vertical Loading (Rotating Swing)	1*	2	1	1	2	1	1	2	1*	2*	2*
Recovery Equipment											
R1 - Parachute	4	4	1	4	1	1	2	2	2	2	N/A
R2.1 - Deployed Hook	3	3	2	1	2	2	3	3	3	3	2
R2.2 - Wing Mounted Hook	2	2	2	3	2	2	4	4	4	4	3
R3 - Capture (Net)	1	1	2	2	2	2	1	1	1	1	1
Combined L & R Equipment											
L3/R3 - Rotating Swing/Net	2	2	1	2	4	2	1	2	2*	2*	2*
L3/R1 - Rotating Swing/ Parachute	6	6	5	3	2	1	3	4	4*	4*	N/A
L1/R3 - Catapult/Net	1	1	2	2	3	2	2	1	1	1	1
L1/R1 - Catapult/Parachute	5	5	6	3	1	1	4	3	3	3	N/A
L1/R2.1 - Catapult/Deployed Hook	3	3	4	1	4	2	6	5	5	5	3
L3/R2.11 - Rotating Swing/ Deployed Hook	4	4	3	1	4	2	5	6	6	6	4

*This candidate is not compatible with high wing loaded airframes.

TABLE 8-4. CANDIDATE RANKING LANDING AIDS

Candidate	Impact on Air Vehicle	Ground Component and System Considerations					Overall Ranking, MSCs		
		System Cost	Deploy-ment	Oper. Flex.	Rel.	Devel. Risk	1.0*	1.0, 2.0	2.5, 3.0
A1 - Cooperative Systems									
A1.1 - Payload Equipment	2	1	1	4	2	2	N/A	1	1
A1.2 - Special Equipment									
A1.21 - Microwave System	4	4	3	2	3	3	3	4	3
A1.22 - Electro-Optical System	3	3	3	1	3	4	2	3	N/A
A2 - Non-Cooperative Systems	1	2	2	3	1	1	1	2	2

*Assumes the use of non-real-time payload sensor (still cameras) to meet mission requirements.

8.5.1.4 Deployment

Deployment is defined as the actions taken to set up the launch system for operation at the launch site. All three candidates are considered to be operable from a flatbed trailer. The catapult would arrive at the launch site essentially ready for operation. The horizontal rotation device and rotating swing would require some erection or extension of their structure, with the extent of this effort dependent on the detailed design of these structures. A disadvantage of the lateral loading device is its longer rotating arm. But whatever the various designs, the catapult will be easiest to deploy.

8.5.1.5 Transportability

Transportability is defined as the degree of difficulty in moving the launch system from one site to another, and the extent to which its identity as a launch system can be concealed during transport. All three of these candidates can be designed for transport on a flatbed truck without major modification to the truck. Each can also be stowed or camouflaged to conceal their function. Therefore, each is equally ranked in transportability.

8.5.1.6 Reliability

Reliability is a judgement of the likelihood that the launch system would enter the RPV into a safe flight condition. A safe flight condition is one in which the airspeed is well above stall speed at the release attitude, and the altitude and direction are such that surrounding obstacles would be easily avoided. Relative to this criterion, the two rotating arm devices have the advantage of restraining the RPV until flight speed is reached and verified. Malfunction of the more complex catapult may release the RPV at less than stall speed. The vertical rotating swing releases the RPV at a higher altitude than the horizontal rotation device, and therefore enhances the RPV's likelihood of clearing surrounding obstacles. Therefore the rotating swing is considered the most reliable of the candidates.

8.5.1.7 Development Risk

The pneumatic catapult used in the Aquila program has been successfully developed and can be considered free of development risk. The rotating swing has been successfully demonstrated for lighter weight mini-RPVs by Development Sciences, Inc. Some development remains to demonstrate that this system can handle heavier RPVs and can operate from a flatbed trailer. The horizontal rotation device conceived by NASA has not been demonstrated in any known configuration, and would represent the greatest development risk.

8.5.1.8 Overall Launch Ranking

The candidate ranking for each mission is based on engineering judgement, considering the factors presented in Table 8-3. For MSC 1.0 the vertical loading system employing a rotating swing launcher is ranked first for low wing-loaded RPVs without displacement gyros, and especially those in the lower weight category indicative of this mission. The longitudinal loading candidate employing a catapult launcher is ranked first for all other RPV vehicles and MSCs. This is primarily because of its low development risk, low impact on the air vehicle, ease of deployment, and its ability to handle heavier mini-RPVs.

8.5.2 Recovery Equipment Ranking

The following is the rationale for the ranking of the recovery equipment candidates as presented in Table 8-3.

8.5.2.1 Impact on Air Vehicle

From Table 8-3, it can be seen that the capture recovery technique has the least impact on the air vehicle, with the parachute system having the greatest impact. The hook systems rank second, with the deployed-hook technique ranked behind the wing-mounted hook due to the additional hardware required for hook extension.

8.5.2.2 Cost

Cost data on the hook and net recovery systems are not available, but the cost of the two candidates can be assumed to be about the same when the onboard and ground components are considered collectively. As will be shown in Section 12, the estimated life cycle cost of the parachute candidate is less than that of the hook or net candidate by approximately 1 percent of the total LCC of the mini-RPV system. Other cost considerations pertaining to use of the parachute system are addressed in the ground equipment discussion (Section 12).

8.5.2.3 Survivability

Survivability is defined here as a measure of 1) detectability of the recovery site, 2) vulnerability of the recovery site, and 3) likelihood of RPV damage during recovery, assuming no system failure and with proper engagement or deployment of the arresting system.

The parachute system is the most readily detectable system during operations, due to the altitude at which it is deployed. It also exposes the recovery crew to a larger area during RPV retrieval, and has the potential of inflicting the greatest damage on the RPV during recovery. From the survivability point of view, the parachute is considered least desirable.

The wing-mounted hook configurations require a vertically deployed restraining cable, usually hung from a balloon to provide the necessary elasticity during impact. This system is also easily detected.

The remaining two candidates, the deployed hook and capture recovery systems, are equally ranked and considered the most desirable with respect to detectability and vulnerability. With respect to RPV damage during recovery, the capture or net system is more likely than the deployed hook system to inflict damage, due to the unpredictable structural loading during each recovery. The deployed hook technique always applies the restraining load through the same structural members.

8.5.2.4 Deployment

Deployment is the action necessary to set up the recovery operations. The parachute system does not require any special operations and is the easiest to deploy. The hook and capture recovery system will require some setup time, dependent on the particular restraint system used. Both of these ground systems can be mounted on flatbed trailers to reduce deployment time.

8.5.2.5 Transportability

Transportability is the degree of difficulty in moving the recovery system from one location to another. The parachute is transported as part of the air vehicle, thereby eliminating the need for special transports and making it the most transportable. The other systems can be mounted on tailers and are equally transportable.

8.5.2.6 Reliability

Reliability is the likelihood that the recovery system would be deployed or engaged, and that the RPV would be recovered within the designated recovery area. Recent experience with the Aquila has proven that the capture or net recovery technique can reliably engage the RPV and restrain it within the designated recovery area; and is considered the most reliable of the candidate recovery methods for the mini-RPV. Parachutes have been used as a reliable backup recovery system for mini-RPVs during development flight tests. The drawback to parachutes is their unpredictable landing point during recovery. In high winds, parachutes can be blown away from the recovery area. This risk can be reduced by using controllable parachutes, which would add an additional function to the autopilot; or by developing a low-altitude recovery method. Low-altitude recovery is the simplest answer, but would require a special development effort for mini-RPVs.

The use of hooks for recovery has proven only partially successful to date. New and unproven methods, such as the wing-mounted hook and high restraining wire, are currently under investigation by Developmental Sciences and All American Engineering, respectively. Each method requires a small recovery window, which reduces the likelihood that the RPV would be engaged by the cable for recovery. Thus, this recovery method is considered the least reliable.

8.5.2.7 Development Risk

The recent successful demonstration of the capture or net system for Aquila has substantially reduced its development risk. However, to adapt the parachute for low-altitude recovery into a small recovery area would require a special development effort. Similar development programs for larger objects such as used for low-altitude cargo drops has been successfully tried, but no effort has been made to apply this technique to air vehicles that must transition from aerodynamic flight to near-vertical ground impact within a small altitude.

Hooks have so far proved unreliable for mini-RPVs. More development into new arresting systems is necessary to improve reliability. In comparison with the other candidates, this development would have to be ranked as the greatest risk.

8.5.2.8 Overall Recovery Ranking

From a review of Table 8-3, it is obvious that the capture or net recovery approach ranks highest among the candidates. The parachute is ranked second, ahead of the hook system primarily because of the recent unsuccessful tests of the Aquila hook system and the risky development remaining to make a hook recovery system reliable. For the all-weather missions (MSCs 2.5 and 3.0), the parachute system is eliminated from the ranking since adaptation of parachutes to all-weather operations is not considered practical.

8.5.3 Combined Launch and Recovery Equipment Ranking

The top-ranked launch and recovery systems are combined and ranked in Table 8-3. The catapult system, when combined with either the net or deployed hook recovery systems, imposes the simplest structural loading on the RPV. Each of these candidates accelerates or constrains the RPV through longitudinal inertial loads only, which makes these candidates especially desirable from a structural point of view. The other rankings presented in Table 8-5 are a combination of the rankings for each launch and recovery system. Overall, the combination of a catapult and net offer the greatest advantage. The combination of a rotating swing and net is ranked second, but is applicable to a low wing-loaded RPV only.

8.5.4 Landing Aid Ranking

The following is the rationale for the ranking of the landing aid candidates present in Table 8-4.

8.5.4.1 Impact on Air Vehicle

From Table 8-2, it can be seen that the cooperative system employing the payload sensors, and the noncooperative system, have the least impact on the air vehicle. The payload sensors may require special design considerations for application as a landing aid. These sensors normally operate at much greater distances than required for landing. At close distances, some sensors are susceptible to saturation, which would require some type of automatic gain control for their use as a landing aid. For this reason, the noncooperative system is ranked first.

8.5.4.2 Cost

The cooperative system employing payload sensors is obviously the least expensive candidate, since it does not entail adding any further equipment. The noncooperative system is ranked second, since it would not reflect the high recurring cost of cooperative systems with special equipment.

8.5.4.3 Deployment

Again, the cooperative system employing payload sensors is obviously the simplest to deploy since it does not entail additional equipment. The noncooperative systems require deployment of a sensor boresighted to the glide slope. The electro-optical system also requires this type of installation, but with the additional complexity of controlling the optical beam so that the beam can be pointed at the RPV for lock-on. Finally, the microwave system requires both a localizer and glide slope transmitter for accurate deployment and boresighting.

8.5.4.4 Operational Flexibility

Operational flexibility is considered here to be the additional operational capability the landing aid adds to the RPV operations. The electro-optical system provides localizer and glide slope information, along with commands to the RPV for recovery. This frees the command and control function of normal data link for launch or flight control of other RPVs, and provides the greatest operational flexibility. The microwave system has a similar advantage but without the command capability. Using the payload sensors as a landing aid limits the selection of sensors to those that can perform under the weather conditions at both the target and the recovery locations. Daytime operations with video sensors would have to allow time to return for recovery before nightfall.

8.5.4.5 Reliability

Reliability as used here is the likelihood of successful operation of the system during recovery. This is primarily a function of the complexity of the system, with the one exception that a noncooperative system can be replaced when failure is suspected prior to recovery. Onboard components of cooperative systems do not have that alternative. For this reason the noncooperative system is considered the most reliable.

8.5.4.6 Development Risk

Noncooperative systems employing television cameras have been developed and incur the least development risk. The same type of development could be applied to infrared or millimeter radar sensors to expand their operational capability to night and all-weather operations. Cooperative systems using payload sensors would require development of the technique but not of the equipment. Microwave systems have progressed substantially, but additional development is required for onboard components to interact with the autopilot. The electro-optical system is a new development and incurs the greatest risk.

8.5.4.7 Overall Landing-Aid Ranking

For MSC 1.0, employing a non-real time payload sensor, the cooperative system employing the payload sensors is obviously not applicable. The noncooperative system ranks ahead of the other cooperative landing aids for this mission except in operational flexibility. This drawback to the noncooperative system may be alleviated somewhat by using a directional antenna at the recovery site to relieve the normal data link systems of antenna tracking duty. The recovery transceiver could then interact with the control van to provide the necessary data for recovery without tying up the tracking antenna.

For all other missions, the cooperative system employing payload sensors has a clear advantage except in operational flexibility as it relates to weather. This could also be improved by augmenting the ground recovery system with lights or infrared sources to extend operations into poor light conditions. As noted, the electro-optical system considered is not operational under most adverse weather conditions.

9
AIRFRAME ANALYSIS

9.1 RANKING OF AIRFRAME TYPES

The types of airframes being considered as candidates for the Army Mini-RPV application are:

a. Fixed wing, cruciform

b. Fixed wing, delta

c. Rotary wing

d. VTOL (ducted fan)

e. Lighter than air

The TOD discusses these airframe types relative to several system-related characteristics. This discussion is summarized in semiquantitative form in Table 9-1, in which each candidate is ranked on a scale of 1 (superior) to 5 for each of the system characteristics. The objective of this ranking procedure was to determine any clearly evident indicators of superiority of airframe types.

Table 9-2 sums the ranking scores for each airframe candidate, e.g., the fixed wing (cruciform) candidate had ten scores of 1 (superior), eight of 2, etc., with a mean score of 1.6 for the system characteristics. The two fixed-wing configurations can be seen to have a significant superiority over the lighter-than-air and rotary-wing configurations; however, their indicated advantage over the VTOL option is not sufficient to eliminate that configuration at this time. The following sections discuss the advantages and disadvantages of the various airframe candidates.

9.2 FIXED WING CONFIGURATIONS

A closer look at the two fixed-wing configurations is in order to determine if either has an overall advantage over the other. Table 9-3 contains information relative to those characteristics from Table 9-1 in which the two fixed-wing versions differ in the ranking. The characteristics seen to be sources of significant differences are 1) susceptibility to launch and recovery damage, 2) crash survivability, 3) ease of sensor integration, and 4) radar cross-section.

The advantages of the delta wing in resistance to launch and recovery damage and in crash survivability are intrinsic to its more durable triangular form. No quantitative data are available on the relative durability of the two airframe configurations. However, launch/recovery experiences in various mini-RPV programs, although limited, have substantiated the superior durability of the delta wing aircraft, particularly when net recovery is employed.

TABLE 9-1. RANKING OF AIRFRAME CHARACTERISTICS

Characteristic	Fixed Wing (Cruc.)	Fixed Wing (Delta)	Rotary Wing	VTOL-Ducted Fan	Lighter than Air
Size	4	3	2	1	5
Weight	2	2	3	4	1
Production cost	1	1	4	3	2
Stability and control	1	2	4	3	2
Aerodynamic performance	1	1	3	2	5
Growth potential	1	1	1	3	2
Modular construction	1	1	1	1	1
Maintainability	1	1	3	1	2
Launch and recovery damage susceptibility	2	1	3	2	4
GSE/TMDE requirements	2	3	4	1	5
Training/MOS requirements	1	1	3	1	2
Assembly/disassembly/checkout	2	1	3	1	4
Vulnerability	1	1	3	2	5
Weather adaptability	2	2	1	1	3
Ease of sensor integration	1	2	1	3	1
Radar cross-section	2	1	4	3	2
Detectability	2	1	4	3	5
Crash survivability	2	1	5	4	5
Safety	1	1	3	2	1

TABLE 9-2. AIRFRAME RANKING EVALUATIONS

Candidate	Ranking Count					
	1	2	3	4	5	Mean
Fixed Wing, Cruciform	10	8	0	1	0	1.6
Fixed Wing, Delta	13	4	2	0	0	1.4
Rotary Wing	4	1	8	5	1	3.0
VTOL (Ducted Fan)	7	4	6	2	0	2.2
Lighter than Air	4	6	1	2	6	3.0

When modular or interchangeable payloads are involved, a serious disadvantage of the delta wing is the limited range of its center-of-gravity location. To accommodate varying payload weights, ballast must be used to maintain the c.g. within acceptable limits. This condition not only leads to the necessity of carrying non-contributing weight, but imposes an additional operational problem, i.e., the determination and accurate installation of the correct ballast to be used in each case. Ease of sensor integration would thus favor the cruciform-wing configuration.

Neither of the fixed-wing configurations appears to have an advantage with respect to radar cross-section (RCS). The average RCS of the Praeire II (cruciform-wing) RPV is reported by Aeronutronic to be 0.16 square meters. Aeronutronic further claims that a 10 dB reduction in this figure appears achievable with further developmental effort. Lockheed reports that the radar cross sections of various configurations of the Aquila (delta-wing) RPV range from 0.1 to 0.5 square meters. At the writing of this report, Lockheed was in the process of determining the optimum configuration relative to RCS for the Aquila.

In the final analysis, the choice is between the delta wing with its more durable structure and the cruciform wing with its greater c.g. range. Neither of these advantages can be judged to be more critical, and therefore a selection between the two configurations cannot be made at this time.

TABLE 9-3. COMPARISON OF FIXED-WING CHARACTERISTICS

Characteristic	Advantages Listed in TOD		Remarks
	Cruciform	Delta	
Size		Slightly smaller in fuselage length	Not significant
Stability and control	Slightly more stable		Not significant
Launch/recovery damage and susceptibility		More durable wing	
Assembly/disassembly and checkout	Wing can be detached for transport convenience	No tail section assembly	Advantages off-set each other
Ease of sensor integration	Greater c.g. range; no ballast		
Radar cross-section		*Smaller radar cross-section	
Detectability		More difficult to determine visually the direction of flight	Not significant
Crash survivability		More durable wing and fuselage	

*Not substantiated by further investigation (see text).

9.3 VTOL (DUCTED FAN)

The VTOL (ducted fan) candidate has a high ratio of gross weight to payload weight because of its relatively large engine. For example, a technology demonstrator vehicle being built by General Dynamics has a gross weight of 299 pounds and will carry a payload of 18 pounds. It uses a 70 horsepower, liquid-cooled Mercury outboard engine especially adapted for this application, and has a low maximum cruise speed (80 knots).

Certain areas of technical risk pose another major disadvantage to the ducted fan configuration. As one example, the close spacing between the shroud and the rotor tips would appear to make the ducted fan highly susceptible to unrepairable damage in crash or abnormal launch/recovery situations.

A positive point for the ducted fan is that the launch and recovery requirements are considerably less complicated than for the fixed wing types.

From the overall view, it would seem that the development of the VTOL/ducted fan type airframe has not progressed to the point where it could be considered for the present-to-1980 application. It is recommended, however, that this candidate be considered as a viable contender for the 1980-to-1985 time frame. Its advantages relative to simplified launch and recovery, with minimum support equipment, are a strong plus factor – particularly if the problems associated with technical risk are satisfactorily resolved during future development.

9.4 SUMMARY

The ranking of airframe candidates for all missions, based on the preceding discussion, is

a. Fixed wing

b. VTOL (ducted fan)

c. Rotary wing

d. Lighter than air

10
PROPULSION ANALYSIS

10.1 APPLICABLE ENGINE DESIGNS

The number of engines available in the power range suitable to mini-RPV applications (5 to 25 horsepower) is relatively small. Further, jet-type engines (ramjet, pulsejet, turbojet, and rocket) have low propulsion efficiency at the low speeds being considered for mini-RPVs.

Although electric propulsion has many advantages, the fact that a lightweight, long-endurance power source is not available disqualified it from consideration.

Rotary engines have the advantage of low vibration, but at present have weight-to-horsepower ratios not compatible with the application.

The most promising engine for the application is the air-cooled, reciprocating type, which can be classified into three categories:

a. Four cycle

b. Two cycle, spark ignition

c. Two cycle, glow-plug ignition

Very few four-cycle engines are available in the power range of concern, and those that are have poor weight-to-horsepower ratios. The main advantage of this type of engine is its low visible emission (smoke).

The glow-plug, two-cycle engine has the lowest weight-to-horsepower ratio and generates the least electromagnetic interference among the three categories, but its specific fuel consumption (SFC) is approximately three times that of the other two types. It also uses an exotic type of fuel, usually a mixture of methanol, castor oil, and nitromethane, which would pose greater logistic support requirements than are associated with the simpler fuels (e.g., motor vehicle gasoline) used by the other two engine types.

The remaining candidate, the two-cycle engine with spark ignition, is judged to be the type most applicable to the mini-RPV because of its low SFC and favorable weight-to-horsepower ratio.

10.2 ENGINE DEVELOPMENT PROGRAM

The Army Air Mobility Research and Development Laboratory, Fort Eustis, has issued an RFP for a min-RPV engine demonstrator program (Solicitation No. DDA-J02-76-Q-0180). The purpose of that program is to demonstrate the propulsion technology base for future Army and other DoD agency requirements for mini-RPVs. Specific objectives of the program are to:

a. Provide lightweight engines in the 15-25 horsepower class (nominal 20 hp).

b. Address and solve present problems of high vibration levels, fuel consumption, weight, and cost; and short life.

c. Deliver engines for evaluation testing at a Government facility.

General goals of this propulsion system development program are to:

a. Provide 1) a technology base of demonstrated performance capabilities for a mini-RPV engine designed to make maximum use of components of current high-production engines, and 2) potential development/manufacturing sources for subsequent small RPV engines.

b. Identify areas where future development (qualification) and procurement costs can be reduced without compromising the capabilities of the propulsion system.

c. Demonstrate significant improvements in performance capability offered by a propulsion system designed specifically for mini-RPV applications.

d. Establish baseline levels of reliability, maintainability, and survivability of the engine.

The engine to be addressed by this RFP is to be an air-cooled, two-cycle type having the characteristics summarized in Table 10-1.

TABLE 10-1. MINI-RPV ENGINE CHARACTERISTICS

Characteristic	Value
Horsepower range	15-25 hp
HP/weight ratio (min)	0.8 hp/lb
Specific fuel consumption	0.8 lb/hp-hr
Fuel type	16:1 gas/oil
Number of cylinders	Multiple
Ignition type	Spark
Unit production cost	Less than $750

10.3 AVAILABLE ENGINE TYPES

The TOD lists 44 available engine types in the 5 to 25 horsepower range, 32 of which are in the horsepower range addressed by the RFP. These engines are listed in Table 10-2, together with their characteristic values. The engine types noted with asterisks are those with superior horsepower-to-weight ratios, identified in the TOD for primary consideration. No exceptions are taken to that preliminary screening. Further elimination would be of the engine using glow-plug ignition because of its higher SFC and the logistics problem involving exotic fuels (see discussion, Section 10.1). The McCulloch MC91/B1 and the Aerotech undesignated 18-horsepower engines can next be eliminated because lighter engines with more power are available.

The end result of these screening steps is the listing of six engine types in Table 10-3. The final selection will be based on the estimated gross weight of the RPV and a power loading factor of 12 lb/hp at that gross weight. That loading factor was established from a survey of 22 two-place light aircraft and two mini-RPVs (Praeire II and Aquila).

Although a final selection will be made from the candidates in Table 10-3, it should be borne in mind that the results of the mini-RPV engine demonstration program should have considerable influence on the engines in this category that will be available in the future.

TABLE 10-2. MINI-RPV ENGINE CANDIDATES LISTED IN TOD

Manufacturer and Model No.		Horsepower	Weight (lb)	HP/Weight Ratio	SFC (lb/HP-hr)	Fuel Type	No. Cylinders	Ignition Type	Displacement (in^3)	Compression Ratio	Engine Type (cycles)	Cost ($)	Remarks/Application
*McCulloch	CP-80	5.2	5.1	1.02	NA (1.0)	Gas	1	Mag.	5	NA	2	NA	
*Kolbo	D238	6	4.5	1.33	3.7	M/N	2	GP (C)	3.8	7:1	2	NA	Model AC, RPV
*McCulloch	MC49E	7	12	0.58	NA (1.0)	Gas	1	Mag.	4.9	6:1	2	100	
Tecumseh		7									2		
Fichtel-Sachs	KM48	8	44	0.18			—				Rotary		Various
*Ross Power, Inc.	525-05	10	7	1.43	NA (3.5)	M/N	4	GP	5.25	NA	2	NA	
Wolf Industries		10					2				2		Proposed
*McCulloch	MC91/B1	10.5	11.6	0.9	0.87	Gas	1	Mag.	6.05	9.4:1	2	120	
*Kolbo	D274	12	7	1.71	NA (3.5)	M/N	2	GP (C)	7.4	7:1	2	NA	
McCulloch	BP169-S	14	39	0.28			1				2		
*McCulloch	MC101M/C	14.5	10	1.45	1.0	Gas	1	Mag.	7.5	9.4:1	2	150	Go-Kart, Aguila Pgm
JLO-Rockwell	L230	14.5	35	0.41			1				2		
*Kolbo	D2100	15	12	1.25	1.2	Gas	2	Mag.	10	NA	2	NA	Proposed for Star
Ross Power, Inc.	(Undes.)	15	22.5	0.67			4				2		Proposed, RPV
Lycoming	(Undes.)	15					22				4		Proposed, RPV
Homlite	(Unk.)	15	38	0.39			2				2		Snowmobile
Fox Mfg. Co.	(Undes.)	15	35	0.43			2				2		Proposed, RPV
Kohler, Wis.	K341	16	120	0.13			1				4		Industrial
Onan	BF	16	100	0.16			2				4		Industrial
McCulloch	BP1995	16	39	0.41			1				2		
Fichtel-Sachs	KM914A	16.5	70.5	0.23			—				Rotary		Various
McCulloch	BP219S	17	39	0.43			1				2		
Kohler, Canada	K250-1AM	18	48	0.37			1				2		Snowmobile
*Aerotech	(Undes.)	18	20.5	0.88	NA (1.0)	Gas	2	Mag.	10.86	NA	2	NA	Development
Kohler, Wis.	K295-[illegible]	20	54	0.3[illegible]			1				2		Industrial
Kiekhaefer	KAM250-1/V	20	65	0.31			2				2		Various
Wolf Industries	(Undes.)	20					6				2		Proposed
Curtis-Wright (Sachs)	RC1-18.5	20	50	0.36			—				Rotary		
Kiekhaefer	290	20	56	0.36			1				2		
*DH Enterprises	(Undes.)	20	12.5	1.6	NA (1.0)	Gas	2	Mag.	16.72	NA	2	NA	Development
Hirth	192R	20.5	50	0.41			1				2		
Yamaha		21	46.6	0.46			1				2		Snowmobile
Fichtel-Sachs	KM914B	21	61.7	0.34			—				Rotary		
JLO	L-295	21.5	48.5	0.44			1				2		
Fichtel-Sachs	KM-24	23	46	0.50			—				Rotary		Various
JLO	L340	23.5	49.5	0.47			1				2		
Kohler, Canada	K295-2AX	24	54	0.44			2				2		Snowmobile
Kawasaki	250	24	50	0.48			2				2		Snowmobile
Kohler, Wis.	K340-2	24	61	0.39			2				2		
Sachs	SA2/290	24	59	0.41			2				2		
Outboard Marine		25					2				2		Snowmobile
Kiekhaefer	290SS	25	51	0.49			1				2		
Yamaha	[illegible]-338B	25	66.6	0.38			2				2		Snowmobile
*Teledyne-Ryan	(Undes.)	25	24.3	1.03	NA (1.0)	Gas	2	Mag.	15.01	NA	2	NA	Development

*Selected as primary candidates for Mini-RPV application

TABLE 10-3. FINAL CANDIDATES FOR MINI-RPV ENGINE

Manufacturer	Model	Power (hp)	Weight (lb)
McCulloch	CP-80	5.2	5.1
McCulloch	MC-49E	7	12
McCulloch	MC-101 M/C	14.5	10
Kolbo	D2100	15	12
DH Enterprises	(Undes.)	20	12.5
Teledyne-Ryan	(Undes.)	25	24.3

11
AIR VEHICLE CANDIDATE SYNTHESIS

From the subsystem evaluations previously discussed, candidate airborne systems were synthesized for each MSC. The selection process proceeded as shown in Figure 11-1 and as discussed below.

For each candidate payload configuration, a set of supporting subsystems was chosen on the basis of indivdual subsystem analyses of autopilot, navigation, airborne launch and recovery, and data link subsystems. From the combined weight of a payload/subsystem set, the gross weight was estimated using a factor determined from a survey of a number of mini-RPVs and light aircraft in the performance category represented by the mini-RPV. This factor assumes a 3-hour endurance and the use of a fixed-wing airframe.

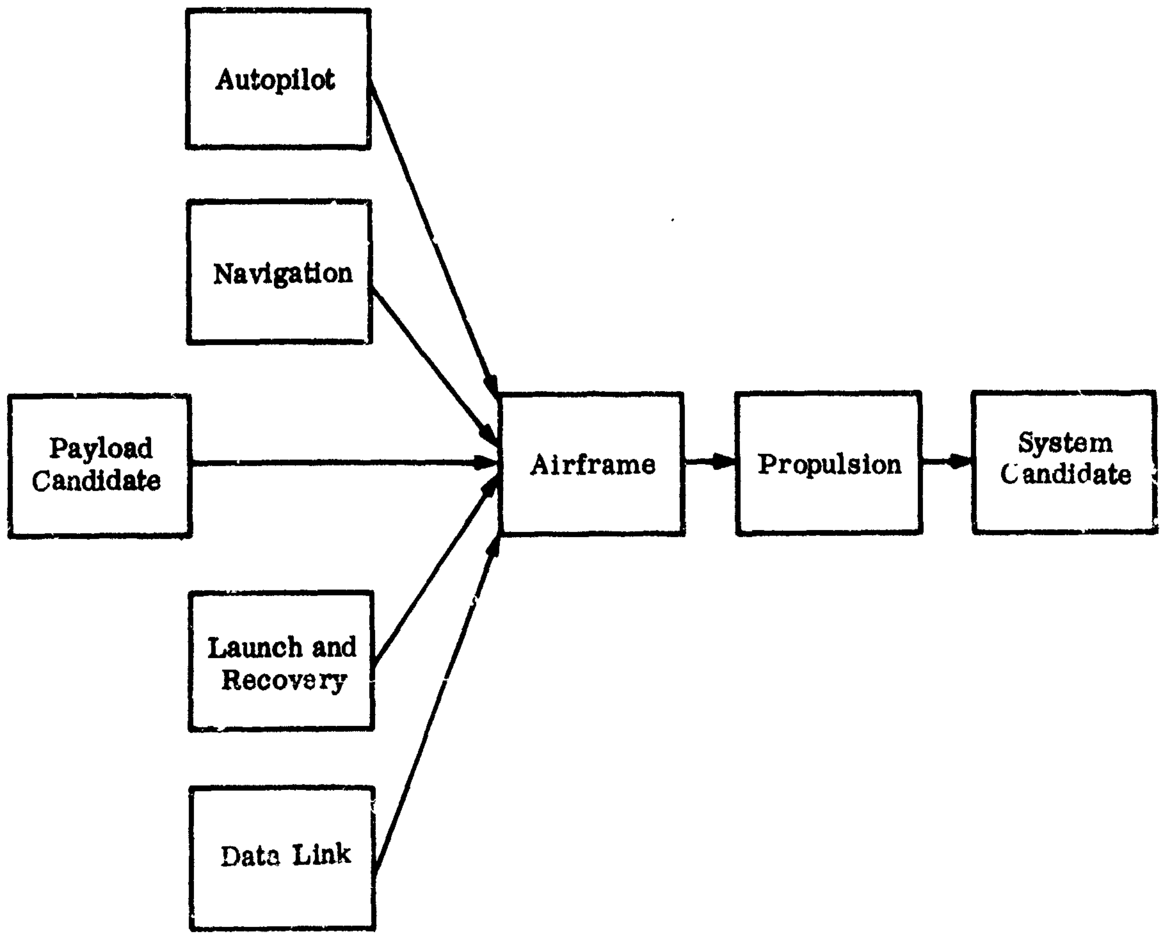


Figure 11-1. System Candidate Synthesis

The next step was to select an engine from the list of top-ranked candidates compiled in the analysis of propulsion systems. The size or power of the engines was estimated on the basis of estimated gross weight and a power-loading factor also determined from a survey of applicable mini-RPVs and light aircraft.

The airborne systems synthesized by this means were classified as either "baseline", comprising top-ranked equipments and supporting subsystems; or "variations", consisting of lower ranked payload equipments and supporting subsystems. The makeup of these systems, together with available cost/weight data, is detailed in Table 11-1.

The next step in the candidate-selection process was to consider life cycle costs. Air vehicle unit costs and life cycle costs were computed by AVSCOM, using its own scenarios with data supplied by ARINC Research. The LCC calculations were based on a 10-year operational life for the system.

The configurations identified in Table 11-1 were examined on a candidate-by-candidate basis relative to the computed life cycle costs of baseline versus variations. The purpose of this examination was to identify any instances wherein significant differences in LCC would override decisions made in the ranking process to this point in the study. No instances were noted in which LCC differences were great enough to change rankings of subsystem candidates already established within individual candidate systems.

The next step was to examine the differences in LCC among system candidates within each MSC group to determine any justification for establishing a particular candidate as the preferred one for that MSC. At the system level, variations in baseline configurations for each MSC are due to differences in the payload configuration. These payload configurations are summarized below.

MSC	Cand.	LCC ($ Million)	Payload
1.0	1.1	626	Panoramic Camera
	1.2	669	Panoramic Camera/TV Sensor
	1.3	659	TV Sensor
2.0	2.1	707	TV Sensor/Laser
	2.2	716	Panoramic Camera/TV Sensor/Laser
2.5	2.5	880	FLIR/Laser
	2.6	814	LLLTV/Laser
3.0	3.1	880	FLIR/Laser
	3.2	814	LLLTV/Laser
	3.3	780	Radar/Laser

The baseline configurations for both MSC 1.0 and MSC 2.0 involve options of real-time imagery, hard-copy imagery, or both to be produced by the payload equipments. The decision in this instance is one of operational policy and is not within the scope of this study.

The low-light-level TV payload is recommended for MSC 2.5 because of both lower LCC and better resolution.

The FLIR payload is recommended for MSC 3.0 as a best technical-risk candidate for approaching the day/night/limited adverse weather requirement by 1985. LLLTV is not recommended for this MSC because of shortcomings in adverse weather and its requirement for ambient light. The radar candidate was eliminated because of relatively low range and resolution capabilities.

TABLE 11-1. AIRBORNE SYSTEM CANDIDATE CONFIGURATIONS AND VARIATIONS (Sheet 1 of 10)

Configuration	Weight (lb)		Cost ($K)		
	Subsys.	Air Veh. Gross	Subsys.	Air Veh. Unit	LCC
A. MSC 1.0, Candidate 1.1					
• Baseline					
Payload Panoramic Camera KS-129A, Perkin-Elmer	15		3.4		
Data Link/Navigation Integrated Comm. and Navigation System	16		20		
Autopilot Rate Gyro	6.7		3.6		
Launch and Recovery Equip. Catapult Net	1		-		
Airframe Fixed Wing			-		
Propulsion McCulloch MC101-M/C	66		-		
Fuel (3-hr duration)			-		
TOTAL	-	105	-	36.97	625,639
• Variations					
Payload Panoramic Camera CAI, Model CA-168 (Mod)	8.5	87	3	36.40	624,360
Launch and Recovery Equip. Parachute	9	126	0.3	37.26*	615,911**

*Increased airframe and propulsion cost not included.
**Increased attrition or repair rate not included.

TABLE 11-1. (Sheet 2 of 10)

Configuration	Weight (lb)		Cost ($K)		
	Subsys.	Air Veh. Gross	Subsys.	Air Veh. Unit	LCC
B. MSC 1.0, Candidate 1.2					
• Baseline					
Payload Panoramic Camera/ TV Sensor KS-129A/Praeire II	33		18.4		
Data Link/Navigation Integrated Comm. and Navigation System	16		20		
Autopilot Rate Gyro Autopilot	6.7		3.6		
Launch and Recovery Equip. Catapult/Net	1		-		
Airframe Fixed Wing					
Propulsion McCulloch MC101-M/C	96		-		
Fuel (3-hour duration)					
TOTAL	-	153	-	54.46	668,809
• Variations					
Payload Panoramic Camera/ TV Sensor Praeire II/CA-168 (Mod)	26.5	136	18	53.91	667,552
Blue-Spot/KS-129	46	188	23.4	60.39	682,952
POISE/KS-129	46	188	23.4	60.39	682,952
Blue-Spot/CA-168 (Mod)	39.5	170	23	59.84	681,689
POISE/CA-168 (Mod)	39.5	170	23	59.84	681,689

TABLE 11-1. (Sheet 3 of 10)

Configuration	Weight (lb)		Cost ($K)		
	Subsys.	Air Veh. Gross	Subsys.	Air Veh. Unit	LCC
B. (Continued)					
Launch and Recovery Equipment Parachute	14.8	190	0.4	54.86*	659,299**
C. MSC 1.0, Candidate 1.3					
• Baseline					
Payload TV Sensor Praeire II	18		15		
Data Link/Navigation Integrated Comm. and Navigation System	16		20		
Autopilot Rate Gyro Autopilot	6.7		3.6		
Launch and Recovery Equip. Catapult/Net	1		-		
Airframe Fixed Wing			-		
Propulsion McCulloch MC101-M/C	71		-		
Fuel (3-hour duration)			-		
TOTAL	-	113	-	50.35	658,649
• Variations					
Payload TV Sensor Blue-Spot POISE	31 31	148 148	20 20	56.28 56.28	672,788 672,788
Launch and Recovery Equip Parachute	10.7	139	0.3	50.67	648,974**

TABLE 11-1. (Sheet 4 of 10)

Configuration	Weight (lb)		Cost ($K)		
	Subsys.	Air Veh. Gross	Subsys.	Air Veh. Unit	LCC
D. MSC 2.0, Candidate 2.1					
• Baseline					
Payload					
TV Sensor/Laser					
Praeire II	26		30		
Data Link/Navigation					
Integrated Comm. and Navigation System	16		20		
Autopilot					
Vertical Gyro Autopilot	10.8		5.3		
Launch and Recovery Equip					
Catapult/Net	1		-		
Airframe					
Fixed Wing			-		
Propulsion	91		-		
McCulloch MC101-M/C					
Fuel (3-hour duration)			-		
TOTAL	-	145	-	69.76	706,559
• Variations					
Payload					
TV Sensor/Laser					
Blue-Spot	39	180	35	75.69	720,701
POISE	39	180	35	75.69	720,701
Autopilot					
Directional Gyro Autopilot	13.2	151	5.6	70.18	707,502
Launch and Recovery Equip					
Parachute	14.8	183	0.4	70.16*	697,049**

TABLE 11-1. (Sheet 5 of 10)

Configuration	Weight (lb)		Cost ($K)		
	Subsys.	Air Veh. Gross	Subsys.	Air Veh. Unit	LCC
E. MSC 2.0, Candidate 2.2					
● Baseline					
Payload TV/Laser/Camera Praeire II/KS-129	41		33.4		
Data Link/Navigation Integrated Comm. and Navigation System	16		20		
Autopilot Vertical Gyro Autopilot	10.8		5.3		
Launch and Recovery Equip Catapult/Net	1		-		
Airframe Fixed Wing	117		-		
Propulsion DH Enterpises, Undesig., 20 HP			-		
Fuel (3-hr duration)			-		
TOTAL	-	183	-	73.90	715,534
● Variations					
Payload TV/Laser/Camera Praeire II/CA-168 (Mod)	34.5	168	33	73.35	714,428
Blue-Spot, CA-168 (Mod)	47.5	203	38	79.27	728,415
POISE, CA-168 (Mod)	47.5	203	38	79.27	728,415
Autopilot Directional Gyro Autopilot	13.2	192	5.6	74.32	716,478
Launch and Recovery Equip Parachute	18	232	0.4	74.37*	706,155**

TABLE 11-1. (Sheet 6 of 10)

Configuration	Weight (lb)		Cost ($K)		
	Subsys.	Air Veh. Gross	Subsys.	Air Veh. Unit	LCC
F. MSC 2.5, Candidate 2.5					
● Baseline					
Payload FLIR/Laser Aeronutronic	32.6		66		
Data Link/Navigation Integrated Comm. and Navigation System	16		20		
Autopilot Vertical Gyro Autopilot	10.8		5.3		
Launch and Recovery Equip Catapult/Nut	1		-		
Airframe Fixed Wing	103		-		
Propulsion McCulloch MC101-M/C			-		
Fuel (3-hour duration)			-		
TOTAL	-	163	-	111.25	880,484
● Variations					
Payload FLIR/Laser Aeronuatronic FLIR and Blue-Spot or POISE Laser	31	159	66	111.24	880,466
Autopilot Directional Gyro Autopilot	13.2	170	5.6	111.67	881,428
Launch and Recovery Equip Parachute	15.6	203	0.4	111.66*	870,995**

TABLE 11-1. (Sheet 7 of 10)

Configuration	Weight (lb) Subsys.	Weight (lb) Air Veh. Gross	Cost ($K) Subsys.	Cost ($K) Air Veh. Unit	Cost ($K) LCC
G. MSC 2.5, Candidate 2.6					
• Baseline					
Payload LLTV/Laser Blue-Spot	44		43		
Data Link/Navigation Integrated Comm. and Navigation System	16		20		
Autopilot Vertical Gyro Autopilot	10.8		5.3		
Launch and Recovery Equip Catapult/Net	1		-		
Airframe Fixed Wing			-		
Propulsion DH Enterprises, Undesig., 20 HP	122		-		
Fuel (3-hour duration)			-		
TOTAL	-	194	-	84.47	813,830
• Variations					
Autopilot Directional Gyro Autopilot	13.2	200	5.6	84.89	814,775
Launch and Recovery Equip Parachute	19	242	0.4	84.96*	804,493**
H. MSC 3.0, Candidate 3.1					
• Baseline					
Payload FLIR/Laser Aeronutronic	32.6		66		

TABLE 11-1. (Sheet 8 of 10)

Configuration	Weight (lb) Subsys.	Weight (lb) Air Veh. Gross	Cost ($K) Subsys.	Cost ($K) Air Veh. Unit	Cost ($K) LCC
H. (Continued)					
Data Link/Navigation Integrated Comm. and Navigation System	16		20		
Autopilot Vertical Gyro Autopilot	10.8		5.3		
Launch and Recovery Equip Catapult/Net	1		-		
Airframe Fixed Wing			-		
Propulsion McCulloch MC101-M/C	103		-		
Fuel (3-hour duration)			-		
TOTAL	-	163	-	111.25	880,484
• Variations					
Payload FLIR/Laser Aeronutronic FLIR and Blue-Spot or POISE Laser	31	159	66	111.24	880,466
Navigation Tactical Global Positioning System Guidance	3	171	7	119.37	900,014
Autopilot Directional Gyro Equip.	13.2	170	5.6	111.67	881,305
Launch and Recovery Equip Parachute	15.6	203	0.3	111.66*	870,995**

TABLE 11-1. (Sheet 9 of 10)

Configuration	Weight (lb)		Cost ($K)		
	Subsys.	Air Veh. Gross	Subsys.	Air Veh. Unit	LCC
I. MSC 3.0, Candidate 3.2					
• Baseline					
Payload LLLTV/Laser Blue-Spot	44		43		
Data Link/Navigation Integrated Comm. and Navigation System	16		20		
Autopilot Vertical Gyro Autopilot	10.8		5.3		
Launch and Recovery Equip Catapult/Net	1		-		
Airframe Fixed Wing	122		-		
Propulsion DH Enterprises, Undesig., 20 HP			-		
Fuel (3-hour duration)			-		
TOTAL	-	194	-	84.47	813,830
• Variations					
Navigation Tactical Global Positioning System Guidance	3	202	7	92.59	833,339
Autopilot Directional Gyro Autopilot	13.2	200	5.6	84.89	814,775
Launch and Recovery Equip Parachute	19	242	0.4	84.96*	804,493**

TABLE 11-1. (Sheet 10 of 10)

Configuration	Weight (lb) Subsys.	Weight (lb) Air Veh. Gross	Cost ($K) Subsys.	Cost ($K) Air Veh. Unit	Cost ($K) LCC
J. MSC 3.0, Candidate 3.3					
• Baseline					
Payload Radar/Laser Designator Norden	42		40		
Data Link/Navigation Integrated Comm. and Navigation System	16		20		
Autopilot Vertical Gyro Autopilot	10.8		5.3		
Launch and Recovery Equip Catapult Net	1		-		
Airframe Fixed Wing					
Propulsion DH Enterprises, Undesig., 20 HP	117		-		
Fuel (3-hr duration)					
TOTAL	-	186	-	80.98	786,021
• Variations					
Navigation Tactical Global Positioning System Guidance	3	197	7	89.12	805,551
Autopilot Direction Gyro Autopilot	13.2	195	5.6	81.40	786,965
Launch and Recovery Equip Parachute	18	234	0.4	81.45*	776,642**

12 GROUND SYSTEMS

Ground systems associated with the Army Mini-RPV System fall into two categories: the ground control station and launch/recovery. Requirements and capabilities of each category are discussed below. These considerations will be combined with the air vehicle synthesis information of Section 11 to generate a final set of candidates for the Army Mini-RPV System (Section 13).

12.1 GROUND CONTROL STATION

12.1.1 Requirements

Requirements for the GCS, as stated in the Concept Formulation Package, are reproduced below.

> The Ground Control Station will be capable of positioning an RPV at any point within its operational radius in 6 degrees of freedom, and of varying the RPV operating conditions, by operator command. The GCS simultaneously will present/display to the system operator(s) the actual RPV operating conditions and the actual RPV position referenced to UTM coordinates, altitude above sea level in meters, and a predetermined horizontal and vertical direction. When the RPV system is employed in a target acquisition role, the GCS will present/display to the operator(s) upon command the target location referenced to UTM coordinates and the target altitude above sea level in meters.
>
> Nuclear survivability is required and the ground support equipment will be designed and constructed to survive nuclear effects. The GCS will be hardened against attack by conventional munitions.
>
> During preparation for and conduct of launch, flight or recovery activities, the ground support equipment will produce no identifiable aural signature of such launch, flight or recovery activities to the unaided ear at a horizontal distance along the ground of 2500 meters under ambient conditions of commonly found favorable sound propagation conditions.
>
> During preparation for and conduct of launch, flight or recovery activities, the ground support equipment will product no identifiable visual signature of such launch, flight or recovery activities to the unaided eye at a horizontal distance along the ground of 2500 meters under ambient conditions of visual defilade of the emplaced ground support equipment.

The Ground Control Station will provide, at the operator's option, a permanent record of sensor-acquired information. The TV tape containing such recorded information must be removable from the GSC without degradation of content of quality and will be suitable for subsequent examination or analysis at the Divisional MI Company or at the GCS itself.

Additional requirements for the GCS as stated in the Operational and Organizational concepts are given below.

(1) Mobility. The RPV system is 100 percent transportable by standard Army tactical vehicles and trailers without requiring major modifications. The ground mobility of the RPV system is equal to or greater than the supported force.

(2) Emplacement/Displacement. The RPV system is capable of operation (less external wire communications) within one hour after arrival at a designated presurveyed, unimproved tactical location. The RPV 's capable of displacing from an occupied location within 30 minutes after receipt of a displacement order.

(3) Electronic Protective Measures. The RPV system electromagnetic control, telemetry, and data link apparatus are designed to preclude enemy or inadvertent friendly interference with operator flight control, operator sensor contr ', operator reception or utilization of sensor acquired information, enemy utilization of sensor acquired information or enemy insertion of false information.

12.1.2 Data Link Consideration

The data link portion of the GCS is directly related to that of the airborne system. As stated in Section 5, no available data link system will meet the combined requirements of anti-jam resistance, baseband frequency, and wideband data rate for the mini-RPV. Since the only known effort to develop a suitable system is the Integrated Communication and Navigation System of Harris Corporation, that system would be ranked as the preferred candidate.

It is recommended that consideration be given to deploying the GCS transmitting antenna remotely from the main portion of the GCS. This would decrease the vulnerability of the ground station by denying the enemy the ability to locate its main position by homing on the command transmitter. An alternate transmitter antenna could be incorporated to maintain operation if the primary antenna were disabled.

The capability of simultaneusly controlling multiple RPVs is implied in the data link description contained in the TOD. This requirement necessitates the use of phased-array antennas. Because of the 60-degree azimuth limit on the coverage of such antennas, three antennas are required to obtain the required 180-degree coverage. The cost of these antenna is quite significant (approximately $400,000 per GCS in quantity), and therefore the multi-control requirement should be examined relative to operational policy.

12.2 LAUNCH AND RECOVERY SYSTEM

12.2.1 Requirements

Launch and recovery system requirements for ground equipment are summarized in Figure 12-1. These requirements are identical for all MSCs, except for weather restrictions. The daytime requirement for MSCs 1.0 and 2.0 is expanded to encompass nighttime and adverse weather conditions for MSCs 2.5 and 3.0. The stated aural null range is for an unaided ear located horizontally from the launch and recovery equipment during favorable sound propagation conditions. The visual null range is for an unaided eye located horizontally from the launch and recovery equipment during ambient conditions of visual defilade of the emplaced equipment.

12.2.2 Ground Equipment Considerations

Launch and recovery ground equipment includes the devices needed to launch and capture the vehicle, plus the equipment necessary to redeploy and rotate the devices. The equipment selected as a result of the air vehicle subsystem analysis (see Section 8) were a catapult for launch and a net for recovery. A parachute was also considered as a possible alternative to the net if the life cycle cost analysis proved it to be the more cost effective.

The life cycle cost analysis revealed that the parachute recovery method offers a net savings of approximately $8 million over the net recovery device for the 10-year life of the mini-RPV system. The savings is generally the same for all configurations identified in Section 11, but with the percent savings of LCC varying from 1.2% to 0.9%.

The LCC analysis is based on a constant attrition rate of one loss per 20 flights. However, the parachute recovery method could be expected to degrade this vehicle life expectancy, for reasons discussed in Section 8. The actual degree of degradation cannot be estimated; however, the break-even point in the LCC savings can be computed.

For a vehicle having a unit production cost of $40,000, the cost saving break-even point is at about 18 flights per vehicle; and for an $80,000 vehicle, it is 19 flights per vehicle. It can be easily envisioned that the attrition level would fall to these values during parachute recovery operations in a field environment. Based on these results, plus the operational limitations and vulnerability of a parachute recovery system, that candidate was eliminated as an alternate recovery system.

Two net recovery approaches are now under study. The present Aquila system employs a vertical net to restrain the vehicle, together with a horizontal net to catch the vehicle before it hits the ground. The other approach considered employs a single net suspended from two high poles. When the vehicle hits the net, the net is payed out and then reeled back in to prevent the vehicle from impacting the ground. From the point of view of cost or capability, not enough data are available to select between these two systems.

For launch, a number of proven catapult systems are available. The most commonly used is a pneumatically powered catapult developed by All American Engineering.

Requirement	MSC 1.0	MSC 2.0	MSC 2.5	MSC 3.0
Wind				
Horizontal component: 10 meters/second, gusting to 16 meters/second	X	X	X	X
Vertical component: 2 meters/second	X	X	X	X
Weather				
Daytime	X	X	X	X
Adverse weather			X	X
Space				
Horizontal distance: 150 meters	X	X	X	X
Obstacle: 15 meters	X	X	X	X
Survivability				
Aural null range: 2,500 meters	X	X	X	X
Visual null range: 2,500 meters	X	X	X	X
Directional flexibility: Rotate system				
90° in 5 minutes	X	X	X	X

Figure 12-1. Ground-Equipment Launch and Recovery Requirements

The final decision on the type of net and catapult system may be dependent on how well they can be integrated and installed on a single ground mover that can be rotated quickly to meet shifts in wind direction. A net on high poles has an advantage here in that it does not require the additional poles and space for a horizontal net as does the Aquila system. This additional equipment would require either a second ground vehicle or ground installation of poles and supporting lines and stakes. Whether the high-net recovery system and catapult system can actually be installed will require a detailed design analysis. It does appear that this combination has the best chance of meeting all of the launch and recovery requirements using a single ground vehicle.

13
FINAL SYSTEM RANKING

The final system ranking for each MSC is summarized in Table 13-1. Since the final selection of candidates for MSCs 1.0 and 2.0 involved decisions of operational policy (not with the scope of this study), the top baseline configuration for each is recommended for further consideration by the Army.

TABLE 13-1. FINAL RANKING OF MINI-RPV SYSTEM CONFIGURATION

MSC	Payload	Data Link/ Navigation	Autopilot	Launch and Recovery	Airframe	Engine
1.0	A. Panoramic Camera • KS-129 (Perkin-Elmer)	Integrated Comm. and Navigation System	Rate Gyro	Catapult/Net	Fixed Wing	McCulloch MC101-M/C
	B. Panoramic Camera/TV Sensor • KS-129/Praeire II					
	C. TV Sensor • Praeire II		Rate Gyro			
2.0	A. TV Target Acquisition and Designation System • Praeire II		Vertical Gyro			McCulloch MC101-M/C
	B. TV Target Acquisition and Designation System/Photo Camera • Praeire II/KS-129					DH Enterprises Undesignated 20 HP
2.5	LLLTV Target Acquisition and Designation System • LLLTV Version of Blue-Spot (Westinghouse)					
3.0	FLIR Laser • Mini-FLIR (Aeronutronic)	Integrated Comm. and Navigation System	Vertical Gyro	Catapult/Net	Fixed Wing	McCulloch MC101-M/C

APPENDIX A
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APPENDIX B

DERIVATION OF EQUATIONS

B-1. OPTICAL IMAGE TRANSFORMATIONS

To assess the capabilities of imaging sensors in tasks involving detection, recognition, and identification of targets, there must be at hand some defined relationship between the number of lines resolved at the target and the corresponding decisions of detection/recognition/identification. Therefore, probabilities of detection/recognition/identification ($P_d/P_r/P_i$) must be related to effective sensor resolution. The usual criterion for $P_d/P_r/P_i$ is related to the number of resolution elements across the minimum target dimension. The exact number is controversial and subject to qualification. Rand Corporation personnel have proposed the equation,

$$P_d = 1-e^{-\left(\frac{N_r}{0.4} - 1\right)^2} \tag{B-1}$$

where N_r = number of scan lines. However, this equation allows P_d to approach 1.0 when N_r approaches 2, a value considered low by others (including the Air Force Avionics Laboratory), who conclude that up to 4 scans provides little more than detection capability, 10 scans allows classification, and up to 20 scans allows identification. To bound these qualified criteria, the above equation is therefore modified to

$$P_d = 1-e^{-\left(\frac{N_r}{1.1} -1\right)^2} \tag{B-2}$$

so that when:

$N_r = 2,\ P_d = 0.5$

$N_r = 3,\ P_d = 0.95$

$N_r = 4,\ P_d \approx 1.0$

and

$$P_r = 1-e^{-\left(\frac{N_r}{3.2} -1\right)^2} \tag{B-3}$$

so that when:

$N_r = 5, P_r = 0.27$

$N_r = 8, P_r = 0.89$

$N_r = 16, P_r \approx 1.0$

and

$$P_i = 1 - e^{-\left(\frac{N_r}{6.56} - 1\right)^2} \qquad \text{(B-4)}$$

so that when:

$N_r = 12, P_i = 0.50$

$N_r = 16, P_i = 0.87$

$N_r = 25, P_i \approx 1.0$

Equations B-2 and B-3 are in good agreement with generally accepted criteria.

Sensor performance requirements are described in the Concept Formulation Package in terms of P_d, P_r, and P_i at specified ranges for two time frames: the present and 1985 (modest increase in performance). The ability of short-wavelength sensors, such as television or FLIR, to perform at a specified range is highly dependent on:

a. Target characteristics, such as light/heat contrast between the target and its background.

b. The time of day the sensor is employed.

c. Atmospheric characteristics, such as visibility or humidity.

It is assumed that these variables will be considered in sensor selection during mission planning so that the sensor, at the specified range, is capable of operating at the effective resolution level.

If successive scan lines are considered to be alternately black and white, adjacent pairs of scan lines would constitute a cycle in the space-frequency domain defined as a line pair. The number of line pairs (N) associated with given probabilities of detection can be determined by transforming equations B-2 and B-3, and setting $N = N_r/2$, i.e.,

$$N = 0.55\left[1 + \sqrt{-\ln(1 - P_d)}\right] \tag{B-5}$$

$$N = 1.6\left[1 + \sqrt{-\ln(1 - P_r)}\right] \tag{B-6}$$

$$N = 3.28\left[1 + \sqrt{-\ln(1 - P_i)}\right] \tag{B-7}$$

Field experiments by Aeronutronic with its Pre-ire II system have demonstrated that two line pairs per minimum target dimension a... required for target detection in clutter with a 50 percent probability.

Table B-1 lists the optical image transformations determined from the foregoing approach.

TABLE B-1. OPTICAL IMAGE TRANSFORMATIONS

Target	Task	Prob.	Line Pairs
Tank	Detect, no clutter	50%	1
Tank	Detect, no clutter	50%	2
Tank	Recognize	50%	3
Tank	Identify	50%	6
1/2-Ton Truck	Detect, no clutter	75%	1.2
1/2-Ton Truck	Detect, no clutter	75%	2.4
1/2-Ton Truck	Recognize	75%	3.5
1/2-Ton Truck	Identify	75%	7.2

B-2. RESOLUTION EQUATIONS

The resolution equations for imaging sensors, as used in this study, are:

$$R_\theta = \frac{1000(X_T)}{ND} \quad \text{(mr)} \qquad \text{(B-8)}$$

$$R_{lp} = \frac{ND}{1000(X_T)} \quad \text{(lp/mr)} \qquad \text{(B-9)}$$

$$R_{TV} = 0.0209 \frac{ND}{X_T} \text{FOV} \quad \text{(TVL/PH)} \qquad \text{(B-10)}$$

$$R_{mm} = \frac{ND}{X_T i} \quad \text{(l/mm)} \qquad \text{(B-11)}$$

The terms in the above equations will be defined in the following discussion of the derivation of the equations.

- Equation B-8

Since the tangent of small angles is closely approximated by the angle in radians, the angle (θ) subtended by a small target at long range can be expressed by:

$$\theta = \frac{X_T}{D} \text{ radians, or } \frac{1000(X_T)}{D} \text{ milliradians}$$

where

X_T = Minimum target dimension in meters
D = Slant range of target from RPV in meters

If the minimum target dimension was required to contain N line pairs as a requisite for a decision, the angle subtended by one of those line pairs would be:

$$R_\theta = \frac{\theta}{N} = \frac{1000(X_T)}{ND} \quad \text{(mr)}$$

• Equation B-9

The reciprocal of R_θ is the number of line pairs per angular unit (R_{lp}) required for a decision, or

$$R_{lp} = \frac{1}{R_\theta} = \frac{1000(X_T)}{ND} \qquad \text{(lp/mr)}$$

• Equation B-10

For a television format with a 3:4 aspect ratio, the vertical field of view (FOV_V) is 3/5 of the diagonal FOV (FOV_D). Therefore, the FOV_V in radians as a function of FOV_D in degrees is:

$$FOV_V = \left(\frac{3}{5}\right)\left(\frac{FOV_D}{57.3}\right) \text{ radians or } \left(\frac{3000}{5}\right)\left(\frac{FOV_D}{57.3}\right) \qquad \text{milliradians}$$

Since FOV_V is the angle subtending a picture height, the angular units (radians) per picture height are identically equal to FOV_V.

Multiplying the required resolution in line pairs per milliradians by the number of line pairs per picture height will result in the required number of line pairs per picture height. Then multiplying by 2, since two TV lines are required for a line pair, provides an overall expression in terms of TVL/PH:

$$R_{TV} = \left(\frac{3}{5}\right)\left(\frac{FOV_D}{57.3}\right)\left(R_{lp}\right)\left(2\right) \qquad \text{radians}$$

Substituting for R_{lp} from equation B-8, and converting to milliradians, gives:

$$R_{TV} = \left(\frac{3000}{5}\right)\left(\frac{FOV_D}{57.3}\right)\left(\frac{ND}{1000\ X_T}\right)\left(2\right) = \left(0.0209\right)\left(\frac{ND}{X_T}\right)\left(FOV_D\right) \qquad \text{radians}$$

• Equation B-11

The equation for resolution in lines per millimeter (R_{mm}) was taken from TM 30-245, Image Interpretation Handbook, dated December 1967.

APPENDIX C

TARGET ACQUISITION ERROR ANALYSIS

The mini-RPV target acquisition requirement is to locate a target in a 100-meter CEP at a slant range from the RPV of 2,000 meters and at an RPV operational range of 30 kilometers from the ground control station. In the 1985 time frame, the requirement is for a target slant range of 3,000 meters from the RPV and an operational range of 50 kilometers, with a target location accuracy of 200 meters for a circular error probability (CEP) of 50 percent.

Equipment errors that contribute to the target location CEP can be grouped into three categories; sensor, RPV attitude, and RPV location. Sensor errors include target range and the sensor azimuth and depression angles relative to the RPV location and attitude. Some sensors gimbal about the roll and pitch axis; however, the more common azimuth and depression (pitch) angles will be used here. The RPV attitude errors include roll, pitch, and yaw angle errors that must be determined by onboard sensors. Depending on the navigational system deployed, RPV location errors include either the RPV altitude, azimuth, and range from the ground control station; or RPV altitude, latitude and longitude.

C.1 DERIVATION OF ERROR EQUATIONS

The target location CEP is determined by the relationship and contribution of each of the parametric errors. To determine the relationship, the target location equation is first derived relative to the ground control station. This equation is derived by sequentially 1) determining the trigonometric relationship of the target from the RPV relative to its frame of reference, 2) rotating the axis into a frame of reference parallel to the earth, and 3) translating the axis to the ground control station. This derivation can be found in a Rock Island Arsenal report (ref. 69, Appendix A). The equations are:

$$\begin{aligned} X_R = & -R\cos\eta\sin\gamma + r\big[\cos\alpha\sin\beta\cos\phi\cos\psi \\ & +\cos\alpha\cos\beta(\sin\Theta\sin\phi\cos\psi - \cos\Theta\sin\psi) \\ & -\sin\alpha(\cos\Theta\sin\phi\cos\psi + \sin\Theta\sin\psi)\big] \end{aligned} \tag{C-1}$$

$$\begin{aligned} Y_R = & R\cos\eta\cos\gamma + r\big[\cos\alpha\sin\beta\cos\phi\sin\psi \\ & -\cos\alpha\cos\beta(\sin\Theta\sin\phi\sin\psi - \cos\Theta\cos\psi) \\ & -\sin\alpha(\cos\Theta\sin\phi\sin\psi - \sin\Theta\cos\phi)\big] \end{aligned} \tag{C-2}$$

$$\begin{aligned} Z_R = & R\sin\eta + r\big[-\cos\alpha\sin\beta\sin\phi \\ & +\cos\alpha\cos\beta\sin\Theta\cos\phi - \sin\alpha\cos\Theta\cos\phi\big] \end{aligned} \tag{C-3}$$

where:

X_R = East coordinate relative to ground station

Y_R = North coordinate relative to ground station

Z_R = Altitude relative to ground station

R = Slant range from ground station to RPV

r = Slant range from RPV to target

β = Azimuth of target from RPV heading

α = Depression angle of target from RPV roll-pitch plane

ψ = RPV heading from north

ϕ = RPV roll angle

Θ = RPV pitch angle

η = RPV elevation angle from ground station

γ = RPV azimuth from ground station relative to north

Figure C-1 illustrates these relationships. In our problem, the RPV altitude relative to the ground station is known but the RPV elevation angle from ground station is unknown. Referring to Figure C-1, we see that:

$$R \cos \eta = \left(R^2 - H^2\right)^{1/2}$$

$$R \sin \eta = H$$

where H = the RPV altitude. Substituting these values in equations (C-1), (C-2), and (C-3), the first terms become:

$$X_R = -\sin \gamma \left(R^2 - H^2\right)^{1/2} + \ldots \tag{C-4}$$

$$Y_R = \cos \gamma \left(R^2 - H^2\right)^{1/2} + \ldots \tag{C-5}$$

$$Z_R = H + \ldots \tag{C-6}$$

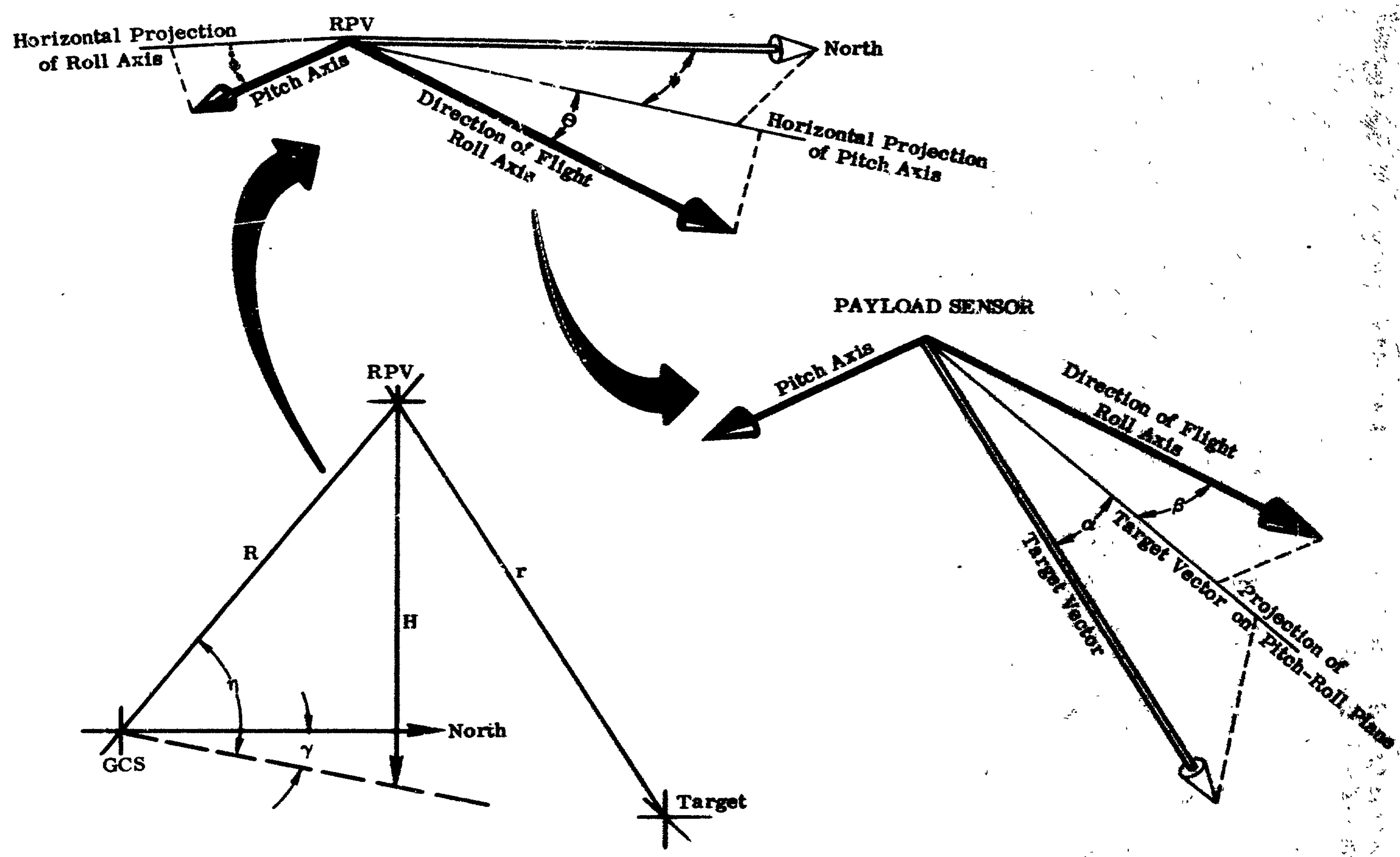

Figure C-1. Target Location Geometry

To find the CEP of the target location, first we find the error (σ) in X_R, Y_R, and Z_R using the general equation:

$$\sigma_P^2 = \left(\frac{\partial P}{\partial X_1}\right)^2 \sigma_{X_1}^2 + \left(\frac{\partial P}{\partial X_2}\right)^2 \sigma_{X_2}^2 + \left(\frac{\partial P}{\partial X_3}\right)^2 \sigma_{X_3}^2 + \ldots \qquad \text{(C-7)}$$

Figures C-2, C-3, and C-4 present the results for X_R, Y_R, and Z_R. To find the target location of CEP, the ratio σ_y/σ_x is found for values of $\sigma_x \neq \sigma_y$ and used along with a 50 percent probability to extract the factor K from a table of circular error probabilities. Then CEP is computed by a product of $K\sigma_x$.

For the special case in which the location of the RPV is determined independent of the ground station, the error in the longitude and latitude is substituted for the first term of Y_R and X_R, respectively. Then the equations take the form of:

$$X_R = X_E + \ldots \qquad \text{(C-8)}$$

$$Y_R = Y_N + \ldots \qquad \text{(C-9)}$$

$$Z_R = H + \ldots \qquad \text{(C-10)}$$

$$\sigma_X^2 = \left(\frac{\partial X_R}{\partial R}\right)^2 \sigma_R^2 + \left(\frac{\partial X_R}{\partial \gamma}\right)^2 \sigma_\gamma^2 + \left(\frac{\partial X_R}{\partial H}\right)^2 \sigma_H^2 \tag{C-11}$$

$$+ \left(\frac{\partial X_R}{\partial r}\right)^2 \sigma_r^2 + \left(\frac{\partial X_R}{\partial \alpha}\right)^2 \sigma_\alpha^2 + \left(\frac{\partial X_R}{\partial \beta}\right)^2 \sigma_\beta^2$$

$$+ \left(\frac{\partial X_R}{\partial \phi}\right)^2 \sigma_\phi^2 + \left(\frac{\partial X_R}{\partial \psi}\right)^2 \sigma_\psi^2 + \left(\frac{\partial X_R}{\partial \Theta}\right)^2 \sigma_\Theta^2$$

$$\frac{\partial X_R}{\partial R} = -R \sin \gamma \left(R^2 - H^2\right)^{-1/2}$$

$$\frac{\partial X_R}{\partial \gamma} = -\cos \gamma \left(R^2 - H^2\right)^{1/2}$$

$$\frac{\partial X_R}{\partial H} = H \sin \gamma \left(R^2 - H^2\right)^{-1/2}$$

$$\frac{\partial X_R}{\partial r} = \cos \alpha \sin \beta \cos \phi \cos \psi + \cos \alpha \cos \beta (\sin \Theta \sin \phi \cos \psi - \cos \Theta \sin \psi) - \sin \alpha (\cos \Theta \sin \phi \cos \psi + \sin \Theta \sin \psi)$$

$$\frac{\partial X_R}{\partial \alpha} = r [- \sin \alpha \sin \beta \cos \phi \cos \psi - \sin \alpha \cos \beta (\sin \Theta \sin \phi \cos \psi - \cos \Theta \sin \psi) - \cos \alpha (\cos \Theta \sin \phi \cos \psi + \sin \Theta \sin \psi)]$$

$$\frac{\partial X_R}{\partial \beta} = r [\cos \alpha \cos \beta \cos \phi \cos \psi - \cos \alpha \sin \beta (\sin \Theta \sin \phi \cos \psi - \cos \Theta \sin \psi)]$$

$$\frac{\partial X_R}{\partial \phi} = r [- \cos \alpha \sin \beta \sin \phi \cos \psi + \cos \alpha \cos \beta (\sin \Theta \cos \phi \cos \psi) - \sin \alpha \cos \Theta \cos \phi \cos \psi]$$

Figure C-2. Solution of General Error Equation for X_R (Sheet 1 of 2)

$$\frac{\partial X_R}{\partial \psi} = r\,[-\cos\alpha \sin\beta \cos\phi \sin\psi + \cos\alpha \cos\beta\,(-\sin\Theta \sin\phi \sin\psi - \cos\Theta \cos\psi) - \sin\alpha\,(-\cos\Theta \sin\phi \sin\psi + \sin\Theta \cos\psi)]$$

$$\frac{\partial X_R}{\partial \Theta} = r\,[\cos\alpha \cos\beta\,(\cos\Theta \sin\phi \cos\psi + \sin\Theta \sin\psi) - \sin\alpha\,(-\sin\Theta \sin\phi \cos\psi + \cos\Theta \sin\psi)]$$

Figure C-2. (Sheet 2 of 2)

$$\sigma_Y^2 = \left(\frac{\partial Y_R}{\partial R}\right)^2 \sigma_R^2 + \left(\frac{\partial Y_R}{\partial H}\right)^2 \sigma_H^2 + \left(\frac{\partial Y_R}{\partial \gamma}\right)^2 \sigma_\gamma^2 \tag{C-12}$$

$$+ \left(\frac{\partial Y_R}{\partial r}\right)^2 \sigma_r^2 + \left(\frac{\partial Y_R}{\partial \alpha}\right)^2 \sigma_\alpha^2 + \left(\frac{\partial Y_R}{\partial \beta}\right)^2 \sigma_\beta^2$$

$$+ \left(\frac{\partial Y_R}{\partial \phi}\right)^2 \sigma_\phi^2 + \left(\frac{\partial Y_R}{\partial \psi}\right)^2 \sigma_\psi^2 + \left(\frac{\partial Y_R}{\partial \Theta}\right)^2 \sigma_\Theta^2$$

$$\frac{\partial Y_R}{\partial R} = R \cos \gamma \left(R^2 - H^2\right)^{-1/2}$$

$$\frac{\partial Y_R}{\partial H} = -H \cos \gamma \left(R^2 - H^2\right)^{-1/2}$$

$$\frac{\partial Y_R}{\partial \gamma} = - \sin \gamma \left(R^2 - H^2\right)^{1/2}$$

$$\begin{aligned} \frac{\partial Y_R}{\partial r} = \; & \cos \alpha \sin \beta \cos \phi \sin \psi \\ & - \cos \alpha \cos \beta (\sin \Theta \sin \phi \sin \psi - \cos \Theta \cos \psi) \\ & - \sin \alpha (\cos \Theta \sin \phi \sin \psi - \sin \Theta \cos \phi) \end{aligned}$$

$$\begin{aligned} \frac{\partial Y_R}{\partial \alpha} = \; & r \, [- \sin \alpha \sin \beta \cos \phi \sin \psi \\ & + \sin \alpha \cos \beta (\sin \Theta \sin \phi \sin \psi \cos \Theta \cos \psi) \\ & - \cos \alpha (\cos \Theta \sin \phi \; \mathrm{six} \; \psi - \sin \Theta \cos \phi) \end{aligned}$$

$$\begin{aligned} \frac{\partial Y_R}{\partial \beta} = \; & r \, [\cos \alpha \cos \beta \cos \phi \sin \psi \\ & + \cos \alpha \sin \beta (\sin \Theta \sin \phi \sin \psi - \cos \Theta \cos \psi)] \end{aligned}$$

Figure C-3. Solution of General Equation for Y_R (Sheet 1 of 2)

$$\frac{\partial Y_R}{\partial \phi} = r[-\cos\alpha \sin\beta \sin\phi \sin\psi$$
$$- \cos\alpha \cos\beta\,(\sin\Theta \cos\phi \sin\psi)$$
$$- \sin\alpha\,(\cos\Theta \cos\phi \sin\psi + \sin\Theta \sin\phi)]$$

$$\frac{\partial Y_R}{\partial \psi} = r\,[\cos\alpha \sin\beta \cos\phi \cos\psi$$
$$- \cos\alpha \cos\beta\,(\sin\Theta \sin\phi \cos\psi + \cos\Theta \sin\psi)$$
$$- \sin\alpha \cos\Theta \sin\phi \cos\psi]$$

$$\frac{\partial Y_R}{\partial \Theta} = r\,[-\cos\alpha \cos\beta\,(\cos\Theta \sin\phi \sin\psi + \sin\Theta \cos\psi)$$
$$+ \sin\alpha\,(\sin\Theta \sin\phi \sin\psi + \cos\Theta \cos\phi)]$$

Figure C-3. (Sheet 2 of 2)

$$\sigma_Z^2 = \left(\frac{\partial Z_R}{\partial H}\right)^2 \sigma_H^2 + \left(\frac{\partial Z_R}{\partial r}\right)^2 \sigma_r^2 + \left(\frac{\partial Z_R}{\partial \alpha}\right)^2 \sigma_\alpha^2 + \left(\frac{\partial Z_R}{\partial \beta}\right)^2 \sigma_\beta^2 + \left(\frac{\partial Z_R}{\partial \phi}\right)^2 \sigma_\phi^2 + \left(\frac{\partial Z_R}{\partial \Theta}\right)^2 \sigma_\Theta^2 \tag{C-13}$$

$$\frac{\partial Z_R}{\partial H} = 1$$

$$\frac{\partial Z_R}{\partial r} = -\cos\alpha \sin\beta \sin\phi + \cos\alpha \cos\beta \sin\Theta \cos\phi - \sin\alpha \cos\Theta \cos\phi$$

$$\frac{\partial Z_R}{\partial \alpha} = r\,[\sin\alpha \sin\beta \sin\phi - \sin\alpha \cos\beta \sin\Theta \cos\phi - \cos\alpha \cos\Theta \cos\phi]$$

$$\frac{\partial Z_R}{\partial \beta} = r\,[-\cos\alpha \cos\beta \sin\phi - \cos\alpha \sin\beta \sin\Theta \cos\phi]$$

$$\frac{\partial Z_R}{\partial \phi} = r\,[-\cos\alpha \sin\beta \cos\phi - \cos\alpha \cos\beta \sin\Theta \sin\phi + \sin\alpha \cos\Theta \sin\phi]$$

$$\frac{\partial Z_R}{\partial \Theta} = r\,[\cos\alpha \cos\beta \cos\Theta \cos\phi + \sin\alpha \sin\Theta \cos\phi]$$

Figure C-1. Solution of General Equation for Z_R

C.2 MISSION PROFILES

Variations of the mission profile are presented in Table C-1. The parameters were selected to explore the target location errors at the extremes of the mission requirements. The base condition was selected as the most probable RPV and sensor attitude at the maximum target slant range and RPV operational range. Then, attitudes were varied to explore the effects of the most critical errors that influence the target location determination. The sensor depression angle, α, was chosen to correspond to the sensor line-of-sight for an effective mission altitude of 2,000 feet.

C.3 EQUIPMENT ACCURACY

The equipment error budget was allocated according to Table C-2. These accuracies are representative of the equipment noted. Errors in UTM coordinates and ground station location and orientation are not considered in this analysis. Errors in installation and alignment of equipment onboard the RPV are included in the equipment errors. The GPS equipment errors are estimates based on development goals.

C.4 RESULTS OF ERROR ANALYSIS

Results of this analysis are presented in Table C-3. For missions 2.0 and 2.5, the RPV system can meet the target location accuracies during level-flight conditions. As shown in Figure C-5, these accuracies degrade during continuous nonlevel or banked flight attitudes. The accuracies presented in the graph are for ideal conditions. When additional flight dynamic forces are introduced, these accuracies deteriorate more quickly. In all cases, therefore, the mission requirements of MSCs 2.0, 2.5, and 3.0 are met except after long periods of nonlevel flight.

C.5 RESULTS OF SENSITIVITY ANALYSIS

Results of the parametric sensitivity analysis are presented in Figure C-6. These graphs show the variation of the target altitude accuracy, σ_Z, and the target coordinate accuracy, CEP, as a function of the error in the target location parameters. For such errors as for roll (ϕ) and pitch (Θ), which are usually equal and vary equally, the combined effects were analyzed. This is also true of the gimbal errors, ϵ_β and ϵ_δ. All the graphs presented represent the base condition for missions 2.0 and 2.5 where $\psi = 0$ and $\beta = 45°$.

As can be seen from Figure C-6, the target location accuracy is most sensitive to gimbal errors, GCS-to-RPV azimuth, and RPV heading. Of these, the GCS-to-RPV azimuth is the most critical. An error in the orientation of the GCS by little more than one tenth of a degree will combine with the azimuth error to degrade the target coordinate accuracy beyond the required 100 meter CEP. Therefore, GCS orientation errors are the dominant type in this application.

The target altitude accuracy is most sensitive to the RPV-to-target azimuth and depression angle errors, and RPV pitch and roll attitude error. None of these is especially critical. From a percentage variation point of view, a variation of the RPV-to-target azimuth and depression angle errors has the greatest impact on the target altitude accuracy.

TABLE C-1. MISSION PROFILES

Parameter	Symbol	MSC 2.0-2.5		MSC 3.0	
		Base Condition	Variation	Base Condition	Variation
Altitude above ground station	H	615.38m	–	615.38m	1538.46m
Slant range to target	r	2 km	–	3 km	–
Slant range to RPV	R	30 km	–	50 km	–
RPV pitch	Θ	0	–	0	–
RPV roll	ϕ	0	–	0	–
RPV heading	ψ	0	90°	0	90°
Target azimuth	β	45°	90°	45°	90°
Target depression angle	α	17.9°	–	17.9°	30.85°
RPV azimuth	γ	0	–	0	–

TABLE C-2. TARGET LOCATION PARAMETER ERRORS

Parameter	Symbol	Type of Equipment	Composite Error, σ, RSS
Selected Configuration			
Target Location			
Azimuth	β	Sensor Gimbal	19.513 mr
Depression Angle	α	Sensor Gimbal	19.513 mr
Range	r	Laser Range Finder	5.0m
RPV Location			
Azimuth	γ	Integrated Communication and Navigation System	1.745 mr
Altitude	H	Barometric Altimeter	15.0m
Range	R	Integrated Communication and Navigation System	20.0m
RPV Attitude			
Roll	ϕ	Vertical Gyro (drift rate = 8.727 mr/min)	12.339 mr
Pitch	Θ	Vertical Gyro (drift rate = 8.727 mr/min)	12.339 mr
Heading	ψ	Vertical Gyro/3-Axis Magnetometer	31.490 mr
Alternative Configurations			
RPV Location			
Longitude	Y_N	Tactical Global Positioning Guidance	50.0m
Latitude	X_E	Tactical Global Positioning Guidance	50.0m
RPV Attitude			
Heading	ψ	Direction Gyro (drift rate = 3.491 mr/min and 2-Axis Magnetometer)	38.030 mr

NOTE: m = meters, mr = millirads

TABLE C-3. ORTHOGONAL AND CIRCULAR ERROR

Mission Profile/System	Variation, degrees		Error, meters			
	ψ	β	σ_x	σ_y	σ_z (alt.)	CEP (50%)
MSC 2.0-2.5						
Base	0	45	73.87	55.83	53.48	76.01
Variation 1	90	45	73.87	55.01	53.48	75.57
Variation 2	90	90	88.23	26.11	46.45	66.08
Variation 3	0	90	54.23	73.68	46.45	74.93
MSC 3.0						
ICNS-Below Line-of-Sight						
Base	0	45	116.22	79.34	59.60	114.48
Variation 2	90	90	137.70	31.71	67.61	99.14
ICNS-Line-of-Sight						
Base	0	45	113.94	75.97	61.38	111.09
Variation 2	90	90	130.67	45.17	61.38	101.34
GPS Base	0	45	91.62	91.62	59.60	107.90

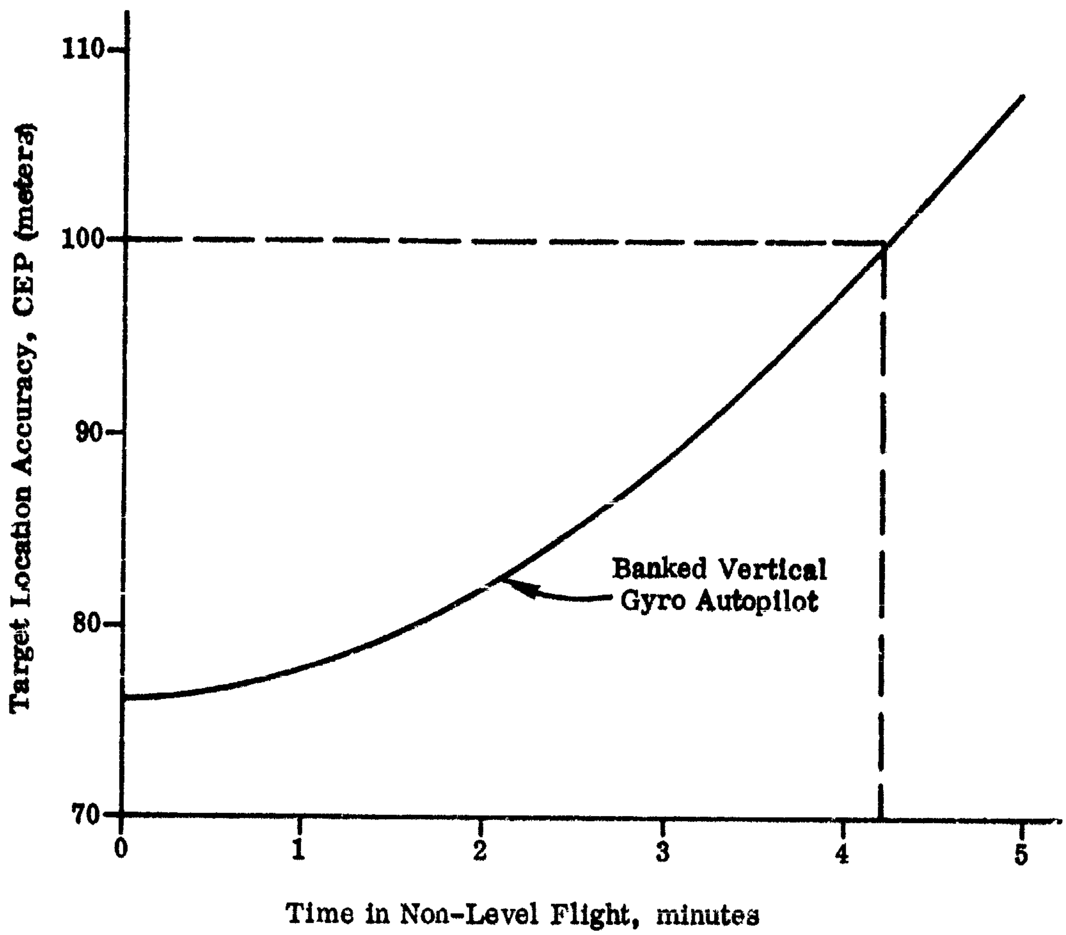

Figure C-5. Target Location Accuracy Vs. Time
(Steady State, Missions 2.0 and 2.5)

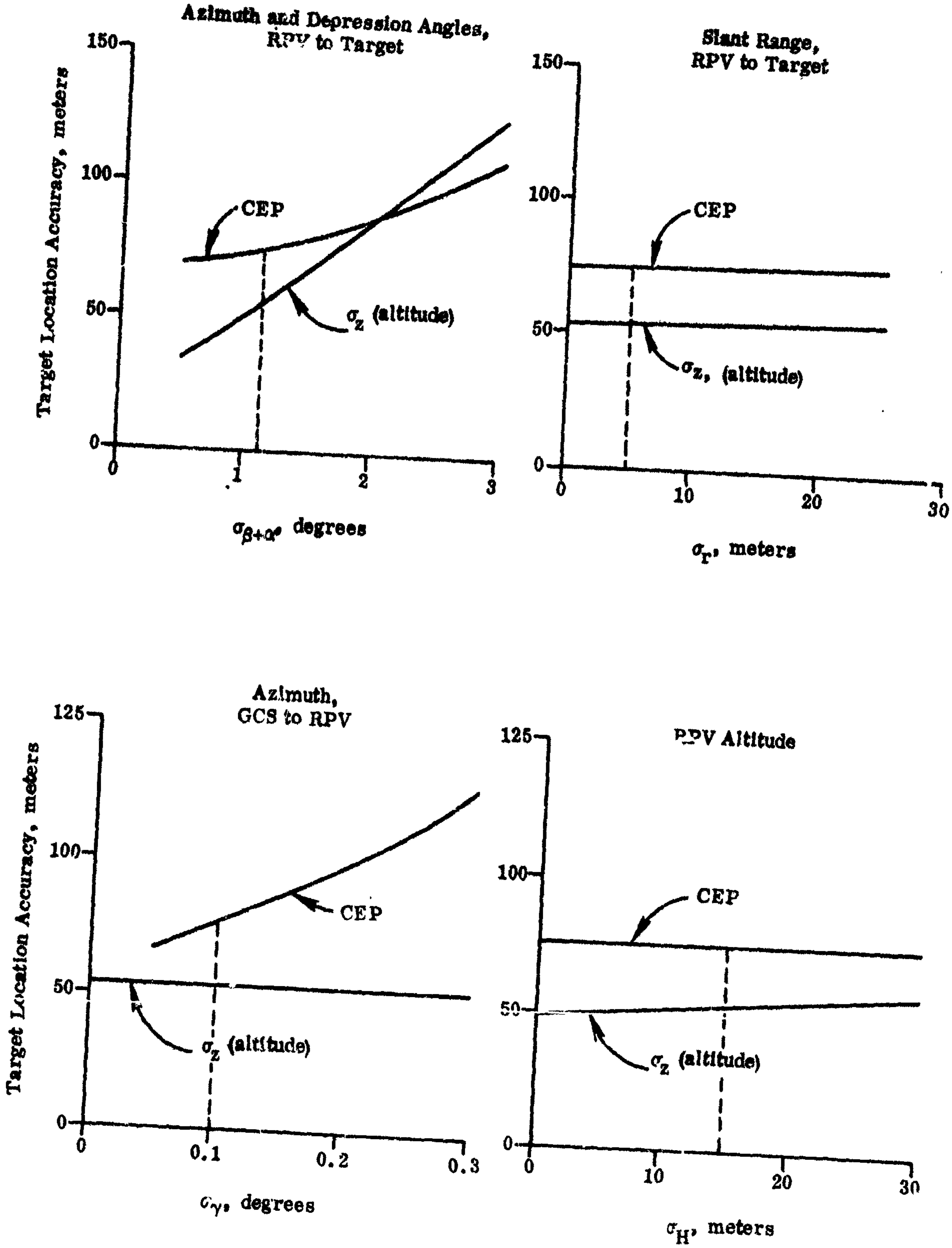

Figure C-6. Parametric Sensitivity Analysis (Sheet 1 of 2)

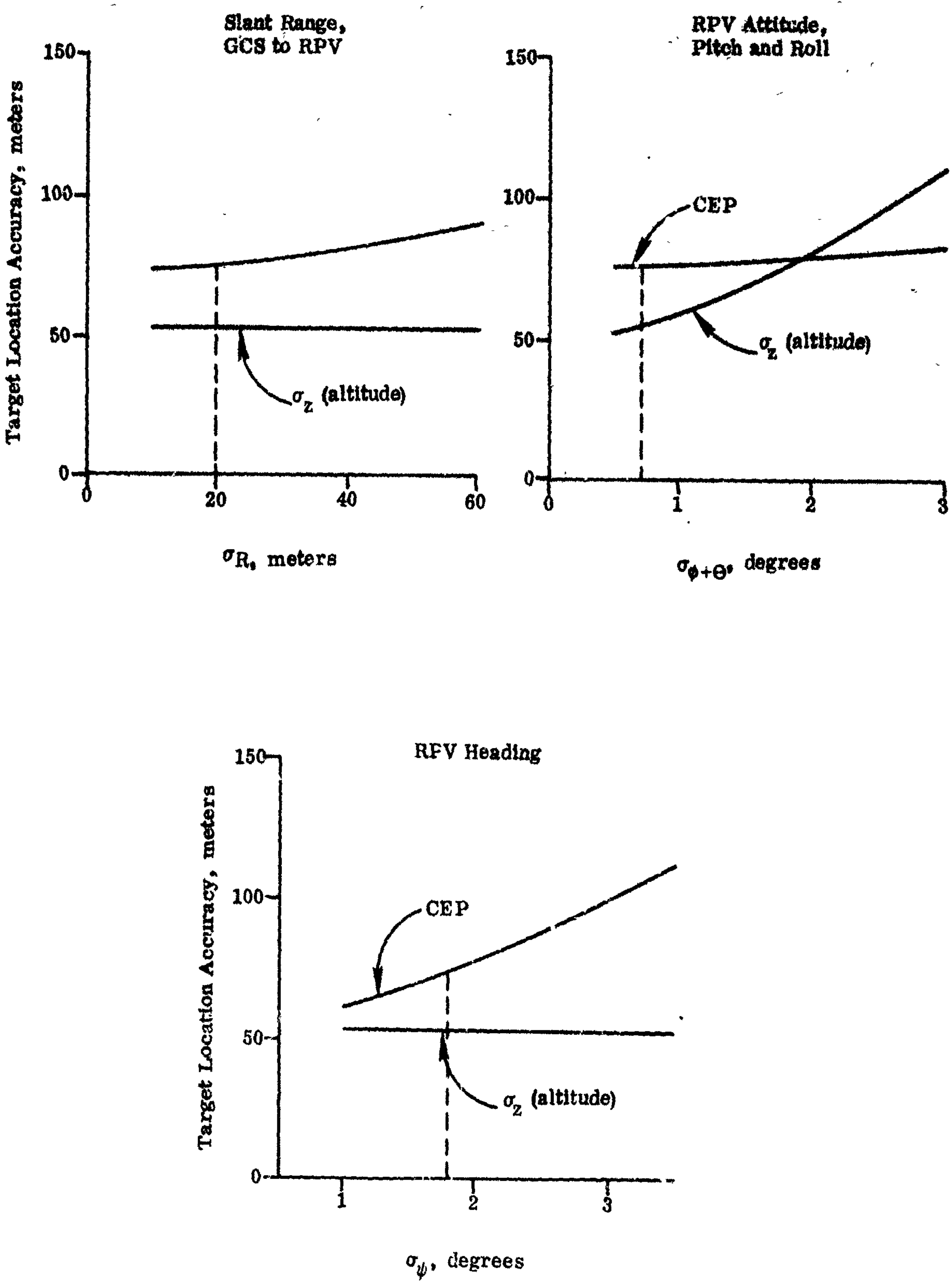

Figure C-6. (Sheet 2 of 2)

APPENDIX D

RECOMMENDED CHANGES TO TOD

Additional hardware items identified by ARINC Research are recommended for inclusion in the TOD for the Army Mini-RPV Program. These items are listed below; full details, including operating characteristics, are given in the text of this report.

Panoramic Photographic Cameras

Manufacturer	Model
Bourns/CAI	CA-168 (modified)
Actron	HP-462X
Itek	3-inch bar panoramic
Itek	3-inch panoramic

Laser Rangefinder/Designator

Manufacturer	Model
Hughes	Undesignated

Forward Looking Infrared (FLIR)

Manufacturer	Model
Aeronutronic	CALERE III
Honeywell	Mini-FLIR

It is also recommended that:

a. The autotracker information presented in the TOD be expanded to include information on the autotracker equipments contained in the Blue-Spot (Westinghouse) and Praeire II (Aeronutronic) systems.

b. The Autopilot section be reformatted to address types of autopilots rather than their components.

c. Data on parachute systems be included in the Recovery section. The current study being conducted by Teledyne-Ryan Aeronautical for the Army should provide this type of information.

d. Data on available laser and microwave landing aids also be included in the Recovery section.

e. Engine data from Army engine study program (see Section 3.8.2) be incorporated as it becomes available.

f. Human factors data from current Army investigations be included in the Ground Control Station section as the information becomes available.

g. Data on the PLRS, GPS, and ICNS navigation systems be included in the Navigation section.

h. The television camera in the description of the Aeronutronic target acquisition system (Praeire II) be changed from a Sony model 3210 to a Systems Research Laboratories model 326J, to reflect the latest configuration of this system proposed by Aeronutronic.

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A tradeoff analysis of equipment applicable to the U.S. Army Mini-RPV Program is described. Candidate equipments are evaluated and ranked for each subsystem of the remotely piloted vehicle, from which alternative complete systems ("baseline" and "variants") are synthesized.

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