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AQUILA REMOTELY PILOTED VEHICLE SYSTEM TECHNOLOGY DEMONSTRATOR (RPV-STD) PROGRAM

Volume I - System Description and Capabilities

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APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

This report provides the results of the program of design, fabrication, integration and test of the AQUILA (XMQM-105) RPV System Technology Demonstrator preparatory to delivery of this system to the US Army for engineering design test and force development test and experimentation. System performance presented herein supports the conclusion that an RPV system can provide capabilities for battlefield reconnaissance, target acquisition, and target designation. However, the reader is advised that system tests reported herein were developmental in nature and the results are limited. Complete performance of the AQUILA demonstrator system can be obtained only through an appreciation of the results in this report and the results of the Army's engineering design and force development tests. Engineering design tests were conducted by the US Army Electronic Proving Ground with results published in *Final Report/Engineering Design - Government (EDT-G) of Remotely Piloted Vehicle - System Technology Demonstrator, TECOM Project No. 6-AI-53E-RPV-005, June 1978.** Force development tests were conducted by the US Army Field Artillery Board and published in *Force Development and Testing and Experimentation of Remotely Piloted Vehicle System/Final Report, TRADOC Project No. 6-AI-RPV-003, January 1978.***

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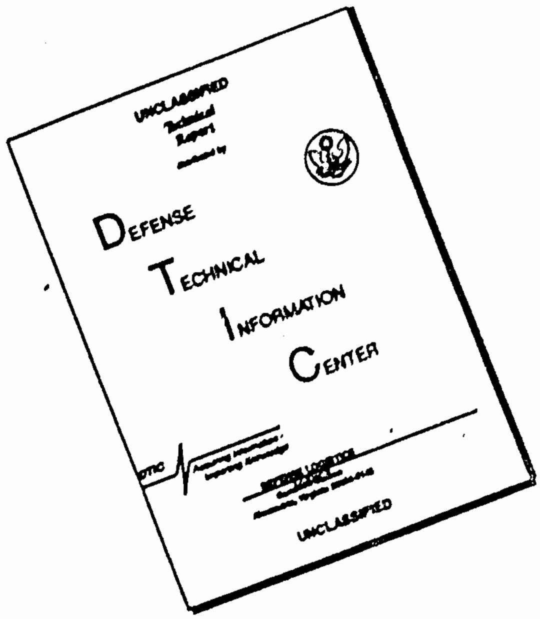

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Army Aquila RPV system technology demonstrator consists of 146-lb RPVs with a 12.35-ft wingspan and a 6-ft length, ground support systems consisting of truck-mounted ground control stations and pneumatic launchers, trailer-mounted vertical barrier RPV retrieval systems, and auxiliary support equipment. The system demonstrated effective targeting and surveillance capabilities at maximum ranges exceeding 20 km, with payload options ranging from unstabilized TV cameras to laser designators.

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SUMMARY

Improvements in electronic and electro-optic sensor technology have led to improved potential for design and effective application of "mini" remotely piloted vehicles (RPVs) in battlefield surveillance and targeting. To examine and test this new technology for battlefield applications, the Army initiated the Aquila RPV System Technology Demonstrator (RPV-STD) program in December 1974 with Lockheed Missiles & Space Company, Inc., Sunnyvale, California. Army direction was provided by the U.S. Army Aviation Systems Command (AVSCOM)*, St. Louis, Missouri. The program was conducted under contract DAAJ02-75-C-0005 and administered by the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory**, Fort Eustis, Virginia. It consisted of (1) the design and fabrication of an RPV system using current airframe, propulsion, sensor, command and control, and data link technology; (2) demonstration of that system and its associated technology in field tests; and (3) training and support for Army hands-on demonstration.

The RPV payload applications examined involved five phases having increasing sophistication. Phase I, real-time TV surveillance, employs an unstabilized, zoom (10:1) TV camera with azimuth and elevation control relative to the RPV. Phase II, real-time surveillance plus photographic reconnaissance, employs the unstabilized TV camera plus a 35-mm mini-pan film camera. Phase III, target acquisition, employs a gyro-stabilized zoom (10:1) TV camera with a lock-on scene tracker. Phase IV, target location and artillery adjustment, adds a laser to the stabilized TV for precise ranging. Phase V, target designation, uses the same payload as Phase IV, but maintains the laser precisely

*Redesignated U.S. Army Aviation Research and Development Command (AVRADCOM), effective 1 July 1977.

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on target to direct laser homing projectiles or missiles. Each RPV can carry any one of these sensor options.

The payloads are flown in an autopilot-stabilized RPV that provides timely access to a wide area of the battlefield. The sea level speed (63 to 168 km/h) and altitude (5,000 m) capability permit the rapid positioning of the RPV so that the greater part of the 3-hour flight endurance can be directed to mission activities. The 12.35-ft span, 6-ft length, and 146-lb (maximum) weight of the RPV permit efficient ground handling. Rapid checkout is accomplished using a semautomatic- or manual-mode suitcase-sized electronic tester.

The mobile ground support system consists of the ground control station (GCS), self-contained pneumatic launcher, and vertical barrier retrieval systems. The GCS and launcher are mounted on standard M36 trucks and the retrieval system is mounted on two M345 trailers. Electrical power for the Aquila system is provided by two trailer-mounted diesel-electric generators. The system is designed to permit examination of the tactical potential of a mobile, deployed RPV system operating from unprepared sites, with multiple sorties per day, battlefield coverage up to 20 km from the launch site, and selectable sensor applications.

System operation offers a broad array of performance, maneuver, search, and targeting capabilities. Following RPV launch, the RPV operator may direct a fully automatic mission of waypoint, search, or loiter options or may elect to manually direct the RPV flightpath, whichever is required by the mission. No pilot-qualified skills are required as the RPV is autopilot stabilized and flight parameters are easily selectable at the RPV operator console. The data link permits operations up to 20 km from the GCS. Independent of RPV flight parameters, the sensor operator has full control of sensor operations and is free to concentrate on targeting functions over the battlefield area.

Recovery of the RPV is semiautomatic. Following preprogrammed waypoints to set up the approach path, the sensor operator selects the video display from a ground-mounted camera aimed precisely up the 4-deg approach path, sights the approaching RPV, and tracks its progress with an electronically generated reticle on his video display. The GCS computer then corrects the RPV flightpath to engage the vertical net of the retrieval system. The longitudinal momentum of the RPV is then absorbed and the RPV settles into the horizontal landing net strung between the two M345 trailers. Checkout and refueling of the recovered RPV, or of another RPV, permit early initiation of the next sortie if desired.

Following contract initiation on 20 December 1974, a concentrated program of design and engineering testing led to the first vehicle flight on 1 December 1975 at Crows Landing Navy Auxiliary Landing Field, California. After six preliminary system check flights by the contractor, field test operations were moved to Fort Huachuca, Arizona. A series of RPV losses early in the test program resulted from a variety of design, recovery technique, and procedural weaknesses. A program of design and operations refinement was then accomplished to improve system reliability. While field testing was in progress, training of Army personnel at LMSC and in the field was accomplished. Validation of the RPV and ground support system operation, including Army training flights, was completed on 22 April 1977. Mission capability, including sensor operations, was then evaluated from 28 April 1977 to 19 July 1977. Participation by Army personnel was increased to finalize Army training. Following successful mission capability demonstration, the first RPV system was formally delivered to the Army on 15 July 1977. Army hands-on flight testing by U.S. Army Training & Doctrine Command (TRADOC) and the U.S. Army Electronic Proving Ground (USAEPG) began in July 1977.

Lockheed and Army tests have validated and defined the operational capability of the Aquila RPV system in 149 test flights. Mission operations were conducted routinely by Army personnel during the course of the test program, and evaluations of the results of these operations are being reviewed for development of tactical system requirements.

The Aquila RPV system has provided the Army with experience in applications of current RPV technology to targeting missions in the modern battlefield. Experience with the system in field tests points toward a greatly improved capability to observe, identify, locate, and strike enemy targets using conventional or guided artillery projectiles or missiles.

PREFACE

The Aquila RPV-STD program was conducted in accordance with contract DAAJ02-75-C-0005, RPV System Technology Demonstrator Program, and Lockheed's proposal, Remotely Piloted Vehicle System Technology Demonstrator Program (RPV-STD) for the U.S. Army, LMSC-D056091, 30 August 1974.

This report is submitted in three volumes. Volume I, Aquila System Description and Capabilities, provides a complete description of the Aquila system, its operation, and its capabilities. Comparison with program requirements and goals is also provided. Volume II, Aquila System Evolution and Engineering Testing, describes the design evolution and ground testing leading to the final Aquila design, and describes the problems encountered and solutions employed. Volume III, Aquila Field Test Program, describes the field testing, including flight tests, and summarizes the results of those tests.

The success of the Aquila RPV-STD program is attributable in large measure to the many Army personnel who supported and participated in the program. They are too numerous to name in this brief paragraph, but LMSC wishes to gratefully acknowledge their support. Two of the Army participants who must be acknowledged are LTC Davies Powers, RPV Development Manager at the U.S. Army Aviation Research & Development Command, St. Louis, Missouri, and COL Sherwin Arculis, U. S. Army Training and Doctrine Command Systems Manager, Fort Sill, Oklahoma. They and their staffs, in providing program direction and coordinating the program with the many participating Army headquarters, planning groups, laboratories, and testing agencies, were essential to program success.

Also contributing directly to the success of the Aquila program were several complementary contract programs, including (1) Trainer Simulator System, DAAJ02-75-C-0055; (2) Installation and Checkout of RPV Sensors in the Otter U-1A Aircraft, DAEA18-75-C-0165; (3) ICNS Aquila-Otter Mini-RPV System Feasibility Demonstration, DAAB07-77-C-2160; (4) ICNS/Aquila Mini-RPV System Integration, DAAB07-76-C-0903; (5) Eye-Safe Training Sensor, DAAK70-76-C-0256; (6) ARMS Model for RPV, Loan Agreement DAAJ02-76-A-0001; Field and Technical Support of Army RPV Programs, DAEA18-77-C-0107 (Note: Code identification 17077 applies to all program references.).

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Section I
INTRODUCTION

1.1 BACKGROUND

The Army has long sought an effective remotely piloted vehicle (RPV) to enhance its capability for battlefield surveillance and targeting. The operational flexibility and utility of a small RPV have constantly attracted Army interest. Continual improvements in RPV technology have increased the potential of RPVs and have made likely the development of the system or systems to meet the Army's needs. This technology includes miniaturized electronics, electro-optical sensors, structural materials, data links, and minicomputers.

During 1973 through 1975, the Defense Advanced Research Projects Agency (DARPA) conducted RPV research in its Praeire, Calare, and Aequare programs. Using airframes ranging from model airplanes to modern, molded fiberglass vehicles, electronics ranging from model airplane radio controls to electronic autopilots, modern satellite-derivative data links, tracking antennas, and high-speed computers, the DARPA programs demonstrated RPVs with modern video, laser, and infrared sensor prototypes. Demonstrations included finding and identifying targets, and even directing a cannon-launched guided projectile to a direct hit on a tank target. A further examination of RPV technology was conducted by the Army in its Remotely Piloted Aerial Observer/Designator System (RPAODS) program at Fort Huachuca, Arizona, in 1974. All of these efforts were conducted by contractor personnel.

Based on the previous RPV experience in the Army and the results of the more recent technology programs, the Little 'r' program was conceived.

The term Little 'r' refers to the less-than-formal required operational capability (ROC) formulated for the Army RPV system. The approach taken by the Army was to use this Little 'r' document as a basis for the requirements of an RPV system technology demonstrator (RPV-STD), to procure such a system with sufficient hardware for conclusive field testing, to operate and evaluate the system with Army personnel, and, after careful review, to reevaluate and formalize the ROC. The Aquila program represents the system procurement and the Army "hands-on" testing portions of that plan.

1.2 EARLY HISTORY

The forward observer and "grasshopper" observation aircraft became legendary in World War II as indespensible and often heroic eyes for the field artillery. Technological advances quickly rendered the light aircraft obsolete and forced the forward observer to evolve different techniques. The net result was a reduction in the range at which artillery targets could be effectively and accurately located.

The technology explosion in tactical missiles during the mid 1950's increased this target-locating deficiency and served as a catalyst for a multimillion dollar intensified drone/RPV development program. The resulting SD series of drones were disappointing in that, whether fielded with insufficient development or being overly sophisticated, they placed too great a maintenance burden on the commanders and/or became too costly to operate.

These disappointments produced significant lessons, including: (1) requirements, relative to both needs and technology, must be realistic, (2) technology demonstrations, allowing user participation and feedback, should precede full-scale engineering developments, (3) adequate funding must be programmed to sustain the necessary development without continuous modifications to avoid cost and schedule overruns, and (4) ease of operation by the troops and minimum maintenance burden are essential. With this background and history, the Army has formulated and is in the process of completing the Aquila RPV-STD program.

1.3 OBJECTIVES

The objectives of the Aquila program, performed under contract DAAJ02-75C-0005, were to (1) integrate and demonstrate the current technology of airframe, propulsion, sensor, command and control, and data link for RPV systems, and (2) provide training and support for Army hands-on training. The underlying purpose of the program was to design and fabricate a quantity of RPVs, sensors, and RPV support systems for use in an Army demonstration program to determine, by actual Army hands-on usage, the capabilities of RPV systems for surveillance, target acquisition, and target designation.

1.4 STATEMENT OF THE PROBLEM

The problems posed by the Aquila contract were to: (1) combine, on an extremely ambitious schedule, existing equipment, modified or adapted components, prototype sensors, and new elements (such as the airframe) into an effective system technology demonstration system which could find, locate, identify, and designate field targets for Army artillery; (2) produce quantities of RPVs and support equipment with minimum engineering development; and (3) adequately train Army crews to deploy, maintain, check out, and operate the system in field maneuvers. In essence, the Aquila RPV-STD system had to effectively represent a postulated tactical system in the field, operated by trained Army personnel, at a small fraction of the cost of the development of the tactical system.

1.5 PLAN OF THE REPORT

This volume, Volume I of three, describes the Aquila RPV-STD system, as delivered to the Army, and its performance as demonstrated in field tests.

Section II provides orientation for the reader by describing the mission of the Aquila system, its relationship to a postulated tactical mission, and validation of the Aquila system mission capabilities. Sections III through V describe the Aquila system hardware and its capabilities, and compare those to program requirements, goals, and objectives. Section III describes the RPV, with subsections detailing the airframe, power plant, flight control system, and sensors. Section IV describes the data link system, including all airborne and ground-based elements. Section V describes the ground support system with subsections detailing the ground control station, the launcher, the retrieval system, the electrical generation system, and ground support, test, and checkout equipment. Sections VI, Site Selection and Geometry, and Section VII, System Operation, describe the field deployment of the system and its operational options and capabilities. Section VIII summarizes the conclusions of the program relative to the Aquila system performance and to the potential for a tactical system.

Section II
MISSION

The basic mission of the Army Aquila Remotely Piloted Vehicle System Technology Demonstrator (RPV-STD) program is to determine, through operation by the Army, the capabilities of RPVs for surveillance, target acquisition, and target designation on modern battlefields.

2.1 MISSION DESCRIPTION

The tactical system that the Aquila RPV-STD represents is shown in Figure 1. Located near the forward edge of the battle area (FEBA), the system provides surveillance, photo reconnaissance, target detection, target identification, target location, artillery fire adjustment, and target designation functions over the local battlefield. The Aquila system, Figure 2, was designed for capabilities that would allow the Army to investigate the utility and effectiveness of the tactical system that it represents. The mission-related capabilities selected are as follows:

- Airframe commonality with all sensors
- Multiple sorties per day
- Operation from unprepared sites
- Minimum crew size
- Minimum time/skill for operation
- Low detectability
- Mobility, using conventional Army ground vehicles
- Compatibility with standard Army equipment
- Adequate RPV performance
- Computer-controlled flightpath and search patterns
- Target detection, identification, location, and designation capability

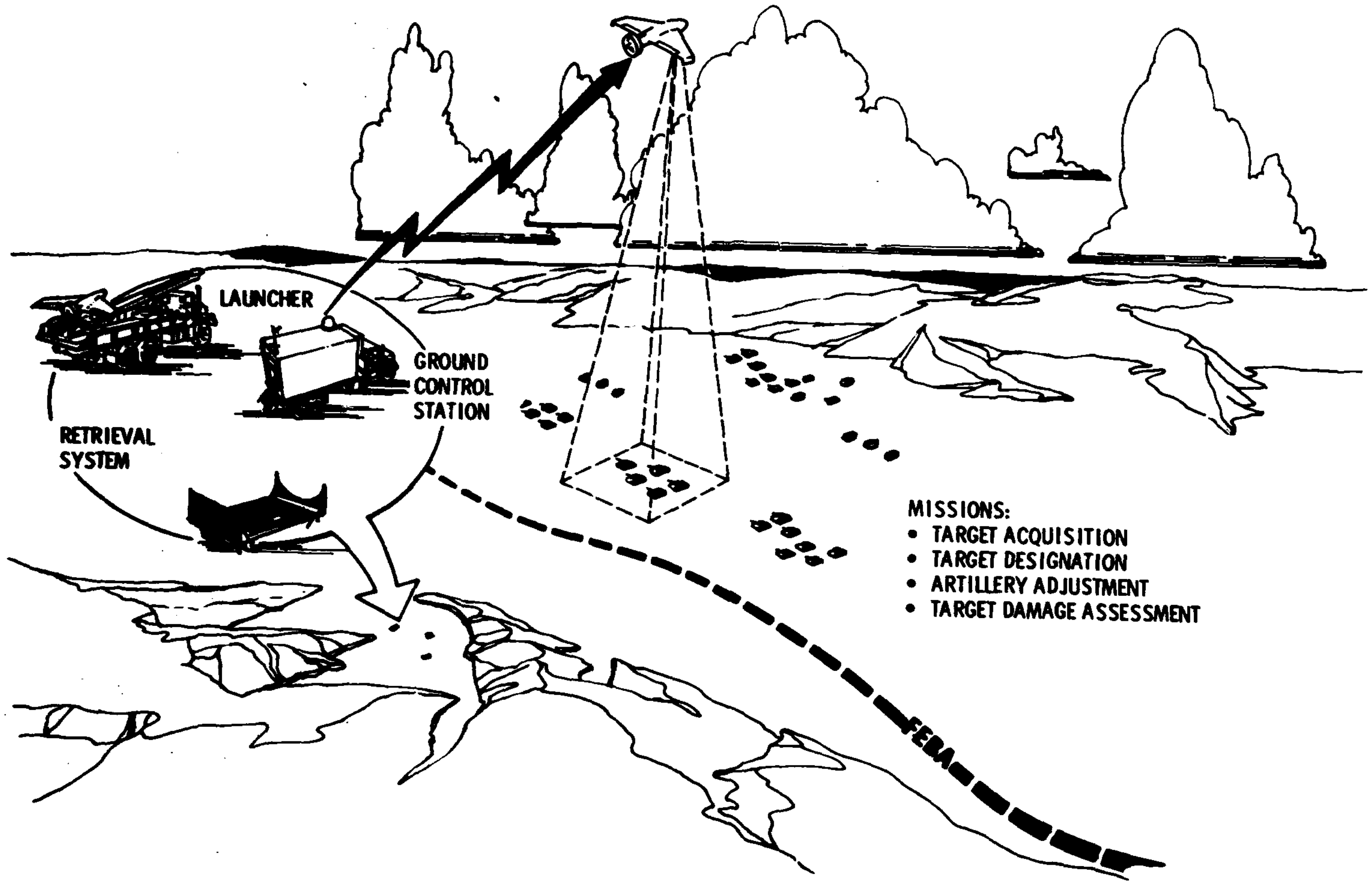


Figure 1. Tactical RPV System Concept

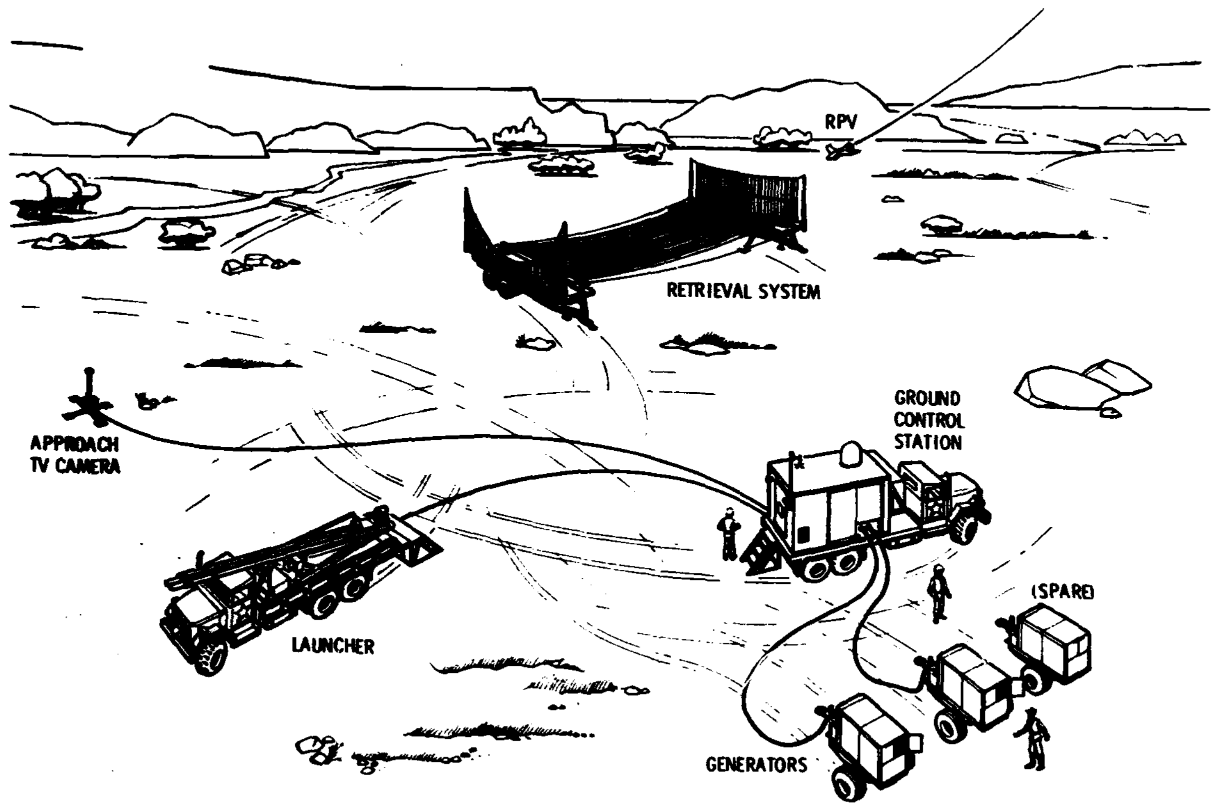


Figure 2. Deployed Aquila System

To conduct its mission, the Aquila system is first transported to a selected site by standard Army trucks. The site is selected and the system set up with consideration given to local terrain, winds, and obstacles to permit reliable launch, tracking, and recovery. The site is located accurately within the UTM coordinate system. The RPVs are then uncrated and assembled. Suitable sensors are installed in the RPVs depending upon the function to be performed. The ground control station (GCS) and RPVs are checked out and readied for flight.

The RPV is launched into a programmed flightpath (with manual operation optional), possibly including automatic search and loiter patterns. Video and status information is constantly provided through the data link to the GCS. The data link also provides for control of the sensor(s) on the RPV to achieve the mission objective. Upon mission completion, the RPV is guided through a preset series of waypoints to the recovery approach path. The RPV is recovered semiautomatically by computer-generated corrections to error signals formed as the sensor operator in the GCS tracks the incoming RPV on a ground-based video camera display looking directly up the glide slope. Data from the flight are recorded on video and electronic tape recorders in the ground control station. Selected information can be recalled immediately while complete data printout and analysis are usually scheduled for a remote computer facility. The recovered RPV can be rechecked or another RPV readied for the next mission. Upon completion of the operations at a given site, the system can be dismantled and moved to the next site or into storage.

2.2 REQUIREMENTS AND CAPABILITIES

To effectively meet the Aquila system mission requirements, certain capabilities were necessary. These requirements and capabilities are discussed in the following paragraphs.

2.2.1 Airframe/Sensor Compatibility

Flexibility in sensor selection was required to permit assessment of RPV/sensor effectiveness without resorting to exclusive RPV/sensor combinations. Therefore, the airframe was designed to accommodate any one of four sensor configurations: (1) an unstabilized TV camera, (2) an unstabilized TV camera plus a 35-mm film camera, (3) a stabilized TV camera, or (4) a stabilized TV camera plus a laser ranger/designator. Since the payload compartment was not on the RPV center of gravity, a ballast kit was provided with each payload. The flexibility was demonstrated in contractor flight tests at Fort Huachuca during May, June, and July 1977 when RPV 014, in test flights 45, 47, 29, and 58, flew the sensors in the order listed above. Sensor changes were also accomplished in other RPVs as mission and test flexibility required.

2.2.2 Multiple Sorties Per Day

The system was designed for up to four sorties per day, limited only by crew endurance, data recording capacity, and the availability of expendables such as fuel for the diesel-powered electric generators. The only other limitations would be mission time and checkout time. During contractor flight testing multiple flight operations were limited to two per day by system checkout time and crew endurance. Flights of two RPVs on the same day (flights 40 and 41 on 22 April 1977, 47 and 48 on 14 May 1977, and 61 and 62 on 7 July 1977), and two flights of the same RPV on the same day (54 and 55 on 12 June 1977, and 68 and 69 on 26 July 1977) were achieved during system field tests.

2.2.3 Simple Low-Cost RPV

The requirement for a simple, low-cost design was approached in several ways: selection of off-the-shelf subsystems to assure an acceptable compromise between cost and reliability, intensive RPV design review during RPV evolution to assure that checkout and maintenance procedures could be accomplished without highly specialized personnel, assembly and maintenance that require no special tools, simplification of equipment interfaces involved in manual operations to provide simple system preparation, closing flight control inner loops onboard the RPV to prevent human error causing out-of-control flights, and use of molded structure and commercial grade components to allow low-cost RPV construction. The scope of the program required extensive use and adaptation of off-the-shelf hardware to minimize cost, and this approach precluded development of "optimum" subsystems.

2.2.4 Operation From Unprepared Sites

This requirement reflects the desire for operational flexibility. The major components of the Aquila system are taken to the site and operated while mounted on wheeled vehicles (M36 trucks for the GCS and launcher, and M345 trailers for the retrieval system). Requirements for system operation dictate a site where clear launch and recovery flightpaths are assured and where height and geometry variations between the GCS, launcher, and retrieval system do not violate tracking antenna slew rates and radio frequency antenna patterns. Limited demonstration of site flexibility was accomplished during the contractor and Army flight tests, with operations conducted at the Fort Huachuca Remotely Piloted Aerial Observer/Designator System (RPAODS) site (flat slope with sagebrush), the Fort Huachuca western range (grassy hilltop), and the Fort Huachuca eastern range (rolling hills with sagebrush and grass). Some site preparation was required, such as cutting brush in the recovery approach path; however, additional preparation was made at some sites to accommodate test support and instrumentation facilities.

2.2.5 Minimum Crew Size

This requirement is directed toward minimum operational cost and flexibility. During early test phases, test crew size was 12 to accommodate manning of the instrumentation test van, simultaneous checkout and flight test operations, and engineering field support during shakedown. As the testing progressed, a basic crew size of eight evolved: test director, RPV operator, sensor operator, launcher operator/recovery system rigger, generator operator/recovery system rigger, safety/range coordinator, technical inspector, and laser range safety officer. The last three relate to range testing, and not to system operation.

2.2.6 Minimum Time and Skill for Operation

This qualitative requirement is directed toward maximum tactical flexibility and minimum operational cost. Early estimates indicated a system setup time of approximately 1 hour. As the Aquila system evolved and emphasis on operational reliability was stressed, it became apparent that the program scope would not allow for the system component development and training necessary to produce such short setup times. However, it is noted that on 15 July 1977 Army personnel moved on Aquila ground support system into the Eastern test range at Fort Huachuca and set it up ready for checkout in approximately 12 hours of accumulated time, including shakedown of a new recovery system. The skill level of Army personnel operating the system during the Army field tests ranged from E3 to E6.

2.2.7 Low Detectability

This requirement applies to both the airborne and ground support systems. Detectability considerations of the ground-based system have been limited to minimizing system element size and using conventional Army paint schemes. Specific camouflage techniques have not been developed; however, the system elements should be no more difficult to conceal than other mobile electronic systems, and in some respects easier due to the absence of large rotating antennas. RPV detectability has been reduced through profile shaping and enclosing the engine. The small size and special contours offer a small radar cross section compared to conventional manned aircraft, similar to that of a large bird.

2.2.8 Mobility Using Conventional Army Ground Vehicles

This requirement is met by mounting the GCS and the launcher on M36 trucks, the recovery system on two M345 trailers, and the generators on smaller trailers. The transportability of the system has been demonstrated in moves to different test sites at Fort Huachuca during the test program.

2.2.9 Compatibility With Standard Army Equipment

This requirement is directed toward operational flexibility. Compatibility with trucks and trailers has been demonstrated. Provisions are made in the GCS for standard Army radio gear. Beyond that, the RPV-STD system is self-contained and requires no other support equipment for operation (other than normal logistic functions). Expanded communication links will be required for the tactical system for suitable communication with fire control and headquarters groups.

2.2.10 RPV Mission Performance

This requirement is directed toward effective, efficient, and timely placement of sensors over areas of interest. The RPV performance has proven effective in this respect. Payloads up to 40 lb have been carried. Maximum flight endurance ranges from 1 hour to 3 hours, depending on the speed and maneuvers planned for the flight; the operating radius is 20 km, determined by the data link; the velocity range is from 63 to 160 km/h; and the maximum altitude attained was 3,660 m above sea level. This performance permits emphasis on search and targeting, with little time required for RPV transient and climb maneuvers.

2.2.11 Computer-Controlled Flightpath and Search Patterns

The flightpath is controlled by the GCS computer through a series of preselected waypoints. These waypoints are selected to fly the RPV over areas of interest where manual sensor scans can locate desired targets. Search patterns such as traveling box, repetitive S, and outward spiral can be stored (one only) in the computer for initiation by the RPV operator. This technique leaves the RPV operator and sensor operator free to concentrate on target search, identification, and designation rather than RPV navigation.

2.2.12 Target Detection, Identification, Location, and Designation Capability

This specification is perhaps the most important for the Aquila system and is the basis for the RPV-STD program. During the latter phase of the contractor flight testing, these capabilities were explored. Contractor flight tests with the various mission sensors were limited to checkout and test for design performance prior to delivery to the Army for field evaluation. The limited testing involved the detection, recognition, acquisition, location, and designation of targets by contractor and Army operators who had been advised (cued) as to the locations of the targets. This technique permitted the evaluation of the targeting system performance and capability with minimum consideration of operator performance. Results of the limited testing are discussed in Section 3.5.2 of this volume and in Volume III of this report with the data tabulated in Appendix E of that volume. A summary of results is given in the following paragraphs.

Target Detection. The specification for the unstabilized video was to detect tank-size targets on roads at 3,000 m, and in the field environment at 1,500 m, with 50-percent probability, using the unstabilized TV camera. Limited flight tests indicated road detection distances of 2,161 m and 1,074 m and field detection distances of 1,135 m and 846 m. The results were degraded by RPV motion which greatly distracted the sensor operator.

Target Recognition. The specification was to recognize tank-size targets, with 50-percent probability, at a slant range of 1,000 m after target selection. The contractor flight test program indicated a range of 938 m. This performance was for the RPV system with the unstabilized video camera. Again, RPV motion degraded the system capability.

Mini-Pan Film Camera Capability. While the desired resolution with the film camera was not specified, film records taken during contractor flight tests show a resolution potential of 75 lines per millimeter. This is a greater resolution than that necessary to verify the target detection and recognition capability of the unstabilized video camera.

Target Acquisition. Using the stabilized video camera, the slant range specifications for 50-percent probability of target detection were 5,000 m for a tank target on a road and 2,500 m in a field. The specification for minimum recognition slant range to the target (50-percent probability level) using the stabilized video camera was set at 2,200 m. Flight tests (17 measurements) indicate a mean value of 4,845 m slant range for target detection on roads, and a mean 2,282 m slant range (11 measurements) in a field. The mean slant range for target recognition (15 measurements) was 1,747 m.

Target Location. A specification of 100-m circular error of probability (CEP) and 75-m (50-percent probability) altitude was assigned for target location accuracy at target ranges of 20 km from the GCS and 2 km from the RPV using a co-mounted laser with the stabilized video camera. Contractor testing was limited to one flight for target location after system shakedown and prior to delivery to the Army. The CEP of the locations indicated by the RPV system (RPV to target range from 1,530 m to 3,425 m and target ranges of 16 km to 21 km from the ground station) was 253 m. The mean altitude error for these data was 71 m.

Burst Offset. No actual artillery burst adjustment was accomplished during contractor testing. Later Army testing accomplished actual artillery burst adjustment operations.

Target Designation. Tracking stabilization was specified such that 90 percent of the laser beam spot will remain on a 2.3-m by 2.3-m, high-contrast, square target 95 percent of the designation time at a slant range of 2,500 m. In the single scoring test prior to Army delivery, all laser hits observed were within a 2.3-m circle offset by 2 m from the center of the target. The sensor was subsequently reboresighted.

RPV Navigation Accuracy. In support of and as part of target location accuracy, RPV location accuracy has to be more precise than that for target location. Demonstrated RPV location accuracy (determined with the AN/FPS-16 tracking radar) was ±40 m CPE and ±15 m in altitude at ranges up to and including 20 km.

RPV Recovery Navigation Accuracy. The recovery guidance system was designed with permissable "center spot" lateral and vertical miss distances of ±10 ft and ±6 ft, respectively. Flight test performance, considering 16 recoveries, shows a 2σ vertical miss of ±1.6 ft and a 2σ lateral miss distance of 3.2 ft, well within the band of acceptable miss distances. The greatest vertical and horizontal miss distances encountered were 1.3 ft vertically and 3.9 ft horizontally during successful recovery.

Section III
REMOTELY PILOTED VEHICLE

The Army XMQM-105 (Aquila) remotely piloted vehicle (RPV) is shown in Figure 3 in launch and recovery operations during contractor field testing at Fort Huachuca, Arizona. The RPV consists of the airframe, the power plant and electrical system, the flight control system, one of four sensor configurations, and airborne elements of the command/control data link. This section of the report describes the RPV and its subsystems, and defines their characteristics and capabilities.

3.1 RPV CHARACTERISTICS

The XMQM-105, shown in general arrangement in Figure 4, provides a stable airborne platform capable of carrying targeting sensors at effective speeds, altitudes, and ranges under simulated tactical battlefield conditions. Its purpose is to provide the U.S. Army hands-on evaluation of sensor and RPV capabilities. The principal mission of the Aquila is surveillance, target acquisition, fire adjustment, and target designation in support of ground forces.

Significant features of this swept-wing, shrouded pusher propeller mini-RPV include:

- A collapsible-bladder fuel tank
- Removable wings for storage
- Lightweight Kevlar construction
- Pneumatic rail launch
- Vertical barrier net recovery

The characteristics of the Aquila RPV are listed in Table 1 and discussed in the following paragraphs.

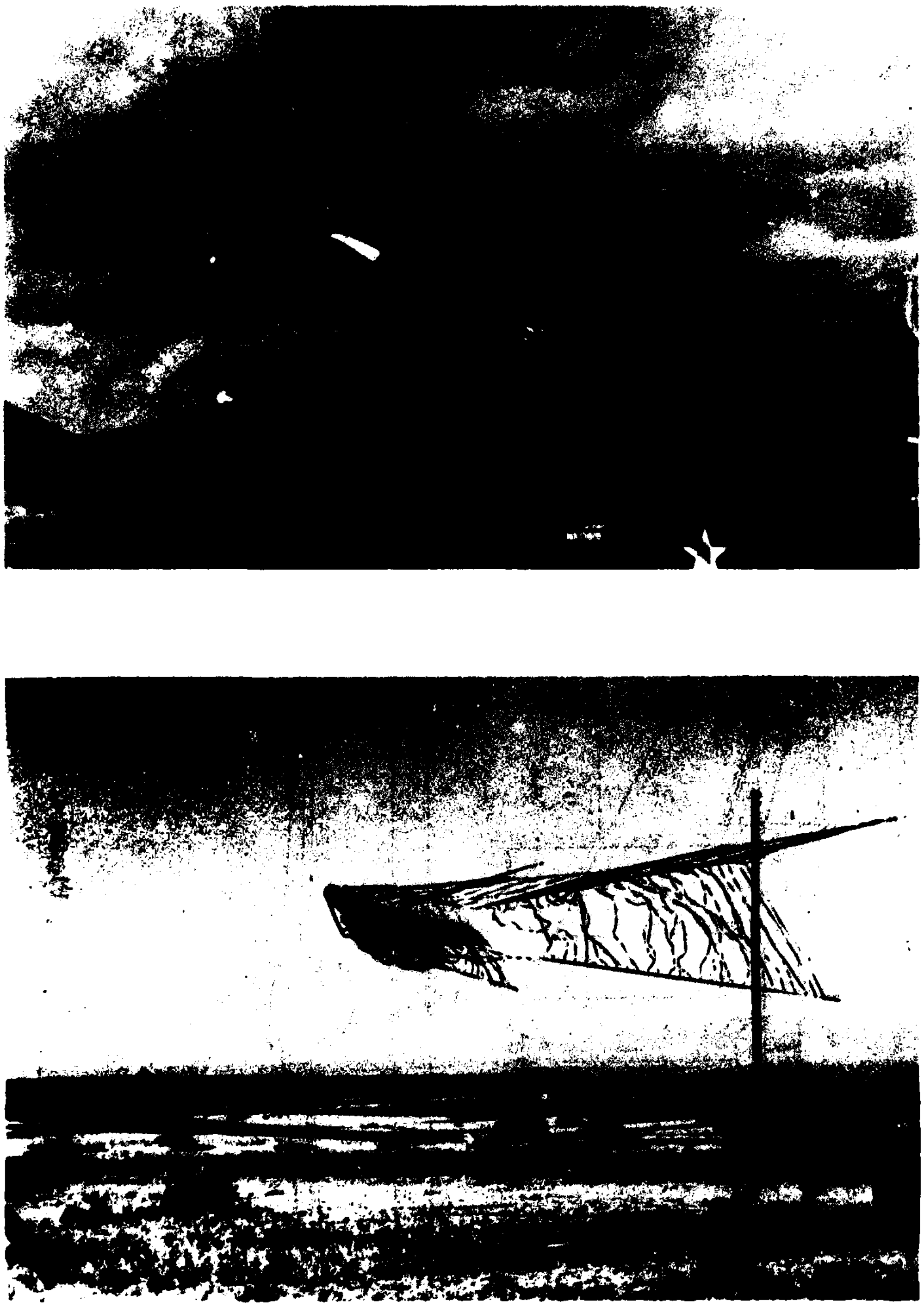


Figure 3. Aquila RPV in Launch and Recovery Operations

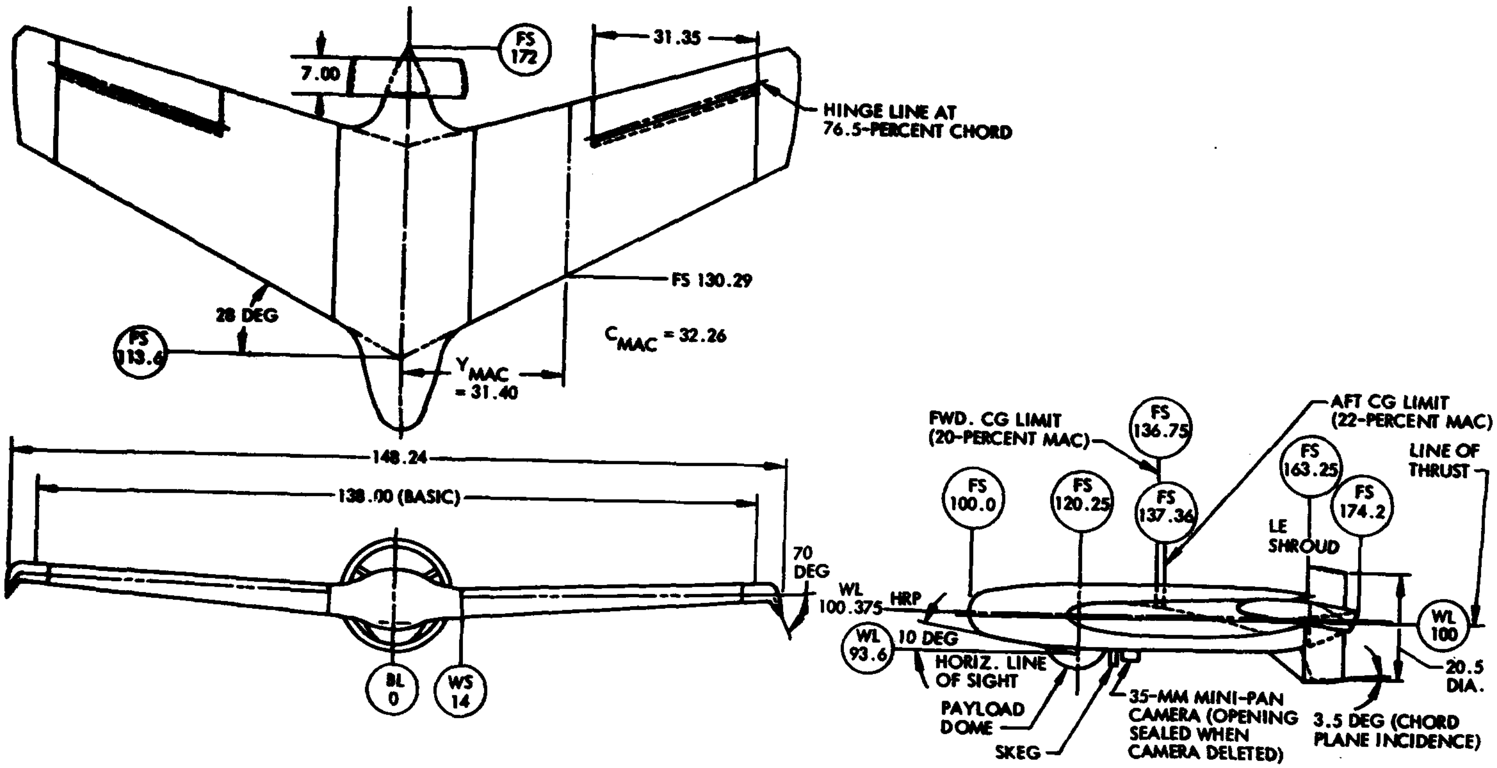


Figure 4. RPV General Arrangement

TABLE 1. STANDARD AIRCRAFT CHARACTERISTICS

(A) DIMENSIONS	
Fuselage	
Length	74 in.
Height	12 in.
Cross Section	Variable ellipse
Wing	
Area (Projected)	31.4 ft^2
Span (Overall)	12.35 ft
Area (Reference)	30.2 ft^2
Span (Reference)	11.5 ft
Root Chord (WS 0)	40 in.
Tip Chord (WS 69)	23 in.
Mean Aerodynamic Chord (MAC)	32.26 in.
LE MAC Location	FS 130.29
0.25 MAC Location	FS 138.36
Aspect Ratio (Overall)	4.86
Taper Ratio	0.58
Sweep, Leading Edge	28 deg
Sweep, 0.25 Chord	25.2 deg
Dihedral, Trailing Edge	4 deg
Incidence (WS 13)	+3 deg
Incidence (WS 69)	0 deg
Airfoil Section	NACA 23015 (modified)

TABLE 1. (Continued)

Elevon (Per Side)		
Area	1.40 ft^2	
Span	2.61 ft	
Hinge Line	76.5-percent wing chord	
Average Chord (Aft of Hinge Axis)	0.54 ft	
Deflection Limits (deg)		
• Pitch (command limit)	-21, +9	Note: elevon deflection
• Phugoid Damping (autopilot limit)	-16, +4	
• Roll (command limit)	-18, +6	TE up -
• Combined Maximum (pitch, roll limit)	-31, +19	TE down +

Duct	
Diameter (Inlet)	21.75 in.
Diameter (Exit)	20.89 in.
Chord	7.0 in.
0.25 Chord Location	FS 165.0
Incidence (Duct Centerline)	0 deg
Airfoil Section	NACA 23015

(B) RPV WEIGHTS

Payload	Sensor (lb)	RPV Weight (lb) Empty	RPV Weight (lb) Gross[a]
Sony TV Camera[b]	–	112	127
Phase I Sensor	25.7	117	132
Phase II Sensor	38.7	130	145
Phase III Sensor	31.7	124	138
Phase IV Sensor	39.9	131.6	146.5
Phase V Sensor	39.9	131.6	146.5

(a) 15 lb of fuel (14.5 lb usable); maximum capability – 160 lb at sea level.
(b) Development flight test only.

TABLE 1. (Continued)

(C) ENGINE RATINGS			
Condition	rpm	HP	Min.
Maximum[a]	8,300	11.7	Continuous
Minimum (idle)	3,900	1.8	Continuous

(D) POWER PLANT	
Number and Model	(1) MC101MC
Manufacturer	McCulloch
Engine Spec. No.	5542016
Engine Type	Reciprocating gasoline; two-cycle, one-cylinder
Length	12.0 in.
Height	10.8 in.
Width	9.0 in.
Weight (Dry) With Propeller Hub	13.4 lb
Propeller Manufacturer	Propeller Engineering Duplication
Propeller Description	Fixed pitch, wood; two blades, 19.5-in. diam., AF 150; blade angle (0.75R), 20 deg
Static Sea Level Thrust	40 lb

(E) FUEL	
Location	Upper center fuselage (fuel bladder)
Number of Fuel Cells	One
Capacity	2.5 gal
Type	Aviation 100/130 octane, mixed 16 to 1 with commercial two-cycle oil
Specification	MIL-F-5572

(a) Maximum, military, and combat power are all the same.

TABLE 1. Continued

(F) ELECTRONICS	
Autopilot	• Analog • Rate Gyro Stabilized (two gyros, three axes) • Waypoint Guidance
Communications (G Band)	• Command and Control • Status • Video
Electrical	• Alternator/regulator (600 W) • Battery (36 Wh) • Servos (Analog) – Elevons (2) – Throttle (1)
(G) PAYLOAD OPTIONS	
Payload	Description
Sony TV Camera	Unstabilized, fixed-mounted, fixed lens
1. SRL TV Camera, Honeywell Platform	Unstabilized, full hemisphere 10:1 zoom lens, 38-deg max. FOV, 3:4 display
2. Perkin-Elmer Photo Camera, Honeywell Platform	Unstabilized, fixed-mounted, fixed lens
3. SRL TV Camera, Honeywell Platform and Tracker	Stabilized, full hemisphere coverage, 10:1 zoom, 38-deg max. FOV, 3:4 display, ALC centroid video tracking
4. SRL TV Camera, Honeywell Platform, and Tracker ILS Laser	Stabilized, full hemisphere coverage, 10:1 zoom, 38-deg max. FOV, 3:4 display, ALC centroid video tracking, YAG laser designator
(H) DEVELOPMENT	
Contract Date	20 December 1974
First Flight	1 December 1975
First Delivery	15 July 1977

3.1.1 Description

General Arrangement. The configuration is 6 ft, 2 in. (1.88 m) long, with a wingspan of 12 ft, 3 in. (3.73 m). The gross weight of the RPV varies with sensor installation from 132 to 146.5 lb. The short fuselage and large wing produce a "flying wing" appearance. From a 4-in.-radius spherical segment nose the body widens to an elliptical fuselage cross section that is maintained at a maximum of 1 ft in depth. The wing-body fairing is generous, creating a blended wing-body effect. The engine is mounted in the rear of the fuselage with a pusher propeller (two-bladed wooden). The rear fuselage is faired in around the engine installation for drag reduction and airflow considerations. A circular shroud suspended on struts from the rear of the fuselage surrounds the propeller disk, providing a safety shield protecting personnel and hardware from the propeller during ground operations – while stabilizing the RPV in both pitch and yaw during flight. The shroud airfoil cross section is a standard NACA 23015 airfoil 7 in. in chord. The duct is 21.75 in. in diameter at its leading edge and 20.89 in. at its trailing edge. Propeller tip clearance is 0.5 in.

The 12-in.-diameter sensor bubble or dome protrudes from the belly of the fuselage at a station (approximately FS 113.6) near the theoretical intersection of the wing leading edge and body side contour. The mini-pan film camera lens housing protrudes from the fuselage belly at a point close behind the sensor dome. Between the payload dome and the mini-pan camera, an aluminum tab or "skeg" protrudes to facilitate attachment to the launcher. Push pads are also attached to the wing at the trailing edge for interface with the launcher. The wings attach to the fuselage at buttline 13. Each wing is attached by eight large countersunk Phillips-head screws. The propeller shroud is attached to the fuselage by the shroud struts, which are structurally integral to the shroud with attach fittings on the ends attaching to the fuselage. Molded fittings integral to the fuselage provide tabs over which are slipped the shroud strut ends. Attachment is accomplished by two countersunk screw-nut assemblies at each strut-fuselage intersection. Access to subsystems within the fuselage is through three access panels on top of the fuselage and one on the bottom of the fuselage, and by removal of the nose cap.

The wings are formed to modified NACA 23015 contours. The modification consists of a slight reflex of the trailing edge to reduce nose-down pitching moment. In addition, the trailing edge is blunted to avoid damage due to handling and strap impact during recovery. The leading edge sweep is 28 deg. The incidence of the airfoil at the wing root is 3 deg with the body centerline. A linear geometric twist of 3 deg produces a tip incidence of 0 deg with the body centerline. Wing dihedral measured at the quarter chord is 2.5 deg. The detachable wingtips are formed to minimize induced drag. Flight control surfaces are limited to the two elevons on the trailing edge of the wing near the tip. Total area of the two elevons is 9 percent of the wing planform area. Differential deflection is used for roll control, while collective surface deflection provides for pitch control and trim.

The body station reference system locates the nosetip at station 100. The RPV is balanced about a fuselage station of 137.0. For a center of gravity tolerance of ±0.3 in. about that position, the RPV is statically and dynamically stable for all flight control and guidance modes. Specified ballast kits are designed and provided as the payload units are exchanged so that the RPV center of gravity can be maintained. (Differences in RPVs and design changes required that the kits be augmented by hand balancing prior to flight after sensor changes.)

Internal Arrangement. The internal arrangement of the RPV is shown in Figure 5. In this figure, the RPV components are identified by name, part number and location. The components are located within the six body compartments and the wing cavities.

The nose cap is closed by bulkhead 104 (i.e., the bulkhead at fuselage station 104). Within the compartment formed by the nose cap and this bulkhead, the rate gyro package, payload protector hinges, and ballast (not shown in Figure 5)

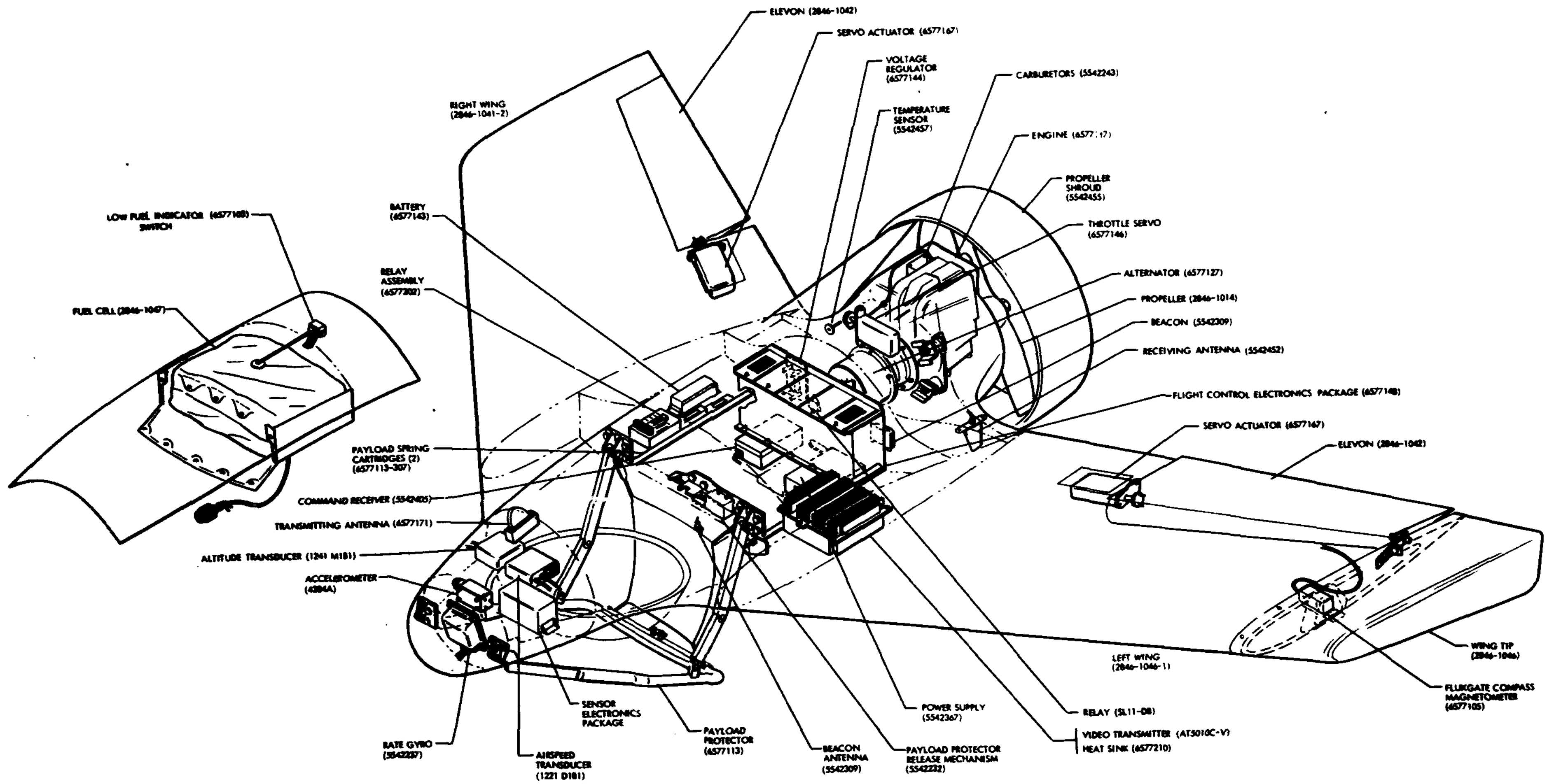


Figure 5. RPV Internal Arrangement

are accommodated. These components are mounted on the bulkhead and are exposed (as shown in Figure 6) by removing the nose cap. A 1.25-in.-diameter hole in the nose cap admits cooling air into the compartment. Slots in bulkhead 104 permit the cooling air to pass into the payload electronic compartment. The pitot pressure port is flush-mounted in the skin of the nose.

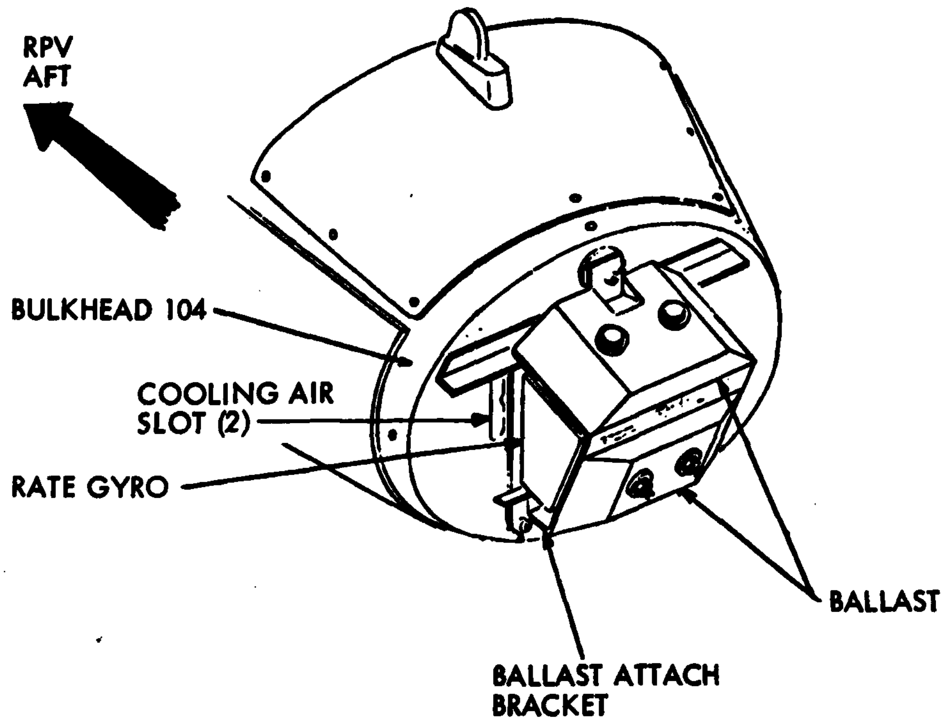


Figure 6. Ballast and Rate Gyro Installation

The payload electronics compartment, between bulkhead 104 and bulkhead 113, houses the accelerometer, the sensor electronics package, the airspeed and altitude transducers, and the transmitting antenna. The accelerometer is mounted on the rear of the bulkhead 104. The sensor electronics package is mounted on a floor that sits atop the clearance channels for the payload protector. The command receiver antenna is cantilever-mounted off the front of bulkhead ring 113. Access to the compartment is through a panel in the top of the fuselage. The airspeed and altitude transducers are mounted on the underside of this panel. The two static pressure ports are flush-mounted in this panel also. Cooling air from the nose compartment is presented directly to the sensor electronics package, circulates through the compartment, and then passes through bulkhead ring 113 into the payload compartment.

The payload compartment lies between bulkhead 113 and bulkhead 130. A dish-like floor in the compartment provides mounting space for the four payload shock mounts. The payload sensor assembly and its mounts are shown in Figure 7. The compartment floor and fuselage belly skin are cut out to permit the cylindrical payload cover and hemispherical plastic dome to penetrate the mold lines and expose the sensor elements to slightly more than a full hemisphere of view. (The sensor locations within the dome permit a look angle of up to 10 deg past the hemispherical plane.) The side and rear walls of the payload compartment incorporate the channels for airborne stowage of the payload protector mechanism. The payload protector release mechanism is built into bulkhead 130.

The payload protector (Figure 8) is stored within the contours of the RPV fuselage for launch and cruise operations. This arrangement minimizes the drag and provides a clear sensor view field during cruise. In the interests of reliability and cost, no fairings or doors are used to streamline the stowed installation. Prior to recovery operations, the payload protector is deployed. The aluminum sheet, tube, and channel frame pivots about the hinges mounted on bulkhead 104. The support arms (anchored to pivots on bulkhead 130) lock into an "over-center" position with spring-driven pins to provide a protective frame around the payload dome. Protection is provided for both normal and emergency landings.

Incorporated into the payload protector frame is a parachute cloth drag brake. This 10-in. by 10-in. drag brake is supported by crossed cables (which help to react side loads on the protector) immediately behind the payload dome and

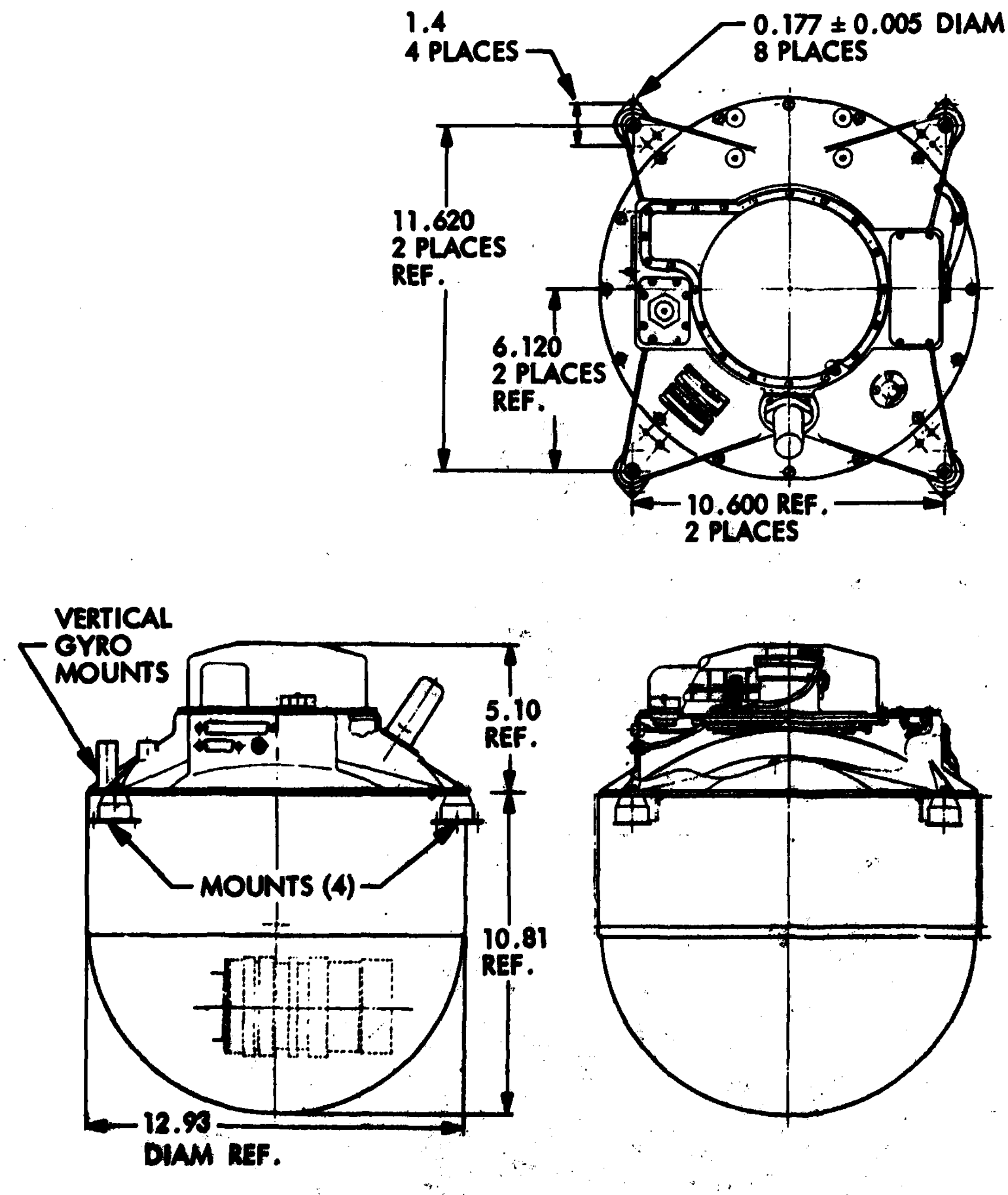


Figure 7. Sensor Gimbal Assembly

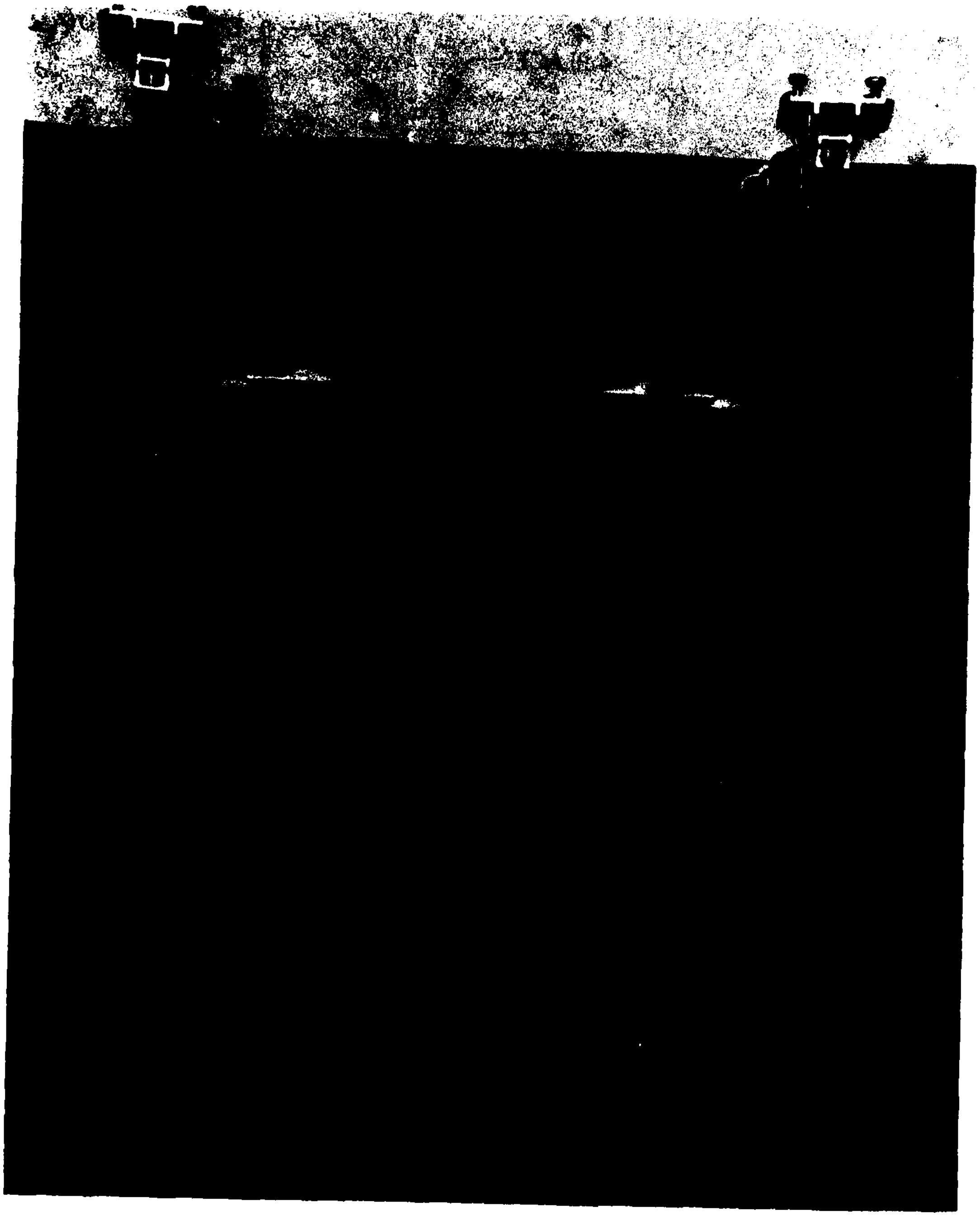


Figure 8. Payload Protector Assembly With Drag Brake

nearly perpendicular to the airstream. The brake-cable assembly is folded within the fuselage contours when the payload protector is stored, and deploys as a natural result of payload protector deployment. Energy for the deployment of the payload protector is supplied by two springs mounted in aluminum tubes in the floor of the avionics compartment behind the payload compartment. Cables from the extended (loaded in tension) springs extend from the tube ends, through fittings in bulkhead 130, to the upper link of the support arms. The resulting torque is sufficient to extend the payload protector frame to its lock position against friction and drag brake loads.

Cooling air flow from the payload compartment exits through two 2.19-in.-diameter circular holes in bulkhead 130. Additional cooling air for the avionics compartment is admitted into a scoop molded into the left wing stub fairing. Air entering this scoop enters the small duct created by the payload compartment side walls, the wing stub root rib, and contours of the wing stub fairing. The duct terminates at bulkhead 130. A 3.18-in. by 2.30-in. hole in that bulkhead admits the cooling air into the avionics compartment and directly into the cooling fins in the video transmitter heat sink.

The avionics compartment lies between bulkheads 130 and 147. Access to this compartment is through a large access panel that covers both the payload and avionics compartments. Additional access to the avionics compartment is provided by a full bay-length access panel on the belly of the RPV.

Attached to the upper access panel and fitting in the upper front of the avionics compartment is the fuel cell assembly and low-fuel indicator switch. This location places the center of gravity (CG) of the fuel cell on the fuselage station corresponding to the CG of the RPV, minimizing CG shift during flight as fuel is burned. A quick-disconnect fitting in the fuel line and a connecting plug in the leads from the low-fuel-level indicator permit complete rapid removal of the fuel system for refueling away from the RPV; thus the 15 lb of fuel can be injected into the fuel cell bladder without jeopardizing other RPV equipment by accidental exposure to spilled fuel and the associated fire hazard.

In addition to the fuel cell, the avionics compartment contains the 35-mm mini-pan film camera (when carried), the video transmitter, the flight control electronics package (FCEP), the power supply, the command receiver, the battery, and the relay assembly. When required by the mission, the 35-mm camera is bracket-mounted in a cantilever fashion from the rear of bulkhead 130. The lens housing extends through an opening in the lower access panel; a solid panel (without the opening) is used when the camera is not installed. The video transmitter and its heat sink are installed on a bracket in the left wing stub, directly in the path of the cooling air from the left wing airscoop. The vented FCEP is mounted on bulkhead 147 by bolts and standoff spacers to provide cooling air passage behind the FCEP and through a 3.75-in.-diameter hole in the bulkhead into the next (alternator) compartment. The power supply and command receiver are mounted on a floor bracket below the FCEP. The battery and relay assembly are mounted on a bracket in the right wing stub.

The alternator compartment is bounded by bulkheads 147 and 155. Compartment access is provided by an upper structural access panel. The compartment contains the alternator, the voltage regulator, the C-band flight test beacon (when carried), and the throttle servo-actuator. The voltage regulator and its heat sink are bracket-mounted on the right rear of bulkhead 147. The beacon is mounted on the left rear of that bulkhead. The alternator and throttle servo are mounted to the front of bulkhead 155. A Kevlar spool-shaped bracket supports the alternator in cantilever fashion from bulkhead 155. The bracket or "spool" flange is bolted to the bulkhead around a 3.84-in.-diameter hole in the bulkhead. This hole directly faces the engine cooling blower intake. Slotted holes in the cylindrical portion of the spool permit cooling air to leave the compartment and be drawn into the engine cooling blower.

The engine compartment lies between bulkhead 155 and the closing bulkhead 164. The engine assembly is cantilever-mounted through four Lord shock mounts bracketed to the rear of bulkhead 155. The engine assembly includes the propeller, the engine, two carburetors and associated linkage, the ignition system (magneto), the blower fan-flywheel, the cylinder head cooling shroud, and the alternator flex-shaft drive that extends through the bulkhead 155 cooling air hole to the alternator shaft. Fuel is carried from the fuel cell to the carburetors through a Tygon tubing fuel line installed through holes in bulkheads 147 and 155. The engine compartment is closed by bulkhead 164. This bulkhead is a removable 0.020-in. aluminum plate, perforated to permit the passage of cooling air.

The elevon servo-actuators are mounted in the wing panels on the closing rib elements forming the inboard edge of the elevon cutout. The centerlines of the actuators are colinear with the hinge line of the elevons. The heads of the actuators are attached directly to bearing-supported end fittings on the inboard ends of the elevons. The outboard hinge of the elevons is provided by a ball fitting; this installation precludes an elevon linkage mechanism and minimizes undesirable backlash (play) in the assembly.

The flux-gate compass is firmly bracket-mounted within the closing structural tip rib of the left wing panel. The rigid bracket positions the flux-gate in proper orientation to the RPV axes and prevents input due to vibration. The compass is covered by the wingtip (fairing) and is accessible through removal of that fairing.

Detailed dimensions and discussion of the RPV elements are provided in subsequent sections of this report.

<u>Mass Properties</u>. The mass properties summary for the Aquila RPV is presented in Table 2, which identifies mission and configuration weight, balance,

TABLE 2. AQUILA RPV MASS PROPERTIES

Mission Configuration	Gross Weight (lb)	Center of Gravity (in.)			Moments of Inertia (slug-ft^2)		
		$\bar{x}$	$\bar{y}$	$\bar{z}$	I_{xx}	I_{yy}	I_{zz}
Phase IV or V	146.46	136.97	-0.08	100.12	7.14	10.05	16.09
Phase III	138.26	136.98	-0.08	100.00	7.15	9.75	15.78
Phase II	145.22	136.98	-0.08	100.02	7.16	10.41	16.43
Phase I	132.22	136.99	-0.09	100.42	7.11	10.49	16.56

and inertial data. The maximum gross wet weight ranges from 132.2 lb for the Phase I sensor installation to 146.5 lb for the Phase IV/V sensor installation. The vehicle longitudinal center of gravity is tightly controlled about FS 137.0 to within ±0.30 in. by locating ballast kits that are payload (sensor) related. The lateral balance limits of +0.8 to -0.2 in. were established to account for slight (plus) lateral vehicle CG and the impact of engine torque at the time of retrieval waveoff and go-around. Actual weight and balance measurements show that lateral ballast is seldom required.

The vertical CG in all cases lies near the thrust axis of WL 100.0. Table 3 is a detailed weight and balance breakdown of the Aquila RPV. This table is an update from Reference 1, which contains a more detailed discussion and tabulation of Aquila mass properties. The weight update contained herein reflects two changes from the data included in Reference 1: (1) revised actual GFE test transponder weight (+0.34 lb), and (2) the addition of the sensor interface electronics package (+1.10 lb). The addition of 1.44 lb to the 90.07-lb weight presented in that report reflects the 91.51-lb value shown in Table 3.

[1]Broadhead, S. G., AQUILA RPV WEIGHT AND BALANCE REPORT, SERIES B, FIRST ARTICLE FLIGHT CONFIGURATION, LMSC-D458268, Lockheed Missiles and Space Company, Inc., Sunnyvale, California, 6 April 1977.

TABLE 3. AQUILA WEIGHT BREAKDOWN

RPV Group or Element	Weight (lb) Element	Weight (lb) Group	Center of Gravity (in.) Longitudinal, x	Lateral, y	Vertical, z
(A) RPV DRY WEIGHTS					
Wing Group		(13.32)	(151.0)	(-1.7)	(101.0)
• Basic Structure	9.36		146.5	0	101.0
• Elevons (2)	1.44		162.2	0	100.0
• Pusher Pads (2)	1.12		162.2	0	100.0
• Tips (2)	0.82		160.5	0	102.5
• Brackets (Servo/Flux Gate)	0.58				
Fuselage Group		(20.66)	(141.3)	(0)	(100.6)
• Basic Structure	12.60		136.9	0	100.0
• Doors & Covers	2.53		136.9	0	104.5
• Shroud & Supports	3.17		164.7	0	100.0
• Motor Mounts & Bulkhead Supports	0.31		159.0	+0.1	100.0
• Attachments & Miscellaneous	1.17		130.0	0	101.5
• Bulkhead Modification	0.29		155.0	0	101.2
• Accelerometer Bracket	0.08		104.9	0	102.9
• Wing Blocks	0.11		137.0	0	100.0
• Skeg & Support Shield	0.40		130.0	0	95.0
Payload Protection		(3.46)	(126.2)	(0)	(95.2)
• Payload Protector, Drag Brake, Actuator, & Latch	3.46		126.2	0	95.2
Propulsion Group		(15.98)	(157.7)	(0.6)	(101.9)
• Engine	13.18		158.8	+0.6	
• Exhaust System	0.35		161.0		102.0
• Throttle Linkage	0.25		157.9	+3.0	102.0
• Propeller Installation	0.91		166.0	0	100.0
• Fuel System	1.05		138.3	0	103.0
• Alternator Mounting	0.24		153.4	0	100.0
Flight Controls Instrument Group		(10.95)	(137.4)	(-1.5)	(101.1)
• Autopilot (FCEP)	6.32		144.5	0	100.4
• System Controls – Elevon Servo	1.66		153.6	+0.3	102.5
• Pitch Rate Gyro	1.45		103.5	0	100.4
• Accelerometer	0.45		104.9	0	102.9
• Flux Gate Compass & Miscellaneous	0.45		156.7	-66.5	102.6
• Speed, Altimeter, & Compass	0.63		110.5	+1.4	103.8
Electrical Group		(18.17)	(142.0)	(3.8)	(99.0)
• Battery	3.39		141.8	11.8	99.0
• Alternator	6.30		144.9	0	100.0
• Regulator & Heatsink	0.47		148.2	5.0	100.0
• Wire Harness	5.62		138.9	3.7	98.0
• Precision Voltage Supply & Relay	2.39		140.7	2.5	98.0

TABLE 3. CONTINUED

RPV Group or Element	Weight (lb)		Center of Gravity (in.)		
	Element	Group	Longitudinal, x	Lateral, y	Vertical, z
(A) RPV DRY WEIGHTS (CONT.)					
Avionics & Data Link		(8.97)	(130.9)	(-5.6)	(98.5)
• Video Transmitter & Heat Sink	4.97		136.5	-11.0	98.5
• Command Receiver	1.25		143.9	3.8	96.6
• RF Cable Assembly	0.25		112.0	0	100.4
• Antenna	0.20		139.0	0	97.8
• Payload Interface Electronics	1.10		106.0	0	97.0
• IFF Beacon (GFE – Test Only)	1.20		120.0	0	101.6
DRY WEIGHT TOTAL:		91.51	143.66	-0.13	100.21
(B) SENSOR & BALLAST GROUP WEIGHTS					
Phase I		(25.71)	(113.23)	(0)	(99.7)
• Gimbal Assembly	14.41		120.2	0	99.1
• Electronics	3.40		109.8	0	100.3
• Ballast	7.90		102.0	0	100.3
Phase II		(38.71)	(121.2)	(0)	(98.4)
• Gimbal Assembly	14.41		120.2	0	99.1
• Electronics	3.40		109.8	0	100.3
• Camera, Film, & Mounts	13.50		135.6	0	96.0
• Ballast	7.40		102.0	0	100.3
Phase III		(31.75)	(117.7)	(0)	(98.1)
• Gimbal Assembly	25.16		120.2	0	97.3
• Electronics	5.19		109.9	0	100.5
• Ballast	1.40		102.0	0	100.3
Phase IV/V		(39.95)	(121.6)	(0)	(98.9)
• Gimbal Assembly	29.81		120.2	0	98.3
• Electronics	5.19		109.9	0	100.4
• Vertical Gyro Assembly	2.85		126.4	0	102.7
• Ballast	2.10		164.0	0	99.5
(C) FUEL WEIGHT					
Fuel		(15.0)	(137.0)	(0)	(103.0)
• Flight	12.9				
• Reserve	1.6				
• Trapped	0.3				
• Start	0.2				

A statistical sample of dry weights for vehicles No. 15 through No. 23 was taken in order to determine statistical weight variation. The results show the average weight for 10 samples to be 90.2 lb with a 3σ population standard deviation of ±2.9 lb.

The predicted weights presented in Table 3 fall well within the 3σ band of measuring and manufacturing uncertainty. The statistical average is 1.3 lb lighter than the values shown in the detailed weight summary of Table 3. In addition to vehicle dry weights shown in part (A) of the table, vehicle sensor and fuel weights and balance are shown in parts (B) and (C), respectively.

Table 4 identifies the growth in vehicle weight and the group that absorbed the bulk of vehicle growth from contract initiation to the present statistical average.

TABLE 4. RPV WEIGHT GROWTH

Item	Goal	Actual	Remarks
Base (Phase IV/V Gross)	120.0[a]	146.5[b]	
• Reduce to Statistical Actual Average Weight		-1.3	Reflects Δ from statistical dry weight
• Remove IFF Beacon		-1.2	GFE test equipment
• Remove Fuel That Was Added for Desired Endurance		-8.0	Reflects added mission duration
	120.0	136.0	ΔWt = +16.0 Nominal

(a) Includes 7 lb of fuel for 1.5-hour endurance.
(b) Includes 15 lb of fuel.

The overall weight growth was limited to 16 lb, or 12 percent of resultant vehicle weight, by judicious control, evaluation, and reporting.

Each design change and its associated weight and center of gravity impact were tracked and evaluated in terms of performance impact.

This weight growth is considered small in view of the state of development and availability of off-the-shelf components that would meet the mission and performance requirements. Most of the Aquila RPV should be considered first-generation development, and as such shows growth of 18 percent above initial estimate.

The following areas account for the bulk of vehicle weight growth:

- Airframe 8.0 lb
- Electrical 5.5 lb
- Data Link 1.0 lb
- Sensor Phase IV/V 1.6 lb

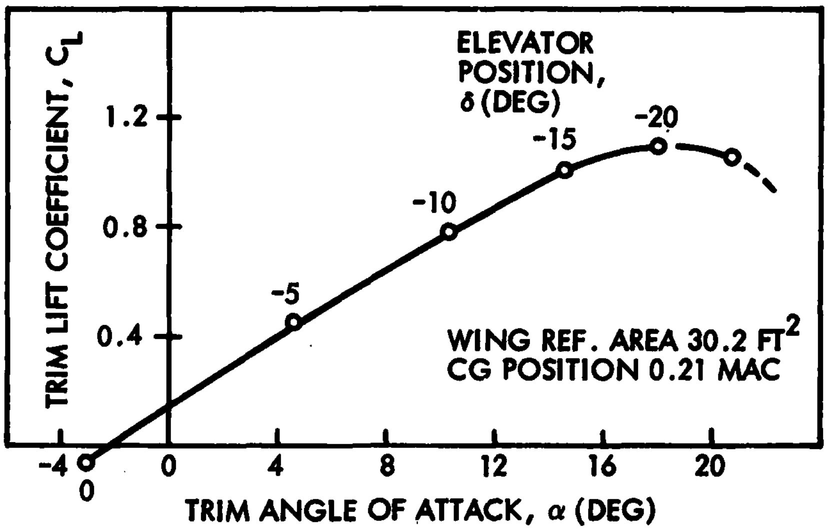
Further mass properties discussion, evaluation, and history may be found in Volume II of this report.

3.1.2 Aerodynamic Characteristics

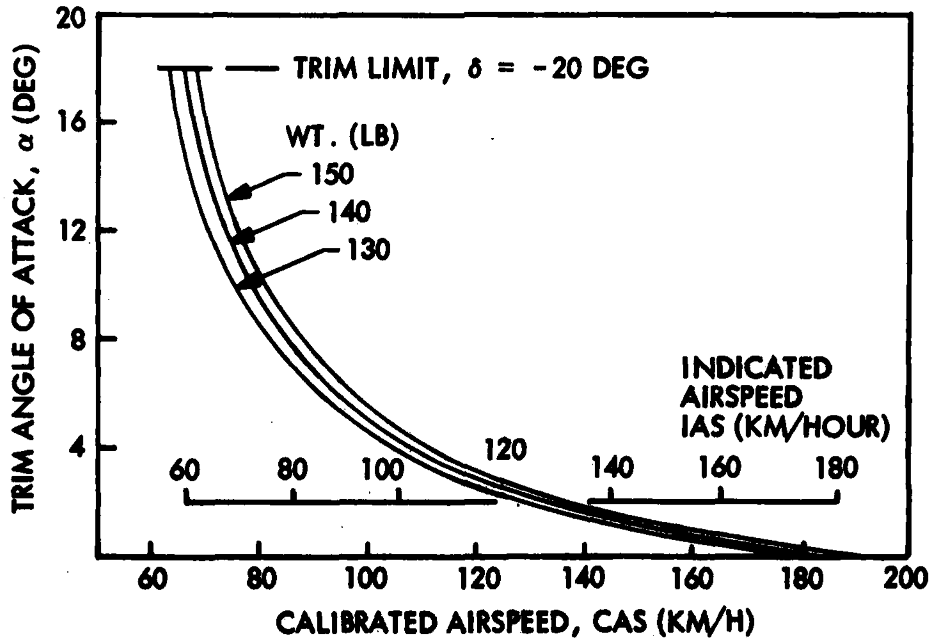
The Aquila RPV, with its light wing loading (approximately 4 lb/ft^2) and its power loading of 12 lb/hp, provides a broad operating speed range (63 km/h to 168 km/h). The RPV is statically and dynamically stable and is controlled using only the two wing elevons. It is also stably damped in all flight modes including the phugoid and dutch roll. The following paragraphs describe and quantify these characteristics.

Performance-Related Aerodynamic Characteristics. Values for the Aquila trimmed lift coefficient and the associated airspeeds are shown in Figure 9. This curve, derived from wind tunnel tests (Reference 2), shows the lift curve

[2] AQUILA RPV SYSTEM TEST REPORT, CDRL A00D, PART 4, AERODYNAMICS, LMSC-L028081, Lockheed Missiles and Space Company, Inc., Sunnyvale, California, May 1977.



a. Trim Angle of Attack and Lift Coefficient



b. Airspeed Variation With Trimmed Angle of Attack

Figure 9. Trimmed Lift and Airspeed Characteristics

slope and gentle stall characteristics expected from a low aspect ratio, swept-wing aircraft. For the typical CG location, 0.21 MAC (mean aerodynamic chord), the control deflections required to trim over the wide speed range are typically small (Figure 10), producing low trim drag. Flight test data are shown to agree reasonably well with the wind tunnel data, with a small reduction in control effectiveness.

Trimmed lift and drag coefficients for the Aquila RPV are given in Figure 11. Lift and drag coefficients are given for both the cruise and recovery configurations. The drag brake and payload protector are shown to increase the drag by 45 percent in the 60-knot trim condition typically associated with the recovery approach. These curves are derived from wind tunnel data and adjusted for Reynolds number, surface irregularities, and cooling drag to account for differences between the wind tunnel model and the flight vehicle.

Figure 12 shows data regarding propeller efficiency and thrust coefficient. The relatively low efficiency numbers are typical of pusher propeller installations. The resulting propeller thrust coefficient is given in Figure 13. Wind tunnel data on these figures are from Reference 3.

The above aerodynamic characteristics, combined with engine shaft horsepower data, provide the basis for performance estimates of the Aquila RPV.

Aerodynamic Stability and Control Characteristics. The predicted aerodynamic and flight mode stability characteristics of the Aquila RPV are summarized in Table 5. These data are derived from wind tunnel data and analytical methods (Reference 4). The data shown reflect static and dynamic stability for

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[3] Iverson, H. B., RESULTS OF THE HARASSMENT VEHICLE TEST IN THE CALAC LOW-SPEED WIND TUNNEL, LMSC-D556812, Lockheed Missiles and Space Company, Inc., Sunnyvale, California, February 1977.

[4] McVernon, J. H., STABILITY AND CONTROL AND PERFORMANCE ESTIMATES, LMSC Engineering Memo A-R111-11A1 02/03, Lockheed Missiles and Space Company, Inc., Sunnyvale, California, 7 March 1975.

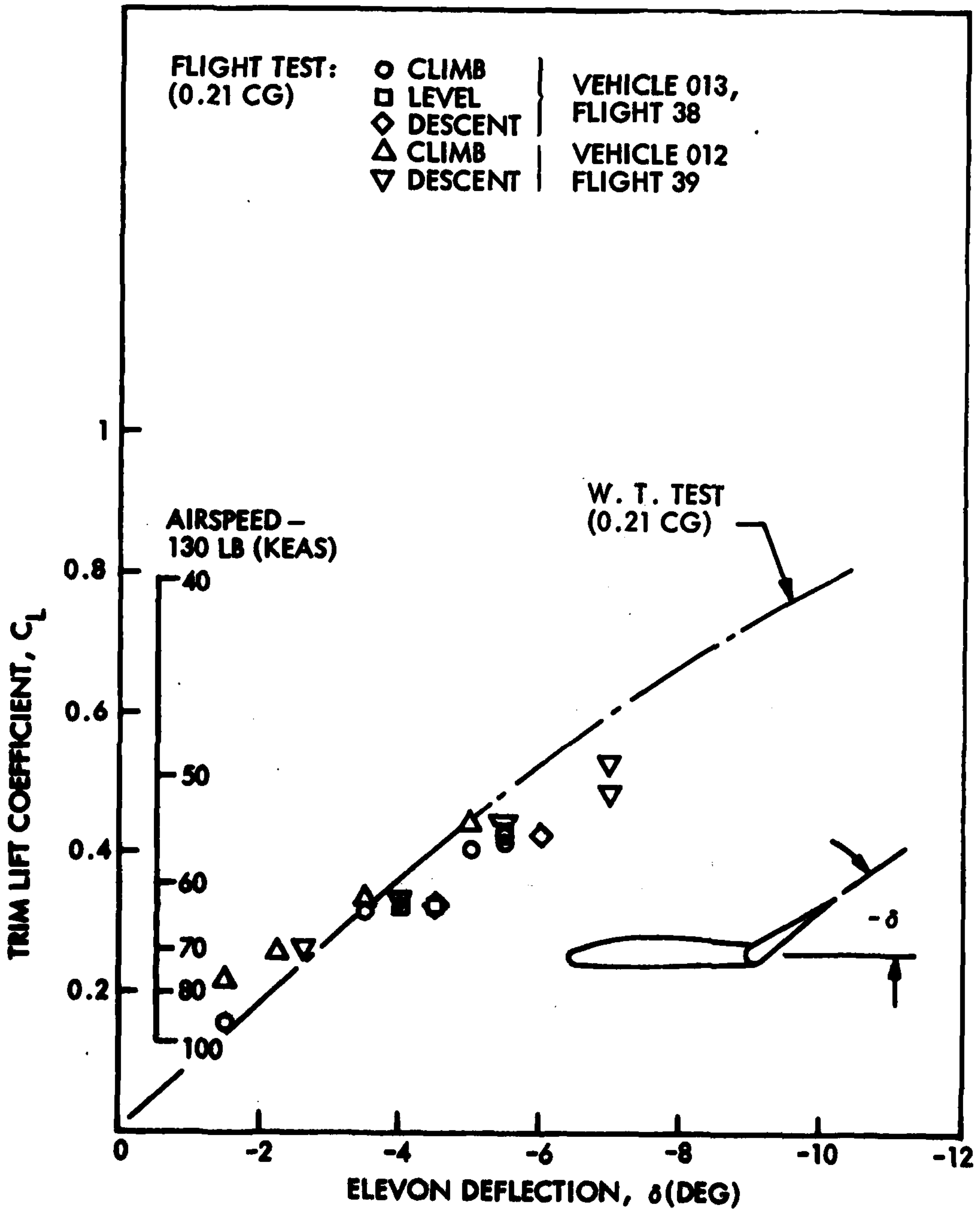

Figure 10. Aquila Elevon Pitch Trim Angles (Cruise Configuration)

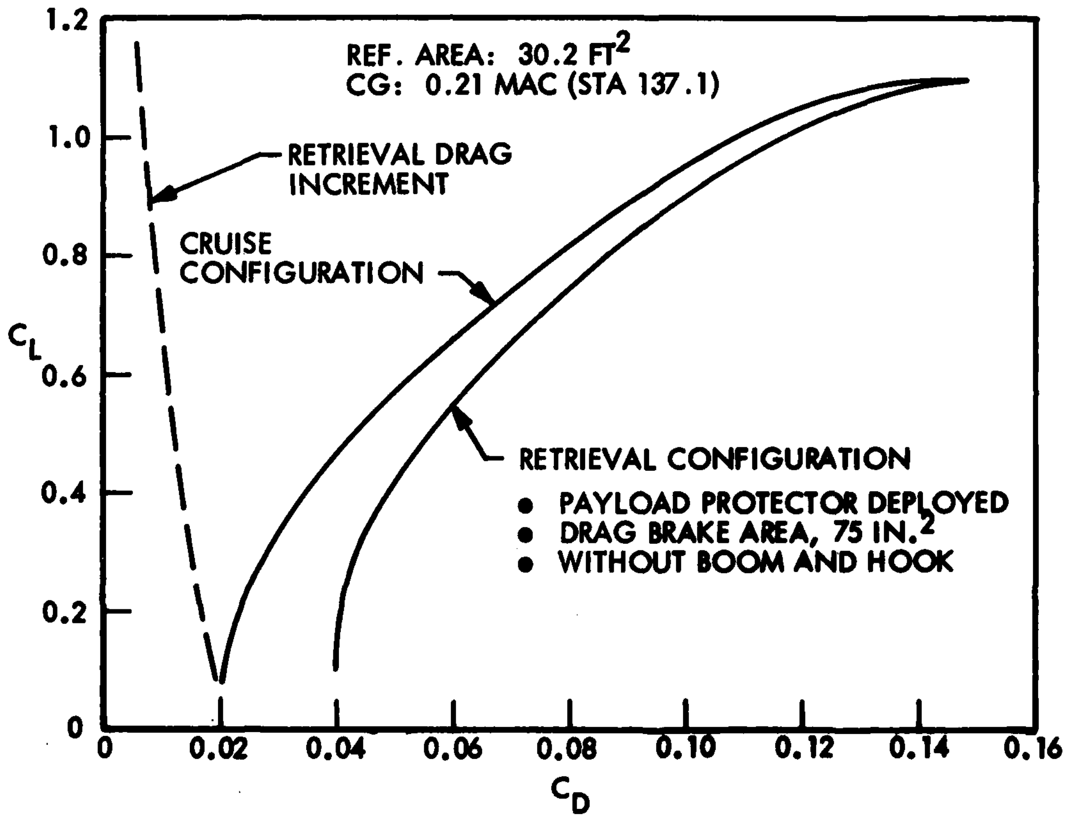

Figure 11. Aquila Trimmed Lift-Drag Polar

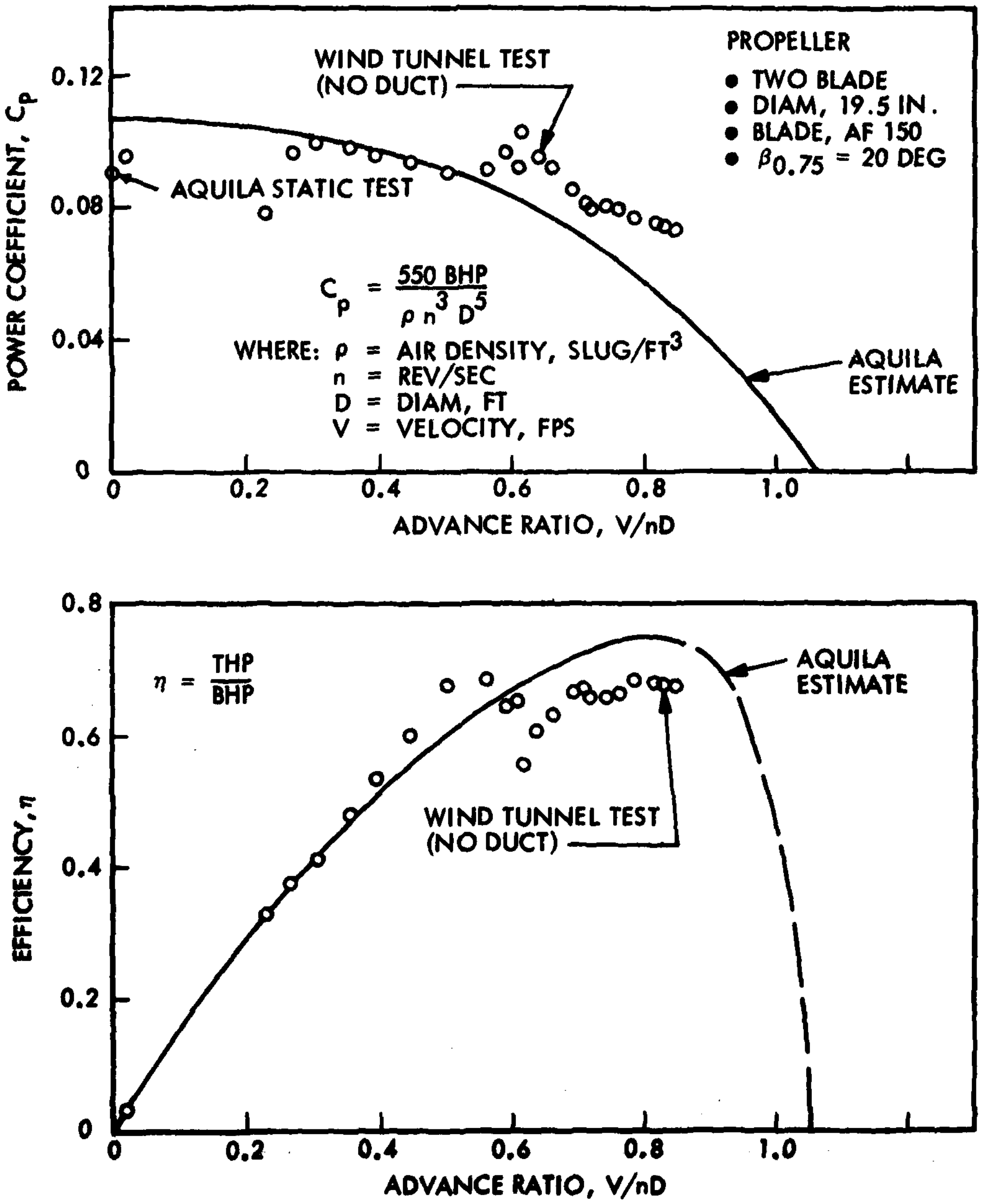

Figure 12. Propeller Power Coefficient and Efficiency

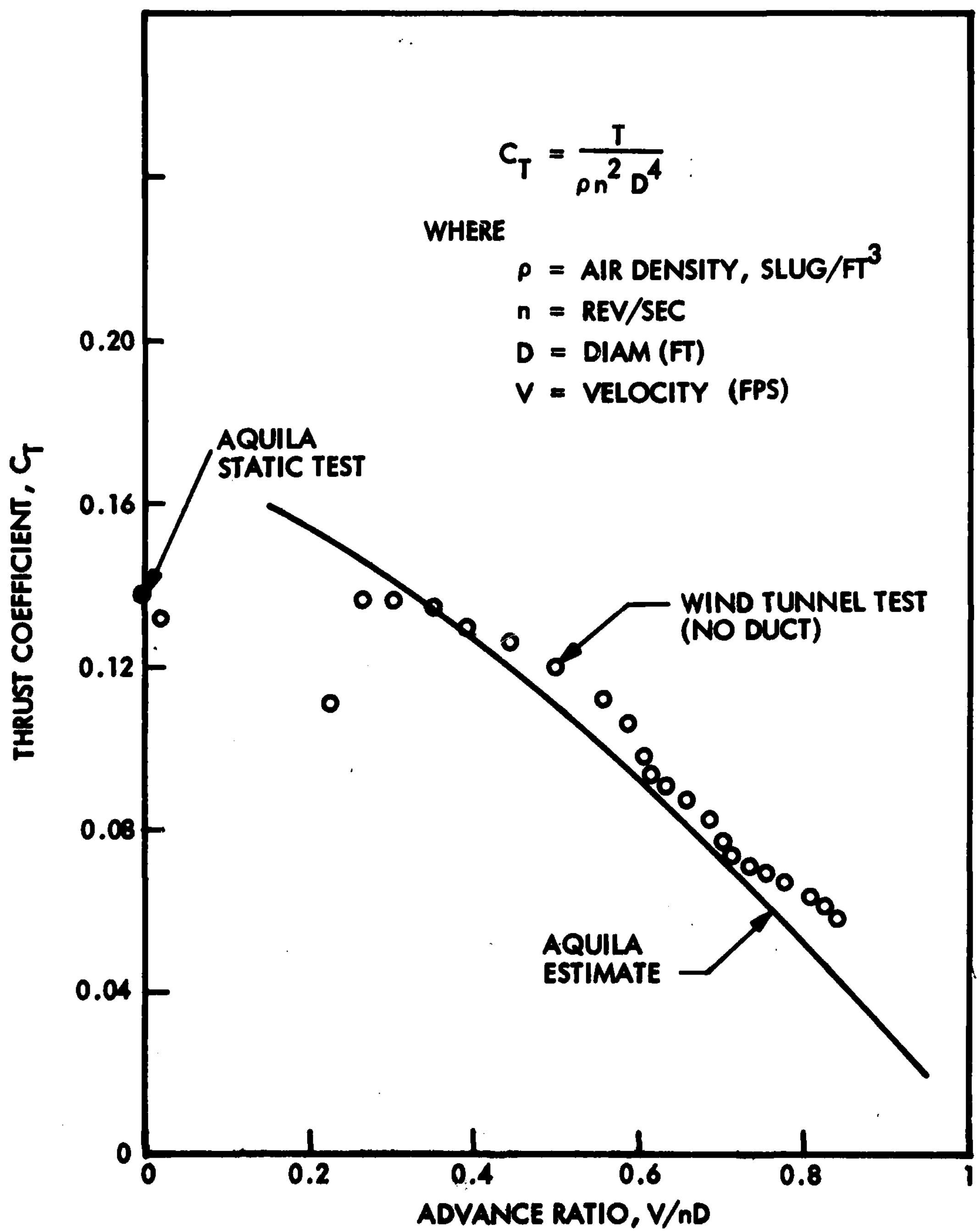

Figure 18. Propeller Thrust Coefficient

TABLE 5. AQUILA STABILITY AND CONTROL CHARACTERISTICS

- Gross Weight = 130 lb
- CG at 21-percent MAC
- Cruise Configuration – Power OFF
- Altitude = 7,000 ft

Longitudinal

Velocity (KEAS)	60
$\delta_{e_{trim}}$ (deg)	-4
α_{trim} (deg)	3
C_L	0.35
C_{L_α} (1/deg)	0.075
C_D	0.033
C_{D_α} (1/deg)	0.005
C_{m_α} (1/deg)	-0.0054
$C_{m_{\dot{\alpha}}}$ (1/radian)	-1.22
C_{m_q} (1/radian)	-1.47
I_{yy} (slug-ft^2)	10.4
Phugoid Mode	
ζ	0.044
ω_n (radian/sec)	0.37
Period (sec)	16.9
Short-Period Mode	
ζ	0.54
ω_n (radian/sec)	5.9
Period (sec)	1.06

Lateral-Directional

Velocity (KEAS)	120	60
$\delta_{e_{trim}}$ (deg)	-1.2	-4
α_{trim} (deg)	-1.0	3
C_{y_β} (1/deg)	-0.0112	-0.0112
C_{y_p}	0	0
C_{y_r}	0	0
C_{n_β} (1/deg)	0.00082	0.0009
C_{n_p} (1/radian)	-0.004	-0.030
C_{n_r} (1/radian)	-0.013	-0.0142
C_{ℓ_β} (1/deg)	0	-0.0005
C_{ℓ_p} (1/radian)	-0.319	-0.335
C_{ℓ_r} (1/radian)	0.032	0.090
I_{xx} (slug-ft^2)	7.1	7.13
I_{zz} (slug-ft^2)	16.5	16.47
I_{xz} (slug-ft^2)	0.2	-0.52
Spiral Mode		
Time Constant (sec)	70.3 (unstable)	16.2 (unstable)
Roll Mode		
Time Constant (sec)	0.06	0.11
Dutch-Roll Mode		
ζ	0.12	0.11
ω_n (radian/sec)	7.1	3.9
Period (sec)	0.9	1.6

Damping Derivatives

Assume Constant With C_L

C_{m_q} = 1.47/radian

$C_{m_{\dot{\alpha}}}$ = 1.22/radian

Control Derivatives

$C_{m_{\delta_e}}$ = -0.0062/deg

$C_{L_{\delta_e}}$ = 0.013/deg

$C_{D_{\delta_e}}$ = 0.0006/deg

the RPV in the cruise configuration, power off, controls fixed. Early in the program, initial data as developed in Reference 4 were used in the RPV autopilot derivation and have been verified qualitatively in the successful RPV flight test program. Table 5 also shows the predicted RPV stability in the various significant flight modes. The phugoid mode is lightly damped; however, the long period of the mode (16.9 sec) makes it easily stabilized. Only the spiral mode was predicted to be unstable without autopilot augmentation, but it too has a long period (16.2 sec) and is easily stabilized by the autopilot. The dutch-roll mode is lightly damped, and a slight dutch-roll tendency is observed in portions of Aquila flights. The extent of oscillation encountered due to this low-frequency dutch roll has not been a gross distraction, even with the unstabilized sensors. The short-period pitch mode is well damped and has a natural period of about 1 sec. Dynamic pitch stability is evidenced for both the cruise and recovery configurations.

No significant change in RPV static or dynamic stability behavior as a result of drag brake deployment has been noted. However, deployment of the drag brake causes a slight transient in the flight path due to the previously defined drag increment (Figure 11) and an increment in pitching moment. This moment increment is shown in Figure 14. The resulting elevon deflection required to trim the moment is small. Control derivatives derived from wind tunnel data are shown in Table 5.

3.1.3 Flight and Operations Characteristics

The following paragraphs define the characteristics related to RPV flight performance, stability and control, and physical characteristics associated with logistic and operational interfaces.

<u>Performance</u>. Performance characteristics of the RPV are summarized in Table 6. Where sufficient data exist, these characteristics are based on flight tests. With true airspeed ranging from 63 to 168 km/h, the Aquila system

TABLE 6. RPV FLIGHT PERFORMANCE CHARACTERISTICS [a]

Velocity – True Air Speed (TAS) at Sea Level (km/h)	
• Cruise Configuration	
– Maximum	168
– Cruise (Optimum Climb)	105
– Launch Velocity (Commanded)	75
– Stall	66 (GW 143 lb) 63 (GW 130 lb)
• Recovery Configuration	
– Maximum	134
– Cruise	95
– Recovery Velocity (Commanded)	90
– Stall	66 (GW 143 lb) 63 (GW 130 lb)
Absolute Ceiling – 0 m/min Rate of Climb (m)	
• Cruise Configuration	5,850
• Recovery	4,530
Service Ceiling – 30 m/min Rate of Climb (m)	
• Cruise Configuration	5,000
• Recovery Configuration	3,680
Maximum Climb Rate – Sea Level (m/min)	
• Cruise Configuration	205
• Recovery Configuration	160
Sink Rate – Sea Level (m/min)	
• Cruise Configuration	
– 95 km/h TAS	64
– 115 km/h TAS	100
• Recovery Configuration	
– 95 km/h TAS	78
– 115 km/h TAS	155
Minimum Time to Climb, 0 to 10,000 ft – Cruise Configuration (min)	
• 143 lb	28
• 120 lb (Design GW only)	19
Maximum-Endurance Mission (min)	
• Maximum Velocity	84
• Maximum Endurance or Range	203
• Typical General Profile	157

(a) Assuming vehicle gross weight of 143 lb unless otherwise indicated.

• WING REFERENCE AREA = 30.2 FT^2
• MEAN AERODYNAMIC CHORD (MAC) = 2.69 FT
• CG AT 0.21 MAC (STA. 137.1)

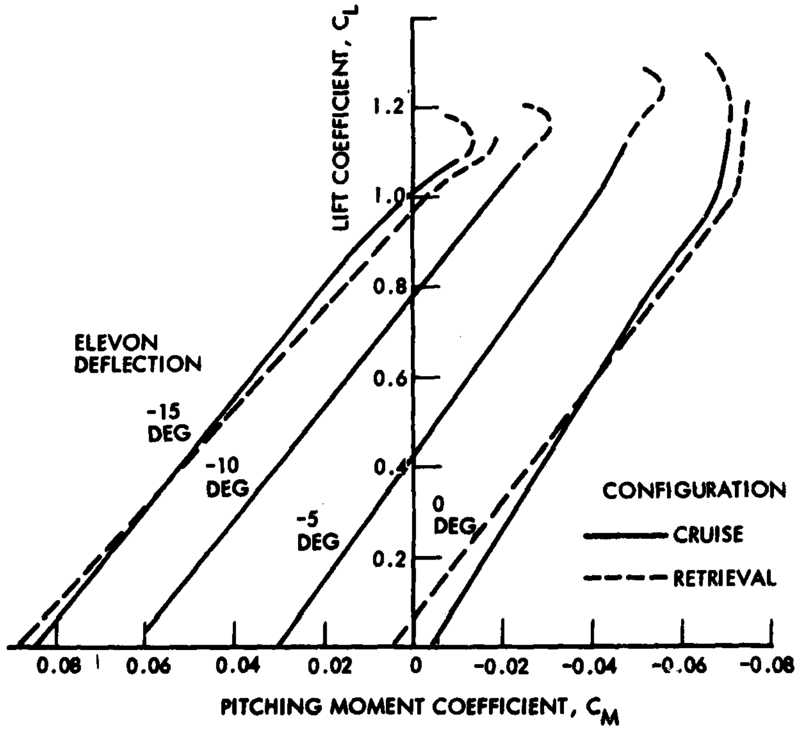

Figure 14. Aquila Pitching Moment Characteristics

provides transient times to the limits of its 20-km operating radius as low as 7 min. Therefore, most of the endurance (up to 3 hours) is available over the target area. Figure 15 shows the speed range variation as a function of density altitude. Included in that figure is the optimum speed schedule for maximum climb rate of the cruise configuration. The low stall speed of 63 km/h for the cruise and recovery configurations permits the RPV to slow to low airspeeds to remain tightly on station while loitering or designating targets, and permits low launch and recovery speeds – with corresponding reduction in RPV loads. The additional drag of the recovery system drag brake, when deployed, is shown to reduce: (1) top speed by 32 km/h, (2) climb rate by 40 m per min, and (3) maximum altitude capability by 1,350 m. Consequently,

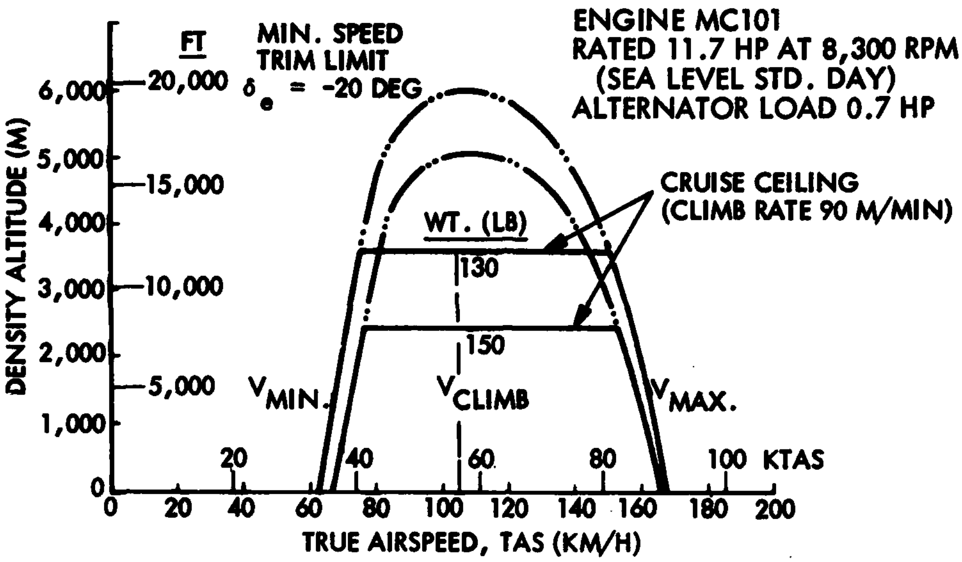

Figure 15. Aquila Airspeed-Altitude Flight Envelope (1976 U.S. Standard Atmosphere)

since the RPV must be immediately recoverable after launch, the performance capability of the vehicle in the recovery configuration becomes the criterion for launch, rather than the performance capability in the cruise configuration. The 143 lb RPV, in the recovery configuration, has a minimal 100 ft per min climb rate at a density altitude of 8,000 ft (2,439 m). This density altitude was considered a launch-limiting criterion during the program. The RPV offers a wide range of altitude capabilities. The normal operational altitude, for which the sensors are calibrated, is 610 m (2,000 ft) above ground level (AGL). The maximum density-altitude capability, Figure 15, is derived from flight test data to be 6,200 m for the 120-lb design gross weight.

Figure 16 shows the climb rate variation with weight and density altitude. Maximum sea level climb rates of 194 m per min and 164 m per min are achievable for the RPV mission weights of 132 and 146.5 lb. Integration of the climb rate curves provides the time-to-climb curves also shown in Figure 16. The original goal of 15 min for a 120-lb RPV to climb from sea level to 3,048 m (10,000-ft) density altitude was missed by 4 min. The maximum-weight RPV (146.5 lb)

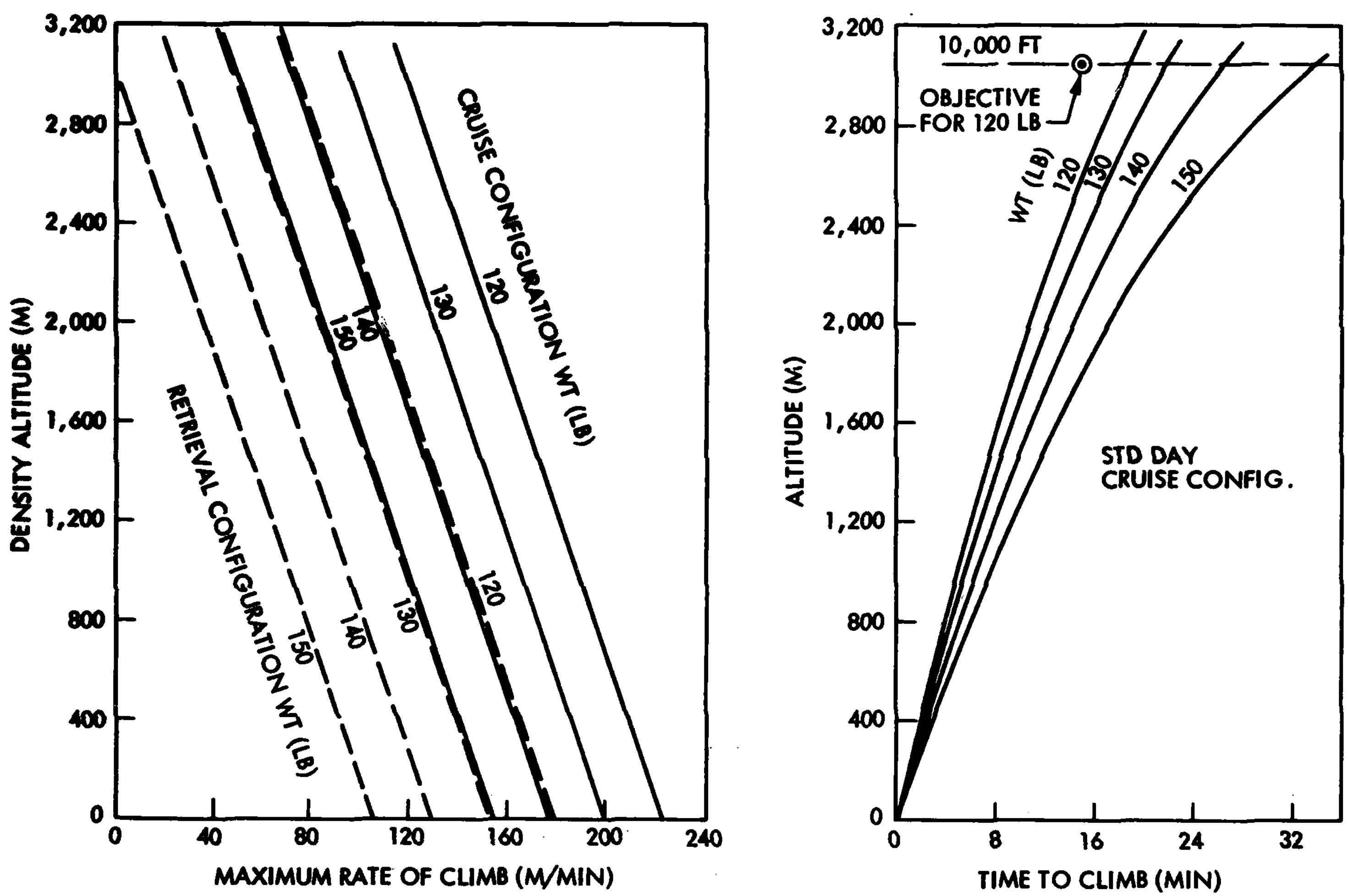

Figure 16. Aquila Maximum Climb Performance

requires a minimum of 28 min to climb from sea level to 3, 048-m density altitude. The time to climb to normal mission altitude of 609 m (2, 000 ft) is 5 min and 4.5 min for the maximum 146-lb weight at Fort Huachuca and Fort Sill, respectively, with standard day conditions. Consequently, for normal mission operations, the time required to climb to altitude will not require a major portion of the vehicle's endurance time.

The RPV provides ample descent capability to represent tactical system operations. Figure 17 shows that for the cruise configuration and idle engine setting, a maximum descent rate of 600 fpm (182 m/min) is available for commanded flight velocities near 140 km/h. This rate provides high operational flexibility, with rapid descent capability available to effect quick altitude positioning of the RPV for subsequent mission activities. An autopilot limit function in the altitude loop limits the descent rate to 182 m/min to prevent inadvertent commands to excessive dive angles. This limit is indicated in Figure 17. The resulting flight path angles must be considered in flight planning – particularly in mountainous or hilly terrain, since altitude changes occur according to altitude, RPV weight, and commanded airspeed, and not in a linear manner from commanded waypoint to commanded waypoint (except in the case of the abort command that interrupts a mission and returns the RPV on a direct linear path to the recovery area).

The descent flightpath angle for the RPV in the recovery configuration is an important recovery parameter. The normal flightpath angle is 4 deg during final approach guidance to the recovery net. The approach camera is aimed directly up this approach path. Flightpath control capability around the 4-deg path is required to successful recovery guidance. The glidepath capability of the recovery configuration is shown in Figure 17. Over 100 successful recoveries have demonstrated that control to be adequate.

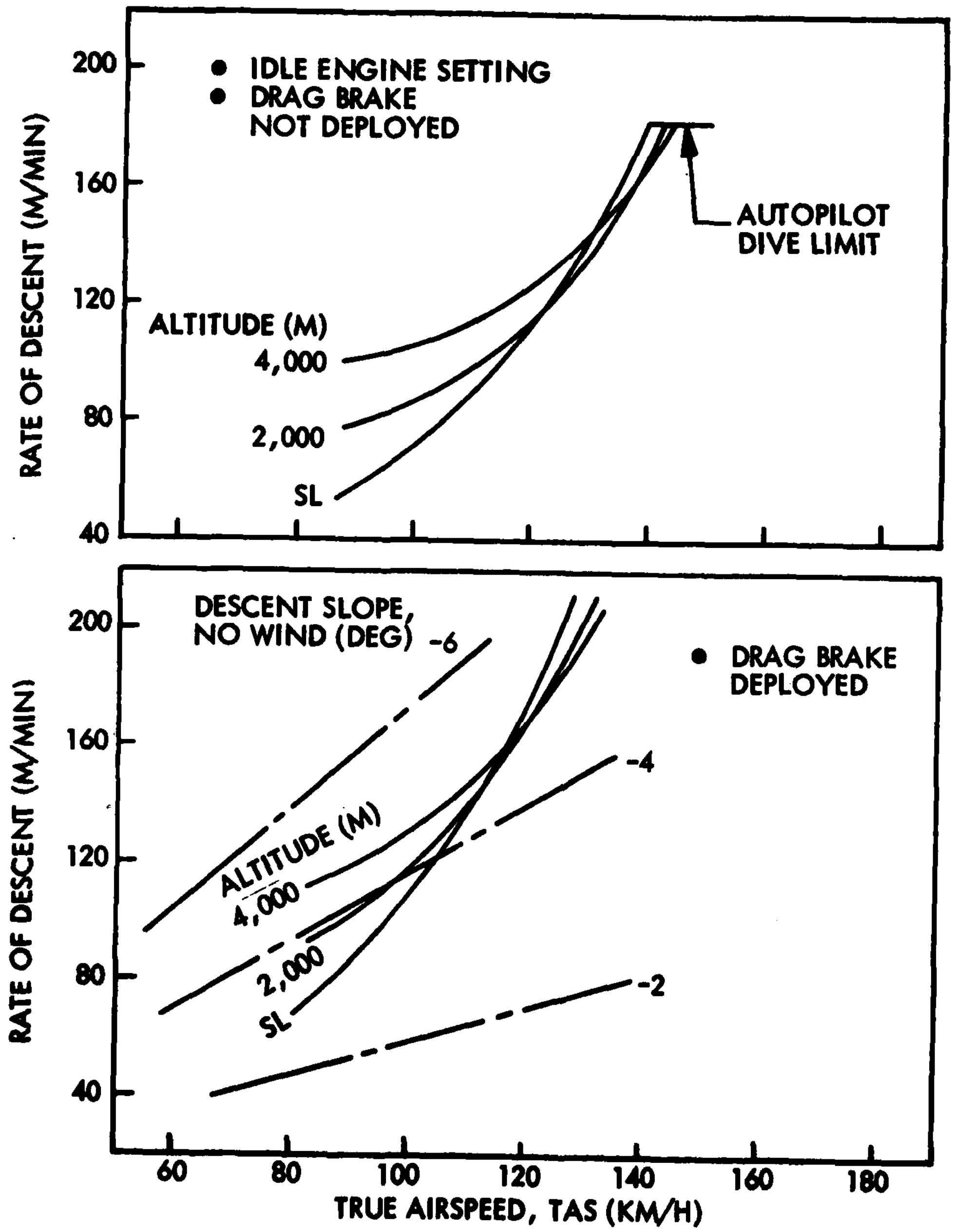

Figure 17. Aquila Maximum Rate of Descent (140-lb Weight)

The maximum flight endurance of the Aquila RPV in its basic mission profile varies from 84 min at maximum velocity (full throttle) to 203 min under optimum flight conditions. The basic mission profiles are summarized in Table 7. This table shows the key parameters relating to endurance for a mission conducted at maximum cruise velocity, a mission conducted at optimum (maximum endurance) velocity, and a mission reflecting normal cruise velocity typical of that selected during field testing. The typical general profile is seen to yield a maximum cruise time of 132 min (over 2 hours). This time is increased to 178.3 min (almost 3 hours) if cruise speed is optimized. Fuel consumption in these basic missions is derived using empirical fuel consumption data from flight tests and altitude chamber engine tests (see Reference 5). To calculate the basic missions of Table 7, a gross launch weight of 140 lb is assumed, and launch is assumed to start at a density altitude of 2,164 m (typical of Fort Huachuca). A full 15-lb fuel load also is assumed, with the breakdown shown in Table 8.

With the above endurance capability, the Aquila more than meets the mission flight endurance objectives of 1.5 hours (minimum) and 3.0 hours (desired).

Field Operation Interfaces. The Aquila RPV incorporates design features to assist in field operations including transportation, storage, assembly checkout, launch, recovery, and repair.

To facilitate transportation and storage, the RPV provides for removal of the wing panels at wing station 13. In addition, the fuel bladder can be removed

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[5] AQUILA RPV SYSTEM TEST REPORT, CDRL A00D, PART 11, ENGINE DEVELOPMENT, LMSC-L028081, Lockheed Missiles and Space Company, Inc., Sunnyvale, California, 22 December 1977.

TABLE 7. AQUILA RPV BASIC MISSION ENDURANCE

Flight Conditions and Characteristics	Basic Mission: I Maximum Velocity	II Maximum Endurance and Range	III Typical General Profile
Launch Density Altitude (m)	2,164	2,164	2,164
Gross Takeoff Weight (lb)	140	140	140
Prelaunch			
• Time (min)	5.0	5.0	5.0
• Fuel Used (lb)	0.5	0.5	0.5
Climb (to 610 m AGL)			
• Time (min)	6.8	6.8	6.8
• Distance (km)	13.8	13.8	13.8
• Fuel Used (lb)	0.6	0.6	0.6
• Velocity, TAS (km/h)	122	122	122
Cruise			
• Altitude (m)	2,774	2,774	2,774
• Time (min)	59.4	178.3	132
• Distance (km)	148	292	261
• Fuel Used (lb)	10.7	10.7	10.7
• Velocity, TAS (km/h)	150	98	119
Descent			
• Time (min)	4.0	4.0	4.0
• Distance (km)	0	0	0
• Fuel Used (lb)	0.2	0.2	0.2
Recovery			
• Time (min)	9.0	9.0	9.0
• Distance (km)	0	0	0
• Fuel Used (lb)	1.0	1.0	1.0
Reserve			
• Fuel (lb)	1.5	1.5	1.5
Total			
• Endurance (min)	84	203	157
• Range (km)	162	306	275

TABLE 8. FUEL USAGE BREAKDOWN

Fuel Category	Fuel Weight (lb)
Total Fuel Load	15
Unusable Fuel (Ullage)	-0.5
Usable Fuel	14.5
10-Percent Reserve	-1.5
5-Percent Fuel Flow Increase	-0.8
Total Mission Fuel	12.2

for separate storage if fuel residue in the vehicle should become a hazard. The air vehicle and its wings (including all components but the sensor) are stored and transported in two specially designed wooden boxes. The fuselage box is 32.75 in. high, 43.5 in. wide, and 80.5 in. long. The wing box is 22.5 in. high, 43.5 in. wide, and 80.5 in. long (clearance dimensions). Each set contains a material repair kit. The components are secured with padded constraints in each box. Total shipping weight of the RPV and its boxes is 368 lb. The more fragile sensors are shipped in separate cartons, provided by the manufacturer.

After removal from the shipping-storage box, the RPV is placed on an assembly stand. Hard points at the trailing edge of the wing stub and at the junction of the wing stub closeout rib and bulkhead 130 are used for support on the assembly stand. The vehicle is clamped to the stand at the wing stub trailing edge and by the launching skeg to prevent slippage and resulting damage during assembly. The RPV may be mounted upright or inverted for maintenance. Assembly and checkout are accomplished in the upright position.

To facilitate power-up and checkout, an umbilical strip is provided on the right side of the RPV belly, alongside the lower access panel frame, just forward of bulkhead 147. The strip provides connectors for insertion of the power umbilical and the checkout-test plug. Checkout and calibration of the pitot-static system through the flush-mounted ports is accomplished through a "putty-seal" fitting clamped against the skin.

Interface with the launcher shuttle involves a support of the vehicle at five points; interface with the starter adds one additional point of contact. The power umbilical is also connected before engine start, and the cooling blower hose is inserted in the air scoop in the left wing. Figure 18 shows the RPV on the launcher prior to engine start. The vertical support arms input support loads at the hard point areas formed by bulkhead 130 and the wing stub closeout ribs.

Figure 18. Aquila-Launcher Interface

The skeg is clamped into the spring-loaded shuttle skeg pin holder to prevent RPV pitch-up rotation about the rear push pads during the launch stroke. Push pads are fitted to the trailing edge of the wing root with aluminum channels carrying the launch loads forward to the wing attach fittings. The push pad fittings carry cylindrical tangs that insert into the shuttle thrust fittings and are secured by soft aluminum rivets to react engine starter and thrust loads. The soft rivets fail in double shear, to release the RPV when the shuttle is decelerated at the end of the launch stroke. This arrangement totally constrains the RPV on the shuttle during prelaunch activities. A cylindrical fitting at the propeller hub, coaxial with the propeller hub, has a steel pin inserted across the cylinder; this provides an interface for the smaller slotted shaft on the starter, and transmits the starting torque to the engine.

The ground-based Aquila recovery system is designed to minimize the impact of recovery operations on the vehicle design. However, certain features were provided to accommodate interface with the recovery system. The payload protector is the most obvious of these, and has the greatest impact on the RPV design. Easily removed wingtip fairings are provided to permit removal for repair or replacement. The propeller shroud is structurally designed for large vertical and side loads to protect the propeller and the recovery system straps prior to engine shutdown after recovery. Faired stub antennas are provided on the upper nose and the bottom of the shroud to minimize snagging in the recovery net and strap assemblies. The flush-mounted pitot-static ports were specifically selected to avoid damage to that system during recovery. Protrusions and sharp corners were minimized to prevent hangup during recovery.

To facilitate repair or replacement, components such as the shroud, wingtips, wing panels, elevons, access doors, nose cap, and payload protector are easily removable. Access to the fuselage structural elements is excellent, with only a few internal skin areas inaccessible – requiring repair of these areas from the outside skin. A repair kit is provided with each RPV set. This kit includes instructions, glass cloth, resin and catalyst, and a mixing tool and container.

3.2 AIRFRAME

The RPV airframe provides (1) the aerodynamic contours required for stable flight; (2) breakdown provisions for storage and repair; (3) mounting provisions for RPV subsystems; (4) hinged control surfaces; (5) access doors for installation, maintenance, and repair; and (6) structure to react flight and ground handling loads. The following paragraphs describe the airframe and its performance of these functions.

3.2.1 Airframe Geometry

3.2.1.1 General Airframe Arrangement. The general arrangement of the airframe is shown in Figures 4 and 5. The configuration consists geometrically of a fuselage with a varying elliptical cross section faired smoothly to a 28-deg swept wing. The wing airfoil is formed to a modified NACA 23015 airfoil section. The ring tail attached by struts to the aft of the fuselage provides a protective propeller shroud and aerodynamic stabilization for pitch and yaw.

3.2.1.2 Fuselage Derivation. The fuselage nose is basically a 4-in.-radius segment faired to a 9.408-to-8.156 major-to-minor axis ellipse at station 104 (4 in. from the tip of the nose). Tables 9 and 10 show the station-by-station variation of the basic body ellipse axis dimensions. From station 124 to 148 the height of the body is maintained at 12 in. Fairings from the basic body ellipses to the wing stubs and fairings to house the engine cylinder head complete the fuselage contours. Master Mylar prints of machine-drawn contours were provided to the airframe subcontractor and were used to guide the development of the master molds.

3.2.1.3 Wing Derivation. Figure 19 shows the projected view of the wing panel geometry and its projection to the airframe centerline. This basic wing geometry shows a stub root chord of 36.73 in. at wing station 13, and a root

TABLE 9. BASIC FUSELAGE CROSS SECTIONS

Fuselage Station	Half Major Axis	Half Minor Axis
104	4.704	4.078
105	5.097	4.267
106	5.476	4.446
107	5.839	4.615
108	6.187	4.774
109	6.521	4.923
110	6.841	5.063
111	7.146	5.192
112	7.437	5.312
113	7.714	5.422
114	7.977	5.523
115	8.227	5.614
116	8.463	5.695
117	8.685	5.766
118	8.895	5.828
119	9.091	5.881
120	9.274	5.924
121	9.444	5.957
122	9.601	5.981
123	9.745	5.995
124	9.877	6.000
125	9.996	6.000
126	10.102	6.000
128	10.276	6.000
130	10.401	6.000
134	10.500	6.000

TABLE 10. AFT FUSELAGE BASIC CONTOUR

Fuselage Station	Half Major Axis	Half Minor Axis (Upper)	Half Minor Axis (Lower)
136	10.472	6.000	6.000
138	10.389	6.000	6.000
140	10.251	6.000	6.000
142	10.057	6.000	6.000
144	9.807	6.000	6.000
146	9.500	6.000	6.000
148	9.135	6.000	6.000
150	8.712	5.964	5.975
152	8.229	5.855	5.899
154	7.686	5.672	5.773
156	7.080	5.416	5.597
158	6.411	5.085	5.369
160	5.676	4.677	5.090
162	4.873	4.191	4.759
164	4.000	3.625	4.375

chord of 23 in. at wing station 69. The 1.92-in. difference in waterline location of the leading edge and the trailing edge of the stub root chord reflects the 3-deg incidence of that airfoil section. A leading edge sweep of 28 deg is indicated.

Table 11 shows the coordinates of the modified NACA 23015 airfoil used for the wing. The coordinates are given in percentage of section chord. The modification affects only the last 10 percent of the upper surface and 30 percent of the lower surface. A 0.5-percent thick trailing edge is indicated. The modification is calculated to eliminate the small nose-down pitching moment characteristic of the standard NACA 23015 airfoils, and to provide structural strength to the wing trailing edge. The wing is assembled to the wing stub by eight bolts per wing. The bolt locations correspond to the front and rear spars and to the 130 and 147 bulkheads of the fuselage.

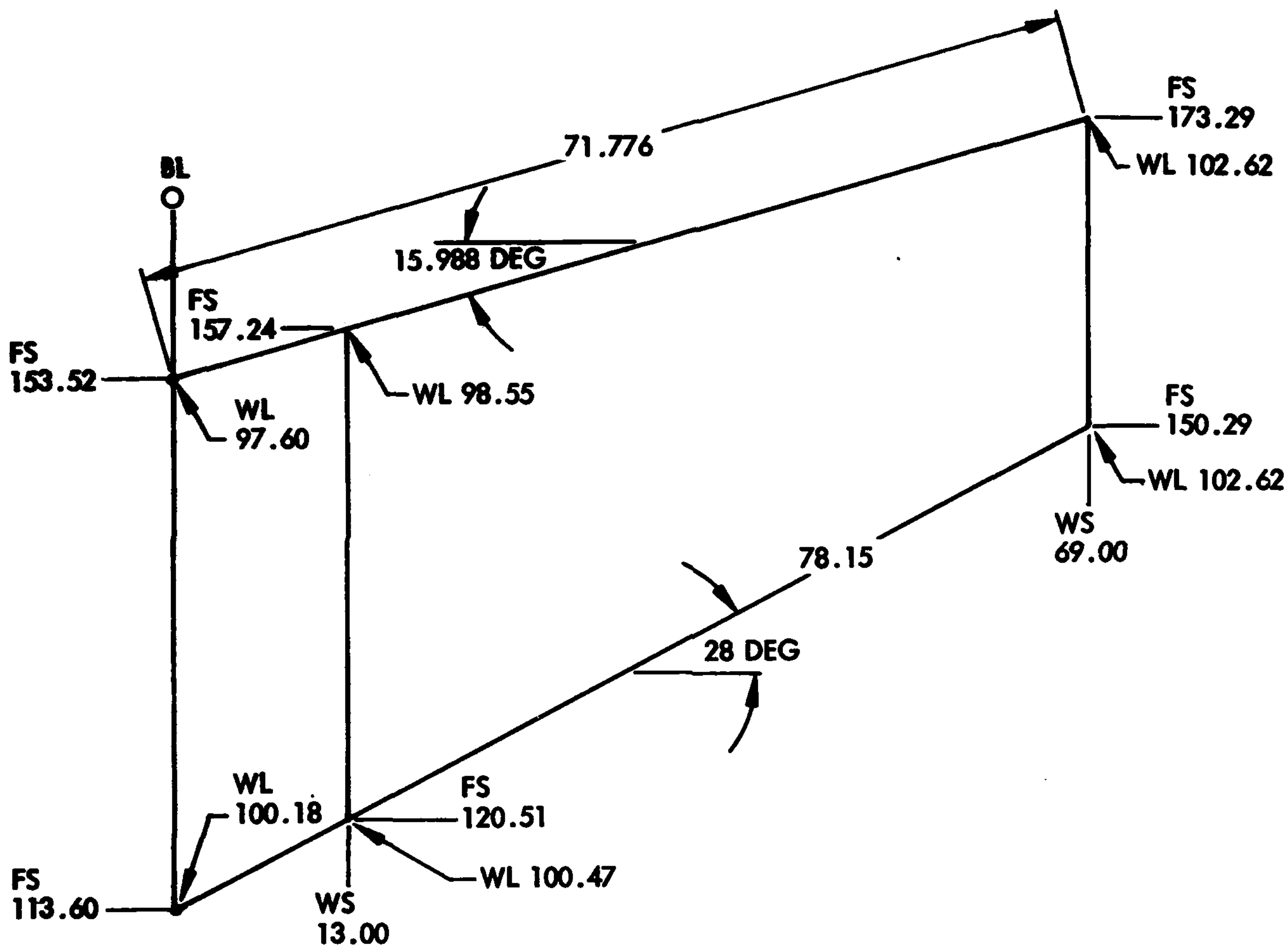

Figure 19. Basic Wing Geometry

TABLE 11. AQUILA WING AIRFOIL COORDINATES FOR MODIFIED NACA 23015 (PERCENT OF CHORD)

Station	Upper Surface	Lower Surface
0	–	0
1.25	3.34	1.54
2.5	4.44	2.25
5	5.89	3.04
7.5	6.90	3.61
10	7.64	4.09
15	8.52	4.84
20	8.92	5.41
25	9.08	5.78
30	9.05	5.96
40	8.59	5.92
50	7.74	5.50
60	6.61	4.81
70	5.25	3.79 (modified)
80	3.73	2.43 (modified)
90	2.26 (modified)	1.000 (modified)
95	1.69 (modified)	0.239 (modified)
100	1.000 (modified)	0.016 + 0.500 (modified)

3.2.1.4 Propeller Shroud Geometry. The circular propeller shroud uses a standard NACA 23015 airfoil section, 7 in. in chord. The section chord is at 3.5 deg angle of incidence with the body centerline, creating a converging duct. The duct centerline is at waterline 100 and parallel to the body centerline of waterline 99.625. This displacement places the propeller thrust line through the center of gravity. The shroud leading edge is located at fuselage station 163.25; the propeller plane is located at fuselage station 165.63. Clearance between the propeller and the duct is nominally 0.5 in. Diameter measurements of the leading edge and trailing edge of the shroud are 21.75 and 20.89

in., respectively. The duct is rigidly supported in its position relative to the fuselage by three tapered struts. These struts are located 120 deg apart around the circumference of the shroud, with one strut located on the lower centerline. The strut ends are structurally molded to the duct lip just inside the leading edge. The struts are 0.5 in. thick. Molded slots on the fuselage end of the struts permit positioning on and fastening to the corresponding formed bosses on the fuselage. This installation is shown in Figure 20. Two countersunk allen head screws with countersunk lock nuts anchor each of the three struts to the fuselage and permit removal for repair or replacement.

3.2.1.5 Elevon Geometry. The two elevon control surfaces span 31.25 in. from wing station 35.125 to wing station 66.375 behind the rear (70 percent) wing spar. Clearance between the elevon end and the cutout edges is 0.375 in. for the inboard edge, 0.125 in. for the outboard edge. Chord dimensions of the elevons are 9.511 in. inboard and 7 in. outboard, as shown in Figure 21. The elevon hingeline is located at 76.5 percent of the wing chord.

3.2.2 Design Loads

The load spectrum of the RPV is indicated in Table 12. The gross weight for design was 120 lb. In some respects the load spectrum is considerably expanded over that of a conventional aircraft (perhaps with the exception of carrier aircraft). This expansion, primarily in the longitudinal and lateral sense, derives primarily from the launch and recovery operations. A design load factor of safety of 1.25 is applied to all loading conditions for structural sizing and analysis.

Figure 22 is the velocity-load factor (V-N) diagram for the RPV. The ±6-g capability is shown. Gust velocities superimposed on the figure show the ability of the RPV to encounter a wide range of gusts without exceeding design

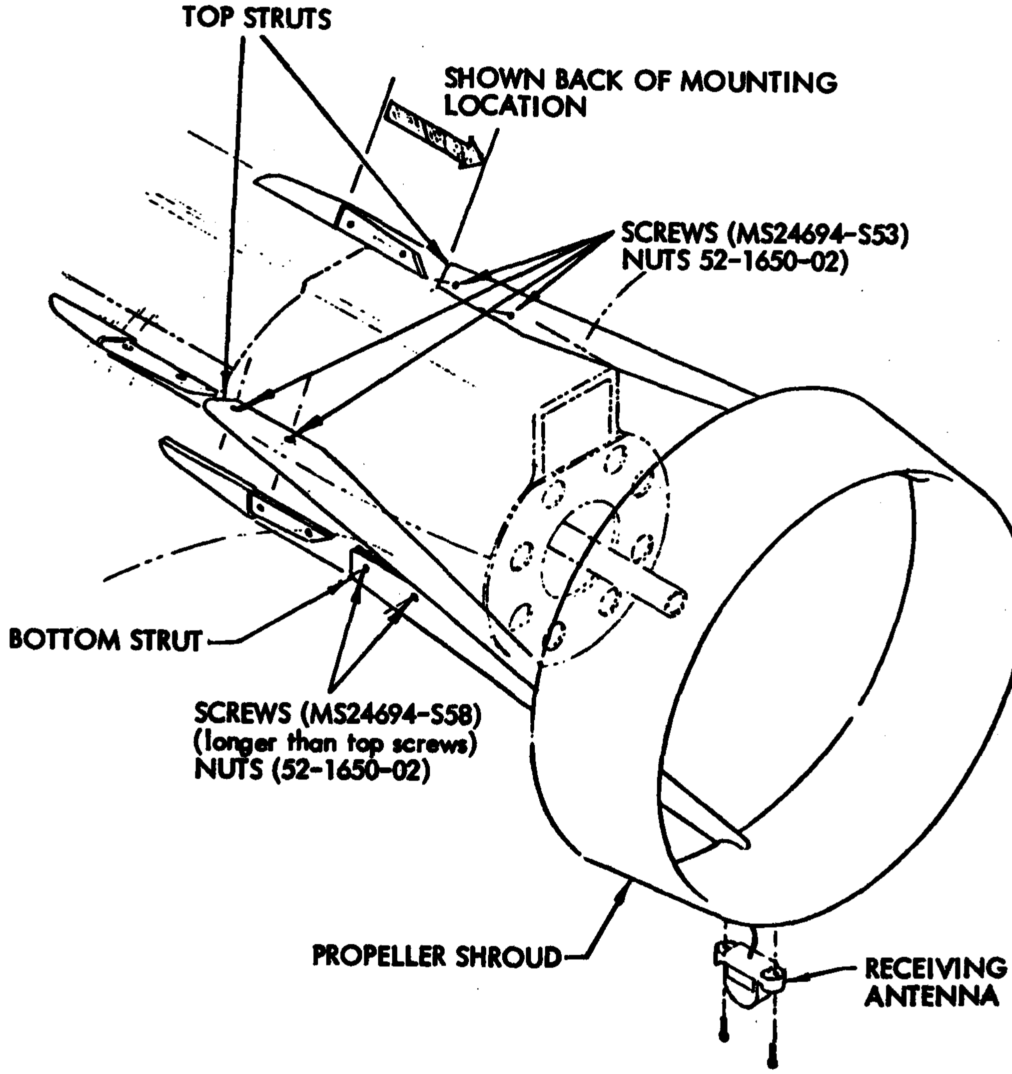

Figure 20. Installation of Aquila Propeller Shroud

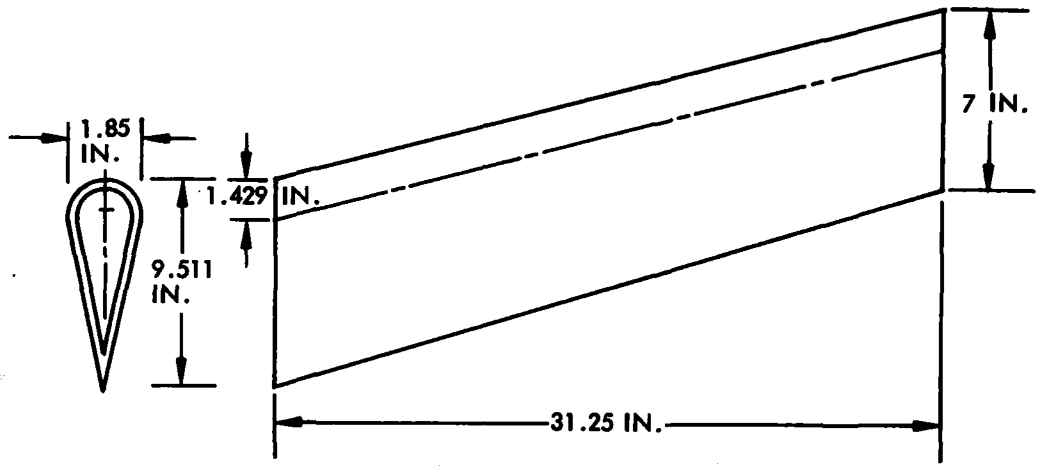

Figure 21. Aquila Elevon Geometry

loads. Detailed loads for the various airframe components, and the structural analyses of those components, are contained in Reference 6 and Reference 7.

3.2.3 Airframe Structural Arrangement

The airframe structural arrangement is strongly affected by subsystem access requirements. This is well demonstrated by considering the access panels and covers shown in Figure 23.

3.2.3.1 Fuselage Structure. The fuselage is particularly dominated by its six access panels, only one of which, the alternator access panel, is structural. Fuselage bulkhead locations are shown in Figure 24. Bulkheads 130 and 147 are located to align with the wing spars and provide the structural carrythrough

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[6]Krachman, Howard E., AQUILA STRUCTURAL INTEGRITY REPORT, Development Sciences, Inc.; LMSC Subcontract GS10B7130A, DSI Job No. 2846-SR, Lockheed Missiles and Space Company, Inc., Sunnyvale, California, 3 October 1975.

[7]Fukuhara, K., AQUILA FUSELAGE STRUCTURAL ANALYSIS, EM No. 5584-36, Lockheed Missiles and Space Company, Inc., Sunnyvale, California, 13 February 1976.

TABLE 12. RPV DESIGN LOADS

Overall Design Load Factors (for a gross weight of 120 lb):		
	• Vertical	±6 g
	• Longitudinal	±6 g
	• Lateral	±2.5 g
Payload Protector		
	• Vertical	+6 g
	• Longitudinal	+6 g
	• Lateral	±2.5 g
Engine Installation		
	• Vertical	6 g
	• Longitudinal	6 g
Propeller Shroud		
	• Maintain propeller clearance with 6-g vertical load	
	• Vertical load: 300 lb	
	• Lateral load: 200 lb	
	• Longitudinal (aft) load: 100 lb	

for wing loads. Other bulkhead locations are due primarily to consideration of subsystem location and geometry. The resulting structural arrangement is shown in Figure 25. This figure shows the schematic of the primary structure. B_1, B_2, B_3, B_4, B_5, and B_6 are the bulkheads. Bulkheads B_3 and B_4 resist the forces carried by the wing connections. The other three bulkheads (exclusive of the B_6 close-out bulkhead) are used for the equipment mounting, the shroud connections, and payload protector connections.

The longitudinal rib or intercostal, a-b-c, connects B_1, B_2, and B_3. This transfers the forebody longitudinal bending to bulkhead B_3. C_1, a closing rib connecting bulkheads B_3, B_4, and B_5, is the structural member carrying the body bending loads between these two bulkheads. C_2 is the root rib of the wing

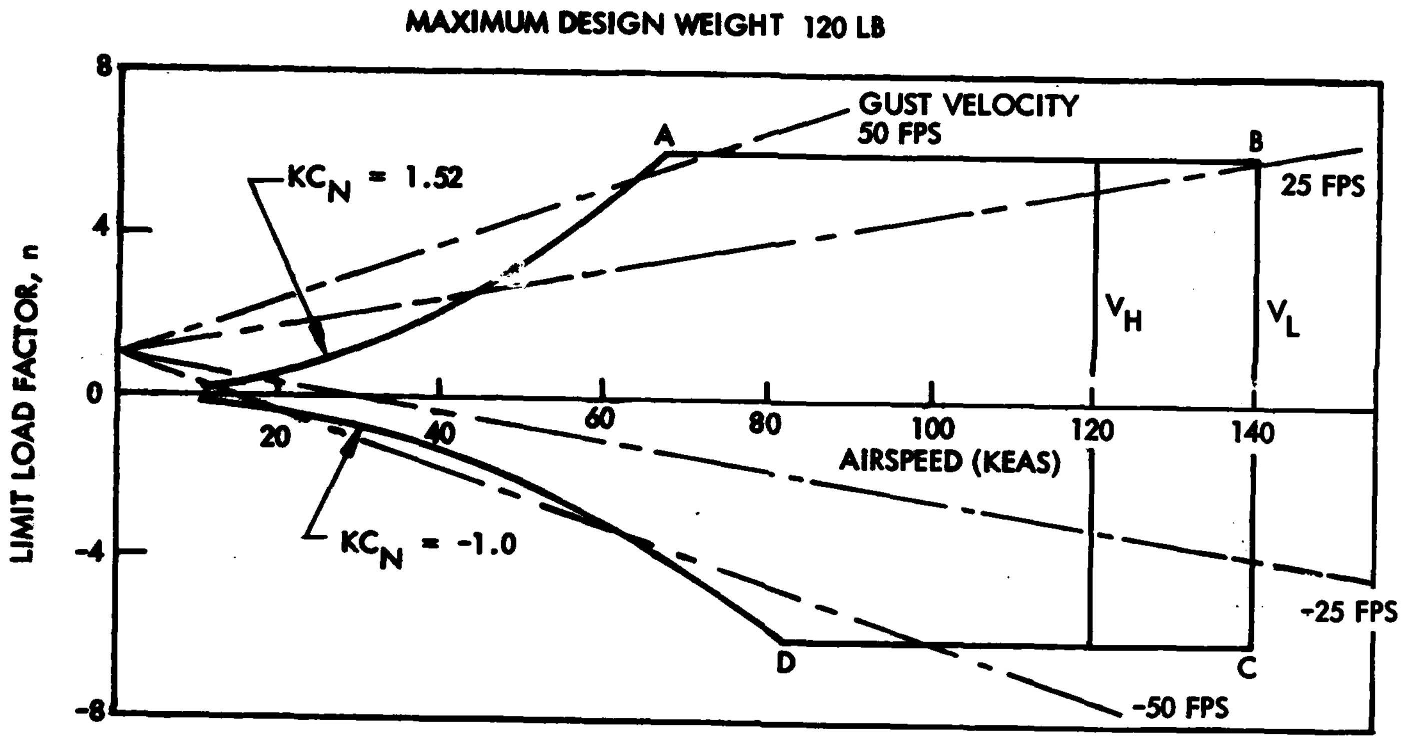


Figure 22. Structural Design Flight Envelope

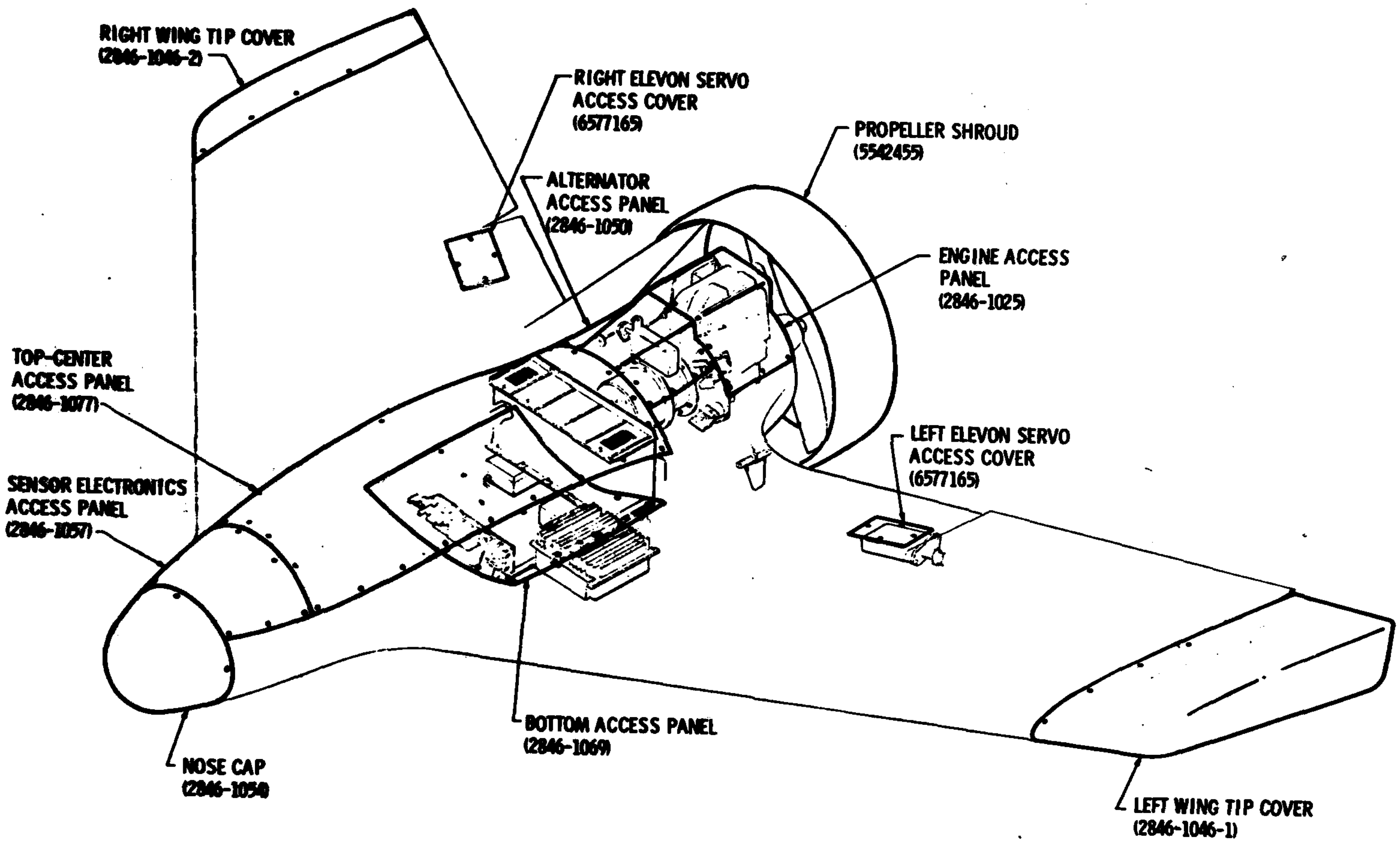


Figure 23. RPV Access Panels and Covers

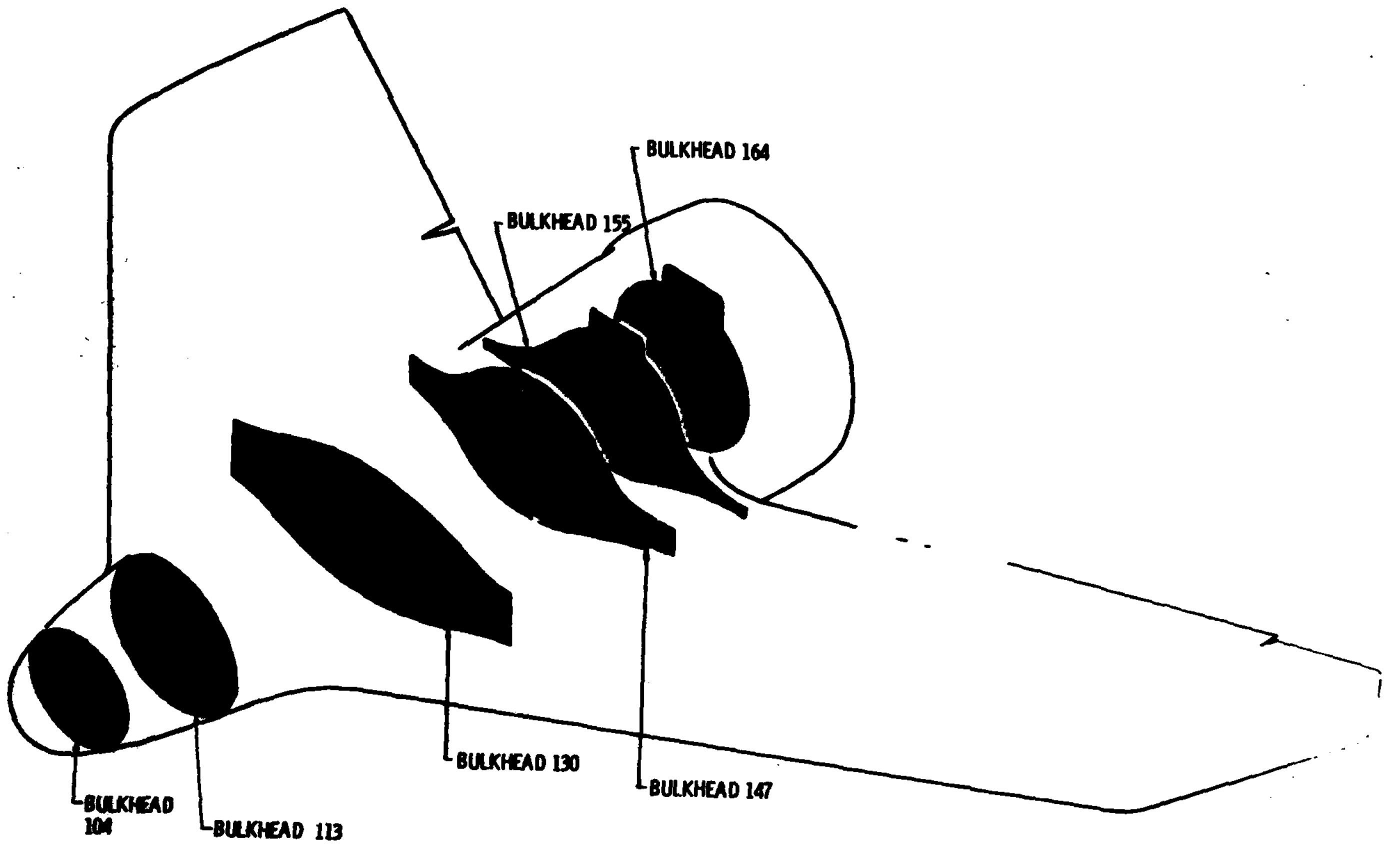
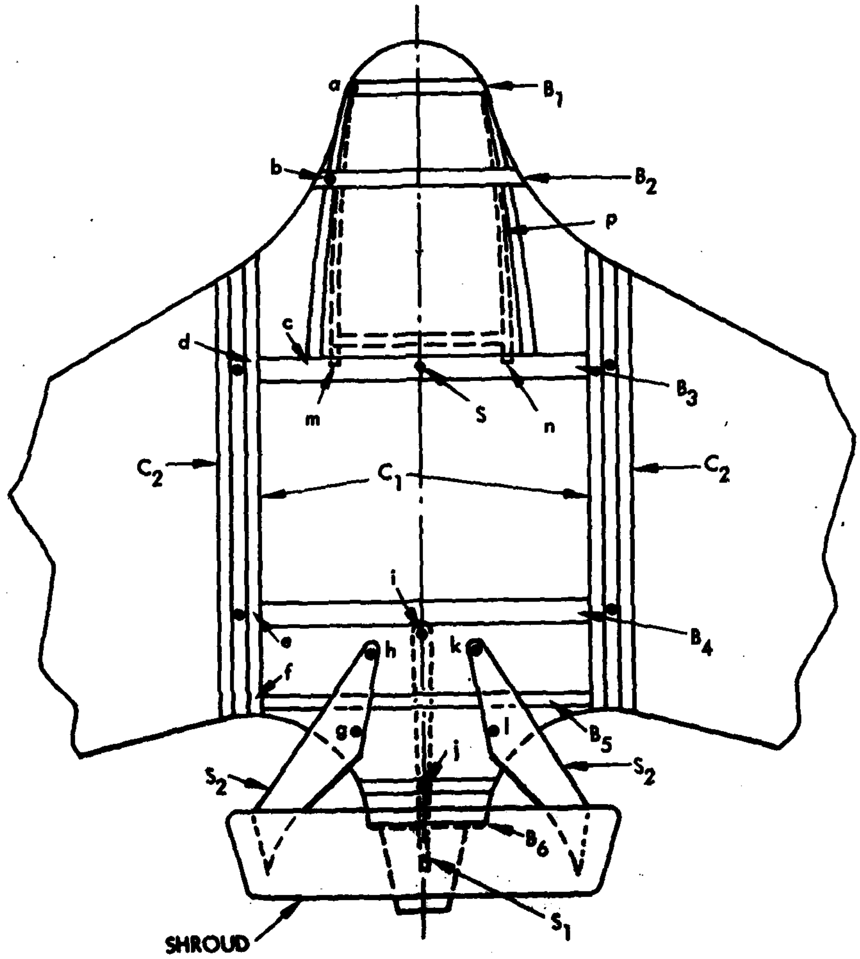


Figure 24. RPV Bulkhead Identification and Location



LEGEND

B_1	BULKHEAD 104	b	INTERCOSTAL/BULKHEAD 113 JOINT
B_2	BULKHEAD 113	c	INTERCOSTAL/BULKHEAD 130 JOINT
B_3	BULKHEAD 130	d	BULKHEAD 130/CLOSING RIB JOINT
B_4	BULKHEAD 147	e	BULKHEAD 147/CLOSING RIB JOINT
B_5	BULKHEAD 155	f	BULKHEAD 155/CLOSING RIB JOINT
B_6	BULKHEAD 164	g	REAR S_2 STRUT BOLT
C_1	WING-STUB CLOSING RIB	h	FRONT S_2 STRUT BOLT
C_2	WING-ROOT RIB	i	FRONT S_1 STRUT BOLT
S_1	BOTTOM SHROUD STRUT	j	REAR S_1 STRUT BOLT
S_2	LEFT SHROUD STRUT	k	FRONT S_2 STRUT BOLT
S_3	RIGHT SHROUD STRUT	l	REAR S_2 STRUT BOLT
a	INTERCOSTAL/BULKHEAD 104 JOINT	p	PAYLOAD PROTECTOR

Figure 25. Structural Arrangements (Top View)

which helps to stiffen the wing at the joints and distributes the bending between connections d and e. The shroud is connected by three struts (two of which are similar), S_1 and S_2, to the fuselage. S_1 is connected at j and k. S_2 is connected at g and h. The skeg (S) is connected directly to the bottom of bulkhead B_3. The payload protector (p) is connected to hinges in bulkhead B_1, and by struts at m-n to bulkhead B_3. The structural access panel to the alternator compartment closes the section between bulkhead 155 and bulkhead 147. The resulting monocoque section (closed by the wing stub closing rib) reacts the engine loads transmitted into bulkhead 155.

3.2.3.2 Wing Structure. The wing structure (Figure 26) is conventional, consisting of the two wing spars at the 25-percent and 70-percent chord locations for reacting bending loads, and the root and tip closing rib. A partial rib from the 70-percent spar to the trailing edge closes the elevon cutout at

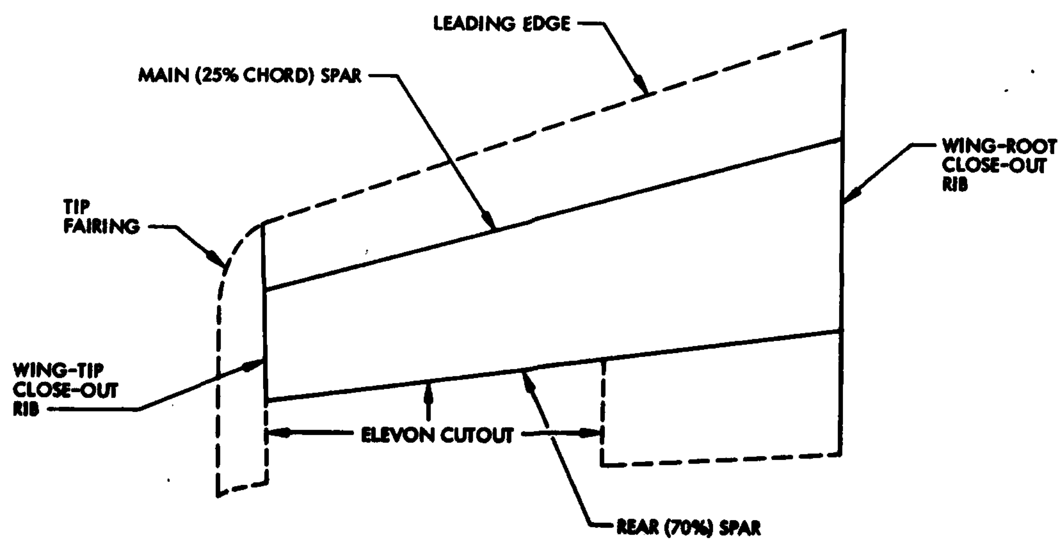


Figure 26. Wing Structural Members

the inboard elevon edge. The wing skins complete the D-shaped leading edge and the torque box between the two wing sparts to react torque loads and chord loads. The nonstructural tip fairing attaches to the tip and completes the elevon cutout.

3.2.3.3 Shroud Structure. The rigid skin-over-foam structure arrangement of the propeller shroud, shown in Figure 27, maintains the circular shroud against vertical, side, and chord loads without significant deformation. The lower shroud strut cross section, also shown in Figure 27, is a double-box structure, so reinforced as to react normal shroud lift loads and landing loads during normal net recovery and emergency skid landings. The inner box also provides for passage of the coaxial cable to the receiving antenna. The upper shroud struts section (Figure 27) are oriented radially so as to assist in reacting vertical loads and to react side loads. The closed cross sections of the three struts combine to react torque loads that would tend to rotate the shroud around its axis. The resulting structurally rigid arrangement, completed by attachment to the body, maintains clearance between the propeller and shroud during all flight and ground handling operations.

3.2.2.4 Elevon. The elevon structure geometry consists simply of the elevon skin and a closeout rib at each end. The resulting closed section reacts the air loads, torques, and ground handling loads on the aileron. These are translated to loads at the aileron hinges and transmitted into the wing structure.

3.2.4 Materials, Characteristics, and Applications

The principal structural material for the Aquila is Kevlar (formerly PRD-49) and epoxy. Kevlar is a DuPont synthetic "Aramid" fiber known for its high strength and light weight. Other current applications include tire cords and bulletproof vests. The material was selected primarily as a means of reducing airframe weight. Lockheed has extensive experience with Kevlar in aircraft

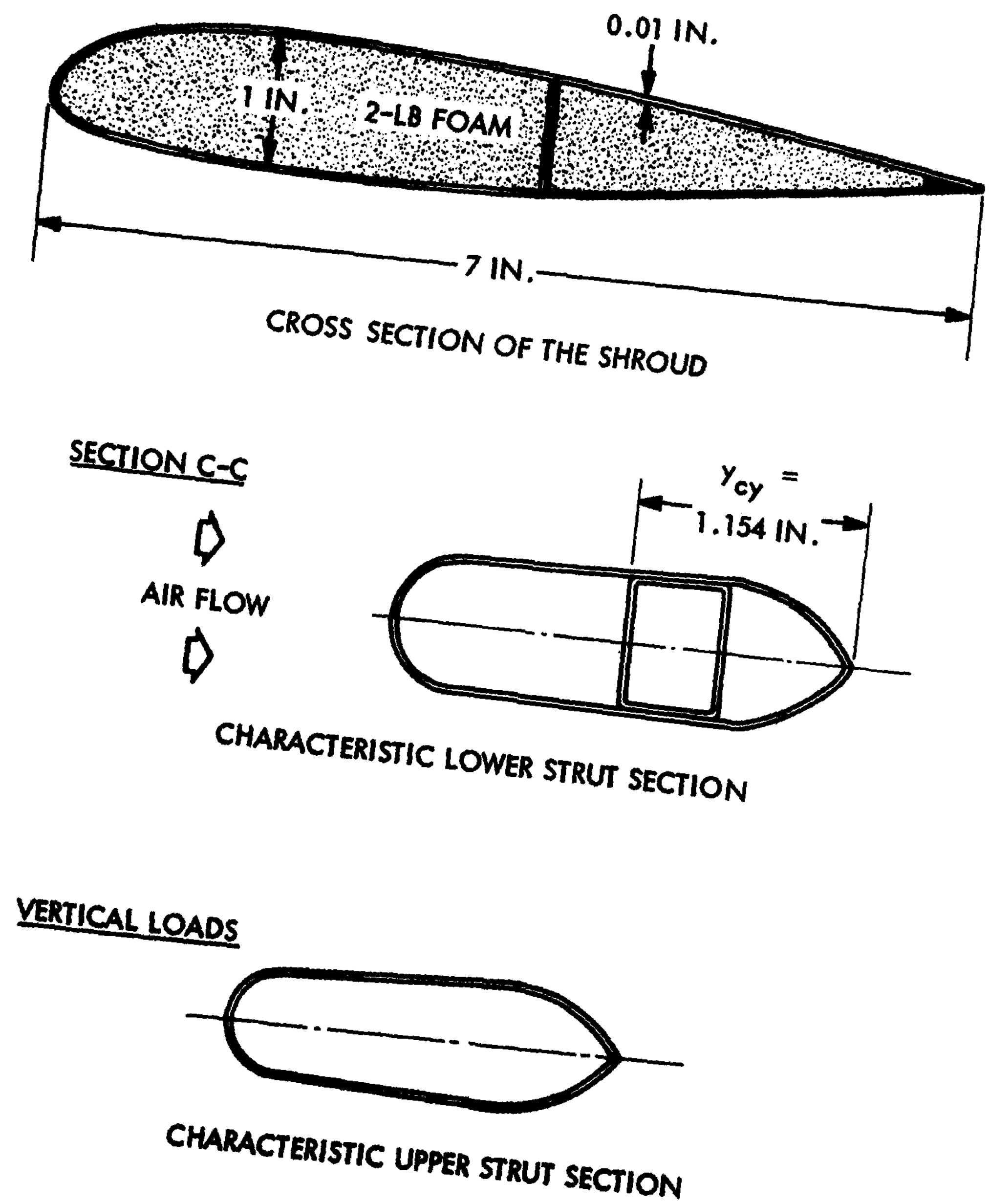


Figure 27. Structural Arrangement of RPV Shroud

applications, and assisted the airframe subcontractor in setting up the fabrication processes. Secondary structures (primarily equipment-mounting brackets) and door-sill reinforcements are made of fiberglass. Polystyrene foam is employed to stiffen shroud elements by preserving section cross sections. Microballoon-filled epoxy is used to stiffen elements where point loads require local strengthening. Nomex honeycomb is employed to stiffen door, bulkhead, and skin areas spanning large areas. Material properties and specific applications are discussed below.

3.2.4.1 Material Properties. Room-temperature properties of the materials used in the Aquila airframe are shown in Table 13. Only basic material properties are given; however, the ultimate allowable stress in a composite structure depends on the structural configuration of the part, e.g., honeycomb sandwich, laminate, etc. Appendix I of Reference 8 defines the maximum stress for design loads and the ultimate stress for the many structural elements in the Aquila airframe. (See also Volume II of this report.)

TABLE 13. AQUILA STRUCTURAL MATERIALS – ROOM-TEMPERATURE PROPERTIES

Material	Tension		Compression		Density ($lb/in.^3$)
	Strength (ksi)	Modulus (psi)	Strength (ksi)	Modulus (psi)	
Kevlar					
Unidirectional	170	10.1	40	10.1	0.048
Style Fabric 120	60	4.4	23	3.5	0.048
Style Fabric 281	70	4.4	26	4.0	0.048
E-Glass					
Unidirectional Fabric	160	5.7			0.072

3.2.4.2 Structural Element Design. The following paragraphs provide a brief description of the material applications for the various components of the RPV structure. Detailed descriptions and analyses are provided in Reference 8, and in detail drawings.

Fuselage. Primary fuselage bulkheads (130, 147, and 155) are constructed of Kevlar caps with a 0.25-in. sandwich web of Kevlar face sheets and Nomex honeycomb. Secondary bulkheads (104 and 113) are laminated Kevlar sheet. The removable bulkhead, 164, is perforated aluminum sheet 0.020 in. thick. Fuselage closing ribs are fabricated of Kevlar cloth. The large upper access panel, extending from bulkhead 130 to bulkhead 155 and containing the fuel cell, is honeycomb with Kevlar face sheets and 0.125-in. Nomex core. The fuel cell box is of similar honeycomb construction. All other access doors (panels) and the nose cap are of Kevlar cloth. Sills of the access holes and edges of the access doors (panels) and nosecap are reinforced with strips of E-glass to accommodate the screw fasteners. Brackets for mounting subsystem elements into the fuselage are predominantly of E-glass. The spool mount for the alternator is an exception, being laid up of Kevlar cloth.

Wings. In the absence of internal ribs, the basic airfoil shape is maintained by a sandwich skin of Kevlar cloth face sheets and 0.25-in. Nomex honeycomb. Full length spars are located near the 25-percent and 70-percent chord points. Each spar consists of Kevlar cloth with Kevlar cap doublers. The caps are bonded to the sandwich skin outer sheet. The spar webs are beaded to increase shear load-carrying ability. The blunt trailing edge is reinforced with microballoon-filled epoxy.

Each spar cap doubler extends through the wing closure rib and is attached by two fasteners to fittings bonded to the fuselage primary bulkhead caps. Aluminum doublers are bonded to the attachment points to increase bearing strength. Elevon construction is similar to the wing, consisting of 0.125-in. Nomex honeycomb with Kevlar face sheets. There are no spars in the elevon. End closures are of Kevlar cloth.

Shroud. The propeller shroud structure consists of Kevlar skin filled with 2-lb/ft^3 density polystyrene foam. The struts are of similar construction, except for the body attachment regions, which are filled with an epoxy/ microballoon mixture to react the attachment bolt loads.

3.3 POWER PLANT

The power plant of the Aquila RPV is composed of the following elements:

- Engine
- Fuel storage and delivery system
- Propeller
- Electrical power generation system

3.3.1 Description

A McCulloch Corp. Model MC-101MC single cylinder, two-cycle, air-cooled engine forms the basis for Aquila propulsion. LMSC-developed procedures (Reference 8) are used to prepare the engine for flight application. This engine directly drives a pusher propeller to generate thrust. A rear view of the installation is shown in Figures 28 and 29. A flexible, wound-steel-wire shaft attached to the engine flywheel drives an alternator at engine speed to produce electrical power.

3.3.1.1 Engine.

McCulloch Specifications. The applicable McCulloch specifications are:

• Displacement	7.5 $in.^3$ (123 cc)
• Bore	2.280 in. (58 mm)
• Stroke	1.835 in. (46.6 mm)
• Compression ratio	9.4:1

[8] Mueller, Jan E., PREPARATION OF AQUILA ENGINES, Specification No. 5542016-C, Lockheed Missiles and Space Company, Inc., Sunnyvale, California, 30 January 1976.

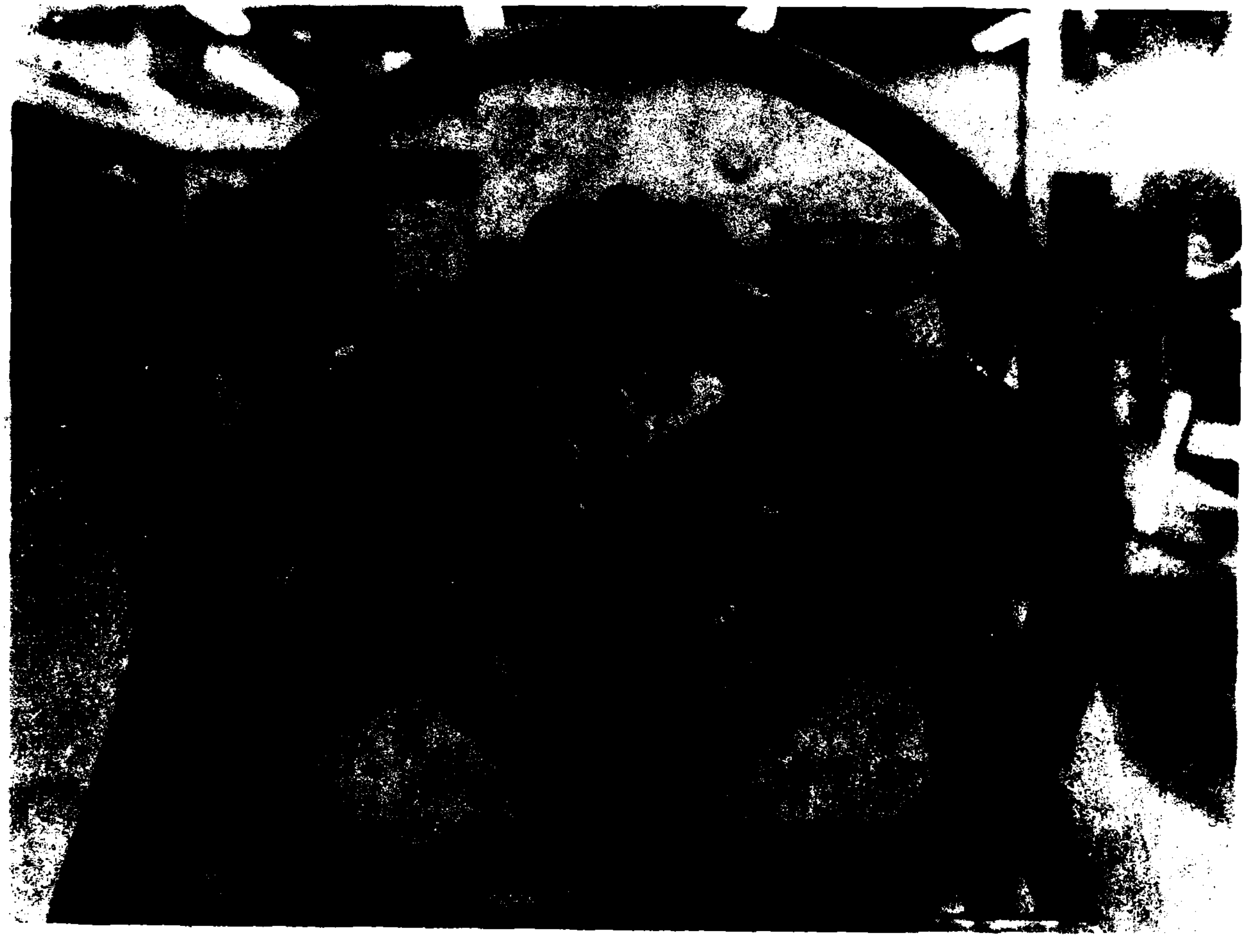


Figure 28. Installation of Cowled Engine, Aft View

Figure 29. Installation of Uncowled Engine

• Inlet valve	Four petal reeds on V-block
• Piston	Heat-resistant aluminum alloy
• Piston rings	Two, narrow tool-steel type, pinned to maintain alignment
• Connecting rod bearings	M-50 tool-steel needle rollers, uncaged
• Wrist pin bearings	Two caged needle roller bearing sets, pressed into piston
• Main bearings	Two caged ball bearings, thrust bearings
• Crankshaft	Engine equipped with SAE J609 0.75-in.-diameter power takeoff shaft; counter-balanced, hot forged steel hardened and ground; extensively shot-peened and tungsten counterweights
• Cylinder-crankcase	Die-cast aluminum alloy with precision-honed cast-iron reborable liner
• Cylinder head	Die-cast aluminum alloy, removable
• Direction of rotation	Clockwise (facing power takeoff shaft)
• Ignition	Waterproof, high-tension, high-output magneto; heat-resistant, moisture-proof coil bonded to lamination
• Flywheel	High-pressure die-cast aluminum alloy with integral magneto magnets, a steel hub, and cast cooling blower vanes

The LMSC development of the Aquila engine is described in Reference 5.

Carburetion. A Hartman Engineering MCM-1 reed valve and induction manifold are employed on the engine. An adapter plate is used to fix two Walbro Corporation SDC-56 chain-saw carburetors to the manifold. The carburetor installation is shown in Figures 30 and 31.

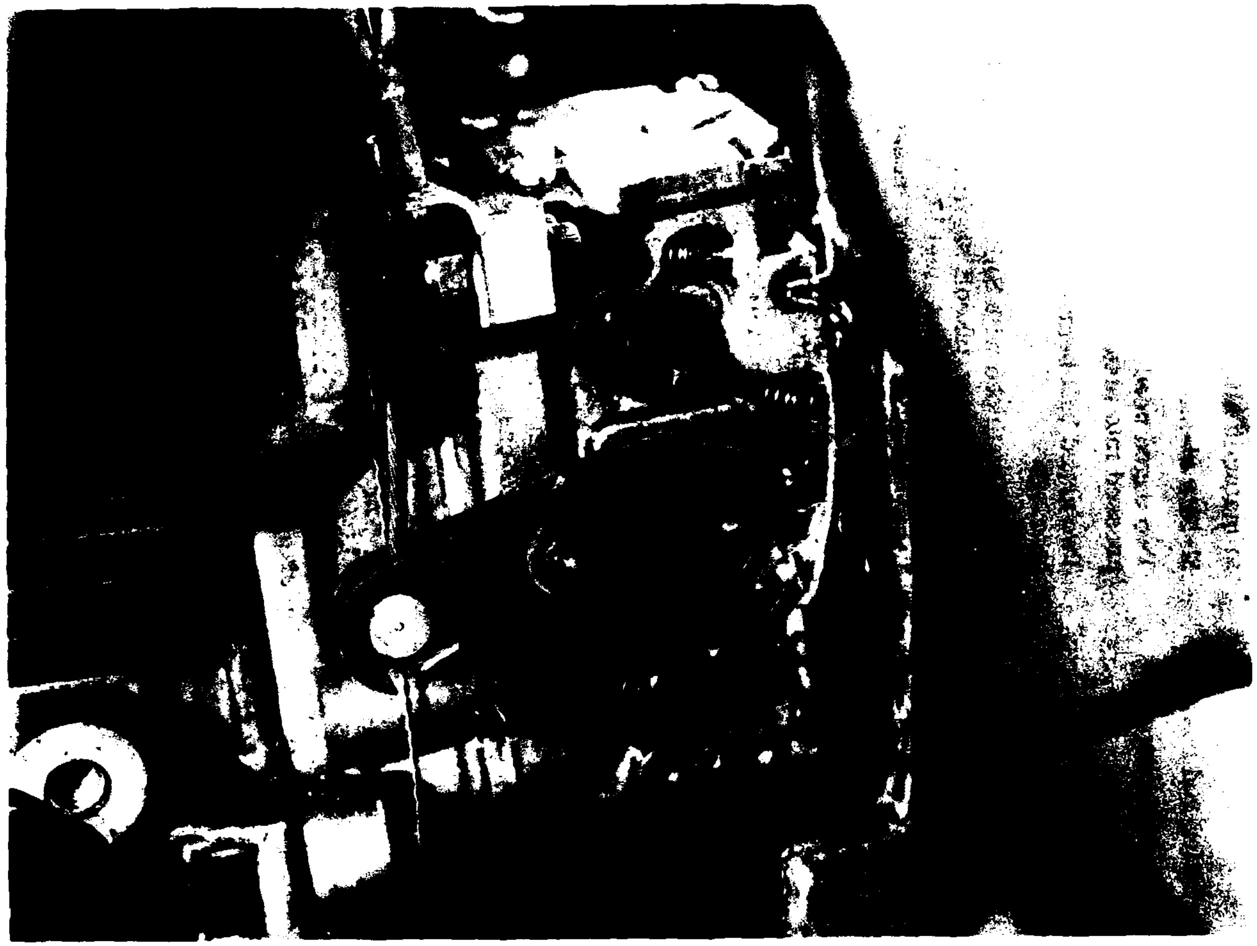


Figure 30. Installation of Carburetor, Aft View

Figure 31. Installation of Carburetor, Forward View

The SDC-58 carburetor fuel-flow regulation system is a diaphram, lever, and spring mechanism that locates a needle valve controlling fuel flow relative to venturi and ambient air pressure differences. Fuel is supplied to the regulator by a diaphram fuel pump integral to the carburetor. One side of the fuel pump diaphram is interconnected to the engine crankcase and is driven by pulsations in crankcase pressures. The fuel inlet fittings of the two carburetors are manifolded to the fuel supply line from the fuel tank. An air bleed is provided on the manifold to allow removal of air bubbles in the fuel line before an engine start. Fuel mixture ratios are controlled by a fixed main jet and an adjustable low-speed jet on each carburetor.

The butterfly valve throttles of the two carburetors are driven by a central cam that pivots about a shaft threaded into the manifold adapter plate. The cam is actuated by a rotary servoactuator through a bell crank and cable mechanism. Idle speed is adjusted by turning a threaded sleeve at the engine bulkhead to shift the position of the cable sheath relative to the servoactuator.

Idle fuel mixture is supplied by both carburetors. The primary carburetor (lower) provides the additional fuel-to-air mixture required to reach approximately 6,000 rpm. Above 6,000 rpm, both carburetors are engaged and reach the fully opened position simultaneously. This progressive-action, two-carburetor arrangement allows the engine to operate on one relatively small carburetor in a fuel-efficient manner under cruise conditions, but provides sufficient carburetor throat area at the full throttle position to obtain the full rated power of the engine.

Cooling Air Blower Shroud. The engine, as delivered from the McCulloch Corporation, is equipped with a two-piece shroud to control the blower inlet and exit flow. Surrounding the blower is a cast magnesium alloy section, to which a formed sheet steel section is attached to confine air flowing past the cooling fins of the engine cylinder head. The Aquila engine configuration uses a one-piece molded fiberglass shroud that reduces engine weight.

Spark Plug. The spark plug, a Champion model RL-78, is a commercially available two-cycle, 14-mm, spark plug; it is unusual in that it is a resistor type developed for use in Canada to meet radio interference restrictions. Use of this spark plug eliminates any need to further shield the engine ignition system to prevent electromagnetic interference problems.

Exhaust Stack. The exhaust system comprises a short stack formed from a length of mild steel seamless tubing, with inside diameter of 1.375 in. A mandrel is used to shape the upstream end to the outline of the engine exhaust port. A steel flange is welded to the stack to provide an interface to the engine mating bolt pattern. The exhaust end of the stack is shown in Figures 28 and 29.

Mounting. A horseshoe-shaped plate machined from aluminum stock is the mounting bracket for the engine. This plate is located against the engine casting surrounding the flywheel. The bracket is secured to the engine block by screws at the points provided by McCulloch to mount the original cooling blower shroud.

Four tabs protrude radially from the bracket and are drilled to accept the mounting studs of the model J 4624-27 Lord isolation mounts. The isolation mounts are in turn bolted to aluminum extrusions mounted from the rear face of bulkhead 155. Shims are placed between the isolation mounts and the aluminum extrusions to center the engine power takeoff shaft within the propeller shroud.

Alternator Drive. An aluminum adapter bolts to the flywheel center on the forward side of the engine. A square broached aperture accepts a square-ended, wound-steel-wire, flexible shaft. The flexible shaft is pinned solidly to the alternator armature shaft. The slip fit of the adapter to the flexible shaft permits engine movement relative to the fixed-position alternator while torque is continuously transmitted.

Propeller Hub and Starter Interface. The engine power takeoff shaft is 2 in. long and 0.75 in. in diameter. A keyway is provided for the transmission of torque to the hub. The three-piece hub is a lathe-turned aluminum part. The propeller is clamped by the washer, secured with four screws, and safety-wired. The hollow-hub tailshaft is pierced by a roll pin that is first pressed in and then safety-wired. This roll pin provides a point of contact for the engine starter shaft, which enters the hub and engages the drive pin with a slotted end.

Instrumentation. A thermistor is installed in the tapped hole in which the McCulloch compression release valve is normally fitted. The temperature signal voltage is telemetered to the ground control station (GCS) so that engine temperature can be monitored by the vehicle operator.

A second thermistor is located on bulkhead 155 to monitor the air temperature of the engine compartment. The data are recorded at the GCS but are not continuously monitored.

Engine speed is derived from circuitry connected to the alternator. This information is used by the flight control system as feedback in the rpm control loop and is telemetered to the GCS, where it is monitored continuously.

3.3.1.2 Fuel Storage and Delivery System.

Fuel Tank. The Aquila fuel tank is a plastic bladder with a capacity of approximately 16 lb of fuel. No vent is used for the tank, which collapses under ambient pressure as fuel is drawn off. The single tank aperture is used both as an outlet and a fill point. A special refueling apparatus is required that will first apply a vacuum to the tank to remove any air or fuel and then to fill the tank without admitting air. This type of fuel tank eliminates the possibility of air entering the fuel supply line when the vehicle assumes unusual attitudes.

The fuel tank is stored on board the RPV within a Kevlar box attached to the underside of the vehicle central access cover. The fuel tank can therefore be removed from the vehicle for refueling.

Fuel Supply Line. Fuel lines are made of clear plastic Tygon tubing, which is resistant to hardening when exposed to gasoline. After exiting the fuel tank, the line is fitted with a quick-disconnect coupling that simplifies removal of the fuel tank from the vehicle. The fuel line is directed aft from the quick-disconnect coupling through two bulkheads to the carburetor fuel inlet manifold. The fuel line has a 0.25-in. internal diameter from the fuel tank to the quick-disconnect coupling. Between the quick-disconnect coupling and the engine, the fuel line has a 0.125-in. internal diameter. Fuel lines are secured at each fitting with a double wrap of safety wire.

Low Level Indicator. A lever arm is pivoted so that the free end bears against the upper surface of the fuel tank bladder. As fuel is consumed and the bladder height drops, a microswitch is tripped, closing a circuit that indicates a preset level of fuel remaining.

Fuel Mixture. The specified fuel mixture for the Aquila RPV is 16 parts aviation grade gasoline, MIL-F-5572, 100/130 octane, to 1 part McCulloch Corporation 2-cycle oil by volume.

3.3.1.3 Propeller. The propeller used for the Aquila RPV is a wooden, two-blade design fabricated by Propeller Engineering Duplicating of San Clemente, California. Four laminations are used to provide strength. The trimmed diameter is 19.5 in., which allows a nominal 0.5-in. clearance between blade tips and the propeller shroud inner surface.

Each propeller is profiled and tested to produce consistent maximum engine speed while running statically. The activity factor and blade pitch angle are chosen to be most efficient at the best climb speed for the aircraft. The nominal full-throttle, static, propeller speed is 8,000 rpm at sea level. A variation of ±100 rpm in the 8,000-rpm range is the allowed difference from the rpm of a standard (calibrated) propeller for acceptance of propellers. Acceptance testing for the engine and propeller combination is conducted in accordance with Reference 9.

Electrical Power Generation System. The RPV electrical power is supplied by an alternator coupled to the engine. This alternator is an ac rotary machine of the Lendell design similar to the machines currently used by the automotive and light-aircraft industry, although of lighter weight and capacity. A solid state rectifier stack is integral to the alternators. Regulation of the alternator output is provided by a remotely mounted solid state regulator.

The alternator/regulator combination provides a maximum of 600 W of power over an engine speed range of 4,000 to 10,000 rpm. The output voltage is regulated at a nominal 28.4 Vdc. The alternator and regulator are built by W. J. Dufresne Company.

A secondary battery is connected across the output of the alternator to provide emergency power if an alternator or power plant fails. This battery will support the essential electronics for approximately 5 min (depending upon initial charge and condition of the battery), allowing time for either normal recovery or a skid landing of the aircraft.

The battery is a series-connected 19-cell, vented secondary nickel-cadmium battery. It is rated at 0.8 Ah at a 1-hour rate, derated to 0.66 Ah at a 10-min rate with end of life voltage defined as 18 V. The battery is supplied by Eagle-Picher Industries.

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[9] Mueller, Jan E., ACCEPTANCE TEST FOR RPV-STD ENGINE TUNING, ATP 5542017-D, Lockheed Missiles and Space Company, Inc., Sunnyvale, California, 22 July 1975.

A power supply built by Gulton contains a dc-to-dc converter and three precision voltage regulators to provide the regulated voltages required by the flight control electronics. This unit operates from the +28 Vdc bus and is capable of providing +5.0 ± 0.3 Vdc at 1.5 A maximum, and +15 ± 0.15 Vdc at 750 mA maximum. In actual operation this unit is derated to 60 percent of its maximum capability.

The RPV power switching is provided by a relay assembly designed and fabricated by LMSC. A command via the umbilical plug activates the primary bus relay, applying power to the flight control electronics, all flight control transducers, and the command receiver. This relay electrically latches and remains latched until commanded off, again via the umbilical. When in the off position, the primary bus relay isolates all the electrical load from the battery.

After the primary bus has been energized and the engine speed has exceeded 1,500 to 1,700 rpm, the secondary bus relay is energized. The secondary bus provides power to the telemetry transmitter and the payload electronics. This bus automatically drops off-line when the engine speed falls below 1,500 to 1,700 rpm or when the primary bus is commanded off.

3.3.2 Requirements and Capabilities

3.3.2.1 Power. Figure 32 shows curves of engine brake horsepower versus rpm for density altitudes of sea level, and 4,000, 8,000, and 12,000 ft. These curves give maximum horsepower available without subtraction of installation losses or reduction due to power absorption by the vehicle alternator.

Since the induction air for the engine is drawn from a closed compartment, temperature rises and pressure drops can cause installed power to be less than the rated maximum. Average alternator power is 0.55 hp at all rpms. Peak available engine power exceeds the 11 hp initially predicted by 0.7 hp.

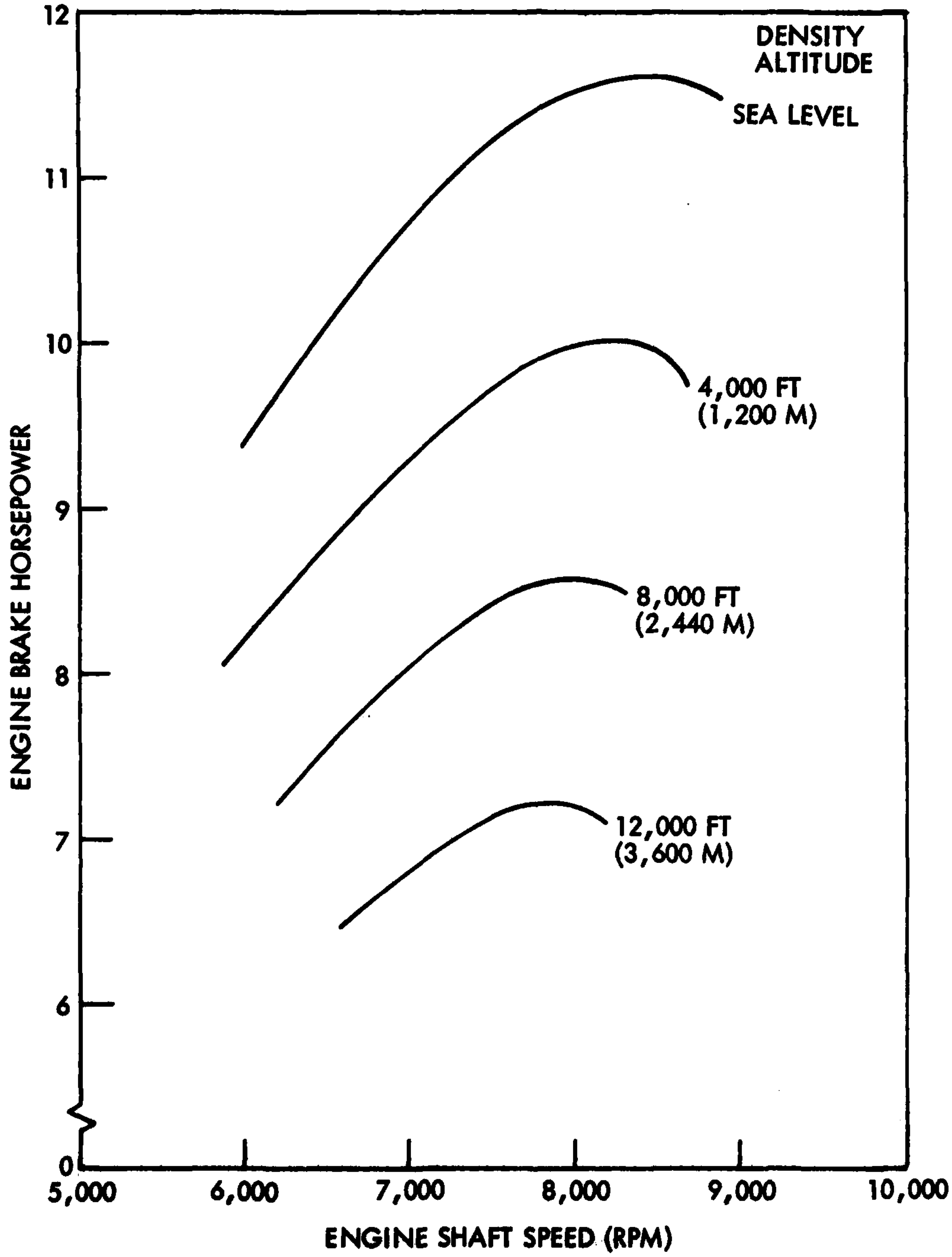


Figure 32. Engine Horsepower

3.3.2.2 Fuel Consumption. Figure 33 provides a graphic representation of specific fuel consumption relative to rpm for a propeller load similar to the flight item. Each of the four curves applies to a different density-altitude condition. Lines of constant horsepower are included for reference.

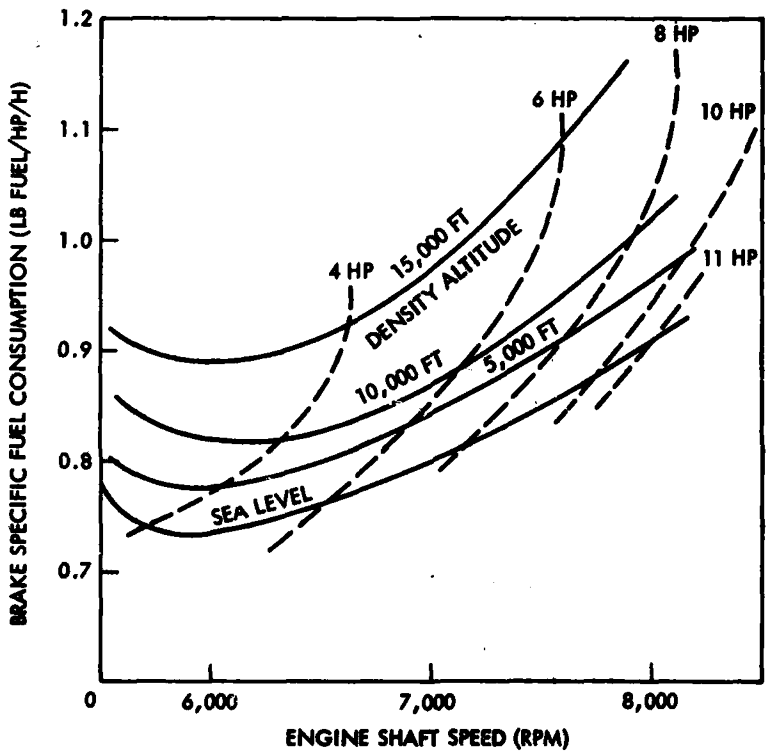


Figure 33. Specific Fuel Consumption, Partial Load

Specific fuel consumption at the full power condition at sea level is 5 percent better than initially predicted. A 30-percent improvement over predicted values exists at the 12,000-ft level. The 0.74 lb/hp/hour value for the sea-level cruise condition is unusually low for two-cycle engines.

3.3.2.3 Weight. Power plant weight is as follows:

Engine (includes carburetion, cooling fan shroud, and ignition)	13.18 lb
Exhaust stack	0.35
Throttle linkage	0.25
Propeller assembly (includes propeller, shaft extension, washer, and hub)	0.91
Fuel system (includes bladder tank, low-level sensor, fuel lines, and quick-disconnect coupling)	1.05
Alternator drive (includes flywheel adaptor, and drive shaft)	0.24
Total	15.98 lb

3.3.2.4 Electrical Power Capability. Figure 34 graphically illustrates alternator output as a function of engine rpm. Constant amperage lines of 20, 16, 12, 8, and 4 demonstrate that a peak power of 566 W is available from 3,900 engine

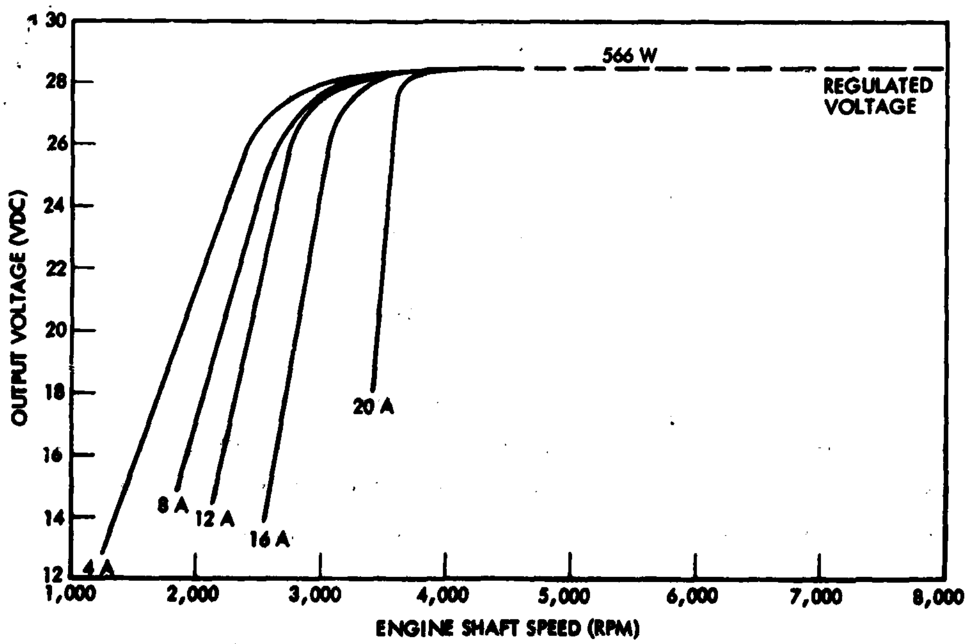


Figure 34. Variation of Alternator Output With RPM

rpm and above. The flight control rpm loop limits minimum engine speed to 4,000 rpm to maintain full alternator power throughout the available engine speed range. The design aim was an alternator of 500-W capability and a regulated voltage of 28.4 Vdc.

An early goal for power plant weight, less the fuel system, was 14.66 lb. The current power plant weight, less fuel system, is 14.93 lb. The difference represents approximately a 2-percent increase for the current design.

3.4 FLIGHT CONTROL SYSTEM

The RPV flight control system performs the dual function of stabilizing the RPV and controlling the flightpath in conjunction with the GCS computer via the uplink telemetry. The system requires no directly applied piloting skills to fly the RPV. Aircraft stabilization is accomplished within the aircraft onboard electronics system; heading rate, altitude, and speed commands from the GCS direct the flight of the aircraft. All RPV position, navigation, target-location, and artillery-adjustment computations are performed by the computer in the GCS.

The system consists of three closed-loop systems that control airspeed, altitude, and heading rate. The closed loops operate in three primary modes: cruise, dead reckoning, and approach. The aircraft is stabilized by onboard closed loops, so the operator is not required to maintain hands-on operation to keep it in the air. The operator is able to command airspeed, altitude, and heading rate from controls on the console in the GCS during manual mode operation. The operator is also able to command automatic launch, preprogrammed navigation to selected geographic waypoints, automatic search and loiter patterns, and semiautomatic approach to recovery during which the computer is generating airspeed, altitude, heading rate, and z-axis velocity commands.

In the cruise mode, airspeed control is achieved by trimming the pitch angle of attack with the elevons operating in phase, altitude control is achieved by advancing or retarding the throttle for ascent and descent, and heading-rate control is achieved by controlling the angle of bank by operating the elevons differentially. During the cruise mode (block diagram in Figure 35), the GCS computer issues airspeed, altitude, and heading-rate commands. These are telemetered to the RPV, where they are compared with the measured status data; the resulting error signals are converted by the FCEP into servo-actuator commands. Dynamic pressure (velocity) and static pressure (altitude) data are provided by the air data system with flush-mounted calibrated pressure ports; heading rate data are supplied through a rate gyro.

In the dead reckoning mode (Figure 36), the RPV responds to commands programmed and stored in the autopilot. Speed and altitude are controlled in the same manner as in the automatic cruise mode except that the airspeed and altitude commands are obtained from storage registers in the autopilot. These registers are programmed via the telemetry link with airspeed and altitude data from the GCS computer for each leg before the start of the dead reckoning mode. The heading rate command is derived internally from circuits that compare the stored heading command in the autopilot (also programmed before the start of the dead reckoning mode) with the measured heading components sensed by the magnetometer. (The rudiments of this flight mode were demonstrated; i.e., dead reckoning legs were flown. Formulation and circuit anomalies, however, prevented reliable use of this flight mode, and evaluation by the Army was not accomplished pending resolution of the design anomalies.)

In the approach mode (Figure 37), command signals from the GCS operate the flight control system in a different manner from that in the cruise mode. Instead of controlling pitch, as in the cruise mode, airspeed commands control the throttle. Also, rather than control of the altitude, z-axis velocity is controlled. On the approach glideslope, the elevons receive in-phase z-axis velocity commands, thereby controlling the rate of descent. The z-axis velocity

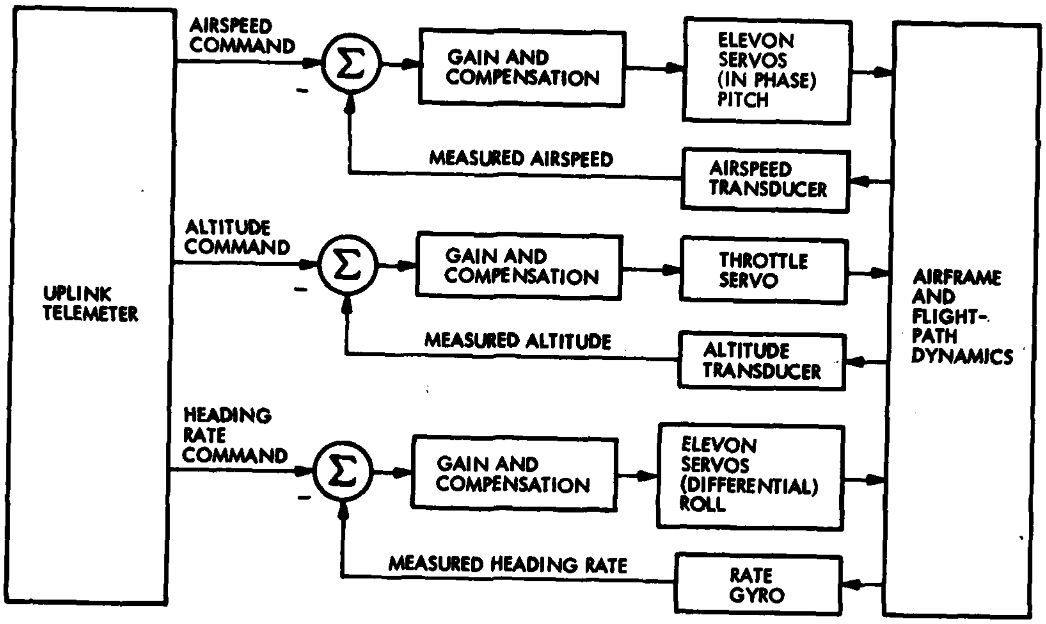


Figure 35. Block Diagram of Flight Control System, Automatic Cruise Mode

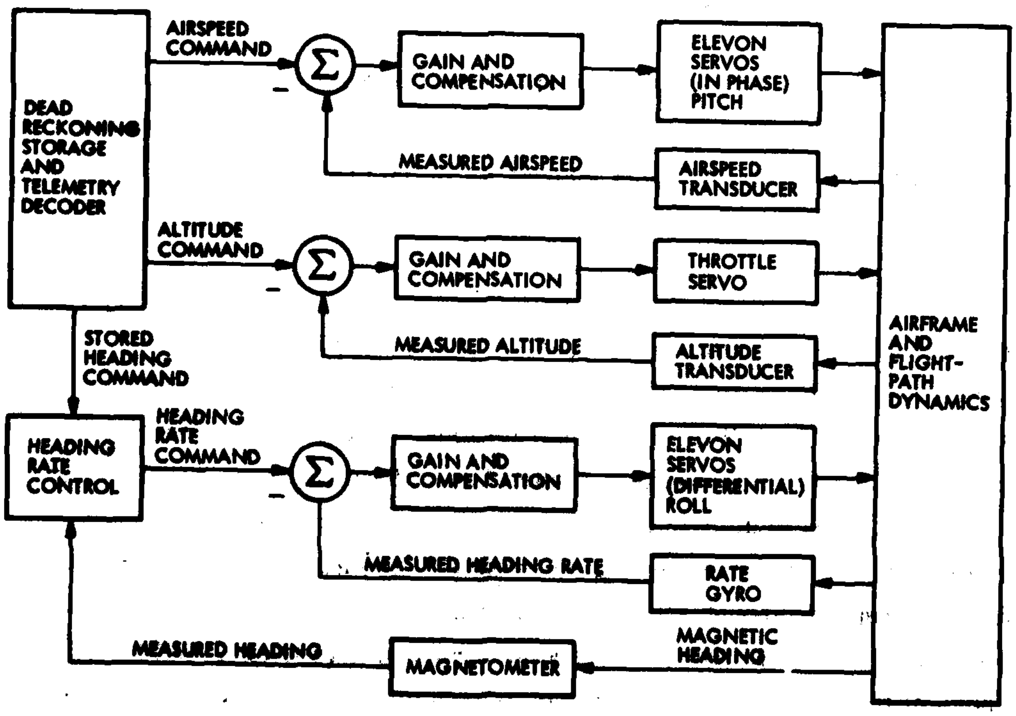


Figure 36. Block Diagram of Flight Control System, Dead Reckoning Mode

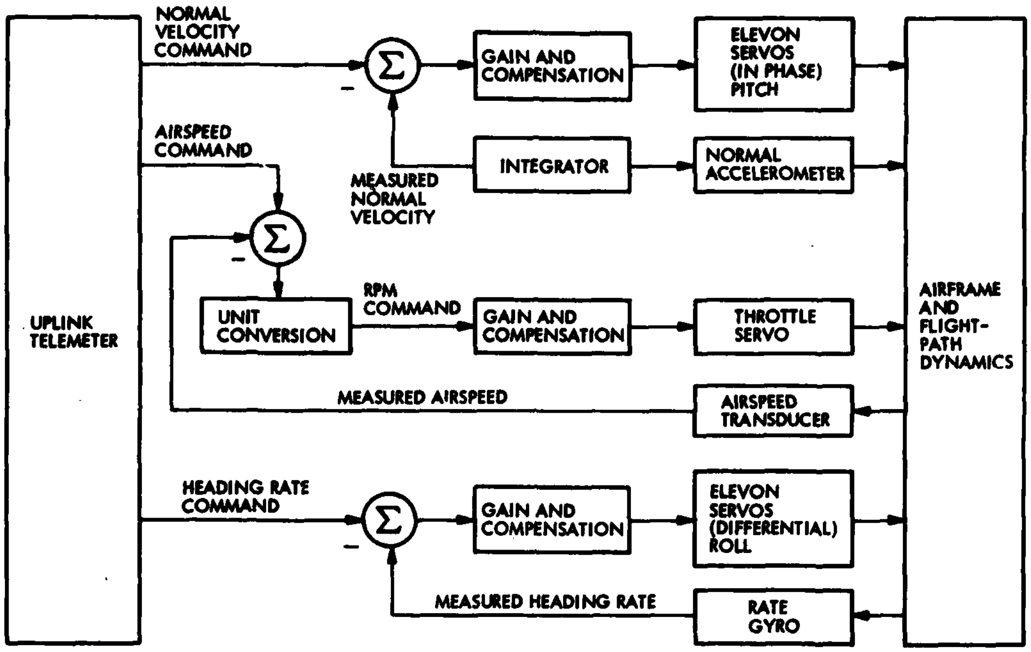


Figure 37. Block Diagram of Flight Control System, Approach Mode

commands are compared with the integrated output of the RPV z-axis accelerometer resulting in application of z-axis velocity error to the elevons. Heading-rate control is achieved in the same manner as in the cruise mode.

4.5.1 Description

The RPV flight control system comprises six units: an autopilot, servo-actuators, an air data system, a rate gyro, a magnetometer, and an accelerometer. These are described in later paragraphs. The autopilot controls the servoactuators and is composed of 8 of the 11 circuit cards in the FCEP. The servoactuators, used to actuate the elevons and engine throttle, are mounted inboard of each elevon and on the engine firewall. The air data system senses altitude and airspeed through static and dynamic ports in the nose of the vehicle, and comprises an altitude transducer and an airspeed transducer, both mounted in the nose of the aircraft. The rate gyro senses pitch and yaw attitude rate and is mounted in the nose section of the aircraft. The magnetometer provides data for deriving aircraft heading and is located near the end of the left wing. The accelerometer provides data for the approach mode and is located in the nose. Figure 38 shows the placement of these components.

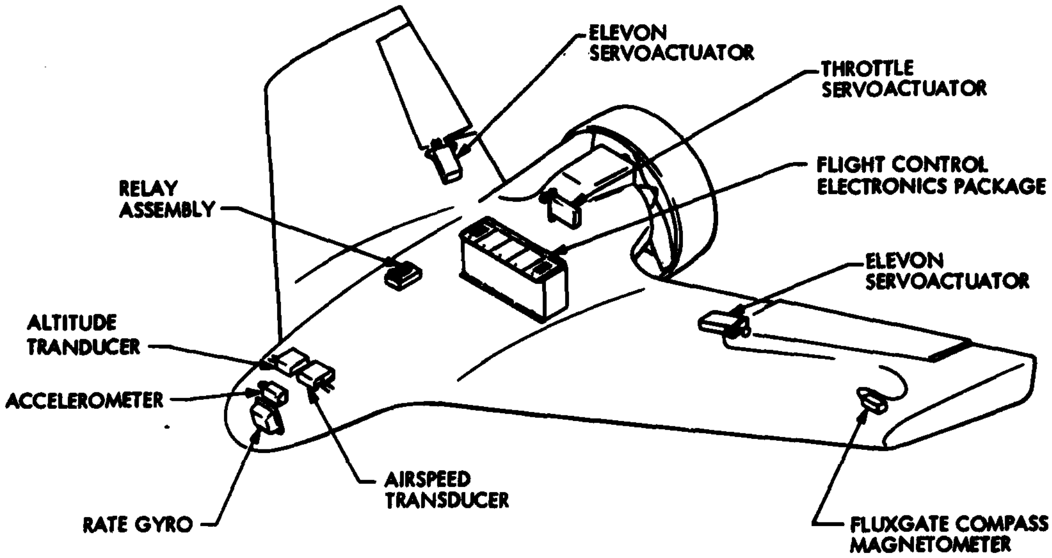


Figure 38. Flight Control System Hardware

3.4.1.1 Autopilot. The autopilot consists of eight plug-in printed circuit boards designed and fabricated by LMSC. These boards are housed in the FCEP, along with the telemetry PCM encoder, decommutator, and bit syncronizer boards built by AACOM, Inc. Figure 39 portrays the board placement in the FCEP. The matrix wiring is shown in Figure 40.

The autopilot pitch-loop electronics are divided between two boards — the pitch-control and the pitch-damping printed circuit boards. The pitch-damping board also provides the control-surface cross coupling required by the heading loop because the RPV lacks a rudder. The pitch-loop electronics are an analog design.

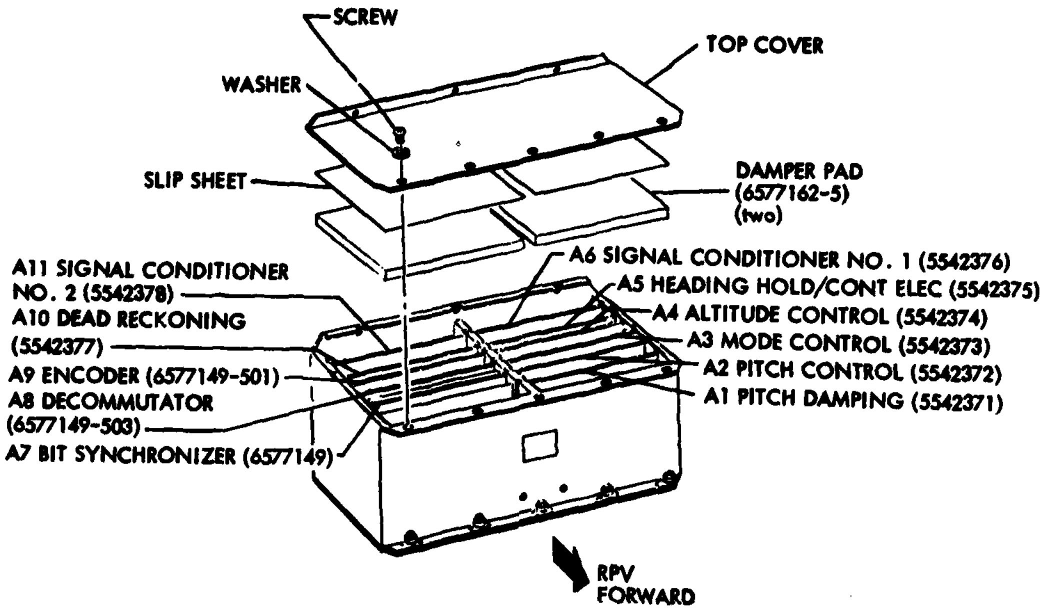


Figure 39. Placement of FCEP Boards

Figure 40. Matrix Wiring

The heading-loop electronics are contained on the heading-control board and are also an analog design. The heading-control board also contains the heading-hold circuitry, which allows the RPV to fly a magnetic compass heading during dead reckoning missions.

The altitude-loop electronics are also contained on a single printed circuit card and are an analog design. The rpm control-loop electronics (an interloop to the altitude loop) are included on the altitude-control board.

The two signal conditioner boards provide a variety of functions and are of both analog and digital design. These circuits include the conditioning of transducer signals for the autopilot and/or telemetry, the dead reckoning recovery tone detection, and the power-switching interfaces between the autopilot logic and the payload protector solenoid or power control relays located externally to the FCEP.

The dead reckoning function is provided by the dead reckoning board. This circuit is a digital design that stores three frames of telemetry command data. Dead reckoning is implemented by repeatedly feeding the PCM decoder a single frame of data for each leg of the dead reckoning mission. This card also includes the timer, which selects the next frame of stored data at the end of each leg. After the third leg, the timer returns control to the telemetry link.

The mode-control board is also a digital design. This board provides the digital signals to control the analog switches on the pitch-damping, pitch-control, heading-control, and altitude-control boards for the various autopilot modes. When the telemetry link is valid, these mode control signals are controlled by decoding a mode control word sent from the GCS via the command telemetry. When the telemetry link is not valid, predetermined link-loss modes are automatically decoded.

Telementry-link validity is tested on the mode-control board. The payload-protector deployment, engine-kill command, and laser-arm and laser-fire telemetry commands are also tested on the mode-control card before use in order to prevent accidental events during telemetry link dropout. The flight-termination timer, which kills the engine after 128 sec of continuous link loss, is located on this board.

The FCEP weighs 6.9 lb and occupies 400 in.^{3} (4.25 in. wide, 6.6 in. high, and 14.4 in. long). The enclosure (Figure 41) is fabricated out of molded graphite using a proprietary technique developed at Lockheed and offers a strong, lightweight package. The card retention techniques have been developed and proved by LMSC in satellite programs.

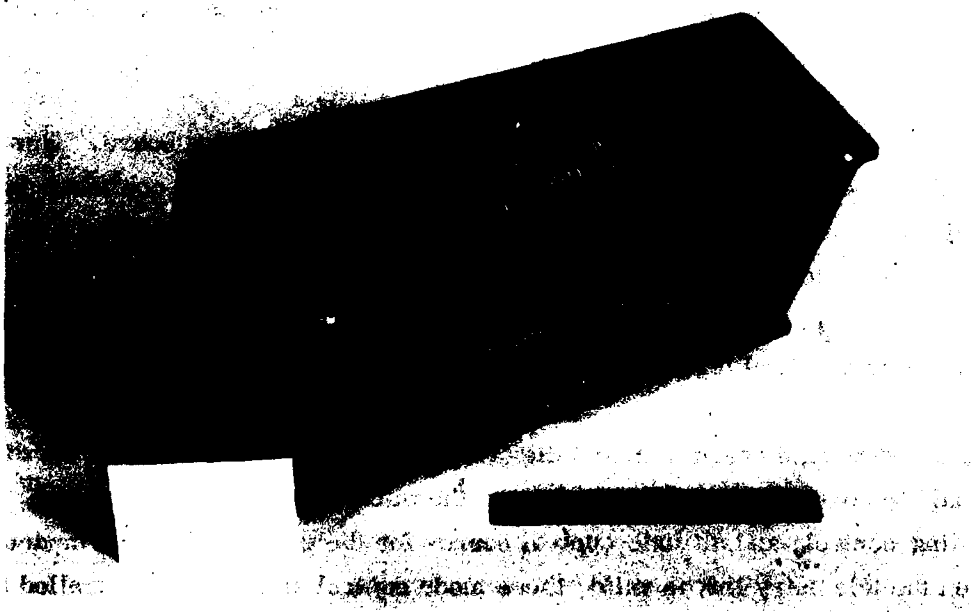


Figure 41. Enclosure for Flight Control Electronics Package

The total power dissipation for the eight autopilot boards is nominally 5.8 W. Power dissipation for the three data-link boards is nominally 7.0 W. Cooling is provided by air directed over the FCEP. Two large screen-covered holes in the FCEP lid on later models allow for additional convective heat transfer.

3.4.1.2 Servoactuators. The servoactuators, used to drive the elevons and throttle on the RPV, consist of a dc motor driving an output shaft through a gear train. The position of the output shaft is measured with a potentiometer and is used as a position feedback to the input amplifier. The complete servo-actuator, which weighs 0.7 lb and occupies approximately 13 in.^{3}, is packaged in a metal housing with the output shaft on one end and an electrical connector on the opposite end. The output shaft is capable of rotation in both directions, with mechanical stops at approximately ±40 deg from the midposition.

The servoactuator operates with a nominal input voltage of 28 Vdc at a peak current of 0.5 A. Regulated ±15-Vdc input voltages (at 20 mA each) are used for the interior circuitry. The servoactuator responds to a control input signal that varies from -2.5 Vdc to +2.5 Vdc, corresponding to rotation of -40 to +40 deg. An output representing the feedback potentiometer position is used for telemetry data and has the same voltage representation as the input.

The servoactuators were purchased from Simmonds Precision Motion Controls, Inc., and extensively modified by Lockheed (Reference 10) to improve their performance and reliability. A photograph of the servoactuator is shown in Figure 42. The actuator shell is 0.98 in. thick, 1.88 in. wide, and 3.5 in. long. The connector, shaft, and mounting flanges expand the total length to 4.3 in. and width to 3 in.

[10]Jones, Ken, AQUILA RPV SYSTEM TEST REPORT, CDRL A00D, PART 7, SERVO-ACTUATOR DEVELOPMENT, LMSC-L028081, Lockheed Missiles and Space Company, Inc., Sunnyvale, California, August 1977.

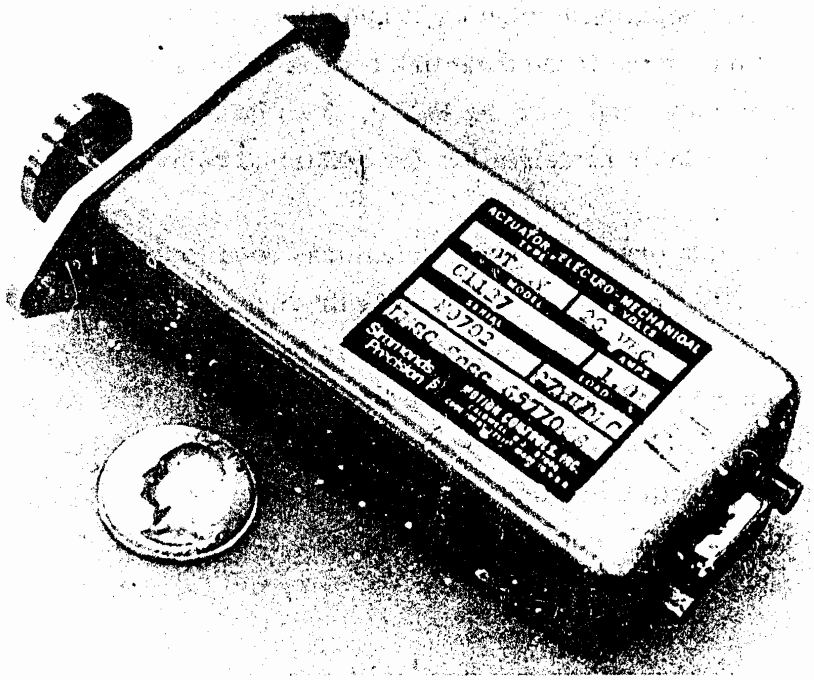


Figure 42. Servoactuator

3.4.1.3 Air Data System.

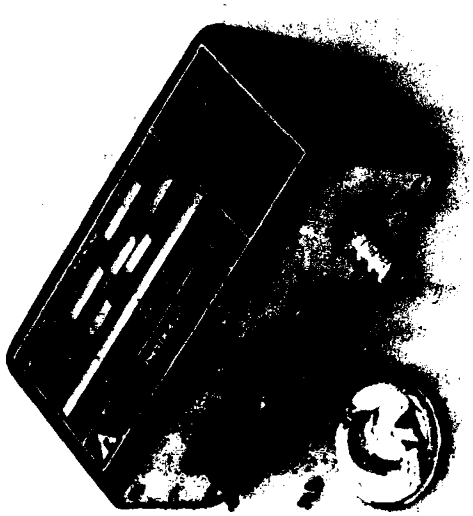
Airspeed Transducer. The airspeed transducer provides an output signal proportional to RPV indicated airspeed. Impact pressure is sensed by a differential capacitive pressure-sensing capsule that consists of a stainless steel case that houses a capacitor plate directly adjacent to a deflecting membrane. The chamber on one side of the membrane is exposed to the total pressure; the other chamber is exposed to the static pressure. The result is a membrane deflection proportional to impact pressure. The capacitance change generated by the pressure capsule as impact pressure changes is converted to a high-level dc voltage by the signal-conditioning electronics also contained in the aluminum enclosure. A controlled product oscillator — consisting of a control amplifier, a feedback network, and an oscillator — excites the pressure capsule with a closely controlled ac voltage. A detector develops a dc signal, proportional to the excitation and capacitance of the capsule, and amplified. The result is an output signal proportional to indicated airspeed.

The airspeed transducer, which weighs 6 oz and occupies 6.25 in.^{3}, is manufactured by Rosemount, Inc. The transducer operates from a ±15-Vdc supply at a nominal input current of 25 mA. The transducer provides a dc output voltage range of 0 to 6.5 V, corresponding to an indicated airspeed range of 30 to 130 knots. A photograph of the airspeed transducer is shown in Figure 43.

Altitude Transducer. The altitude transducer provides an output signal proportional to RPV altitude. Static barometric pressure is sensed by a capacitive pressure-sensing capsule. The capsule consists of a stainless steel case that houses a capacitor plate positioned directly adjacent to a free-edge diaphragm. This free-edge design allows for a low-stress, hinge-like deflection of the diaphragm to provide superior hysteresis, repeatibility, and resolution performance. The chamber on one side of the diaphragm is exposed to the static pressure; the chamber in the opposite side is evacuated and sealed off. The result is a diaphragm deflection proportional to barometric absolute pressure. The capacitance change generated by the pressure capsule as barometric pressure changes is converted to a high-level dc voltage proportional to altitude by the signal-conditioning electronics in a manner similar to the electronics in the airspeed transducer.

The altitude transducer, which weighs 6 oz and occupies 6.25 in.^{3}, is manufactured by Rosemount Inc. The transducer operates from a ±15-Vdc supply at a nominal input current of 25 mA. The transducer provides a dc output voltage range of 0 to +6.5 V, corresponding to altitude ranges from -1,000 ft to 12,000 ft. A photograph of the altitude transducer is shown in Figure 43.

3.4.1.4 Rate Gyro. The rate gyro is used to provide sensing of the inertial rate over two orthogonal axes. The package contains two rate gyros. The installation in the RPV is such that one rate gyro corresponds to pitch rates and the other corresponds to a composite of yaw and roll rates. The rate gyro, manufactured by Hamilton Standard, was modified by Lockheed by the addition of laboratory-set resistors to isolate the null bias drift with power supply variations.



a. Airspeed

b. Altitude

Figure 43. Air Data Transducers

The rate gyro weighs 1.75 lb and occupies 27 in.^{3}. The unit operates off +28 Vdc with a nominal input current of 0.3 A. The output voltage range varies from -2.5 Vdc to +2.5 Vdc for a pitch rate range of -30 deg/sec to +30 deg/sec and for a roll rate range of -50 deg/sec to +50 deg/sec. A sketch of the rate gyro is shown in Figure 44.

3.4.1.5 Magnetometer. A three-axis fluxgate magnetometer, manufactured by Develco, senses components of the earth's magnetic field vector to derive a heading reference. The magnetometer senses the three components of the magnetic vector (pointing towards magnetic north) and outputs three proportional dc voltages. This magnetometer uses ring-core technology to take advantage of the size and power economies associated with multiple-axes-per-core construction. The complete magnetometer, with its ring-cores and sensor electronics, is housed in an rfi-shielded enclosure. One of the outstanding features of the magnetometer is its nonmagnetic construction – which means that zero offset error due to the "perming up" of the instrument (magnetization in parts when subjected to strong fields) has nearly been eliminated.

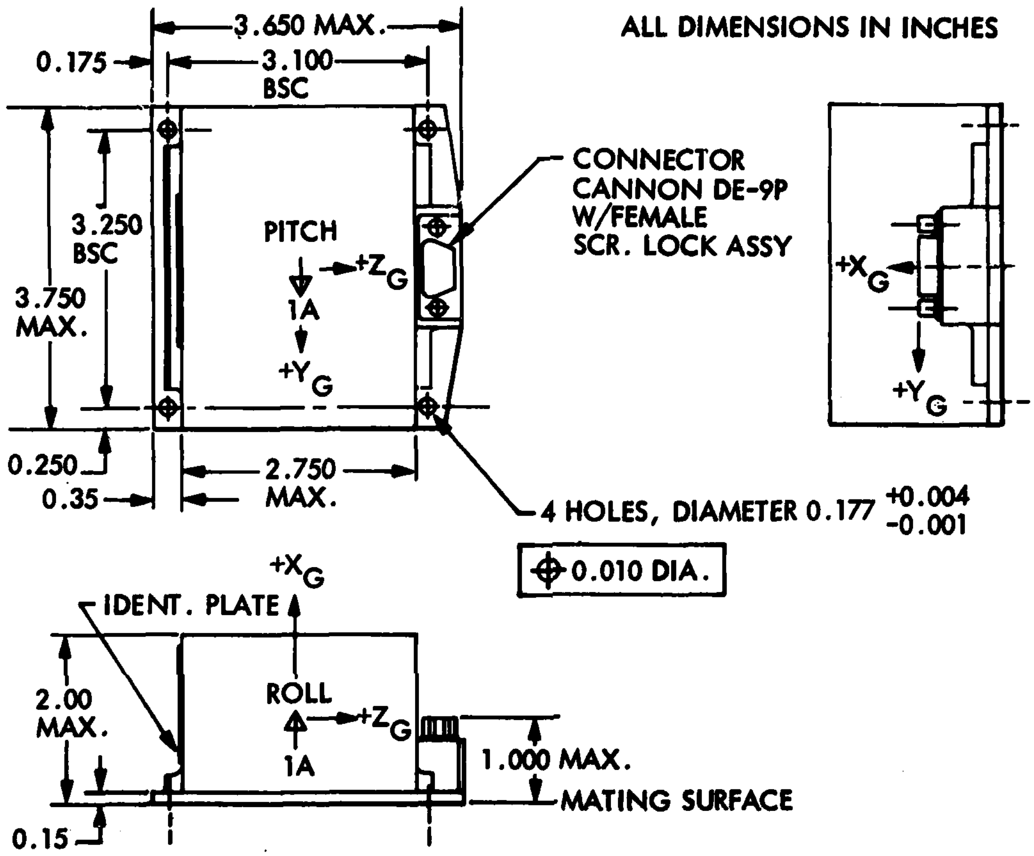


Figure 44. Two-Axis Rate Gyro Package

The magnetometer weighs 3.5 oz and occupies 4.5 $in.^3$. The unit operates off +28 Vdc at a input current of 35 mA. A dc output voltage of 2.5 V full scale corresponds to 600 mG. A sketch of the magnetometer is shown in Figure 45.

3.4.1.6 Accelerometer. The linear accelerometer, manufactured by Systron Donner, functions as a miniature servosystem responsive to input accelerations along its sensitive axis. Input acceleration creates a force that tends to move the seismic mass. This movement, which upsets the servo's balance, is detected by the position-error detector. The servo-nulling amplifier

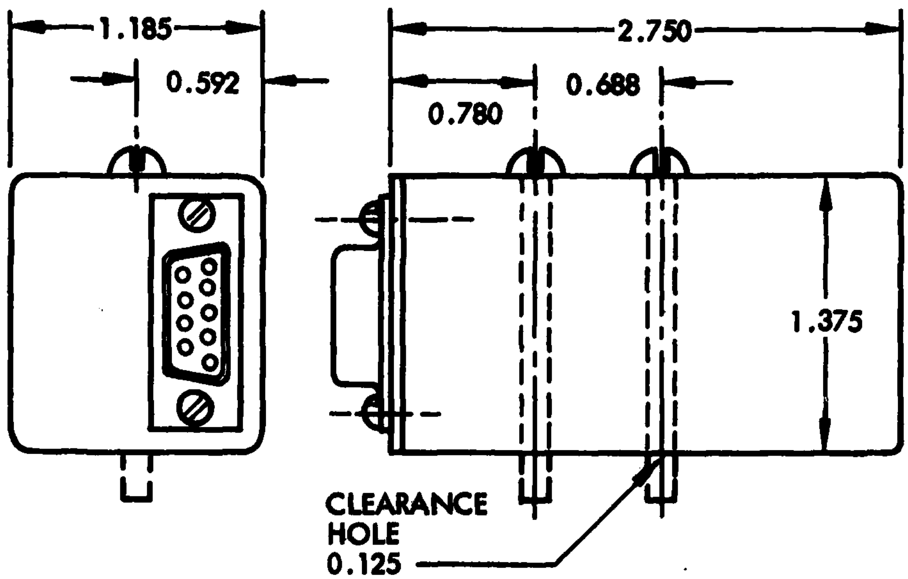


Figure 45. Magnetometer

requires a given preset input from the position-error detector. The amplifier sends a feedback current through the restoring coil, which is located in a permanent magnetic field, and causes a force exactly equal and opposite to the input force caused by acceleration. The restoring force returns the seismic system to its original position and in turn reduces or increases the output of the position-error detector until it reaches null. The servo system is now in a force-balance condition. The servo current required to achieve this balance is directly proportional to the input acceleration.

The accelerometer weighs 3 oz and occupies 2.7 in.^{3}. The unit operates off ±15 Vdc at an input current of 17 mA. The signal output voltage corresponds to a 0.80 V/g. A sketch of the accelerometer is shown in Figure 46.

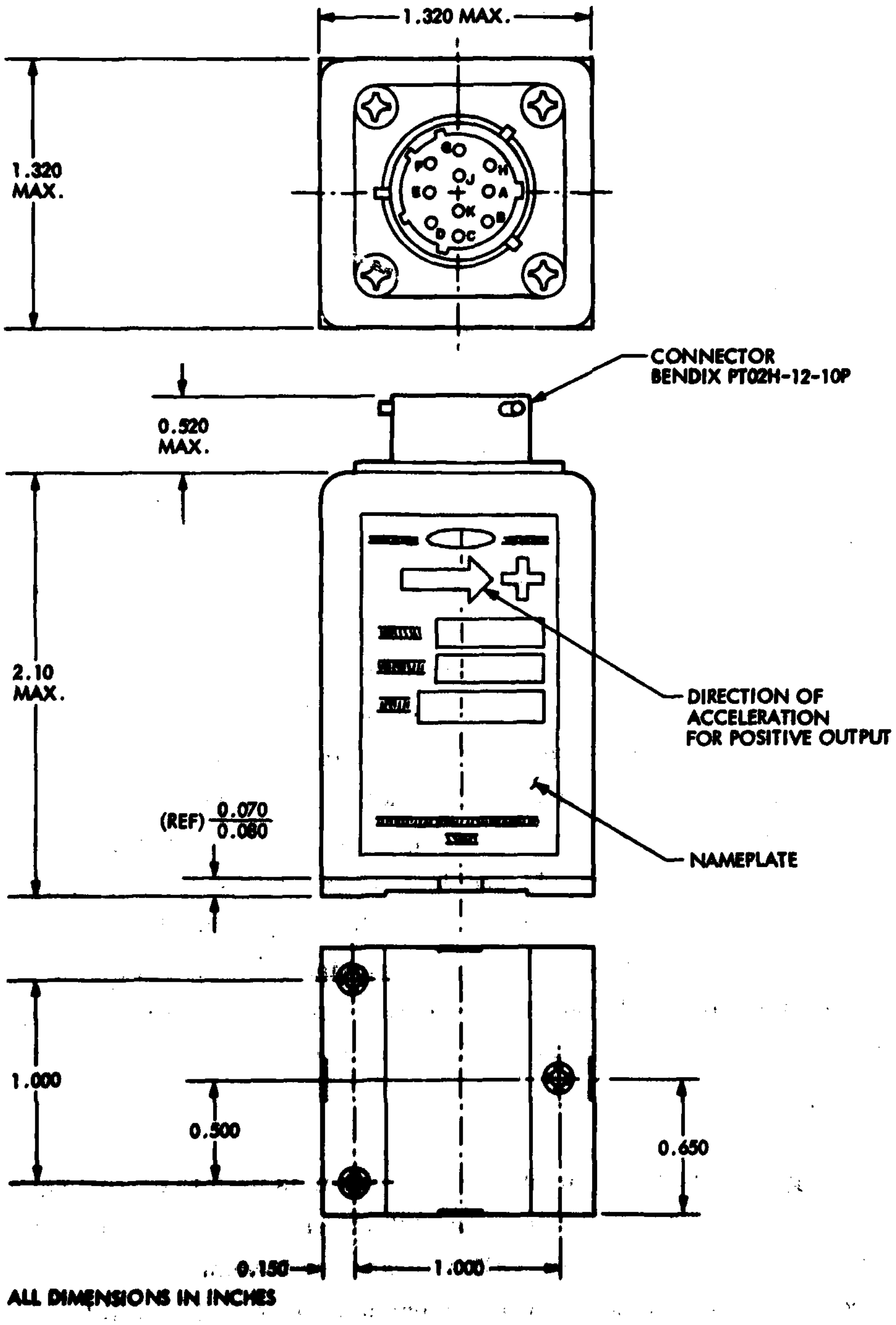


Figure 46. Accelerometer

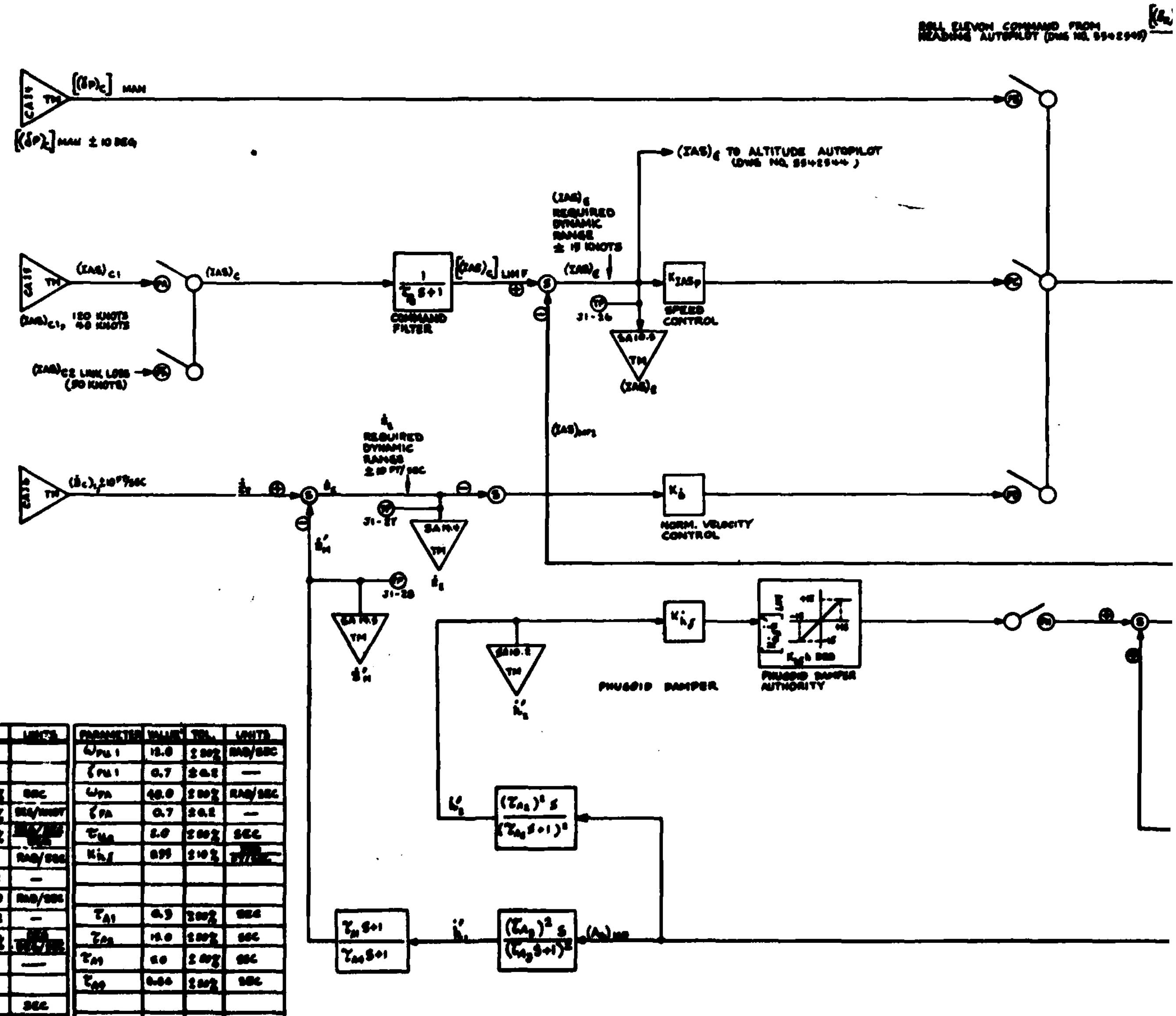
3.4.2 Requirements and Capabilities

The three principal control loops of the Aquila RPV-STD flight control system — pitch, altitude, and heading — are illustrated in the functional block diagrams of Figures 47, 48, and 49. Signal flow during the various control modes is determined using these block diagrams together with the autopilot switching matrix (Figure 50).

3.4.2.1 Pitch Autopilot. Control in the pitch autopilot is exercised through symmetric elevon action. During all flight modes except final approach, this elevon action is used to control indicated airspeed to a commanded value, IAS_c. The commanded airspeed is normally received by data-link transmission; however, during link loss, the command is switched to a fixed onboard value of 50 knots. The command is passed through a first-order lag circuit with a 4-sec constant to reduce high transient loads due to step changes in the command.

Primary control is achieved through a proportional gain in the forward loop of the pitch autopilot. A weak integral gain provides elevon trim with no steady state velocity error. A pitch-rate gyro signal is fed back to the elevon to provide adequate damping for the RPV short-period mode. A phugoid damper signal is obtained by passing the filtered output, $(A_n)_{MF}$, of an accelerometer (approximately vertical for straight-and-level flight) through a filter designed to approximate altitude rate for phugoid range frequencies. A dc washout is included in the filter to eliminate accelerometer bias errors. All elevon signals are attenuated by the elevon gain scheduler to permit lower effective gains at higher speeds. The elevon gain scheduler is essentially a function generator whose input is the filtered airspeed.

In the final approach mode, symmetric elevon action is used to control vertical motion of the RPV relative to the recovery TV camera boresight. The vertical command, $\dot{Z}_c$, is generated in the GCS software and transmitted to the aircraft. The command is compared with the output of a filter designed to

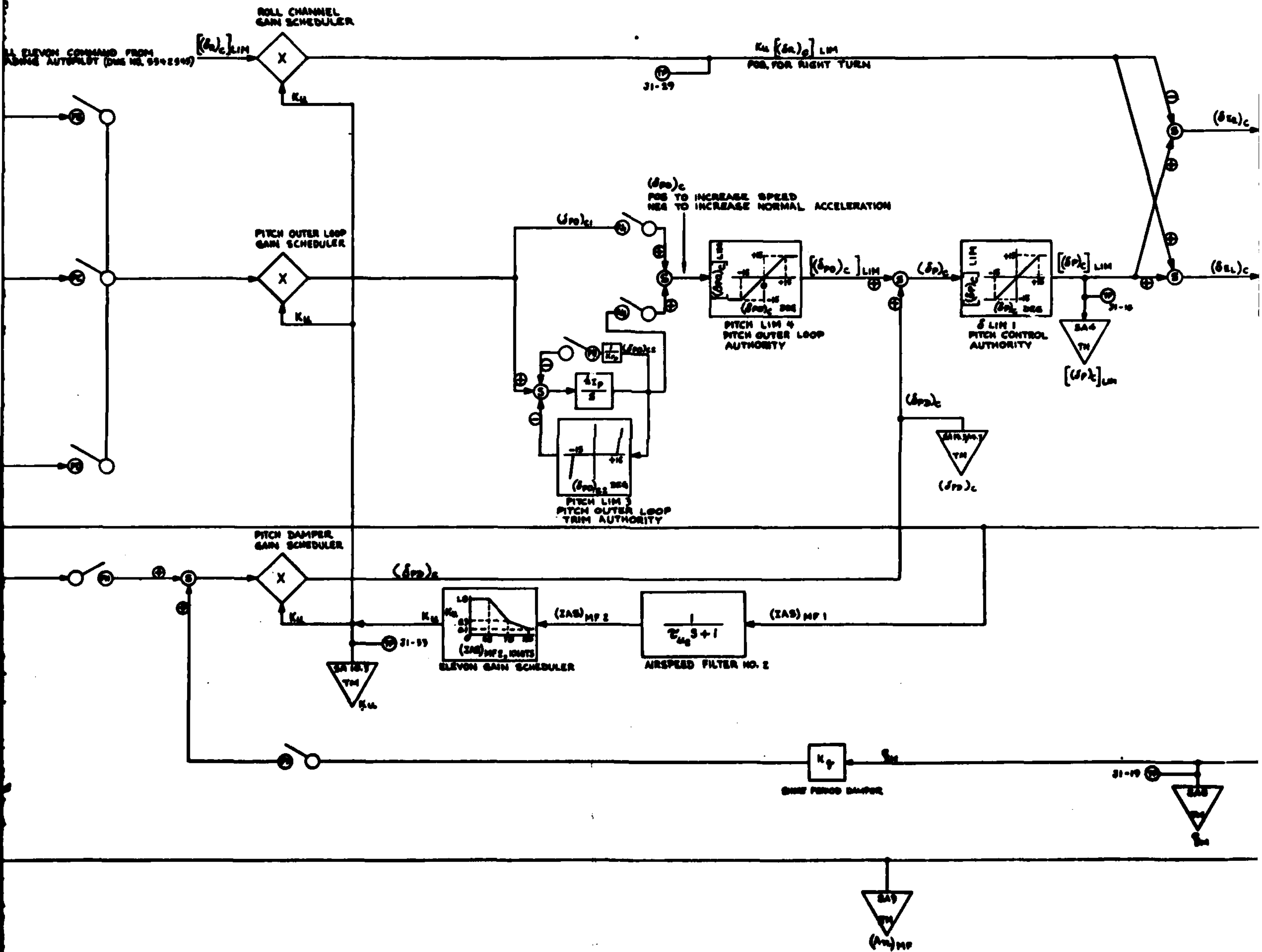


PARAMETER	VALUE	TOL.	UNITS
τ_c	4.0	±20%	SEC
K_{IAS_p}	1.0	±10%	[illegible]
[illegible]	[illegible]	±20%	[illegible]
ω_s	10.0	—	RAD/SEC
ζ_s	0.7	±0.2	—
ω_g	126	±10.0	RAD/SEC
ζ_g	0.7	±0.2	—
K_q	0.3	±10%	[illegible]
[illegible]	0.004	±10%	—
τ_N	[illegible]	—	SEC
ω_A	100	—	RAD/SEC
ζ_A	0.7	±0.3	—
K_{δ}	1.0	±10%	[illegible]

PARAMETER	VALUE	TOL.	UNITS
ω_{PL1}	12.0	±20%	RAD/SEC
ζ_{PL1}	0.7	±0.2	—
ω_{PA}	40.0	±20%	RAD/SEC
ζ_{PA}	0.7	±0.2	—
[illegible]	2.0	±20%	SEC
$K_{\dot{h}_f}$	0.95	±10%	[illegible]
τ_{A1}	0.3	±20%	SEC
τ_{A2}	10.0	±20%	SEC
τ_{A3}	6.0	±20%	SEC
[illegible]	0.06	±20%	SEC

Figure 47. Functional Block Diagram of Pitch Autopilot

1

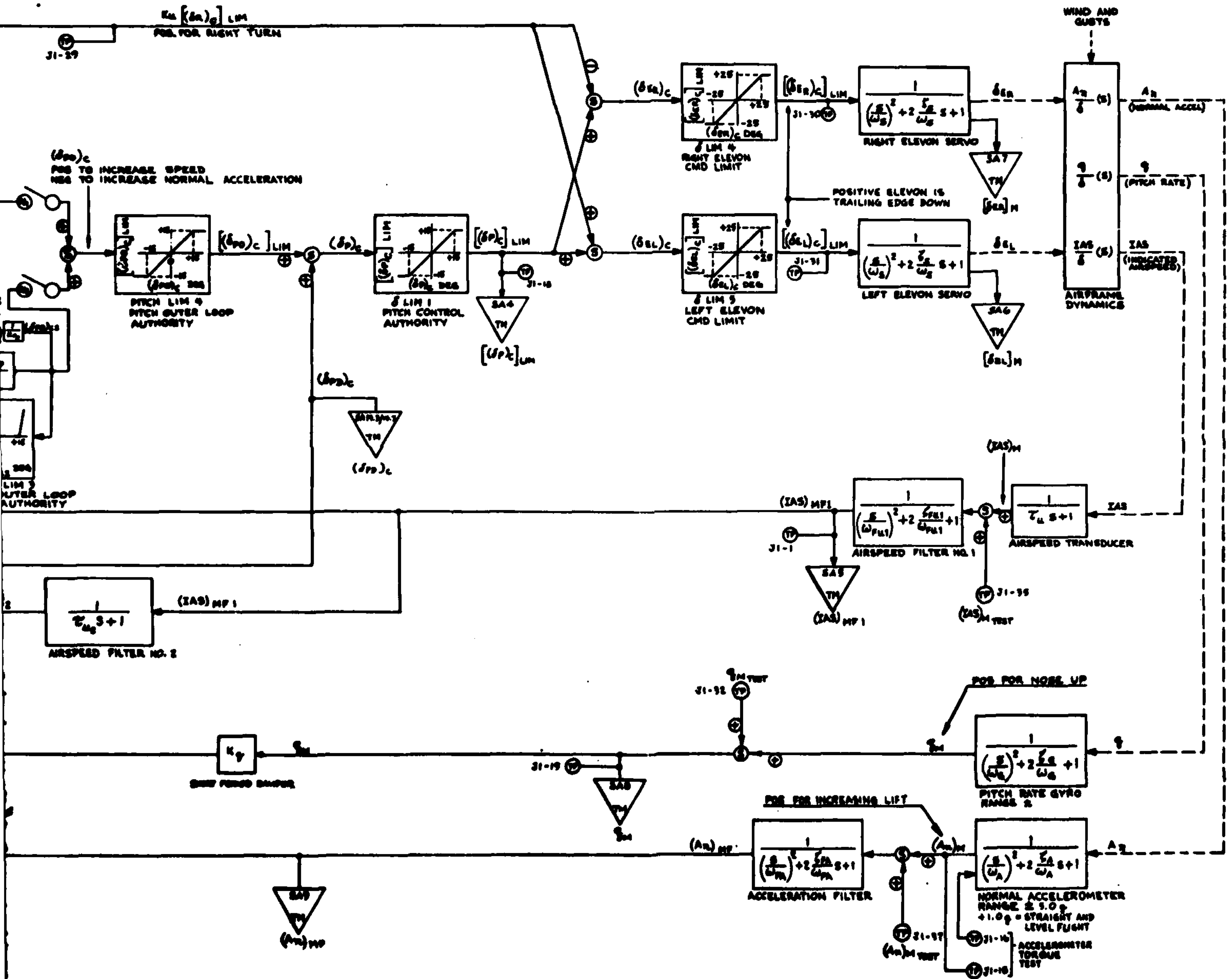


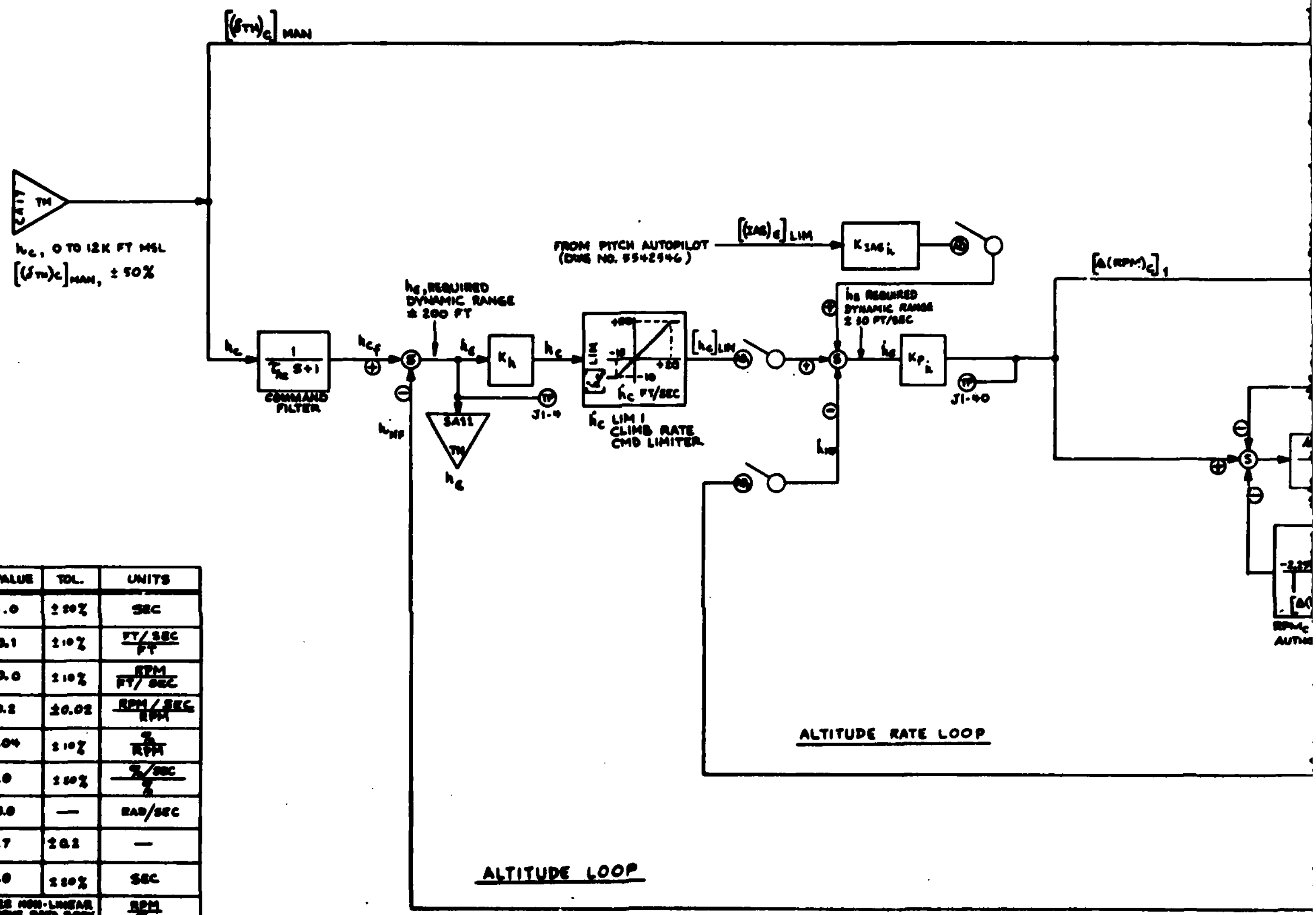
ROLL CHANNEL GAIN SCHEDULER
PITCH OUTER LOOP GAIN SCHEDULER
PITCH DAMPER GAIN SCHEDULER
POS. FOR RIGHT TURN
POS TO INCREASE SPEED
NEG TO INCREASE NORMAL ACCELERATION
PITCH LIM 4 PITCH OUTER LOOP AUTHORITY
δ LIM 1 PITCH CONTROL AUTHORITY
PITCH LIM 3 PITCH OUTER LOOP TRIM AUTHORITY
ELEVON GAIN SCHEDULER
AIRSPEED FILTER NO. 2
31-29
31-39

2

NOTES: RIG ELEVONS 6 DEG T.E. UP
FOR $[(\delta_R)_c]$ LIM = 0.0 DEG AND
$[(\delta_P)_c]$ LIM = 0.0 DEG

NOTES:
1. REFERENCE 5542547 RPV-STD AUTOPILOT SWITCHING MATRIX

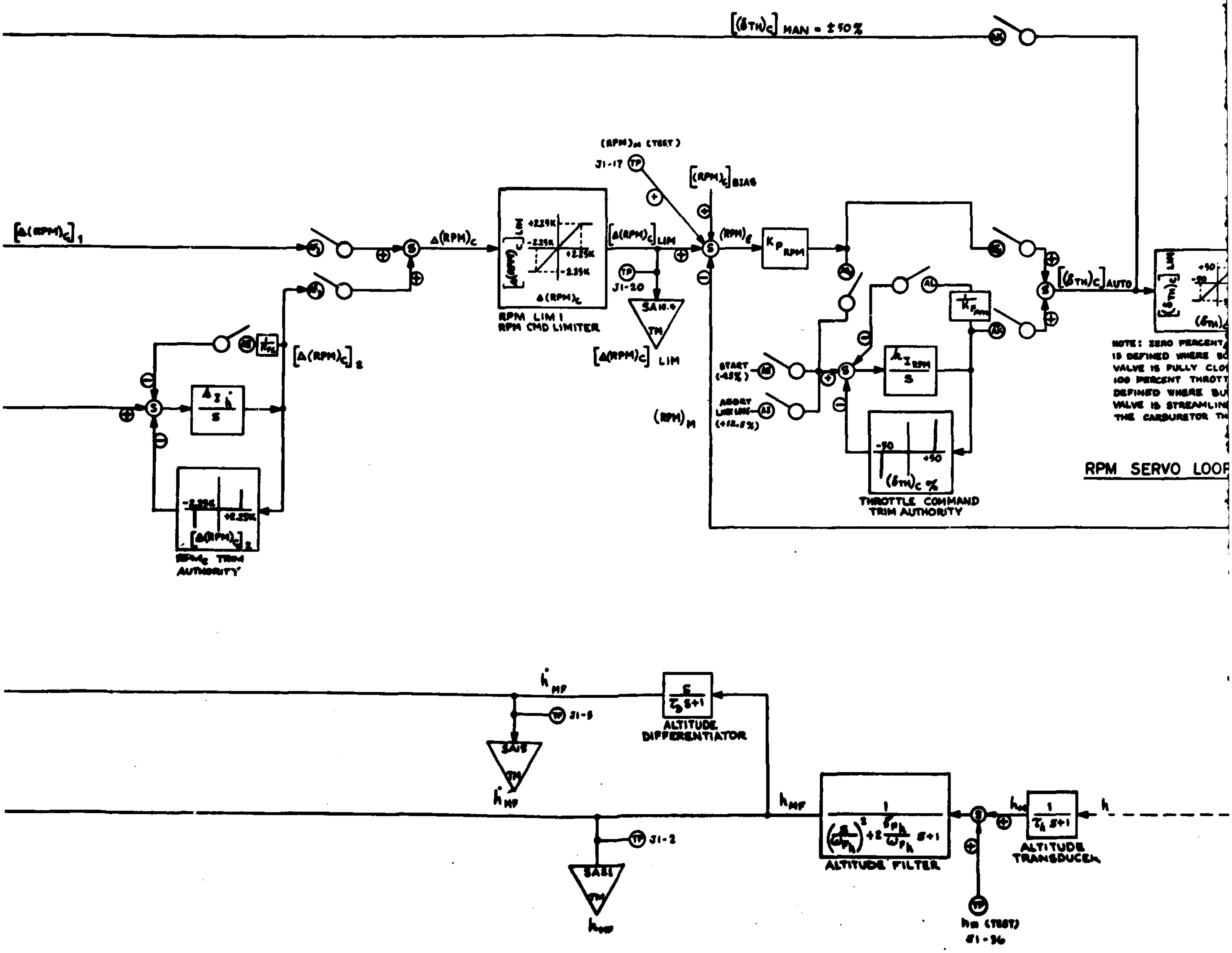




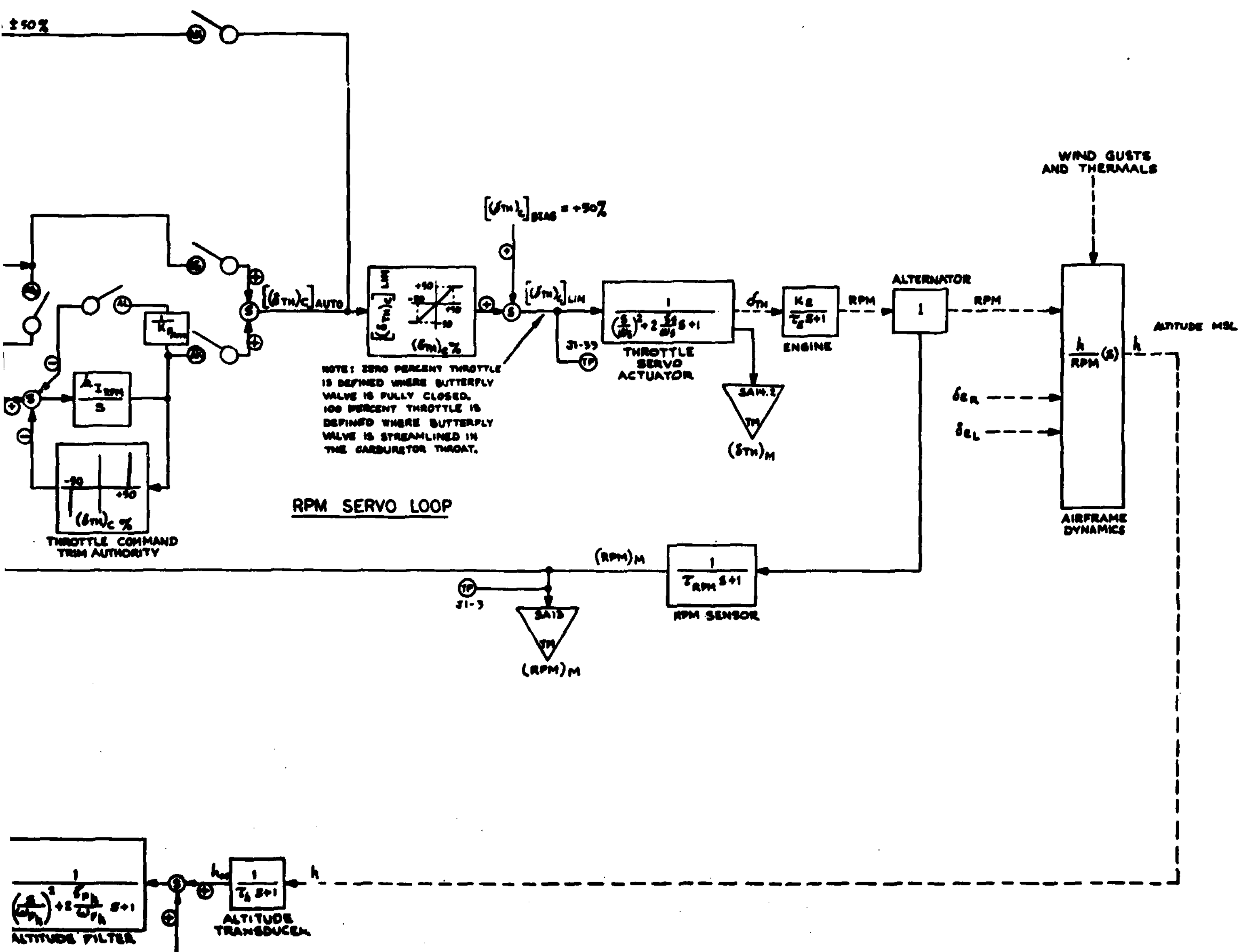
[illegible]METER	VALUE	TOL.	UNITS
[illegible]	1.0	±50%	SEC
[illegible]	0.1	±10%	FT/SEC / FT
[illegible]	50.0	±10%	RPM / FT/SEC
[illegible]	0.2	±0.02	RPM/SEC / RPM
[illegible]	0.04	±10%	% / RPM
[illegible]	2.0	±50%	%/SEC / %
[illegible]	18.0	—	RAD/SEC
[illegible]	0.7	±0.2	—
[illegible]	1.0	±50%	SEC
[illegible]	SEE NON-LINEAR CURVE DATA BOOK [illegible]		RPM / %
[illegible]	0.090	±50%	SEC
[illegible]	0.030	—	SEC
[illegible]	19.0	±2.0	RAD/SEC
[illegible]	0.7	±0.2	—
[illegible]	4.0	±50%	SEC
[illegible]	232	±10%	—
[illegible]	6.29K	±0.1K	RPM
[illegible]	4.0	±50%	FT/SEC / KNOT
[illegible]	0.6	±10%	—

Figure 48. Functional Block Diagram of Altitude Autopilot

1



[(δTH)C] MAN = ±50%
(RPM)M (TEST)
J1-17
[(RPM)C]BIAS
[Δ(RPM)C]1
Δ(RPM)C
[Δ(RPM)C]LIM
(RPM)E
J1-20
RPM LIM 1
RPM CMD LIMITER
[Δ(RPM)C] LIM
[Δ(RPM)C]2
[(δTH)C]AUTO
START (-45%)
ABORT (+12.5%)
(RPM)M
THROTTLE COMMAND
TRIM AUTHORITY
RPMC TRIM
AUTHORITY
RPM SERVO LOOP
ALTITUDE
DIFFERENTIATOR
J1-5
J1-2
ALTITUDE FILTER
ALTITUDE
TRANSDUCER
hm (TEST)
J1-36



NOTES.

1. REFERENCE 5542547 RPV STD AUTOPILOT SWITCHING MATRIX

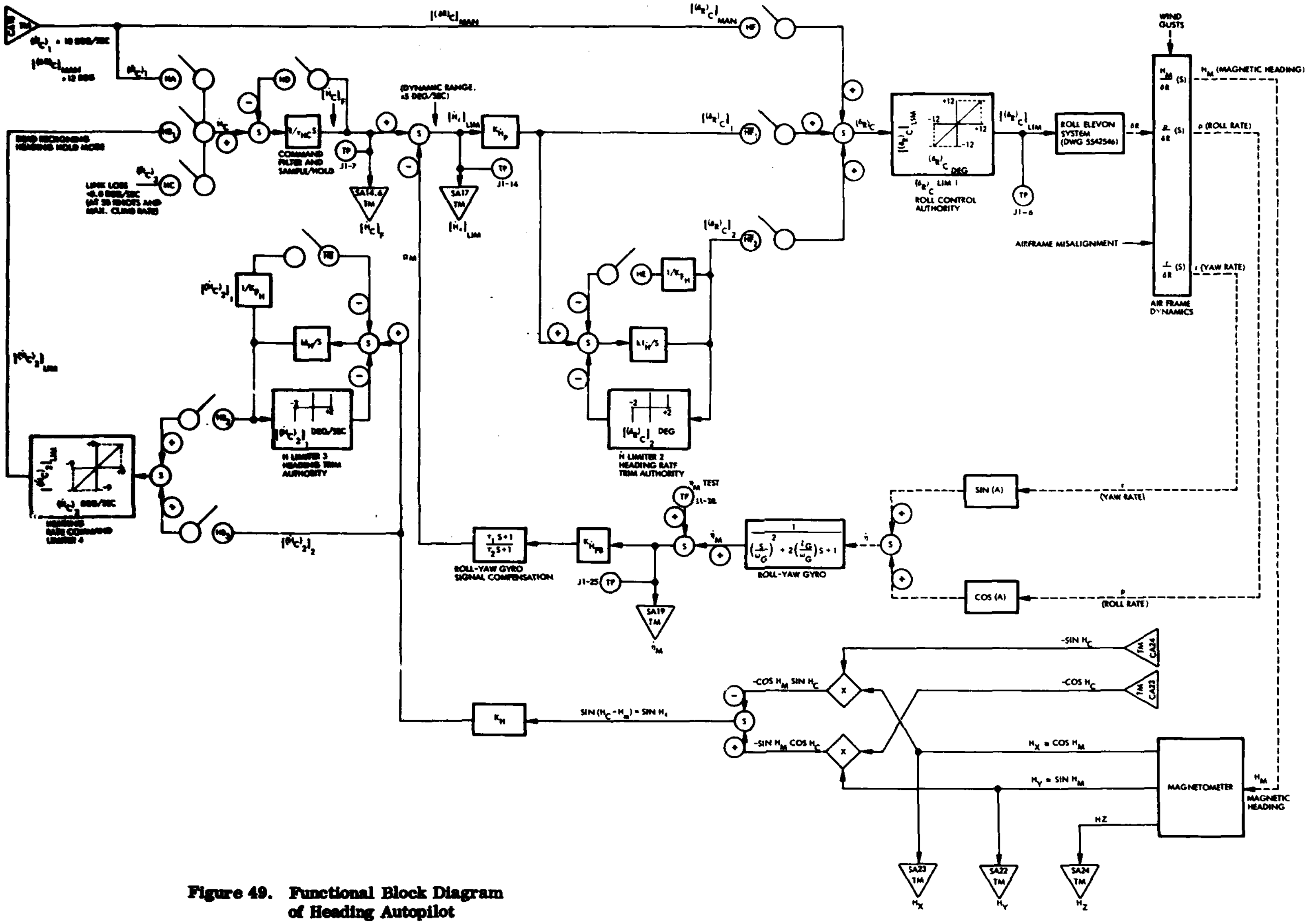


Figure 49. Functional Block Diagram of Heading Autopilot

PARAMETER	VALUE	TOL	UNITS
τH_C	0.1	±20%	SEC
$K_{\dot{H}_P}$	2.35	±10%	DEG/(DEG/SEC)
$kI_{\dot{H}}$	0.1	±10%	(DEG/SEC)/DEG
K_H	0.1	±10%	(DEG/SEC)/DEG
kI_M	0.08	±10%	[DEG/(SEC)^2]/(DEG/SEG)
ω_G	126	±10%	RAD/SEC
ζ_G	0.7	±0.2	-
τ_1	0.222	±20%	SEC
τ_2	10.0	±20%	SEC
$K_{\dot{H}_{FB}}$	3.82	±10%	-
LIM 1	±12	±10%	DEG
LIM 2	±2	±10%	DEG
LIM 3	±2	±10%	DEG/SEC
LIM 4	±9	±10%	DEG/SEC
A	20	±1 DEG	DEG
K_{F_H}	0.0008	±10%	-
$K_{F_{\dot{H}}}$	0.002	±10%	-

NOTE:
REFERENCE 5542547 RPV-STD
AUTOPILOT SWITCHING MATRIX

CONDITION	G.S TO RPV	RPV CMD MODE	HEADING								ALTITUDE										PITCH									CONTROL		
			HA	HB	$\overline{HB}$	HC	HD	HE	HF	$\overline{HF}$	AD	$\overline{AD}$	AE	AF	AG	AH	AJ	AK	$\overline{AK}$	AL	PA	$\overline{PA}$	PB	PC	PD	PE	PH	PJ	PK	1ST. APP.	D.R.	H.R.
PRE-ENG START. ENGINE ON-HOLD	10010	2	X	O	X	O	X	X	O	X	X	O	X	X	O	X	O	O	X	X	X	O	O	X	O	X	X	X	X			
PREPARE TO LAUNCH	10001	1	X	O	X	O	X	X	O	X	X	O	O	X	X	O	O	O	X	O	X	O	O	X	O	X	X	X	X			
LAUNCH, WAYPOINT. LOITER. SEARCH	10000	0	X	O	X	O	X	O	O	X	X	O	O	X	X	O	O	O	X	O	X	O	O	X	O	O	X	X	X			
DEAD RECKONING	10011	3	X	X	O	O	X	O	O	X	X	O	O	X	X	O	O	O	X	O	X	O	O	X	O	O	X	X	X		✓	
FINAL APPROACH	11110	14	X	O	X	O	X	O	O	X	O	X	O	X	X	O	O	O	X	O	X	O	O	O	X	O	O	X	X	✓		
ABORT	10101	5	X	O	X	O	X	O	O	X	X	O	X	X	O	O	X	O	X	O	O	X	O	X	O	O	X	X	X			
LINK LOSS, 0-8 SEC. PRIOR TO 1ST. APPROACH	0XXXX	A	O	O	X	O	O	O	O	X	X	O	X	X	O	O	X	O	X	O	O	X	O	X	O	O	X	X	X			
LINK LOSS, 0-8 SEC. AFTER 1ST. APPROACH	0XXXX	B	O	O	X	O	X	O	O	X	X	O	X	X	O	O	X	O	X	O	O	X	O	X	O	O	X	X	X			
LINK LOSS, 8 SEC & UP	0XXXX	C	O	O	X	X	X	O	O	X	X	O	X	X	O	O	X	O	X	O	O	X	O	X	O	O	X	X	X			
R.C. CONTROL	11111	15	X	O	X	O	X	X	X	O	X	O	X	X	O	O	O	X	O	X	X	O	X	O	O	X	O	X	O			
TEST 1 (RC + HDNG RATE)	10110	6	X	O	X	O	X	O	O	X	X	O	X	X	O	O	O	X	O	X	X	O	X	O	O	X	O	X	O			
TEST 2 (TEST 1 + PITCH RATE)	10111	7	X	O	X	O	X	O	O	X	X	O	X	X	O	O	O	X	O	X	X	O	X	O	O	X	O	X	X			
TEST 3 (TEST 2 + PHUGOID)	11000	8	X	O	X	O	X	O	O	X	X	O	X	X	O	O	O	X	O	X	X	O	X	O	O	X	X	X	X			
TEST 4 (TEST 3 + AIRSPEED)	11001	9	X	O	X	O	X	O	O	X	X	O	X	X	O	O	O	X	O	X	X	O	O	X	O	O	X	X	X			
TEST 5 (TEST 4 + ALTITUDE)	11010	10	X	O	X	O	X	O	O	X	X	O	O	X	X	O	O	O	X	O	X	O	O	X	O	O	X	X	X			
SPARE	10100	4	X	O	X	O	X	O	O	X	X	O	X	X	O	O	X	O	X	O	X	O	O	X	O	O	X	X	X			
SPARE	11011	11	X	O	X	O	X	X	O	X	X	O	O	X	X	O	O	O	X	O	X	O	O	X	O	O	X	X	X			✓
SPARE	11100	12	X	O	X	O	X	X	O	X	X	O	X	X	O	X	O	O	X	X	X	O	O	X	O	X	X	X	X			✓
SPARE	11101	13	X	O	X	O	X	X	X	O	O	X	O	X	X	O	O	O	X	O	X	O	O	O	X	O	O	X	X			✓

LEGEND:

X = CLOSED SWITCH
O = OPEN SWITCH
✓ = ENABLE

Figure 50. Switching Matrix for Autopilot

simulate the rate of change of vertical displacement from the camera boresight. Input to the filter is the output of the normal accelerometer, $(A_n)_{MF}$. The filter includes a dc washout to eliminate accelerometer bias errors.

3.4.2.2 Altitude Autopilot. The altitude autopilot is controlled through engine rpm. During all flight modes except final approach, engine rpm is used to control the altitude to a value transmitted from GCS. The altitude command, h_c, is filtered through a first-order lag network having a 1-sec time constant to reduce transients resulting from step commands. The filtered command, h_{cf}, is then compared with the filtered altitude measurement, h_{MF}, and the error signal, h_ϵ, is passed through a proportional gain. The output of the gain block is then passed through a climb-rate command limiter, which limits the climb-rate command $(\dot{h}_c)$ to a 20-fps climb and a 10-fps descent. The resulting climb-rate command, $(\dot{h}_c)_{LIM}$, is compared with $\dot{h}_{MF}$, the output of the altitude differentiator, and the resulting error signal, $\dot{h}_\epsilon$, is passed through a proportional-plus-integral gain to $\Delta\ (RPM)_c$, which is limited to ±2,250 rpm. This command, combined with a bias command of 6,250 rpm, permits a range of rpm commands from 4,000 rpm to 8,500 rpm. No engine speed outside this range can be commanded. The rpm command trim authority output from the integral gain filter is likewise limited to ±2,250 rpm, permitting zero-error trim at any rpm within the 4,000- to 8,500-rpm range.

An rpm servo loop inside the altitude loop provides quick and accurate control of engine rpm by feeding back the measured rpm and comparing it with the commanded rpm. The error signal, RPM_ϵ, is passed through a proportional-plus-integral control to produce a throttle command, $\left[(\delta_{TH})_c\right]_{AUTO}$, limited to ±50 percent of full throttle. This command, when combined with a 50-percent throttle bias command, permits a range of throttle command from 0 to 100 percent of full throttle. The throttle command is applied to a throttle servo positioned to rotate the engine butterfly valve from a fully closed (0 percent) to fully open (100 percent) throttle according to the magnitude of the command.

An additional use of the engine is to control speed during the final approach phase of the RPV mission. In this mode, the normal climb-rate command is switched out and replaced by a signal from the speed error, IAS_{ϵ}, channel, multiplied by an appropriate gain. The output of the altitude differentiator is also switched out during this mode.

3.4.2.3 Heading Autopilot. The function of the heading autopilot is to control the direction of flight of the RPV. The autopilot consists of an inner control loop to control heading rate, $\dot{H}$, and an outer loop to control heading angle, H. During all flight modes except dead reckoning, the outer loop is open and heading control consists of controlling to a heading rate command, $\dot{H}_c$, transmitted from the ground and applied to the summing junction of the inner loop. This command may be an open-loop constant command, as in the manual autopilot mode, or it may be generated by the ground computer to satisfy a guidance steering requirement, in which case the guidance system constitutes an outer loop about the heading-rate loop. Discussion in this section, however, is limited to those loops that are mechanized aboard the aircraft.

The inner loop, $\dot{H}$, of the heading autopilot consists of a strong proportional gain and a weak integral gain (for trimming aerodynamic asymmetries). The integral term allows ±2 deg of differential elevon motion for trim. The heading-rate loop includes a roll-yaw gyro as a sensor, having its sensitive axis in the plane of symmetry of the RPV, tilted downward by 20 deg from the aircraft longitudinal axis. When the RPV flies straight and level at a 5-deg angle of attack, the roll-yaw gyro axis will then be tilted downward from the horizontal at an angle of 15 deg. In a steady turn, the gyro in this case would have an output of approximately $\dot{H}$ sin 15 deg, so a feedback gain of 1/sin 15 deg would be needed to generate a feedback signal with a steady state value equal to the true heading rate.

Since the steady state angle of attack changes with speed, the gain required to achieve zero steady state heading-rate error would likewise change with speed.

For simplicity, however, a constant value was used to correspond to a mid-range speed. Steady state errors associated with speeds other than this mid-range speed are not significant enough to warrant the incorporation of a velocity-dependent gain. The roll-yaw gyro signal compensation filter is designed to produce a signal approximately proportional to the heading rate during the initial portion of a step heading-rate command. This transfer function also incorporates a zero, which cancels the pole associated with the air-frame open-loop roll mode. These features permit the design of a high-bandwidth roll-control mode.

The outer loop of the heading autopilot incorporates a three-axis fluxgate magnetometer for measuring the aircraft heading. The orthogonal axes of the magnetometer are arranged so that the X axis is parallel to the longitudinal axis of the aircraft, the Z axis is downward in the plane of symmetry, and the Y axis is to the right. Only the X and Y magnetometer components are active in the autopilot feedback loop. For level flight, the X magnetometer output is proportional to cos H, and the Y magnetometer output is proportional to -sin H. Outputs of these magnetometers are calibrated so that $H_x = \cos H$ and $H_y = -\sin H$ in level flight.

To minimize the complexity of onboard processing, the sine and cosine of the heading command are stored onboard the aircraft and accessed in the proper order as each dead reckoning leg is flown. These commands are mixed with the magnetometer outputs, H_x and H_y, according to the trigonometric sine difference formula to generate the error signal, $\sin(H_c - H)$. The outer loop of the heading autopilot contains a proportional gain for primary control with an integral gain to trim out errors due to a roll-yaw gyro bias error. Aircraft roll and pitch corrupt the X and Y magnetometer outputs because of the declination of the magnetic field vector. Studies have shown, however, that the corrupting influence is not disastrous if the outer-loop proportional gain is kept below a calculable critical value. Although this magnetic declination effect causes differences in the aircraft response for northerly and southerly commands, the gain has been set low enough that stability is present for all heading commands.

3.4.2.4 Link-Loss Mode. In the event of data-link transmission loss, a sequence of events is programmed to maximize the probability of survival of the aircraft. A distinction is made between two cases: (1) no final approach has been attempted; (2) final approach attempt has occurred.

In the first case, recognition of link loss triggers a sample-hold circuit in the heading autopilot, causing the flight control system to hold the last commanded value of heading rate. If link loss prevails after 8 sec, a heading rate of 3 deg/sec to the right is commanded thereafter until the data link is reestablished. Full engine throttle is commanded through the throttle command integrator, resulting in a ramped throttle command that increases at a rate of 25 percent/sec until full throttle is reached. If link loss is not reestablished within 128 sec after link loss, the engine is killed and the RPV descends to a landing. The speed command is set to 50 knots at the time of link loss and is maintained at that value thereafter.

In the second case, where at least one final approach attempt has been made, the sequence of events after link loss is identical to that of the first case with one exception: during the first 8 sec following link loss, zero heading rate is commanded.

3.5 PAYLOAD SENSORS

The tactical requirements of the Aquila RPV include target detection, recognition, and location, and laser designation. It is also required to perform laser measurement of burst offset in order to determine the required artillery adjustment when vectoring artillery onto a selected target. In the Aquila RPV-STD program, these requirements are pursued by using a variety of daytime sensors. The sensor program is divided into five phases, with sensor complexity progressing from the simple unstabilized TV and photographic cameras in Phases I and II, through the stabilized Phase III sensors having video tracking capability, to the Phase IV and V sensors, which include full laser capability.

Various sensors were investigated during the early part of the program, and a decision was made to use the Honeywell pointing and stabilization element (POISE) platform as the basic sensor platform. Honeywell built 13 Phase I sensors and four each of the Phase II, III, IV, and V sensors. The majority of these were delivered to Lockheed for integration into Aquila RPVs. A few were dedicated specifically to other military programs.

A 2.5-month test program was performed during the summer of 1977 at Fort Huachuca, Arizona. This program achieved several objectives including: (1) testing the performance of the Aquila system, including ground and RPV hardware; (2) testing the performance of the various sensor systems against a variety of target situations; and (3) training LMSC and Army personnel to operate the Aquila and to perform simulated tactical missions.

A suitably modified Otter manned aircraft was also employed during this program to check out specific system features. The Otter contained an RPV payload, including sensor and data link. During the sensor test program, 24 Aquila flights and 9 Otter flights were made.

Because of the nature of the test program, operator training was performed concurrently with data gathering. As the program progressed, the test results reflected a steady improvement for three reasons:

- Hardware and software discrepancies observed for the first time were corrected as they occurred.
- Sensor performance improved from Phase I to Phases IV and V.
- Operator performance and operational procedure matured extensively.

The performance of the sensor was originally defined at specific confidence levels, i.e., 50-percent confidence of target detection, etc. This statistical confidence level has meaning only if a sufficiently large data base exists. The limited contractor testing of sensors did not provide a sufficient data base for statistical evaluation. Also, design and software/formulation changes, found to be necessary as results of early "shake-down" flights with each sensor, rendered much of the early data useless. Another characteristic of the contractor test program was the use of extensive cueing of the sensor and RPV operators as to target locations. This removed most of the operator performance limitations and permitted a closer evaluation of the limits of capability of the targeting system. These evaluations are summarized in Section 3.5.2 of this report.

Sensors used are an unstabilized TV camera, a 35-mm film camera, a stabilized TV camera, and a laser rangefinder designator. A simplified block diagram of the sensors and the data-link interconnection is shown in Figure 51. GCS commands are received by the airborne command receiver and processed by the airborne data-link decoder. Commands from the decoder are sent to the sensor electronics assembly, which commands the TV azimuth and elevation gimbals and various TV drive motors, such as focus, zoom, and filter wheel. Status signals – e.g., gimbal azimuth and elevation, zoom position, and laser range – are sent to the sensor electronics assembly, which sends them to the airborne data-link encoder, then to the transmitter for transmission to the GCS. Video from the TV camera is sent to the command transmitter, where it is multiplexed with the status data before transmission.

3.5.1 Payload Sensor Descriptions

3.5.1.1 Phase I. Phase I uses the unstabilized TV sensor system to provide real-time TV surveillance. The system is designed to detect, with 50-percent probability, vehicle-size targets on a road at 3.0-km (1.9-mile) slant range and in a field of 1.5 km-(0.9-mile) slant range. The system is designed to recognize, with 50-percent probability, vehicles at 1.0-km (0.6-mile) slant range both on the road and in a field. The operating range is limited by the

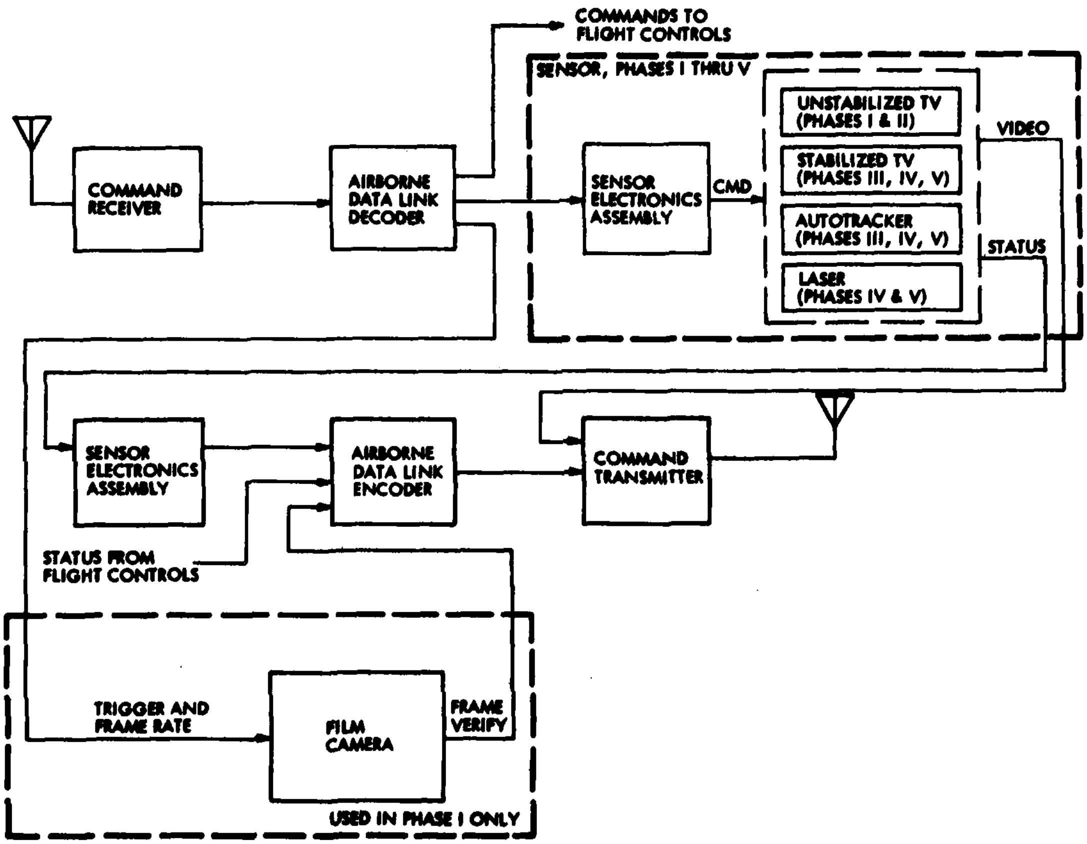
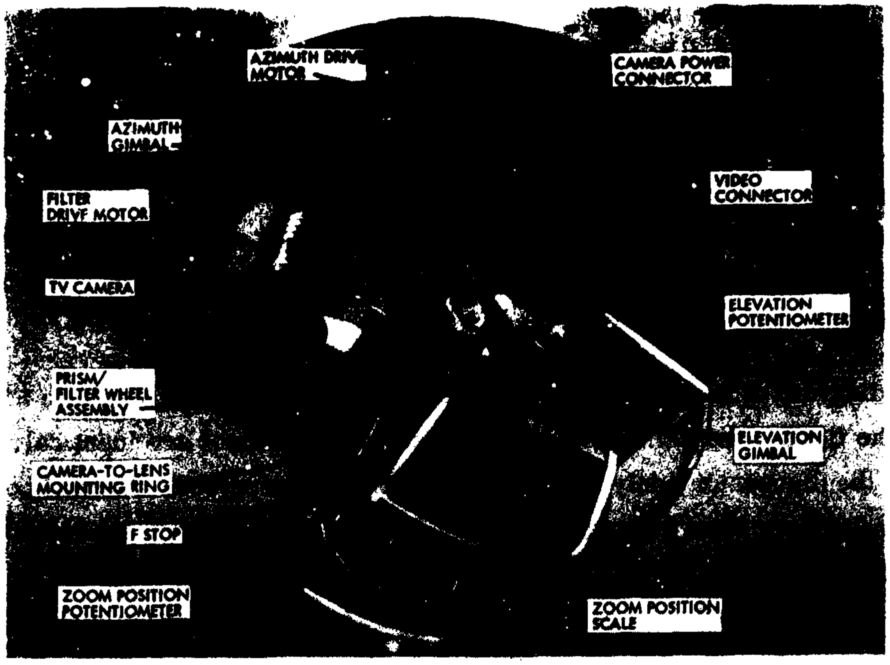


Figure 51. Block Diagram of Sensors and Data-Link Interconnection

data link to 20 km (12.4 miles) and requires direct line of sight to the RPV. The autopilot on the aircraft allows the ground operators to command the RPV to fly a preprogrammed flight pattern in the target area; the ground operators may then conduct a concentrated TV search of that area by remotely directing the TV sensor as desired, with the manual control stick.

The TV sensor comprises a 12.93-in.-diameter dome of transparent acrylic plastic with an unstabilized TV camera mounted inside on a gimbal system supported from the sensor body. The sensor, with the dome removed, is shown in Figure 52. The gimbal system allows the camera to rotate to 15 deg up and approximately 90 deg down, and to swing from straight ahead to approximately 180 deg left or 180 deg right. The sensor weighs about 17 lb, is installed through the top of the aircraft, and protrudes through the bottom. Ballast



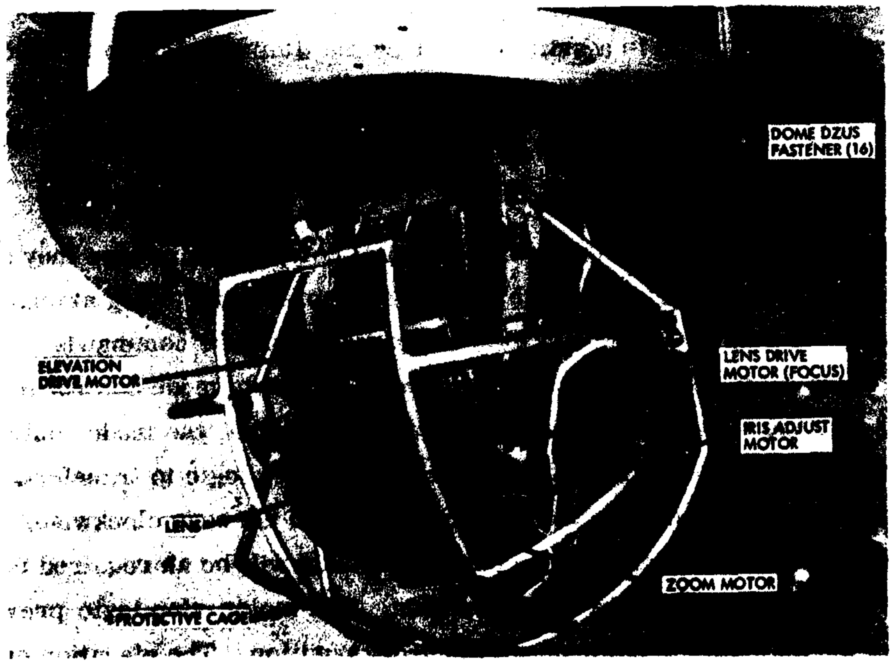


Figure 52. Unstabilized TV Sensor

requirements increase the payload weight to 25.71 lb. The TV camera has a standard 525-line format. Also, the camera has a remotely controllable 10:1 zoom lens, focus, and neutral-density filter wheel. The iris is internally controlled, automatically responding to the amount of light detected by the camera. The TV portion of the sensor is a standard 525-line commercial system and therefore is not discussed in detail. The various motor drives for filter wheel, zoom, and focus, for example, are commanded by discrete signals, such as turn right and turn left.

A block diagram of the gimbal position and control circuitry is shown in Figure 53. In the figure, the azimuth control and elevation control are identical. To simplify the discussion, only the azimuth control is described. Normal control from the GCS is a clockwise or counterclockwise discrete command routed to the switch logic, which in turn commands the motor drive circuits to drive the azimuth motor clockwise or counterclockwise. A high-low slew discrete from the GCS tells the motor drive to drive at 2 deg/sec or 10 deg/sec in the direction commanded. As the drive motor turns the azimuth gimbal, the azimuth potentiometer senses the gimbal position. Its output is converted to an 11-bit digital word and is loaded in a shift register by the timing and control logic. At the appropriate position in the telemetry frame, the shift-enable signal allows the telemetry clock to clock the 11-bit position data out through a logic "OR" gate to status telemetry in sync with the other status data.

The 11-bit position data are also sent to a digital comparator, where they are compared with a fixed 11-bit azimuth cage angle representing 0 deg azimuth. The comparator outputs cage clockwise or counterclockwise commands that are sent to the switch logic. If a cage command is sent to mode control from the GCS, or if the sensor is in a power shutdown sequence, the mode control will generate a cage command that will cause the switch logic to transfer from the azimuth clockwise/counterclockwise commands to the cage clockwise/counterclockwise commands. These cage commands will be as required to drive the azimuth gimbal to the 0-deg position. The motor-stop logic prevents hunting as the azimuth gimbal crosses the 0-deg position. The elevation circuit operates in the same manner except that the elevation angle is -6 deg (down) and consists of a 10-bit binary word.

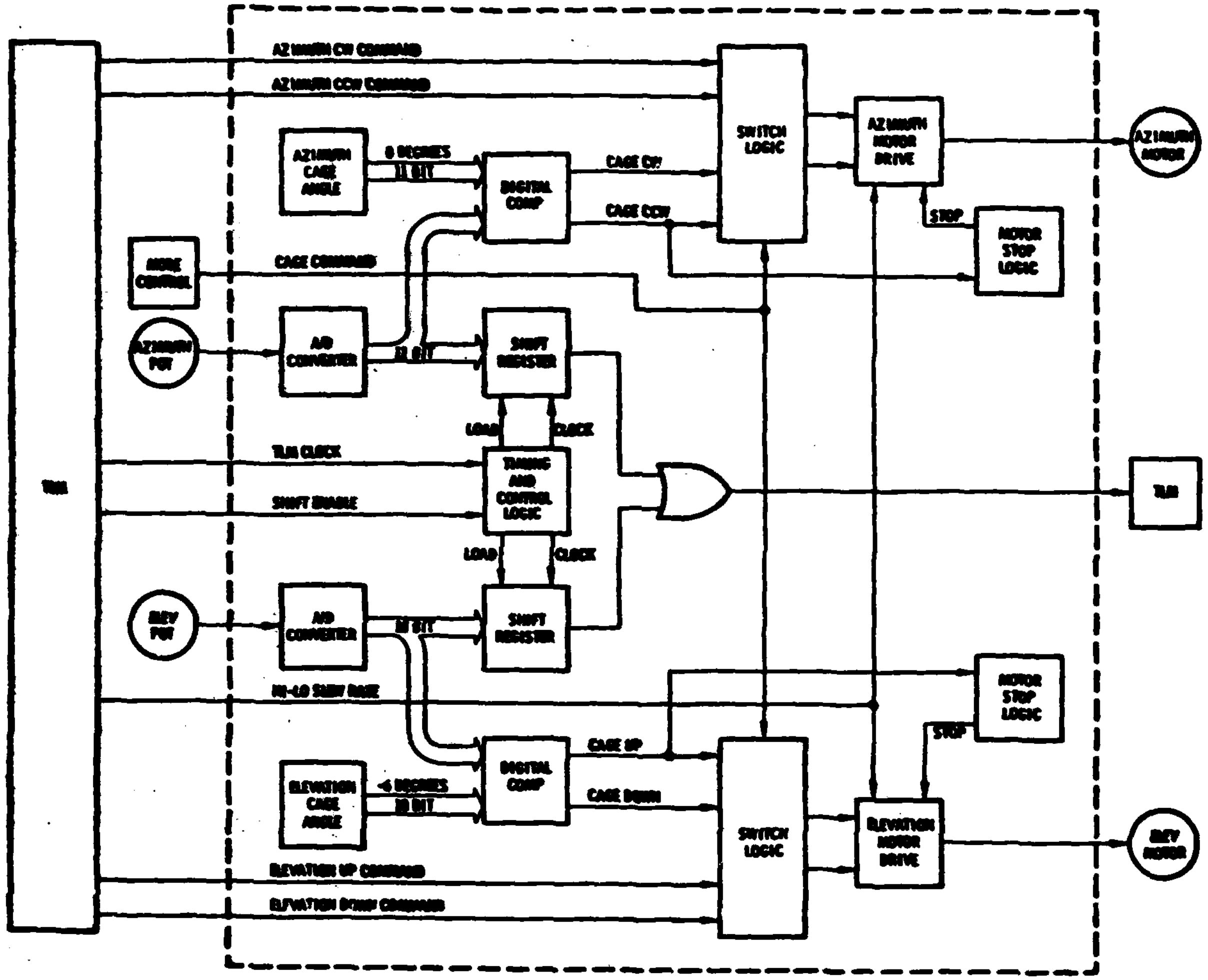


Figure 53. Block Diagram for Unstabilized TV Sensor Position and Control

3.5.1.2 Phase II. Phase II uses a sensor system that consists of the unstabilized TV camera plus a 35-mm panoramic camera to provide photographic reconnaissance as well as real-time TV surveillance. The 35-mm camera (Figure 54) is mounted behind the TV sensor dome with its protective window projecting through the bottom of the RPV. The camera has a field of view of 34 deg, and is pointed straight down. The film is wrapped on a curved surface within the camera, and the camera prism sweeps side to side from horizon to horizon to give a panoramic picture. About 450 frames are contained on the 69 m (225 ft) of thin-base film, and the frame rate can be varied from 4 frames/sec to 1 frame/13.5 sec. The resolution of 75 lines/mm (and using pan-X film) provides approximately 0.5-m (1.6 ft) ground resolution at a slant range of 670 m (2,200 ft).

The Type 2-18 PRW Minipan camera is designed specifically for aerial photography. Image motion control is not required since high resolution is obtained through use of high shutter speeds and a design that combines continuous film with a rotating folded mirror and lens system.

The light path to the film is as follows (Figure 55). Light from the scene being photographed enters the camera mechanism by striking a scanner mirror. This light is reflected from the mirror through the lens to the lower mirror where it is reflected through an adjustable slit to the film plane. The light duration on the film plane is adjusted by varying the slit width in the scanner assembly. Since the slit is rotating in a direction opposite to the direction of the film movement, the shutter speed is a function of the scanner's rotational speed plus the film linear speed.

The shutter speed is manually adjustable in one-half f-stop increments from 1/500 to 1/4,000 of a second; the lens aperture is manually adjustable from f 2.3 to f 22. An intervalometer within the camera allows the frame rate to be remotely adjustable from the GCS at any of nine frame rates: 4, 2, and

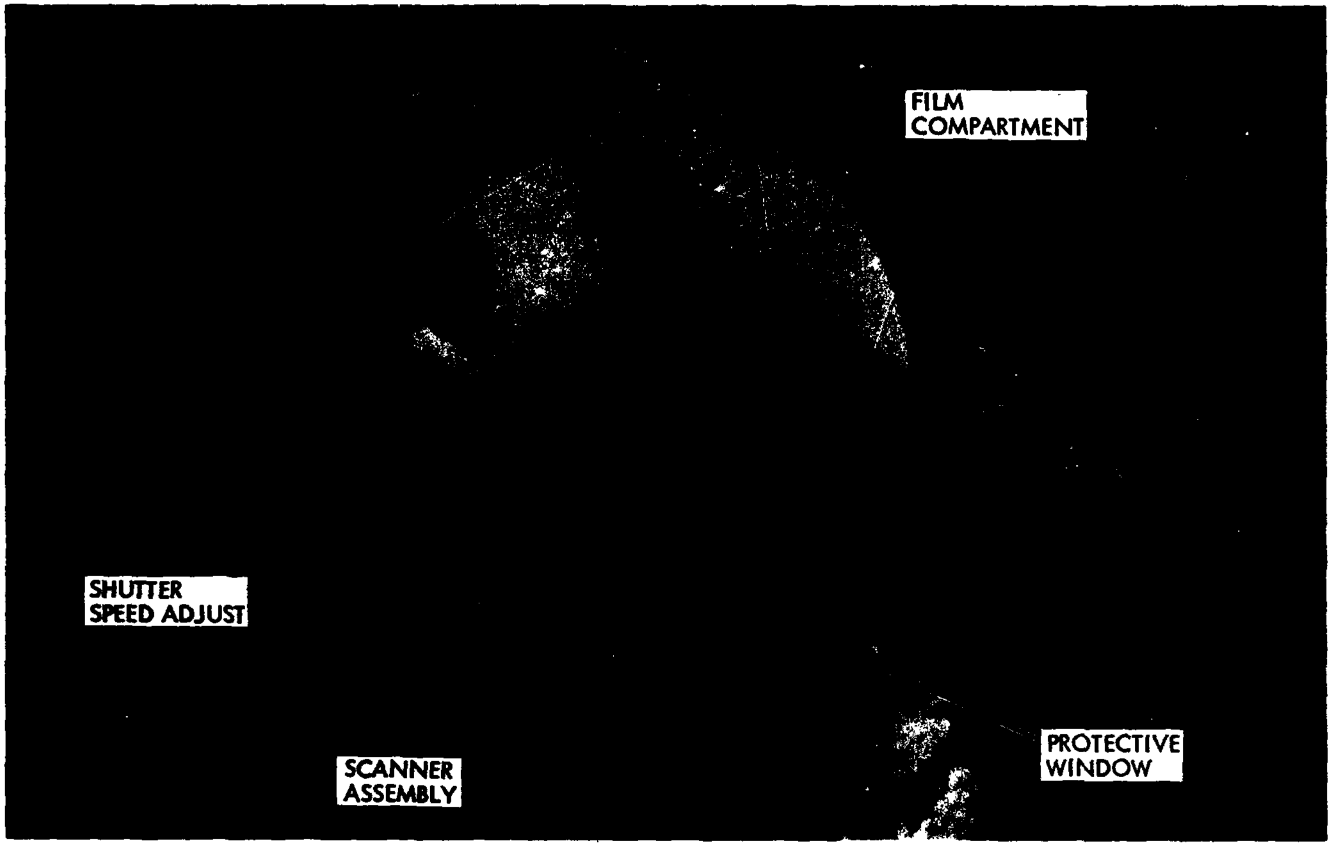


Figure 54. 35-mm Film Camera

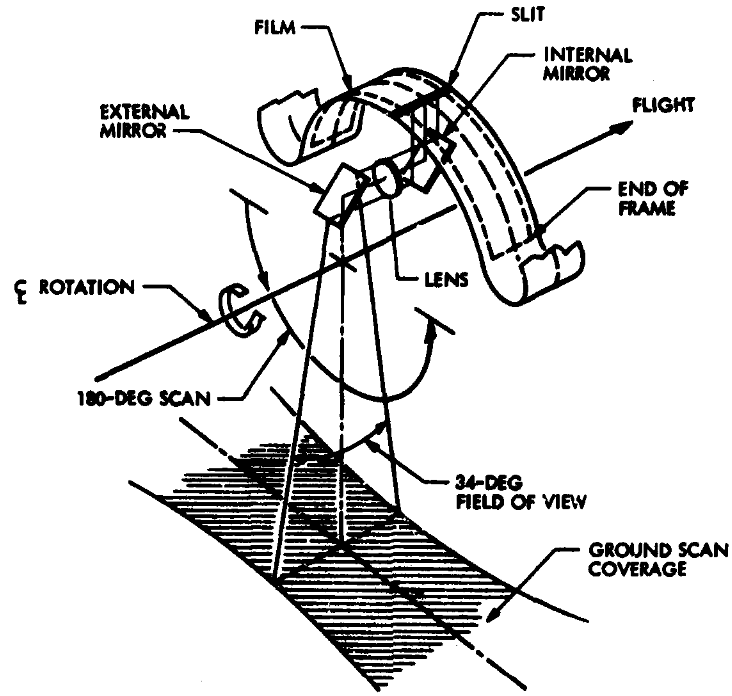


Figure 55. Lens System of 35-mm Camera

1 frame/sec, and one frame every 2, 3, 4, 5, 10, and 13.5 sec. Picture size is 6.12 by 1.12 in. with 0.25 in. between frames.

The drive motor assembly is mechanically coupled to the capstan assembly and takeup shaft assembly by Mylar belts. The capstan assembly is also coupled to the scanning assembly by a Mylar belt. This mechanical power transmission system compensates for speed variations caused by slippage in a manner that does not degrade the photography. The only variation that the operator may observe would be a change in the frame rate. If the capstan drive belt should slip, the frame rate would be reduced; however, since the capstan assembly drives the scanning assembly with a separate belt, the speed relationship between these assemblies is maintained.

An electrical schematic diagram of the camera is shown in Figure 56. When the RPV 28-Vdc power is applied to the camera, the camera accepts a start

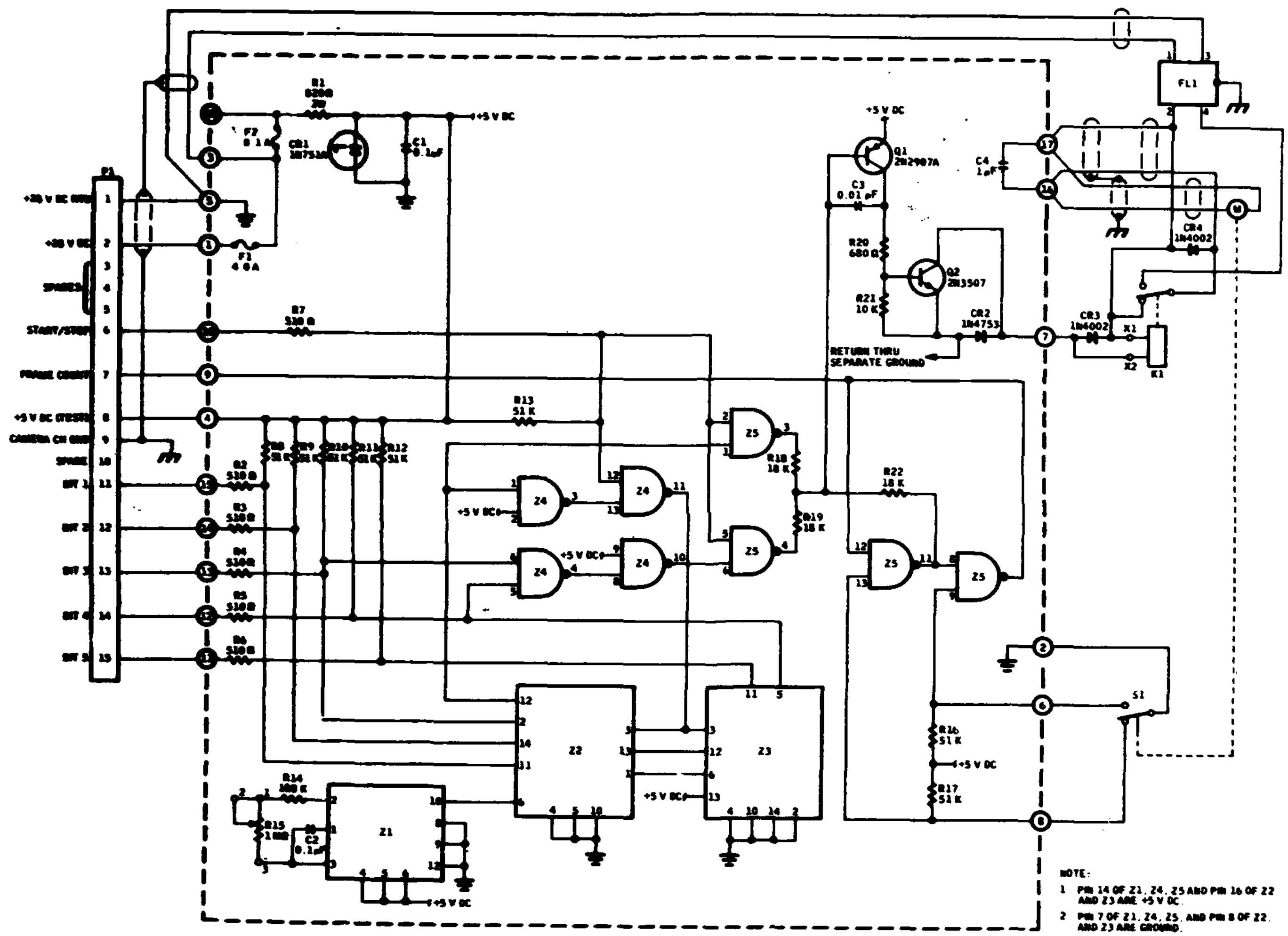


Figure 56. Electrical System for 35-mm Camera

command consisting of a trigger signal and a frame rate signal. The trigger (start/stop) signal is a logic 1 (5.00 ± 0.25 Vdc), which is applied to connector P1-6 for the duration of the camera operational period desired. To stop the camera, the voltage level at P1-6 must be returned to a logic 0 (less than 0.5 Vdc). The frame rate is commanded by a 5-bit binary code from the RPV logic circuitry. The camera motor is activated when power is applied to relay K1 from the intervalometer (bounded by the heavy dashed line in Figure 56). When power is removed from the relay, the drive motor will continue to run until the cam-actuated switch S1 opens. When the motor stops running, the scanning mirror should be oriented toward the scanner enclosure. For frame-counting purposes, the camera provides a pulse at logic level 1 for 187 (+20) ms. This frame count is initiated at the start of each frame exposure and is present on connector P1-7. The intervalometer voltage (5 Vdc) is present at P1-8 for test reference purposes only. The camera is protected by a 28-Vdc 4-A fuse and a 5-Vdc 0.1-A fuse, both located on the intervalometer printed circuit board.

3.5.1.3 Phase III. Phase III uses the stabilized TV sensor to demonstrate target acquisition. The system, containing a centroid-of-brightness video tracker, is designed to autotrack 2.3- by 2.3-m (7.6- by 7.6-ft) targets 2.5 km (1.6 miles) from the RPV. The stabilized system (Figure 57) is designed to detect, with 50-percent probability, vehicle-size targets on a road at 5.0-km (3.1-mile) slant range and in a field at 2.5-km (1.6-mile) slant range. The system is designed to recognize, with 50-percent probability, vehicles at 2.2-km (1.4-mile) slant range both on a road and in a field. The operating range is the same as that of the unstabilized TV sensor system.

Like the unstabilized TV sensor, the stabilized TV sensor comprises a 12.93-in.-diameter dome of transparent acrylic plastic, with a stabilized TV camera mounted inside on a gimbal system supported by the sensor body. The gimbal system allows the camera to rotate 15 deg up, approximately 90 deg down,

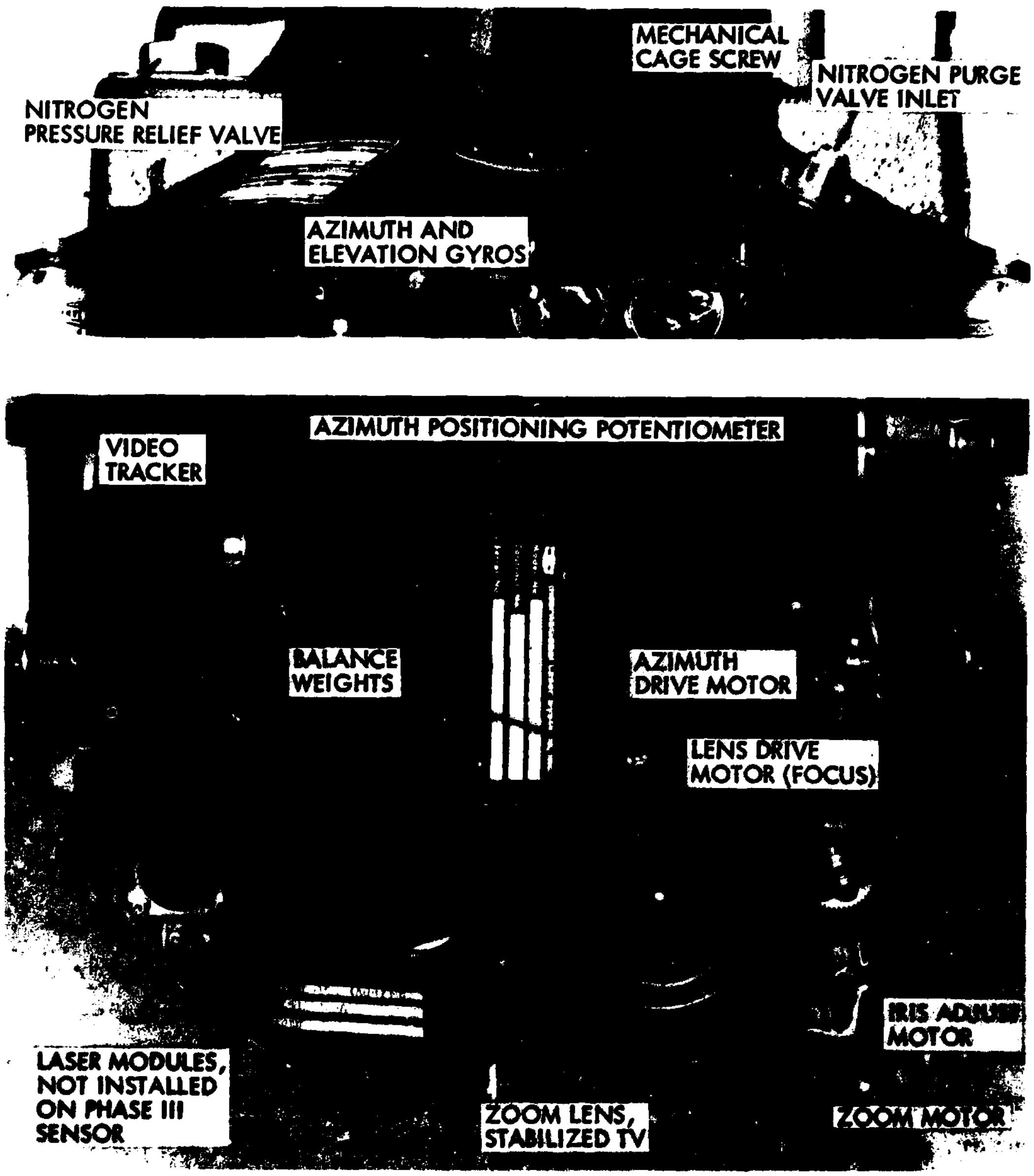


Figure 57. Stabilized TV and Autotracker

and to rotate 360 deg continuously either to the left or to the right. The sensor weighs about 33 lb, and is installed through the top of the aircraft and protrudes through the bottom. Like the unstabilized system, the TV camera has a standard 525-line format, but the tracker stabilizes the scene, which allows 300 lines versus 230 lines, for the improved resolution required for target acquisition. As in the unstabilized system, the camera has a remotely controllable 10:1 zoom lens, focus, three-position neutral-density filter wheel, and internally controlled iris responding automatically to the amount of light detected by the camera. The system can be mechanically caged by a signal from the GCS.

The TV portion of the sensor is a standard 525-line commercial system mounted on a POISE system – an inertially stabilized, direct-drive, two-gimbal system for stabilization and control of the line of sight of optical systems carried by aircraft.

The Aquila POISE system electronics (Figure 58) allows remote control of the camera/lens system, video tracker functions, laser functions, and gimbal position from the GCS. Output information includes the video picture with tracker information, and azimuth and elevation position readouts. The POISE system is composed of two major assemblies – gimbal and electronics – and a video tracker.

Gimbal Assembly. The POISE gimbal system is a direct-torque-motor-driven assembly. The azimuth, or outer gimbal, is driven with a torque motor under the top cover of the system and has a full 360 deg of freedom. Slip rings in the azimuth hub transfer electrical power and signals to the gimbal. The elevation, or inner, gimbal is also torque-motor-driven and has an angular freedom of +15 (up) to -87 (down) deg. Electrical power and signals are transferred to the elevation gimbal by flexible conductors in tapes. Mounted on the elevation gimbal are the TV camera and lens, the centroid-of-brightness video tracker, gyroscopes for stabilization, and, for Phases IV and V, the laser rangefinder and designator. The pointing direction is measured in azimuth by

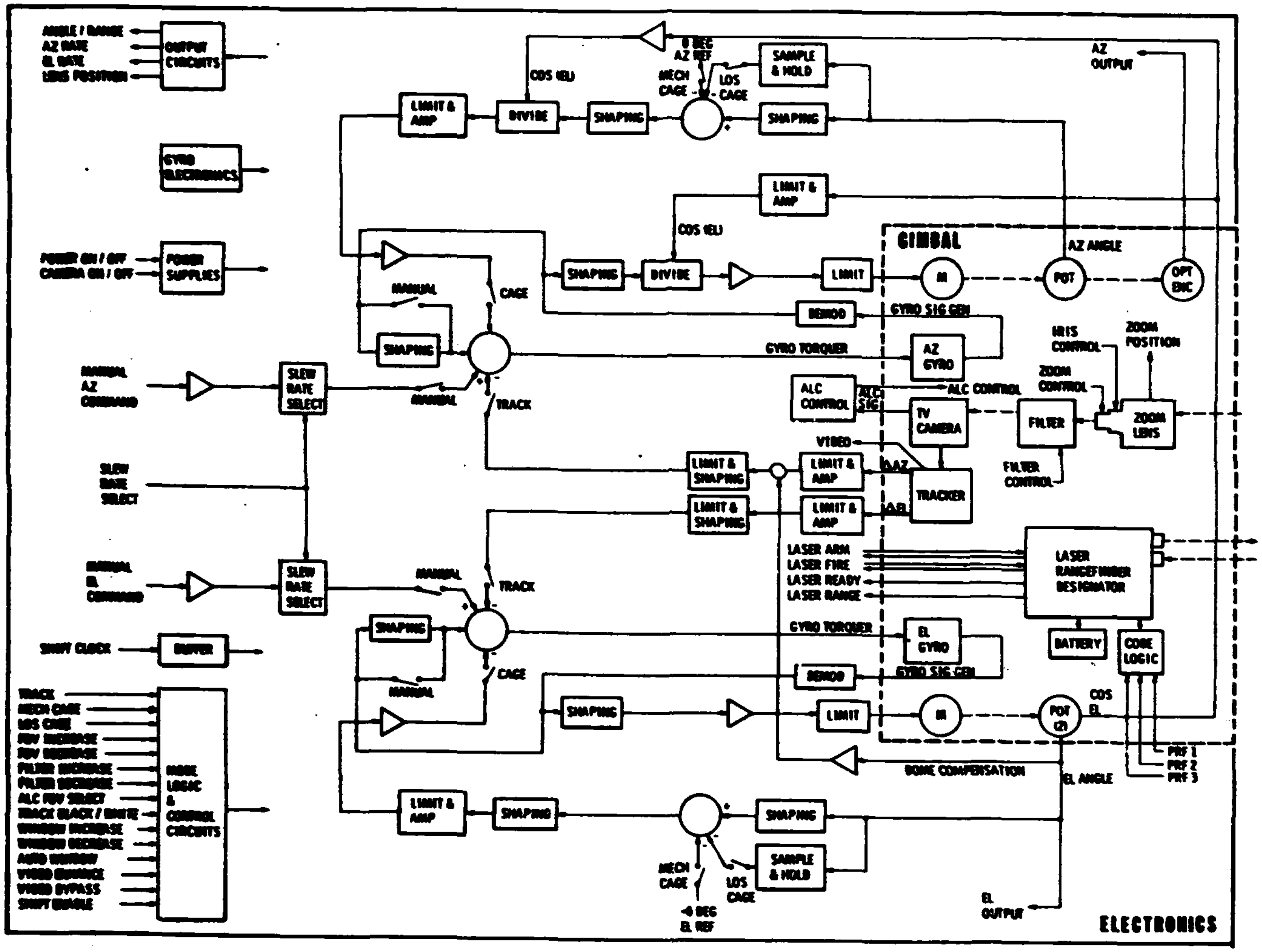


Figure 58. Functional Block Diagram of POISE

an optical encoder also located under the top cover and in elevation by a potentiometer mounted on the azimuth gimbal. Conversion of elevation angle to a digital word is accomplished in the electronics assembly.

Electronics Assembly. The electronics assembly contains all the power-conversion circuitry, azimuth and elevation servo loops, and signal buffers. Nine printed wiring boards are used, with the high-power dissipating elements mounted to the assembly end panels. A connector on the assembly interfaces all power and input/output signals, except for video, to the aircraft. Two other connectors interface the electronics with the gimbal assembly.

Video Tracker. The centroid-of-brightness video tracker (i.e., autotracker) is located above the lens systems on the elevation (inner) gimbal. Video from the TV camera is connected directly to the tracker. Two functions are provided by the tracker. A reticle is generated, appears on the video monitor as a horizontal and vertical line approximately in the center of the display, and indicates the line of sight. At the intersection of the lines is a box (gate) indicating the area in the field of view on which the centroid computation is being performed. The second function is to compute a command proportional to the error in alignment of a target from the reticle. This error signal is fed into the command loop, which then causes the gimbals to move and center the target on the reticle. The tracker is capable of tracking light or dark objects as selected by the operator.

3.5.1.4 Phases IV and V. Phases IV and V use the stabilized TV sensor system together with a laser rangefinder and designator. In the Phase IV mission, the system is used for artillery adjustment, first locating the target, then measuring the distance between artillery impact and the target position. In the Phase V mission, the system is used for target designation, first locating the target as in Phase IV, then illuminating (i.e., designating) the target for an incoming projectile.

The laser rangefinder and designator comprise an Nd-YAG (neodymium yttrium-aluminum-garnet) laser, an electronics package, a receiver telescope, a transmitter telescope (Figure 59), and a battery (Figure 60). The laser is a Class IV laser and can cause permanent eye damage if proper eye protection is not worn. Characteristics of the laser designator include the following:

- Rangefinder accuracy — Range 5 m with 50-percent probability out to at least 3 km and a 10-percent reflecting target on a standard clear day
- Energy level — Greater than 65 mJ per pulse at dome exit
- Pulse width — 15 to 23 ns
- Pulse rate and wavelength — Exact rates classified; pulse rates 1 pps and approximately 10 and 20 pps can be selected from the GCS
- Laser duty cycle

Rate	Fire	Cooldown
20 pps	1 min	3 min
10 pps	2 min	3 min
1 pps	-continuous-	

- Battery capacity

Rate	Total Firing Time
20 pps	10 min
10 pps	18 min
1 pps	70 min

The Phase IV system is designed to determine the location of a target within 100 m (330 ft) of its true position. Once a conventional round is fired, the displacement between the impact and the target (both of which are shown on a GCS TV monitor) is to be calculated automatically for artillery adjustment of succeeding rounds. Reticle adjustment screws (Figures 61 and 62) allow boresighting the video tracker with the laser beam.

In Phase V, the initial target position is to be determined as in Phase IV. Once a cannon-launched guided projectile is fired, the laser is fired at one of two predetermined high pulse rates, illuminating the target, which then reflects the laser energy in a form that designates the target for an incoming homing

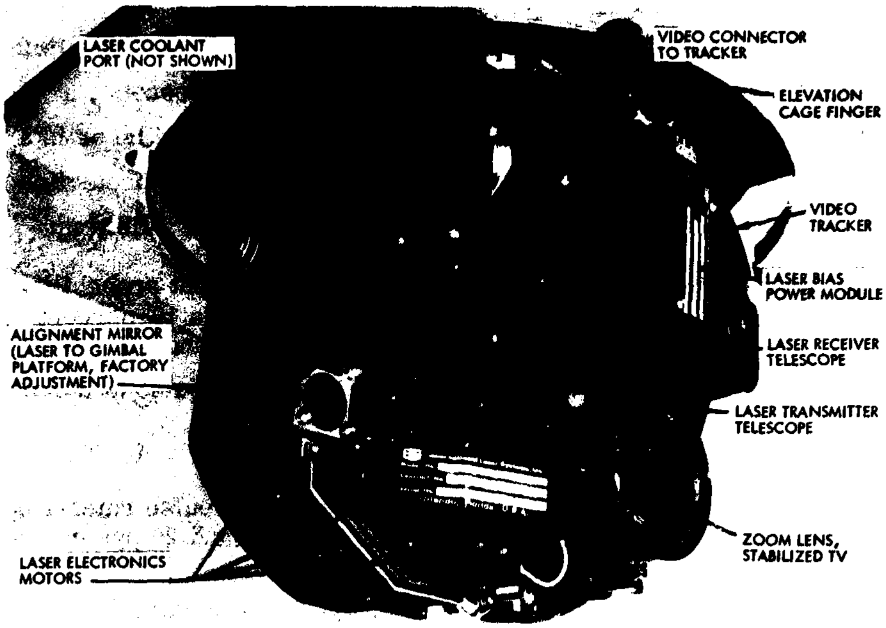


Figure 59. Laser Rangefinder and Designator, Front View

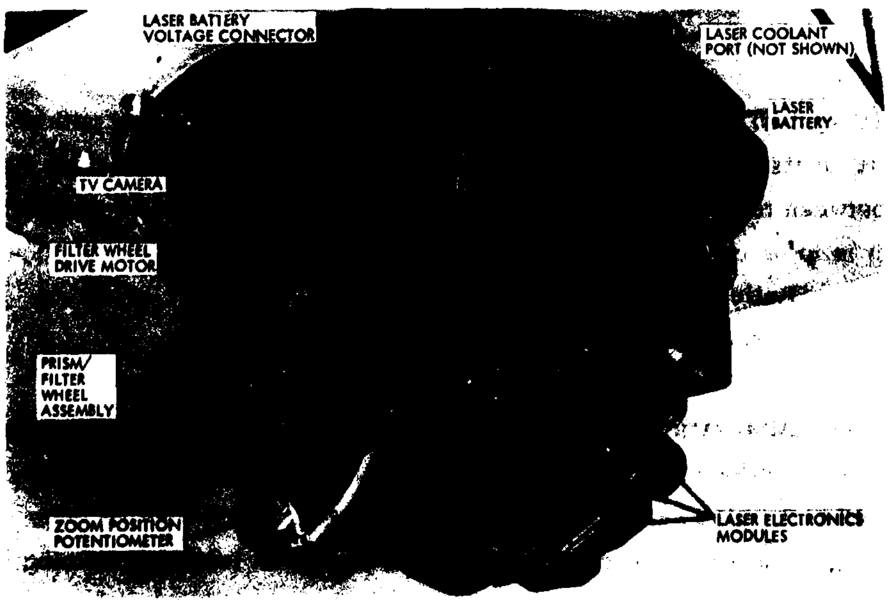


Figure 60. Laser Battery

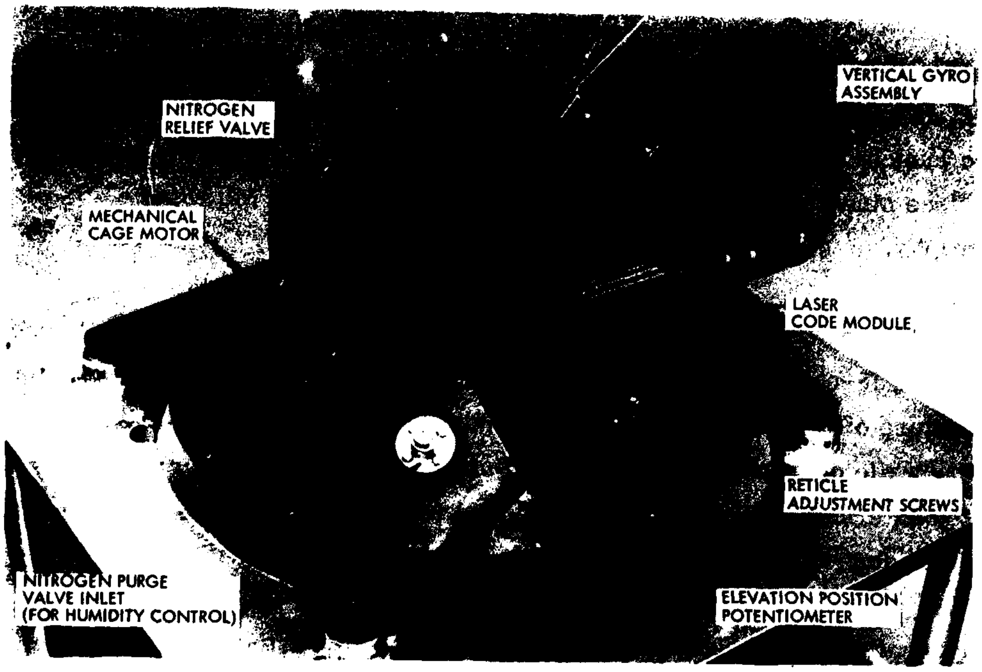


Figure 61. Laser Rangefinder and Designator, Top View

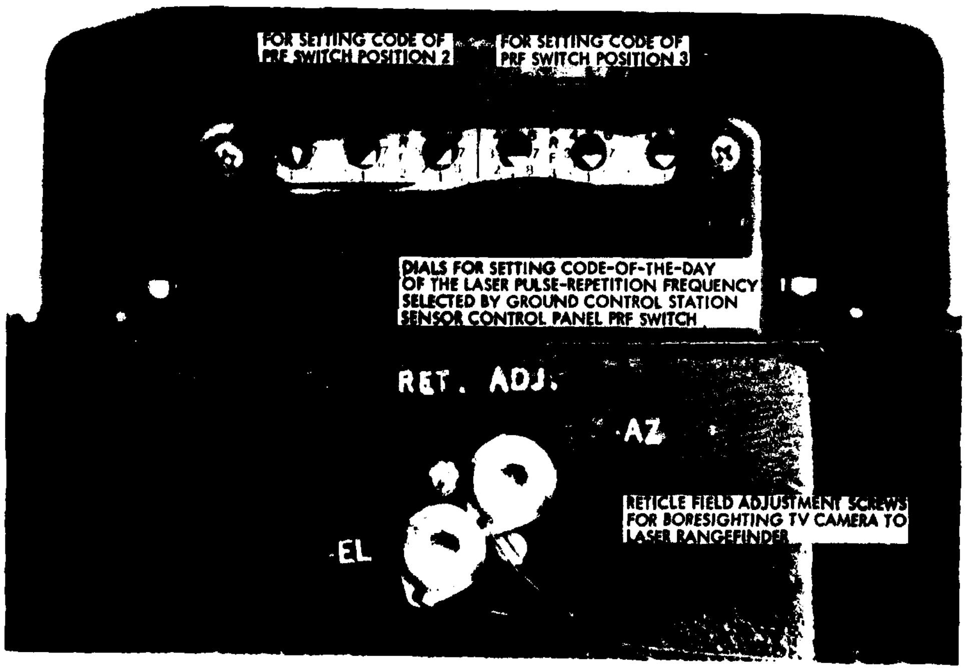


Figure 62. Laser Code Module and Reticle Adjustment

projectile (a semiactive laser seeker). A code module, shown in Figures 61 and 62, is used for setting in the code of the day for the two high pulse rates before launch. The laser system, shown in block diagram form in Figure 63, comprises nine modules, each of which is described in the following paragraphs.

Battery Module. The battery energy source for the entire laser system is provided by an 18-cell, 28-Vdc battery. The module is maintained at a minimum temperature of 50°F by a thermostat and battery heater to ensure maximum capacity while operating at low ambient temperatures. Power for the heater is supplied externally. The module is mounted to the main frame assembly cover with three screws and can be replaced readily when discharged.

Power Supply Module. The 28-V battery energy is converted by an inductive-aided, capacitor-changing dc-dc converter to a 700- to 930-Vdc level appropriate for flashlamp discharge. Pseudosimmer, energy storage, and pulse-shaping functions are accomplished by the power supply circuits. The power supply converter also provides a 300-V and 250-Vdc source for the pockels cell trigger and flashlamp trigger modules, respectively.

Transmitter Module. Flashlamp input energy is converted to 1.064-μm Q-switched laser output pulses. The module comprises porro prisms, optical pumping cavity, vertical and horizontal transfer prisms, retardation plate, dielectric polarizer, pockels cell electro-optical switch, folding mirror, and wideband output filter assemblies mounted to the optical bed. Transmitter module components, arranged to show the beam path, are illustrated in Figure 64.

Encoder Module. Circuits in this module provide output signals for synchronizing the laser system: pseudosimmer, flashlamp trigger, pulse-forming network trigger, and pockels cell trigger. In addition to these synchronizing

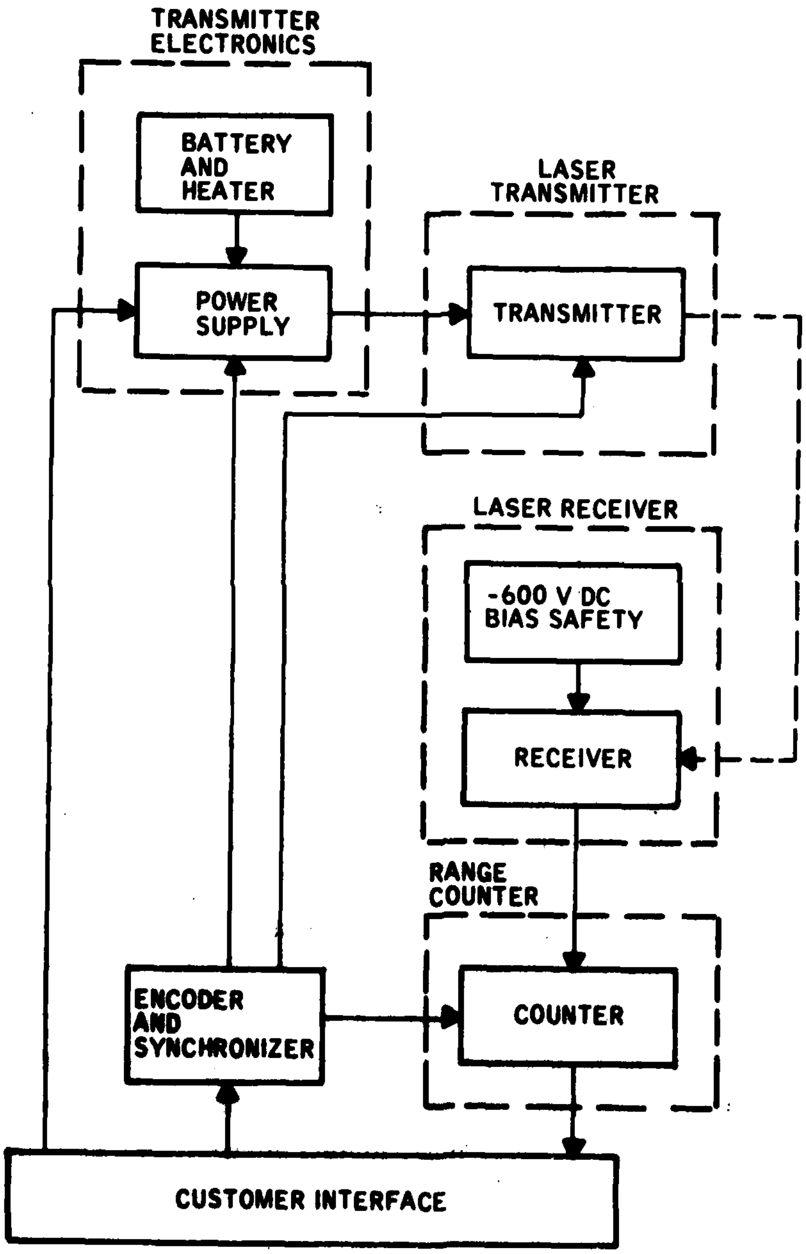


Figure 63. Block Diagram of Laser System

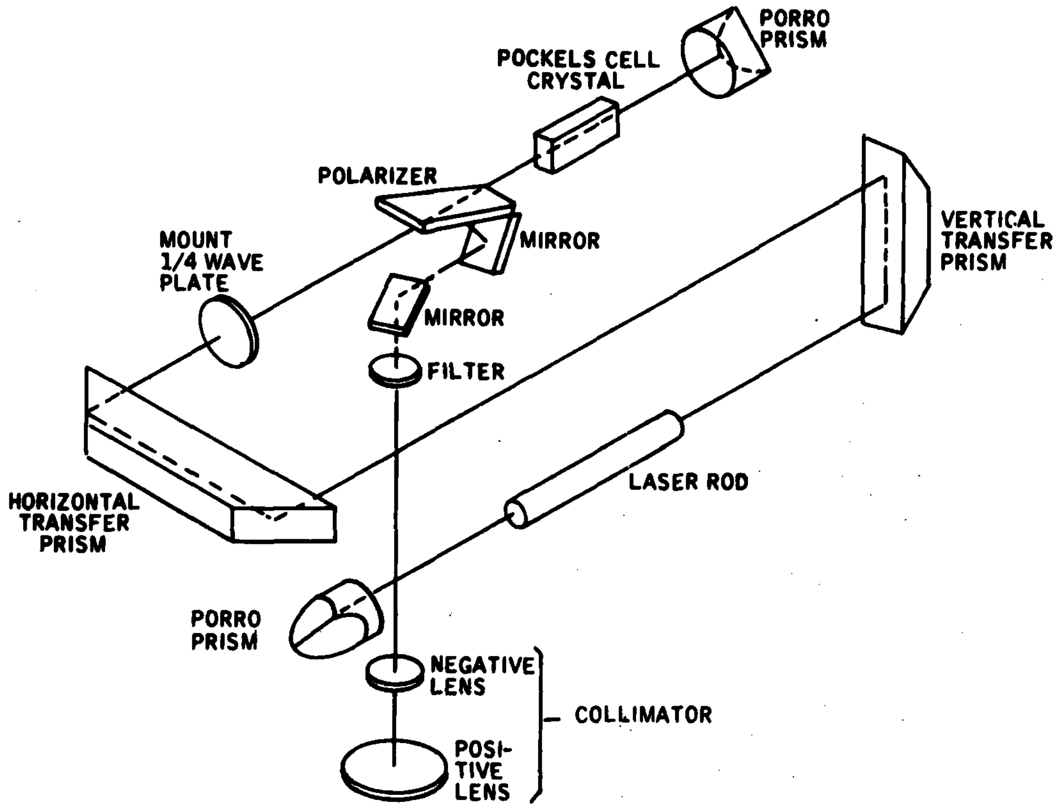


Figure 64. Optical Components of Laser Transmitter Module

signals, six switches are provided to allow the input of any of the band I or II pulse repetition frequency (PRF) codes as defined in Reference 11.

Range Receiver Module. Optical elements and circuits in this module receive and detect reflected 1.064-μm energy and provide essentially two signal outputs. The first signal is generated when near scattered output beam energy from the transmitter pulse is detected. The second signal is received from the target as transmitter energy and is reflected in the direction of the receiver. A 1.064-μm narrow-bandpass filter, lens, folding mirror, field stop aperture,

[11] INTEROPERABILITY OF LASER GUIDED WEAPONS SYSTEMS, Memorandum for the Assistant Secretaries of the Military Departments (Research and Development), 28 April 1973 (CONFIDENTIAL).

and silicone avalanche detector constitute the optical elements. The folding mirror and field stop are on movable mounts to allow for alignment of the receiver optic axis with the transmitted beam axis.

Range Counter Module. In this module, a 29-MHz clock is started by the signal generated by near scattered output beam energy and is stopped by the subsequent reception of the target signal from the range receiver module. Additional circuits are included in the counter complementary metal oxide semiconductor (CMOS) logic to provide range data for the target that is received last before the maximum permissible range return (9.995 km). The output data format is 13-bit serial at 5 V.

Main Frame Module. All modules of the laser system, except for the encoder module, are attached to the main frame. Subassemblies considered to be a part of this module are, with their functions, as follows:

- Cooling pump and reservoir: provides cooling to the pump cavity
- Transmitter collimating scope: reduces the laser raw beam from nearly 2.0 to 0.2 mrad
- Boresight alignment mirror: provides a reflective surface perpendicular to the laser output beam axis to within 0.25 mrad
- Main interface connector and wiring harness: provides for external electrical interface and interconnection of all laser modules, except for the encoder module (the encoder is part of the external, off-platform wiring)
- Main frame cover assembly: provides a sealed enclosure for the transmitter module when it is mounted to the main frame, a mounting for the 600-Vdc receiver bias power supply, and a mounting for the battery module

Pockels Cell Driver Module. This module contains an avalanche transistor circuit that generates a fast-rise, high-voltage trigger to actuate the electro-optic switch in the transmitter module. It receives 300 Vdc from the power supply module and triggers from the encoder module.

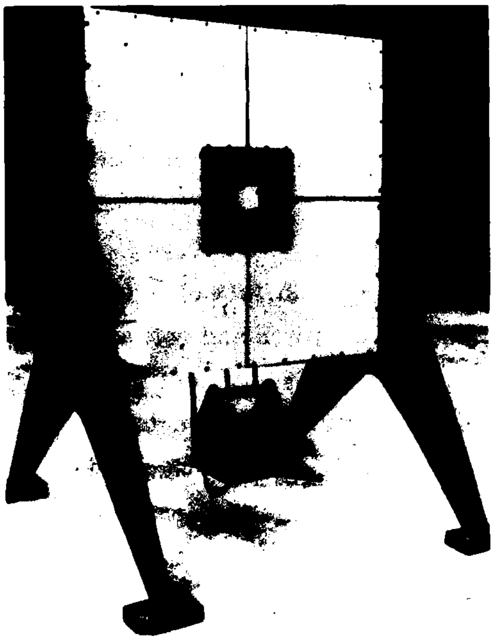
Flashlamp Trigger Module. The flashlamp trigger module contains a silicon-controlled-rectifier (SCR) capacitor discharge circuit that provides a 7-kV pulse to ionize the flashlamp gas. This ionization begins the pseudosimmer mode before the discharge of the pulse-forming network (PFN) energy. A 250-Vdc input from the power supply module and a trigger signal from the encoder module provide for the operation of this circuit.

In addition to the nine modules, a laser boresight target and a vertical gyro perform important functions as described in the following paragraphs.

Boresight Target. A laser boresight target is used to align the autotracker with the laser beam. The target comprises a target board (Figures 65 and 66) and a power supply. The target presented by the board is similar to the display shown on the sensor operator's TV monitor in the GCS. When the sensor is pointed at the target, the target image is, in effect, superimposed on the crosshair and tracker gate display shown on the monitor. The boresight target is set up 1,000 ft away from the sensor. The sensor can be controlled either by the GCS or by a sensor checkout controller interconnected with the sensor and a TV monitor. The sensor checkout controller, or POISE test box, is described in Reference 12.

The sensor is first slewed onto the target and the autotracker is turned on. The laser is then fired. When the laser is fired, the beam should hit in the middle of the tracker gate; if it does, the target board flashes in a manner that indicates a properly aligned beam. If the beam hits off center, the target board flashes to indicate which quadrant was hit. The azimuth and elevation screws on the sensor (Figure 62) are adjusted in the direction of the quadrant that was hit, which electronically moves the crosshairs and target gate to the laser spot. As this occurs, the autotracker error signals transmitted to the sensor gimbal

[12] AQUILA POISE FIELD CHECKOUT AND MAINTENANCE MANUAL FOR YG1165B01 AND YG1165C01, Honeywell Avionics Division, Minneapolis, Minnesota, April 1977.



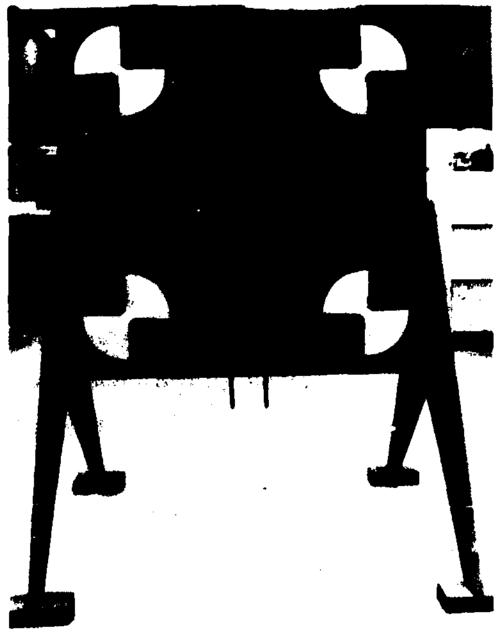


Figure 65. Laser Boresight Target

Figure 66. Laser Boresight Target, Front Cover Removed

system cause the gimbals to move, bringing the laser beam to the center of the tracker gate. The laser is then fired again, and the process is repeated until a proper indication is received from the target board.

So that the target board can indicate where it is being struck by the laser beam, five laser energy detectors are located within the board, one in each quadrant and one in the center. Those within the quadrants are each located within a laser-energy diffusing material, and each is connected to a rotating disk. When the laser strikes a particular quadrant, the laser energy diffuses within the material so that it may be sensed by the detector. Once sensed, the detector causes the disk within the quadrant to rotate 90 deg back and forth, so that it flashes black then white at a 1-sec rate. This flashing is easily seen on the TV monitor and the azimuth and elevation controls can be adjusted accordingly. If the laser hits the boundary between two quadrants, the disks in both quadrants flash again at a 1-sec rate. If the beam hits the center of the target, the detector in the center of the target causes all four disks to rotate at a 1-sec rate, the indication of a properly boresighted laser beam. If the beam hits the center of the target but is too wide and spills over to one of the four quadrants, all four disks will rotate at a 4-sec rate. If this occurs, the sensor is faulty and must be returned to the factory for repair.

Vertical Gyro. The vertical gyro (Courter Inc. P/N 18-1883), attached to the top of the laser sensor as shown in Figure 61, detects the pitch and roll axes of the sensor relative to the local vertical. This allows the position of the target to be determined in universal transverse mercator (UTM) coordinates. The 28 Vdc, 12 W, 2.5 lb gyro is controlled by two commands: a cage command and an erect command. The cage command is wired into the sensor control panel MECH CAGE switch. The mechanical caging system constrains the gyro gimbals and is utilized for gyro protection during launch and recovery. When the gyro is uncaged, the erection circuits are energized and the gyro spin axis is torqued to the dynamic vertical. The dynamic vertical is coincident (approximately) with the lift vector which approaches the true vertical for straight unaccelerated flight. The erection circuit is disabled when the gyro senses a roll angle greater than 5 deg. This threshold allows the erection to be active during normal flight conditions but not during sustained turns. When the erection is inhibited, the gyro spin axis drifts approximately 0.5 deg per minute.

During normal loiter the RPV turns in the same direction as the gyro spins. Under these conditions the gimbal friction tends to keep the gyro erect to the true vertical, and the gyro drift tends to be reduced.

During periods of extended turns and/or loiter, the vertical gyro spin axis will drift from the true vertical and can generate a significant targeting error.

3.5.2 System Targeting Performance

The sensor flight test program was run from May to July in 1977 at Fort Huachuca, Arizona. Aircraft characteristics were exercised and tested, as well as GCS functions of launch, recovery, data link, and navigation. A limited sensor evaluation program was included that used military vehicles set up as road and field targets at predetermined target locations on the eastern test range. The operators were cued as to target location to permit assessment of the maximum hardware capability.

The primary purpose of the flights was to determine the readiness of the system to perform target surveillance, reconnaissance, acquisition, location, and designation in accordance with design capabilities. Consequently the sensor and RPV operators were cued as to target location. Heavy emphasis was placed on operating the more sophisticated sensor types. In fact, of the 33 flights in this series, 18 were made with Phase IV and V sensors. The selected targets were:

- Location 48: usually a large truck situated crosswise in the road
- Location of the tank mockup
- Location apex, pole 33: a small truck supporting a large board target, specifically used for laser scoring and burst offset

The sensor testing is more thoroughly described in Reference 13 and in Volume III of this report.

Table 14 lists the test results of the sensor test program. The measurements are indicated in the large boxes, with the specifications in the small boxes. With the possible exception of Phases IV and V data, consistent data are insufficient for statistical evaluation. Target location data taken with the sensor for Phases IV and V during flight 65 were sufficiently consistent for a reasonable average to be obtained.

[13] AQUILA RPV SYSTEM TEST REPORT, CDRL A00D, PART 12, SENSOR -- MISSION AND SYSTEM VALIDATION, LMSC-L028081, Lockheed Missiles and Space Company, Inc., Sunnyvale, California, December 1977.

TABLE 14. SENSOR TEST PROGRAM, SPECIFICATIONS, AND RESULTS

Parameter	Phase I (Flight 61)		Phase II (Flight 47)		Phase III		Phase IV – V	
	Spec.	Results	Spec.	Results	Spec	Results	Spec.	Results
Dynamic Resolution TV Lines/Picture Height (Measured with Vertical Lines)	200	180 (single measurement)	TV resolution as in Phase I		200	Low = 180 High = 250 4 readings – Flights 49, 50, 65	See Phase III results, identical camera therefore results combined with Phase III	
			Panoramic 40 lp/mm (goal)	Photo camera 24 lp/mm				
Target Detection								
Slant Range (m) Road	3,000[a]	Low = 1,075 High = 2,161 (FOV = 20 deg)[b]	See Phase I results		5,000	Low = 1,287; Mean = 4,845; High = 8,014 (FOV 12 deg); σ = 2,506	17 measurements of combined Phases III, IV, V flights 49, 50, 65[b]	
Slant Range (m) Field	1,500	Low = 846 (FOV = 12 deg)[b] High = 1,135	See Phase I results		2,500	Low = 1,526; Mean = 2,282 High = 3,371; σ = 762	11 measurements of combined Phases III, IV, V flights 49, 50, 65[b]	
Target Recognition Slant Range (m)	1,000	936 single measurement Flight 61	See Phase I results		2,200	Low = 826; Mean = 1,747; High = 3,233; σ = 604	15 measurements of combined Phases III, IV, V Flights 49, 50, 65	
Sensor Stabilization (µradians)	Not applicable		Not applicable		50	<500 single value measured on flight 64. Imprecise result due to measurement restrictions.		
Automatic Tracking (percent of time inside 2.3-m[2] target)	Not applicable		Not applicable		95	>95, based on flight 65 laser scoring run at 9:29:20. All observable hits appeared to be within 2.3-m circle for 15-sec duration RPV to target range = 3,142 m (start); 3,425 m (end). Imprecise result because of measurement restrictions.		
Laser Range (m)	Not applicable		Not applicable		Not applicable		Range = 3,000; Accuracy = ±5	3,435 – single point measured on flight 65 (accuracy not measured)
Target Location Accuracy (m) CEP	400	Not measured	Not applicable		400	Not measured	100	CEP = 253 (centroid offset by north 190 and east 63)[c] MRE = 248 (σ = 378) [MRE = 135 see note (d)]
Target Altitude Accuracy (m)		Not measured	Not applicable			Not measured	75	Mean = 71, σ = 87 see note (c) [Mean = 56] see note (d)
Laser Designation Accuracy (percent of time inside 2.3-m[2] target)	Not applicable		Not applicable		Not applicable		95	>95; see automatic tracking notes

(a) Very few meaningful Phase I results. Two road targets; two field targets; flight 61.
(b) Unless otherwise stated the FOV was not measured. Refer to individual flight tests for more data.
(c) Computed from 26 readings on flight 65.
(d) Three gross location errors discarded because of suspected transient magnetometer errors.

3.5.2.1 Phase I Test Results. All the dynamic resolution measurements in all phases fell short of the specifications. The Phase I sensor showed considerable motion because of turbulence and the resulting airframe motion coupling directly to the sensor. Another major source of aircraft motion observed during the testing resulted when antenna polarization changes caused cyclic errors in indicated RPV location. Automatically commanded corrections produced a roll oscillation. The severity of this roll oscillation and the significant efforts required to resolve it are discussed in Section 3.4.4.2, Volume II of this report.

Other factors which can affect resolution are as follows:

- The measurements were nominally made at a 30-deg down look angle. With this geometry the resolution target is fairly large and almost fills the screen. This means that the smaller resolution elements are usually observed at one edge of the screen. The measurement therefore represents edge resolution rather than center resolution. The camera resolution varies from 450 TV lines/picture height in the horizontal direction and 350 TV lines in the vertical direction, with a degradation to 340 TV lines horizontal and 260 TV lines vertical in three corners and the fourth corner to be greater than 300 TV lines horizontal and 230 lines vertical. Hence, the resolution of the system will not be as good at the edge as in the center.
- The measurements were made from tapes of the original video. Degradation due to video data processing is possible.
- No automatic tracking is available on the Phase I sensor. This means that the TV image is moving continuously, as the aircraft moves, and is therefore difficult to interpret. Stop-frame techniques were attempted on the tape recorder to overcome this; however, this also caused image degradation.

It therefore appears that the resolution values could improve by more precisely controlling the test conditions and by making the observations directly from the operator's TV console.

Both target detection and recognition fell short of the specifications in the few measurements made. There were two major reasons:

- Many of the Phase I data were taken at the beginning of the program before any operator skill had been acquired.
- Considerable image motion made searching and identifying very difficult.

The sensor field of view (FOV) can significantly affect detection and recognition performance. If the FOV is too large, the image motion is not a problem, but resolution of small objects is difficult. If the FOV is too small, the image motion is excessive and consistent area search becomes impossible. Selecting an optimum field of view (about 12 deg) gave the best compromise.

3.5.2.2 Phase II Test Results. The Phase II system embodies both a Phase I unstabilized video camera and a panoramic photographic camera. The photographic camera performance is shown under dynamic resolution and is given as 24 line pairs/mm. The static resolution of this unit is rated at 75 line pairs/mm.

The image degradation has several contributing factors:

1. Focus precision of the camera.
2. High vibration causes image smear during the 1/2,000-sec shutter time.
3. A gamma value of 1.3 was used for processing. The gamma value should be increased to 1.6 to increase contrast and resolution.

No specification has been placed on the dynamic resolution of the camera. The stated goal of 40 line pairs/mm could be achievable by concentration on the above factors.

Target detection and recognition of the Phase II sensor are quoted as being equal to those of Phase I because this part of the system is in fact a Phase I video system.

3.5.2.3 Phase III Test Results. Dynamic resolution for this sensor was less than the specified 300 TVL per picture height. The reasons for this are stated previously in Section 3.5.2.1. The stabilized video camera performed consistently in the Phase III, IV, and V applications. Consequently, the TV performance is averaged for all stabilized sensors. Seventeen measurements of target detection with the stabilized video produced a mean target detection distance of 4,845 m for targets on a road. A maximum range of 8,014 m was achieved. This maximum was achieved with the wide field of view (12 deg). The average range for targets in a field environment was 2,282 m, with a maximum range of 3,371 m. The automatic tracking feature was also demonstrated.

3.5.2.4 Phases IV and V Test Results. Target detection, recognition, and tracking characteristics are the same as for Phase III.

While the burst offset functions were demonstrated – i.e., ranging, cursor operation, and offset measurement – formulation/software errors were found which precluded successful burst offset demonstration. Consequently, this option was not available for contractor or Army evaluation, pending correction of the identified anomalies.

As previously mentioned, the dynamic resolution remained less than the specification. This is fully explained in subsection 3.5.2.1.

Sensor stabilization is extremely difficult to measure in a moving vehicle. Stabilization is intended to compensate for aircraft pitch, roll, or yaw, but does not compensate for the typical vertical buffeting which occurs. It is almost impossible to separate this kind of vehicle motion from the sensor motion since both contribute directly to the image motion of a distant scene. When sensor stabilization is measured, the tracker cannot be used because it immediately corrects for any sensor or vehicle motion. One flight (number 64) performed some low-altitude maneuvers with the sensor pointing straight ahead and slightly down. An attempt was made to measure the sensor stabilization by measuring the movement of the observed FOV center point on the target over a period of about 10 sec. This was estimated to be 3 to 4 ft at a range of between 6,000 and 7,000 ft. Obviously, therefore, the stabilization is better than this if it equates to about 500 μrad. It is impossible to indicate how much better without performing some more specialized flights. The sensor itself is known to have a passive stabilization of 30 μrad. Most of the image motion observed in this test is therefore probably due to normal aircraft motion.

Laser range was measured at every firing and varied from 1,531 to 3,770 m. The accuracy of this measurement is defined by pulse width and rise time of the laser pulse, as well as the digital word quantization. Range accuracy of the laser system is ±5 m. Again, this accuracy could not be confirmed by the tests because of the relatively low measurement accuracy for location of the RPV and target. The best agreement between laser-measured range and computed range was 18 m.

Target location accuracy was evaluated during flight 65. Twenty-six separate target locations were accomplished, indicating a location CEP of 253 m against a specification of 100 m. The mean altitude error determined was 71 m. Three of the target sightings yielded unexplained anomalies in the data, including large laser ranging errors (see Volume III, Appendix E). If these data are considered as nonrepresentative, a location CEP of 135 m and a mean altitude error of 56 m are indicated.

Laser designation at 20 pps was performed several times during flight 65. This was made against a scoring target, which consisted of a large black board about 24 ft square with a 2.3-m white square in the center. A designation pass was selected in which the laser range was consistently greater than 3 km, and the scoring data were analyzed by observing the individual hits over a 20-sec firing period. It was apparent that the center of the laser beam was offset by about 2 m in the upper right-hand side of the white target. This could have been caused by a combination of several effects:

- Boresight error
- Tracking offset
- Dome distortion

The total distribution of hits was observed by using the actual laser beam center and counting the hits inside a 2.3-m-diameter circle around this point. Some hit observations may have been lost when they landed on the black background, which made counting difficult. However, all observed hits were within the 2.3-m circle. The approximate distribution was found to be 60 percent within a 1-m circle, 30 percent within the 2-m ring, and 10 percent in the remaining 0.3-m ring.

Section IV
DATA LINK

The data-link system provides for the command, control, and transfer of data between the RPV and ground control station (GCS). The data-link system consists of the RPV airborne data-link subsystem and the GCS data-link subsystem. The block diagram of the total system is shown in Figure 67.

4.1 GENERAL DESCRIPTION

The data link operates as a duplex link providing for simultaneous and continuous two-way communication between the RPV and GCS. The command link (uplink) operates at 4.861 GHz and provides command and control of the RPV from the GCS. The video/telemetry link (downlink) operates at 4.530 GHz and provides RPV status information and sensor data to the GCS. In addition to the two-way communication function, the data link also provides for locating the RPV in real time.

4.1.1 Command Link

The command link, or uplink, provides command and control data to the RPV flight controls and payload sensor controls. The flight control commands are generated by the GCS computer; the sensor control signals are provided by the sensor operator through the sensor control panel. These command and control signals are serially encoded into digital words by the encoder. The digital data are then used to phase-modulate a 117-kHz subcarrier modulated with an 11-bit Barker Code. This coding technique provides protection against inadvertent friendly interference. The subcarrier encoded with data is fed to the command transmitter, which is used to frequency-modulate the 4.861-GHz

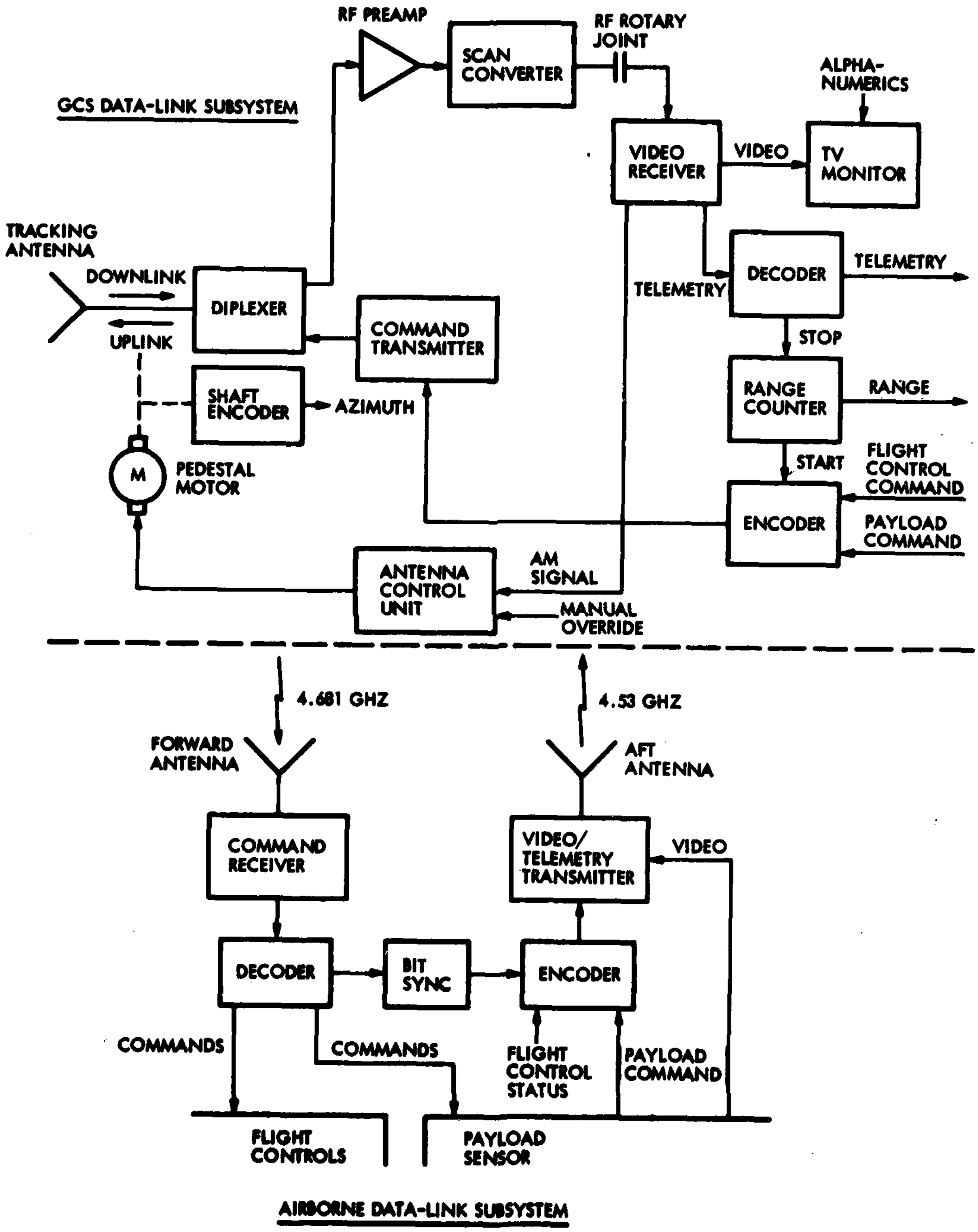


Figure 67. Block Diagram of Data-Link System

carrier. The signal is then transmitted through the GCS tracking antenna to the RPV. The RPV receives the command signal through the aft-mounted antenna; this signal is fed to the command receiver, where the FM signal is detected. The received digital bit stream output is fed to the decoder in the flight control package. In the decoder, the commands are sorted out and channeled to the various RPV and sensor controls.

4.1.2 Video/Telemetry Link

The video/telemetry link, or downlink, provides sensor data and RPV status information to the GCS. The sensor video data are contained on a wideband data channel with capacity to accommodate a conventional TV picture. The video sensor data are fed directly to the video transmitter. The telemetry and status data are input to the encoder board in the flight control electronics package, where the data are encoded to a serial digital bit stream. The digitized data are used to phase-modulate the 11-bit Barker Code. The phase-modulated coded signal is then fed to the video/telemetry transmitter. Both the sensor video data and telemetry data are combined in the transmitter by using the encoded telemetry data to frequency-modulate a 6.5-MHz subcarrier, which is added as a sideband of the 4.530-GHz carrier. The sensor video data directly frequency-modulate the 4.530-GHz carrier.

The subcarrier with the telemetry data and the video-modulated carrier are transmitted out of the top, forward-mounted, RPV antenna down to the GCS tracking antenna. The GCS tracking antenna tracks the RPV in azimuth by comparing the rf signal strength of a left beam and right beam generated by the rf network mounted behind the parabolic dish. The receiver video/telemetry data are detected and separated at the GCS video/telemetry receiver. The output of the video signal is mixed with computer-generated alphanumerics and connected to the TV monitor. The telemetry data are fed into the decoder, where the serial digital data are decoded for display and recording.

4.1.3 Requirements and Capabilities

4.1.3.1 Range. The data link is required to provide a reliable two-way communication link between the RPV and GCS over its operational envelope of 20-km range and from 2,000-ft to 10,000-ft above-ground-level (AGL) altitude. Table 15 shows both the uplink and downlink values for an operating range of 20 km and an altitude of 2,000 ft AGL. The command uplink, as shown in the table, has 15 dB of fade margin; with a 0-dB margin, the command link will operate with a 0.99 reliability at a line-of-sight range of 20 km. The video/telemetry downlink has a 12-dB fade margin; the link will close with 0.95 reliability at a line-of-sight range of 20 km.

TABLE 15. DATA-LINK VALUES FOR 20-KM RANGE AND 2,000-FT AGL ALTITUDE

Item	Value
UPLINK	
Command Transmitter Power (10 W)	+40 dBm
Transmit Antenna Gain	24 dBi
Space Loss (20 km)	-133 dB
Airborne Receive Antenna Gain (2σ)	-10 dBi
Receiver Sensitivity	-(-94) dBm
Fade Margin	+15 dB
DOWNLINK	
Video Transmitter Power (10 W)	+40 dBm
Transmit Antenna Gain (2σ)	-7 dBi
Space Loss (20 km)	-133 dB
Ground Receive Antenna Gain	24 dBi
Receiver Sensitivity	-(-88) dBm
Fade Margin	+12 dB

However, within the RPV operation envelope, the maximum range of 20 km is not the weakest area of closure for the data link. Figures 68 and 69 show the overlay of the ground-station tracking-antenna elevation coverage versus range and altitude with 0-dB fade margin. As shown, the uplink had adequate coverage over the total RPV operational envelope. For the downlink, however, at 16 to 19 km and altitudes above 2,286 m AGL, the reliability of downlink closure falls to 0.75. This is caused by a tradeoff on minimizing the tracking problem of the GCS antenna and elevation coverage. As shown in Figure 69, the peak of the low-gain antenna is pointed at an elevation angle of 30 deg. From the standpoint of coverage, the antenna should be pointed at +15 deg, but because of multipath problems the antenna tracking is severely degraded. Therefore, the elevation beam on the antenna was set at 30 deg and the degradation in downlink coverage was accepted.

		HIGH GAIN	LOW GAIN
TRANS. POWER (DBM)	=	40.00	40.00
TRANS. ANT. GAIN (DBI)	=	24.00	13.60
RCV. ANT. GAIN (DBI)	=	-9.75	-9.75
RCV. SENS. (DBM)	=	-94.00	-94.00
POL. LOSS (DB)	=	0.00	3.00
FREQ. (GHz)	=	4.861	4.861

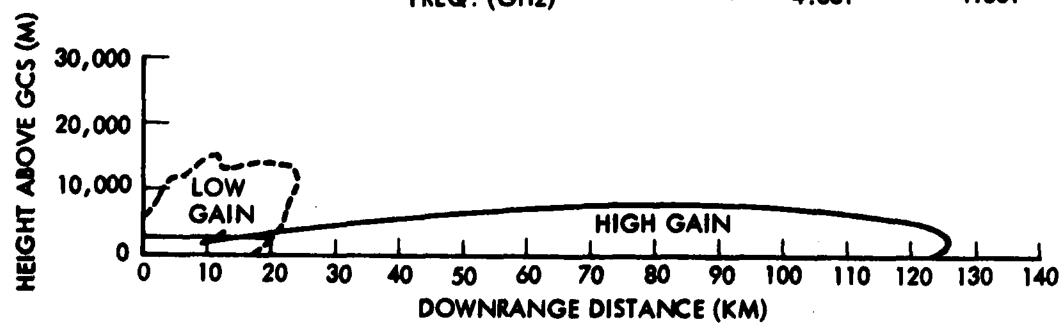


Figure 68. Range and Coverage of Command Link

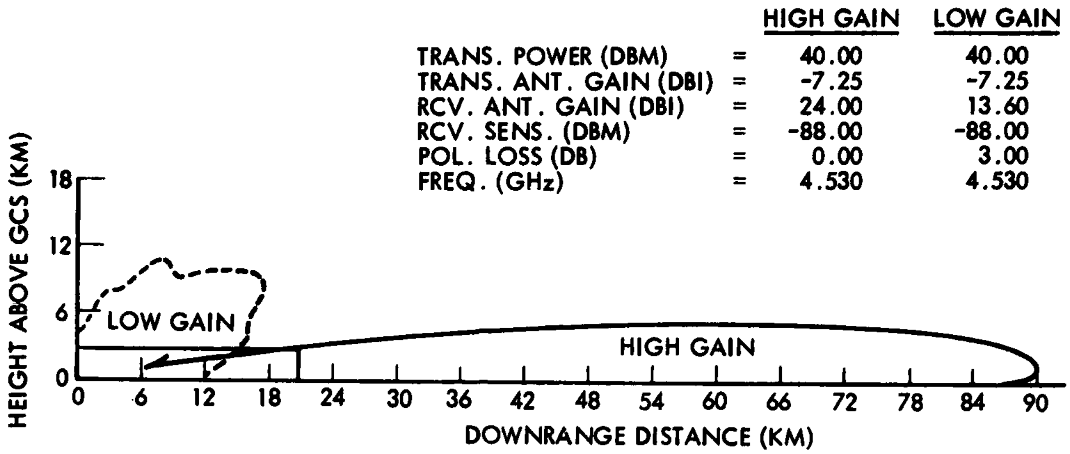


Figure 69. Range and Coverage of Video/Telemetry Link

4.1.3.2 Uplink Format. The data link is required to provide command and control data to the RPV. This is accomplished by transmitting a command digital bit stream at approximately 10 frames/sec. Each frame consists of 32 8-bit words. These command words provide for:

• Frame sync	2 words
• Analog commands	9 words
• Discrete commands	5 words
• Ground Status	6 words
• Undefined	10 words
TOTAL	32 words

A breakdown of the use of each word is shown in Table 16. The undefined words are unused and no hardware is provided for these words.

4.1.3.3 Downlink Format. The data link is required to provide information about the RPV and payload. This is accomplished, as in the command link, by transmission of digital data at approximately 10 frames/sec. Each frame consists of 32 8-bit words. These 32 status words are as follows:

TABLE 16. DIGITAL DATA FOR UPLINK

IV Channel	GCS Address	Function	Symbol	Subsystem	Range	Resolution	Phase I	Phase II	Phase III	Phase IV	Phase V	Remarks
CA1	Enc 00	Frame sync word no. 1	F/S No. 1	–	–	–	X	X	X	X	X	$(260)_8$
CA2	01	Frame sync word no. 2	F/S No. 2	–	–	–	X	X	X	X	X	$(117)_8$
CA3	02	Gnd. rcvr. signal strength		D/L	0 to +2 V		X	X	X	X	X	
CA4	03	Low gain antenna select		D/L	0 to +2 V		X	X	X	X	X	Low gain = OV
CA5	04	GCS status lock		D/L, CPU	0 to +2 V		X	X	X	X	X	Lock = OV
CA6	05	GCS valid data		D/L, CPU	0 to +2 V		X	X	X	X	X	Valid = OV
CA7	06	Manual/auto track		D/L	0 to +2 V		X	X	X	X	X	Manual = OV
CA8	07	Spare										
CA9	08	Antenna servo error		D/L	±2.5 V	0.5 V/deg						
CA10	09	Spare (unaddressable)										
CA11	10	↓										
CA12	11	↓										
CA13	12	↓										
CA14	13	↓										
CA15	14	Pitch elevon angle command, manual	$[(\delta_P)_C]_{MAN}$	Pitch autopilot	+4 to -16 deg	0.08 deg	X	X	X	X	X	
		or										
CA16	15	Indicated airspeed command 1	$(IAS)_{C1}$	Pitch autopilot	74 to 222 km/h	0.6 km/h	X	X	X	X	X	
CA17	16	Normal velocity command	$(\dot{Z}_C)_1$	Pitch autopilot	+3 to -3 m/sec	0.02 m/sec	X	X	X	X	X	
CA18	17	Altitude command	h_C	Altitude autopilot	0 to 3,600 m (MSL)	14.0 M	X	X	X	X	X	
		or										
		Throttle angle command, manual	$[(\delta_{TH})_C]_{MAN}$	Altitude autopilot	0 to 100%	0.4%	X	X	X	X	X	
CA19	18	Heading rate command	$(\dot{H}_C)_1$	Heading autopilot	-12 to +12 deg/sec	0.1 deg/sec	X	X	X	X	X	
		or										
		Roll elevon angle command, manual	$[(\delta_R)_C]_{MAN}$	Heading autopilot	-12 to +12 deg	0.1 deg	X	X	X	X	X	
CA20	19	Azimuth LOS slew	$\dot{\psi}_{LOS\ sl}$	Sensor	0 to 10 deg/sec	20 mV			X	X	X	CW = +V
CA21	20	Elevation LOS slew	$\dot{\theta}_{LOS\ sl}$	Sensor	0 to 10 deg/sec	20 mV			X	X	X	Up = +V
CA22	21	Spare										
CA23	22	Spare										

TABLE 16. (CONTINUED)

IV Channel	GCS Address	Function	Symbol	Subsystem	Range	Resolution	Phase I	Phase II	Phase III	Phase IV	Phase V	Remarks
CSD24-0	Enc23-0	Sine heading command	sin H_c	Heading autopilot	-1 to +1	0.007	X	X	X	X	X	
CSD24-1	-1											
CSD24-2	-2											
CSD24-3	-3											
CSD24-4	-4											
CSD24-5	-5											
CSD24-6	-6											
CSD24-7	-7											
CSD25-0	Enc24-0	Cosine heading command	cos H_c	Heading autopilot	-1 to +1	0.007	X	X	X	X	X	
CSD25-1	-1											
CSD25-2	-2											
CSD25-3	-3											
CSD25-4	-4											
CSD25-5	-5											
CSD25-6	-6											
CSD25-7	-7											
CSD26-0	Enc25-0	Spare (unaddressable)										
CSD26-1	-1											
CSD26-2	-2											
CSD26-3	-3											
CSD26-4	-4											
CSD26-5	-5											
CSD26-6	-6											
CSD26-7	-7											
CSD27-0	Enc26-0											
CSD27-1	-1											
CSD27-2	-2											
CSD27-3	-3											
CSD27-4	-4											
CSD27-5	-5											

TABLE 16. (CONTINUED)

W Channel	GCS Address	Function	Symbol	Subsystem	Range	Resolution	Phase I	Phase II	Phase III	Phase IV	Phase V	Remarks
CD27-6	Enc26-6	Spare (unaddressable)										
CD27-7	-7	Spare (unaddressable)										
CD28-0	Enc27-0	Sensor power on/off	S	Sensor	On = 0	1 bit	X	X	X	X	X	1 req. by sensor
CD28-1	-1	Engine kill command	IGN	Propulsion	Kill = 1	↓	X	X	X	X	X	
CD28-2	-2	Mechanical cage	M_c	Sensor	Cage = 1	↓	X	X	X	X	X	0 req. by sensor
CD28-3	-3	Electrical cage or LOS cage	E_c	Sensor	Cage = 1	↓	X	X	X	X	X	
CD28-4	-4	Slew rate	SR	Sensor	Increase = 1	↓	X	X	X	X	X	
CD28-5	-5	Azimuth slew ccw	$[\text{Az LOS}]_{ccw}$	Sensor	ccw = 1	↓	X	X				
CD28-5	-5	Track auto window size enable	T_{auto} WSE	Sensor	Enable = 1	↓			X	X	X	
CD28-6	-6	Azimuth slew cw	$[\text{Az LOS}]_{cw}$	Sensor	cw = 1	↓	X	X				
CD28-6	-6	Track window increase	TWI	Sensor	Increase = 1	↓			X	X	X	
CD28-7	-7	Elevation slew up	$[\text{El LOS}]_{up}$	Sensor	Up = 1	↓	X	X				
CD28-7	-7	Track window decrease	TWD	Sensor	Decrease = 1	↓			X	X	X	
CD29-0	Enc28-0	Flight control mode command	$(B1)_c$	F/C	F/C Mode	↓	X	X	X	X	X	
CD29-1	-1	↓	$(B2)_c$	↓	↓	↓	X	X	X	X	X	
CD29-2	-2	↓	$(B3)_c$	↓	↓	↓	X	X	X	X	X	
CD29-3	-3	↓	$(B4)_c$	↓	↓	↓	X	X	X	X	X	
CD29-4	-4	Link loss command	(B5)	↓	Link Loss = 0	↓	X	X	X	X	X	
CD29-5	-5	Dead reckoning enable	DRE	F/C	Enable = 1	↓	X	X	X	X	X	
CD29-6	-6	Dead reckoning time	DRT	F/C	LSB (2 sec)	↓	X	X	X	X	X	LSB
CD29-7	-7	↓	↓	↓	↓	↓	X	X	X	X	X	
CD30-0	Enc29-0	↓	↓	↓	↓	↓	X	X	X	X	X	
CD30-1	-1	↓	↓	↓	↓	↓	X	X	X	X	X	
CD30-2	-2	↓	↓	↓	↓	↓	X	X	X	X	X	
CD30-3	-3	↓	↓	↓	↓	↓	X	X	X	X	X	
CD30-4	-4	↓	↓	↓	↓	↓	X	X	X	X	X	MSB
CD30-5	-5	Payload gyro erect	↓	↓	Erect = 1	↓			X	X	X	
CD30-6	-6	Manual shield deploy	↓	↓	Deploy = 1	↓	X	X	X	X	X	

TABLE 16. (CONTINUED)

IV Channel	GCS Address	Function	Symbol	Subsystem	Range	Resolution	Phase I	Phase II	Phase III	Phase IV	Phase V	Remarks
CD30-7	Enc29-7	ALC FOV	ALC FOV	Sensor	Window = 1	1 bit	X	X	X	X	X	Full = 0
CD31-0	30-0	Elevation slew down	$\theta_{LOS\ dn}$	Sensor	Down = 1	↓	X	X				
	-0	Laser range compute		CPU	Offset = 0	↓				X	X	
CD31-1	-1	TV FOV (increase)	FOV_{inc}	Sensor	Inc. = 1	↓	X	X	X	X	X	
CD31-2	-2	TV FOV (decrease)	FOV_{dec}	Sensor	Dec. = 1	↓	X	X	X	X	X	
CD31-3	-3	Camera trigger	C_t	Sensor	On = 1	↓		X				
CD31-3	-3	Video bypass	V_{byp}	Sensor	Bypass = 1	↓			X	X	X	
CD31-4	-4	Laser safe/arm	L_{sa}	Sensor	Arm = 1	↓				X	X	
CD31-5	-5	Iris (increase)	I_{inc}	Sensor	Inc. = 1	↓	X	X	X	X	X	
CD31-6	-6	Iris (decrease)	I_{dec}	Sensor	Dec. = 1	↓	X	X	X	X	X	
CD31-7	-7	Focus (increase)	F_{inc}	Sensor	Inc. = 1	↓	X	X				
CD32-0	Enc31-0	Focus (decrease)	F_{dec}	Sensor	Dec. = 1	↓	X	X				
CD32-1	-1	Camera frame rate	C_{fr}	Sensor	1 /13.5 to 4 frames/sec	↓		X				
CD32-2	-2	↓	↓	↓	↓	↓		X				
CD32-3	-3	↓	↓	↓	↓	↓		X				
CD32-4	-4	↓	↓	↓	↓	↓		X				
CD32-5	-5	↓	↓	↓	↓	↓		X				
CD32-1	-1	Laser PRF-1	L_1	Sensor	1, 10, or 20 pps	↓				X	X	
CD32-2	-2	Laser PRF-2	L_2	↓	↓	↓				X	X	
CD32-3	-3	Laser PRF-3	L_3	↓	↓	↓				X	X	
CD32-4	-4	Track contrast	T_c	↓	White = 1	↓			X	X	X	
CD32-5	-5	Target enhance enable	TE_{en}	↓	Enhance = 1	↓			X	X	X	
CD32-6	-6	Track enable	T_{en}	Sensor	Enable = 1	↓			X	X	X	
CD32-7	Enc31-7	Laser fire	L_f	Sensor	Fire = 1	↓				X	X	

- Frame sync 2 words
- Analog data 22 words
- Discrete data 4 words
- Serial data 4 words

TOTAL 32 words

The telemetry assignments are listed in Table 17.

4.1.3.4 RPV Location. The data link is required to provide RPV location data in real time. These data are obtained from azimuth-angle and range outputs of the GCS tracking antenna. The range is obtained by measuring the round-trip time delay of the data code transmitted from the GCS through the command link to the RPV and back from the RPV through the status link. The respective accuracies of the system are 1 mrad and 20 m.

4.2 AIRBORNE DATA-LINK SUBSYSTEM

The airborne data-link element consists of: (1) command receiving antenna; (2) command receiver; (3) decoder/encoder/bit synchronizer; (4) video/telemetry transmitter antenna; and (5) video/telemetry transmitter. The characteristics of these data-link elements are shown in Figure 70. The size, weight, and power input are summarized in Table 18.

The connections between the receiver and antenna and between the transmitter and antenna are made through semirigid coaxial cables with an outside diameter of 0.141 in.

Constraints were placed on size, weight, and location of the various airborne data-link elements. The location and type of transmitting and receiving antennas were dictated by the requirement to provide data-link coverage over all phases of RPV operation. Both the transmitting and receiving antennas

TABLE 17. DIGITAL DATA FOR DOWNLINK

IV Channel	GCS Address	Function	Symbol	Subsystem	Range	Resolution	Phase I	Phase II	Phase III	Phase IV	Phase V	Remarks
SA1	Dec 02	Frame sync word no. 1	F/S No. 1	–	–	–	X	X	X	X	X	(260)8
SA2	03	Frame sync word no. 2	F/S No. 2	–	–	–	X	X	X	X	X	(117)8
SA3	04	Vertical gyro roll	ϕ_{vg}	Sensor	-60 to +60 deg	1.0 deg			X	X	X	
SA4	05	Pitch elevon command angle, limited	$[(\delta_p)_C]_{LIM}$	Pitch autopilot	+5 to -17 deg	0.1 deg	X	X	X	X	X	
SA5	06	Indicated airspeed, measured and filtered no. 1	$(IAS)_{MF\ 1}$	Pitch autopilot	74 to 222 kph	0.6 kph	X	X	X	X	X	
SA6	07	Right elevon angle, measured	$[\delta_{ER}]_M$	Pitch autopilot	+40 to -40 deg	0.3 deg	X	X	X	X	X	
SA7	08	Left elevon angle, measured	$[\delta_{EL}]_M$	Pitch autopilot	+40 to -40 deg	0.3 deg	X	X	X	X	X	
SA8	09	Pitch rate, measured	q_M	Pitch autopilot	+20 to -20 deg/sec	0.2 deg/sec	X	X	X	X	X	
SA9	10	Normal acceleration, measured and filtered	$(A_\eta)_{MF}$	Pitch autopilot	+15 to -15 m/sec^2	0.12 m/sec^2	X	X	X	X	X	
SA10.0	11	Battery voltage	V_6	Electrical	+18 to 30 Vdc	0.05 Vdc	X	X	X	X	X	
SA10.1		Receiver AGC		D/L		Nonlinear	X	X	X	X	X	
SA10.2			h_2	Autopilot	±44.5 fps	0.36 fps	X	X	X	X	X	
SA10.3		Gain scheduler	Ku		0 to 1.0	0.008	X	X	X	X	X	
SA10.4			(RPM) C-UM		8.56 to 3.94 krpm	0.018 krpm	X	X	X	X	X	
SA10.5			IAS_e		±16.29 knots	0.13 knot	X	X	X	X	X	
SA10.6		Spare	–									
SA10.7		Spare	–									
SA11	12	Altitude error	h_ϵ	Altitude autopilot	+60 to -60 m	0.45 m	X	X	X	X	X	
SA12	13	Azimuth LOS rate	$\dot{\psi}_{LOS\ r}$	Sensor	2 to 10 deg/sec	0.1 deg/sec			X	X	X	
SA13	14	RPM, measured	$(RPM)_M$	Altitude autopilot	2,500 to 10,500 rpm	31.25 rpm	X	X	X	X	X	

TABLE 17. (CONTINUED)

IV Channel	GCS Address	Function	Symbol	Subsystem	Range	Resolution	Phase I	Phase II	Phase III	Phase IV	Phase V	Remarks
SA14.0	Dec 15	Engine temp.	T_e	Propulsion	-45 to 538°F	1.16°F	X	X	X	X	X	
SA14.1		Carburetor temp.	T_a		-14 to 250°F	0.65°F	X	X	X	X	X	
SA14.2		Throttle position	(th) m	Autopilot	±40 deg	0.32 deg	X	X	X	X	X	
SA14.3		Pitch damping	(pd) c		±25.5 deg	0.20 deg	X	X	X	X	X	
SA14.4		Vertical error			±1.44 fps	0.011 fps	X	X	X	X	X	
SA14.5					±28.7 fps	0.23 fps	X	X	X	X	X	
SA14.6		Heading rate cmd.	$(Ha)_f$		±12.1 deg/sec	0.097 deg/sec	X	X	X	X	X	
SA14.7		Pitch damping	$(pd)_c$		±25.5 deg	0.20 deg	X	X	X	X	X	Same as SA14.3
SA15	16	Altitude rate, measured and filtered	$\dot{h}_{MF}$	Altitude autopilot	+7 to -7 m/sec	0.06 m/sec	X	X	X	X	X	
SA16	17	Elevation LOS rate	$\theta_{LOS\ r}$	Sensor	2 to 10 deg/sec	0.1 deg/sec			X	X	X	
SA17	18	Heading rate error, limited	$[\dot{H}_\epsilon]_{Lim}$	Heading autopilot	+5 to -5 deg/sec	0.04 deg/sec	X	X	X	X	X	
SA18	19	Vertical gyro pitch	Φ_{vg}	Sensor	-60 to +60 deg	1.0 deg			X	X	X	
SA19	20	Roll-yaw gyro rate	$\dot{\eta}_M$	Heading autopilot	-60 to +60 deg/sec	0.5 deg/sec	X	X	X	X	X	
SA20	21	Zoom lens position	Z_{lp}	Sensor	4.1 to 38 deg	0.1475 V/deg	X	X	X	X	X	-2.5 V = 4.1 deg 0 = 21 deg +2.5 V = 38 deg
SA21	22	Altitude, measured and filtered	h_{MF}	Altitude autopilot	0 to 3,600 m (MSL)	14 m	X	X	X	X	X	
SA22	23	Magnetometer X (H_x = 2.5 cos α_x V)	H_x	Heading autopilot	+2.5 to -2.5 Vdc	20 mV	X	X	X	X	X	
SA23	24	Magnetometer Y (H_y = +2.5 cos α_y V)	H_y	Heading autopilot	+2.5 to -2.5 Vdc	20 mV	X	X	X	X	X	
SA24	25	Magnetometer Z (H_z = +2.5 cos α_z V)	H_z	Heading autopilot	+2.5 to -2.5 Vdc	20 mV	X	X	X	X	X	
SSD25-0	26-0	Azimuth gimbal angle	ϕ_g	Sensor	MSB	0.17578125 deg	X	X	X	X	X	LSB = 0.176 deg
SSD25-1	-1						X	X	X	X	X	
SSD25-2	-2		↓	↓	↓	↓	X	X	X	X	X	0 to 360 deg

TABLE 17. (CONTINUED)

IV Channel	GCS Address	Function	Symbol	Subsystem	Range	Resolution	Phase I	Phase II	Phase III	Phase IV	Phase V	Remarks
SSD25-3	Dec 26-3	Azimuth gimbal angle	ψ_g	Sensor	MSB	0.17578125 deg	X	X	X	X	X	
SSD25-4	-4						X	X	X	X	X	
SSD25-5	-5						X	X	X	X	X	
SSD25-6	-6						X	X	X	X	X	
SSD25-7	-7						X	X	X	X	X	
SSD26-0	27-0						X	X	X	X	X	
SSD26-1	-1						X	X	X	X	X	
SSD26-2	-2				LSB		X	X	X	X	X	
SSD26-3	-3	Elevation gimbal angle	θ_g		MSB	0.2 deg	X	X	X	X	X	Two's complement
SSD26-4	-4						X	X	X	X	X	+60 to -90 deg
SSD26-5	-5						X	X	X	X	X	
SSD26-6	-6						X	X	X	X	X	
SSD26-7	-7						X	X	X	X	X	
SSD27-0	28-0						X	X	X	X	X	
SSD27-1	-1						X	X	X	X	X	
SSD27-2	-2						X	X	X	X	X	
SSD27-3	-3						X	X	X	X	X	
SSD27-4	-4				LSB		X	X	X	X	X	
SSD27-5	-5	Laser Range	R_1		MSB	5 m				X	X	LSB = 5 m
SSD27-6	-6									X	X	
SSD27-7	-7									X	X	
SSD28-0	29-0									X	X	
SSD28-1	-1									X	X	
SSD28-2	-2									X	X	
SSD28-3	-3									X	X	
SSD28-4	-4									X	X	

TABLE 17. (CONTINUED)

IV Channel	GCS Address	Function	Symbol	Subsystem	Range	Resolution	Phase I	Phase II	Phase III	Phase IV	Phase V	Remarks
SD28-5	Dec 29-5	Laser range	R_1	Sensor	MSB	5 m				X	X	
SD28-6	-6		↓	↓		↓				X	X	
SD28-7	-7				LSB					X	X	
SD29-0	30-0	Laser safe/arm	L_{sa}		Arm = 1	1 bit				X	X	
SD29-1	-1	Laser off/fire	L_{of}		Fire = 1	↓				X	X	
SD29-2	-2	Laser ready/overheat	L_r O/H		Ready = 0					X	X	Overheat = 1
SD29-3	-3	CMD TLM quality	Q_{tlm}	D/L	Lock = 1		X	X	X	X	X	TLM full lock
SD29-4	-4	Fuel-low indicator	Fuel	Propulsion	Fuel low = 0		X	X	X	X	X	
SD29-5	-5	Camera frame counter	C_{fc}	Sensor	Count = 1			X				
SD29-6	-6	Laser range compute	L_{rc}	CPU						X	X	
SD29-7	-7	Valid track	T_v		N/A				X	X	X	
SD30-0	31-0	ALC FOV	ALC FOV	Sensor	Full = 0		X	X				Window = 1
SD30-1	-1	Flight control mode	$(B1)_s$	F/C			X	X	X	X	X	
SD30-2	-2		$(B2)_s$	↓			X	X	X	X	X	
SD30-3	-3		$(B3)_s$				X	X	X	X	X	
SD30-4	-4		$(B4)_s$				X	X	X	X	X	
SD30-5	-5		$(B5)_s$				X	X	X	X	X	Link loss = 0
SD30-6	-6	DR recovery	SQ	D/L			X	X	X	X	X	Recovery = 0
SD30-7	-7	Unused (blank)										
SD31-0	00-0	Shield release	–	F/C			X	X	X	X	X	Release = 0
SD31-1	-1	↓										
SD31-2	-2											
SD31-3	-3											
SD31-4	-4											
SD31-5	-5											
SD31-6	-6											
SD31-7	-7											

TABLE 17. (CONTINUED)

IV Channel	GCS Address	Function	Symbol	Subsystem	Range	Resolution	Phase I	Phase II	Phase III	Phase IV	Phase V	Remarks
SD82-0	Dec 61-0	Subcontractor address					X	X	X	X	X	1
SD82-1	-1	↓					X	X	X	X	X	1 Fixed
SD82-2	-2	↓					X	X	X	X	X	0
SD82-3	-3	↓					X	X	X	X	X	X Subcom
SD82-4	-4	↓					X	X	X	X	X	X Address
SD82-5	-5	↓					X	X	X	X	X	X
SD82-6	-6	↓					X	X	X	X	X	1 Fixed
SD82-7	-7	↓					X	X	X	X	X	0

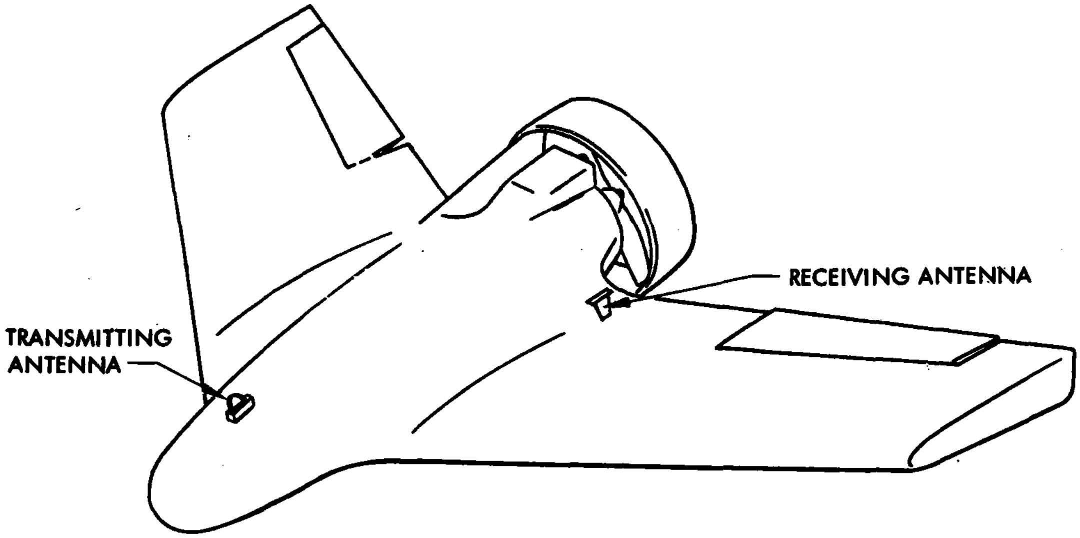


Figure 70. Location of Components in Airborne Data Link

TABLE 18. AIRBORNE DATA-LINK ELEMENTS

	Size (in.)	Weight (lb)	Power (W)
Command Receiver Antenna	2 × 1.6 × 0.4	0.1	N/A
Command Receiver	4 × 3 × 2	3	5
Decoder/Encoder	6 × 7 (3 cards)	0.4	7
Video/Telemetry Transmitter Antenna	2 × 1.6 × 0.4	0.1	N/A
Video/Telemetry Transmitter	6 × 6 × 1.5	5	140

are vertical sleeve dipoles at locations that produce minimum blockage between the RPV line of sight with the GCS. Antenna patterns of the transmitting and receiving antennas are shown in Figures 71 and 72. The gain of both antennas varies between +2 and -12 dBi, depending on azimuth look angles.

The transmitter is a solid state G-band transmitter, which is a version of a standard G-band unit designed by AACOM, Inc., a division of Systron Donnor. A summary of the performance is:

• Center frequency	4,530 ± 2.2 MHz
• Power output	10 W
• Subcarrier output	-20 dBc
• Video modulation input	Standard CCIR405
• Telemetry modulation input	2 V pulse to pulse
• Power dissipation	130 W
• Maximum allowable baseplate temperature	+80°C

To accommodate the high power-dissipation requirements of the transmitter, cooling fins are mounted on the top of the transmitter, and air ducts are designed into the RPV structure to provide cooling air flow.

The command receiver is a superheterodyne solid state receiver manufactured by AACOM, Inc. The receiver performance is:

• Center frequency	4,861 MHz
• RF bandwidth	2.5 MHz
• Receiver noise figure	11 dB
• Detected signal output sensitivity	6 mV/kHz
• AGC output	0 to 2 Vdc

The minimum received rf signal input required to obtain command data lock is -94 dBm.

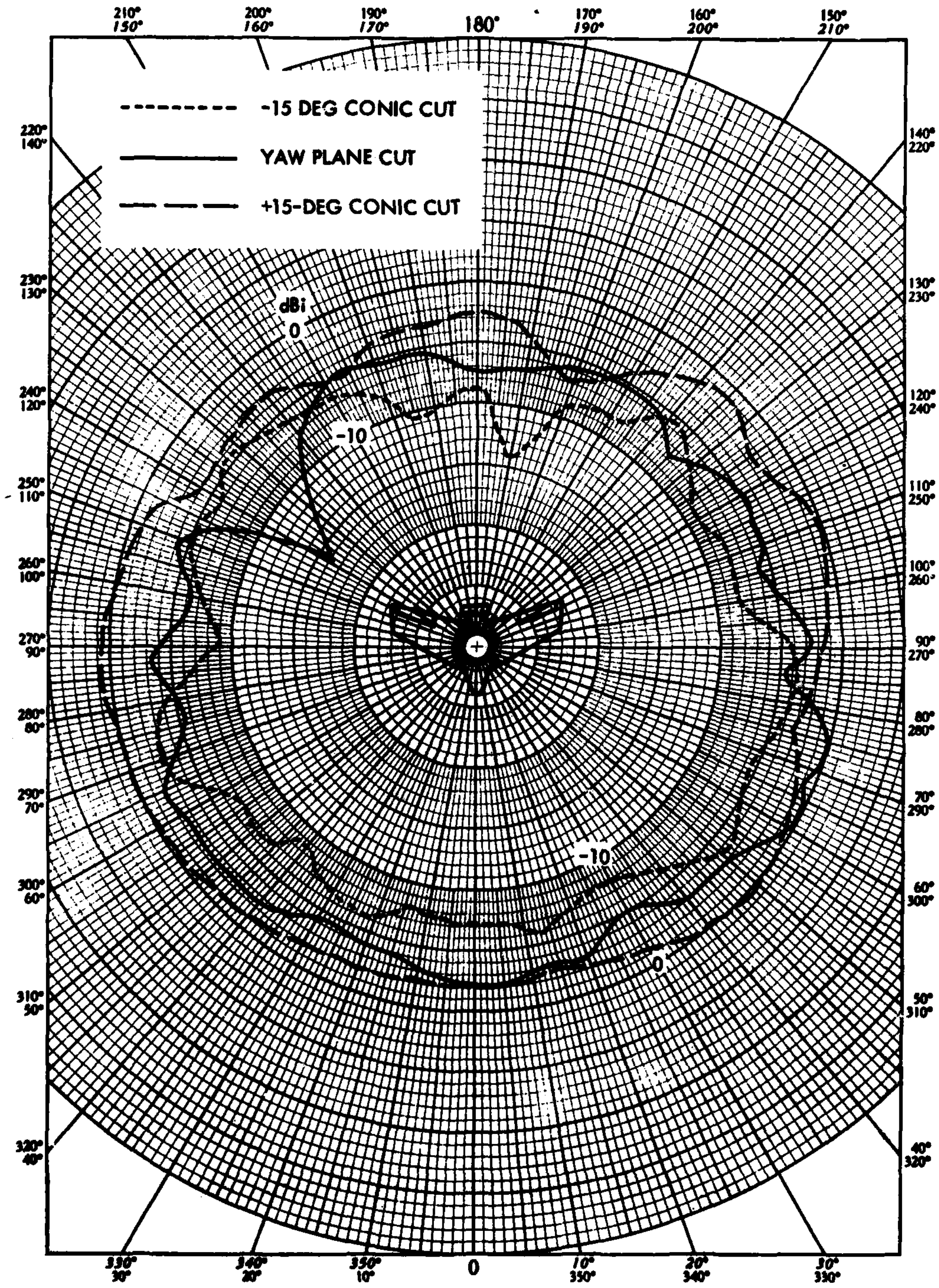


Figure 71. Airborne Transmitter Antenna Pattern

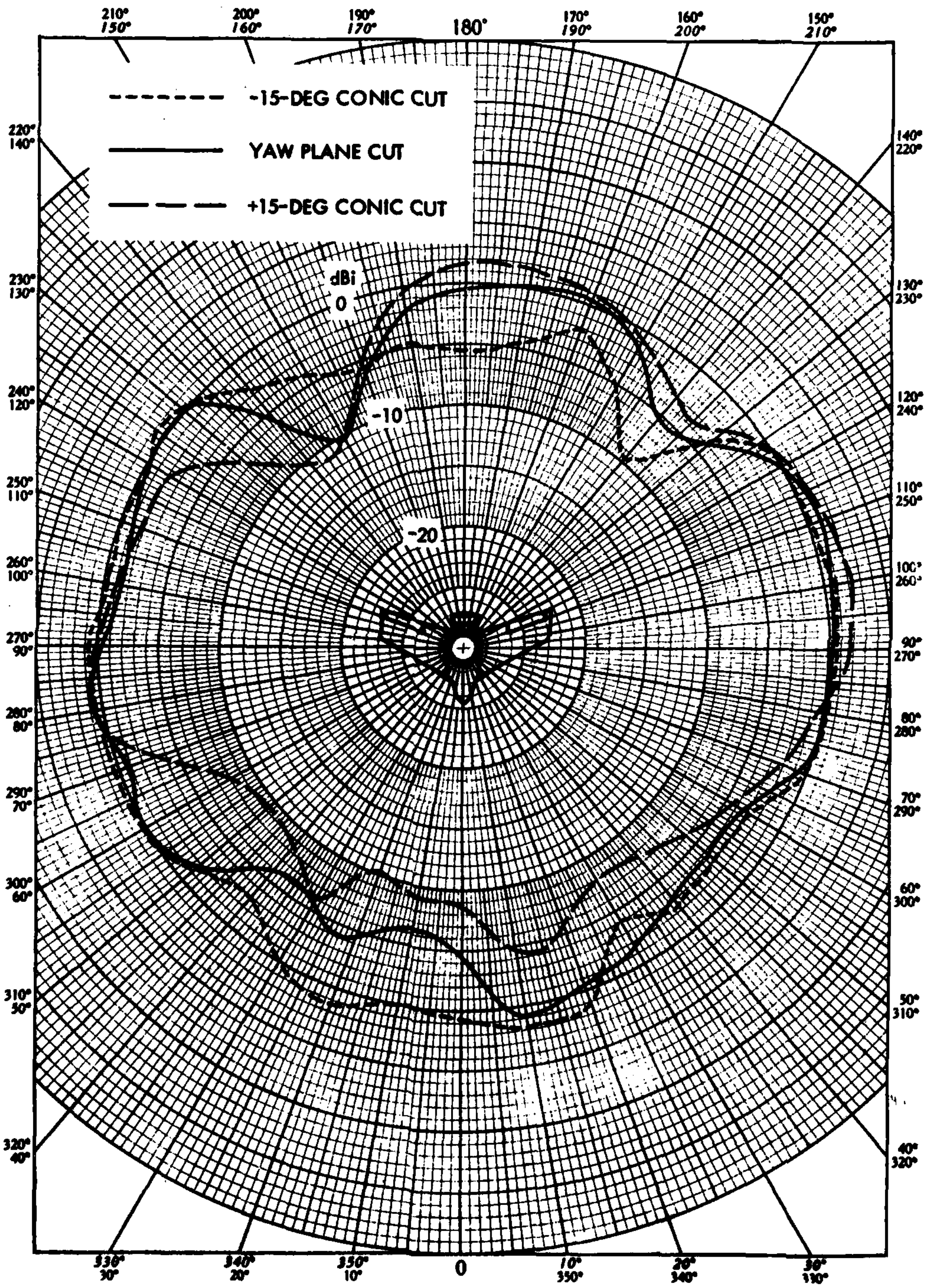


Figure 72. Command Receiver Antenna Pattern

The decoder/encoder is required to decode the commands and encode the RPV status. The decoder provides for decoding the analog plus discrete flight and payload control functions. A bit synchronizer is incorporated to synchronize the command data and provide clock to the status data encoder. This synchronization provides for interference immunity and ranging functions. The encoder provides for encoding the analog plus discrete flight control and payload statuses.

The encoder/decoder is packaged on three printed circuit boards and housed in the flight control electronics package. This provides for a saving in volume and weight.

4.3 GCS DATA-LINK SUBSYSTEM

The GCS data-link subsystem consists of: (1) command transmitter, (2) tracking antenna pedestal assembly, (3) antenna control unit, (4) video/telemetry receiver, (5) radome, and (6) encoder/decoder. A block diagram of the subsystem is shown in Figure 73. The tracking antenna pedestal assembly is a one-axis azimuth tracker. The antenna tracks the received video/telemetry signal from the RPV. Since the antenna tracks in azimuth only, a dual antenna system (high-gain and low-gain antennas) is employed to provide the required gain and elevation coverage. The high-gain antenna comprises a pair of vertical dipoles feeding a 2-ft parabolic reflector; this antenna has a gain of 24 dBi and a 7-deg half-power beamwidth. The low-gain antenna is a horizontal linear array of four helical antennas. The array gain is +13 dBi with a half-power beamwidth of 15 deg in azimuth and 90 deg in elevation. Selection between the high-gain and low-gain antennas is controlled by the GCS computer through a pair of electromechanical rf relays.

The tracking information is obtained by monopulse tracking techniques. The left and right antenna-feed received signals are phase-compared in the scan converter, forming a sum and difference antenna pattern. A solid state phase shifter in the difference signal line is modulated at approximately 800 Hz.

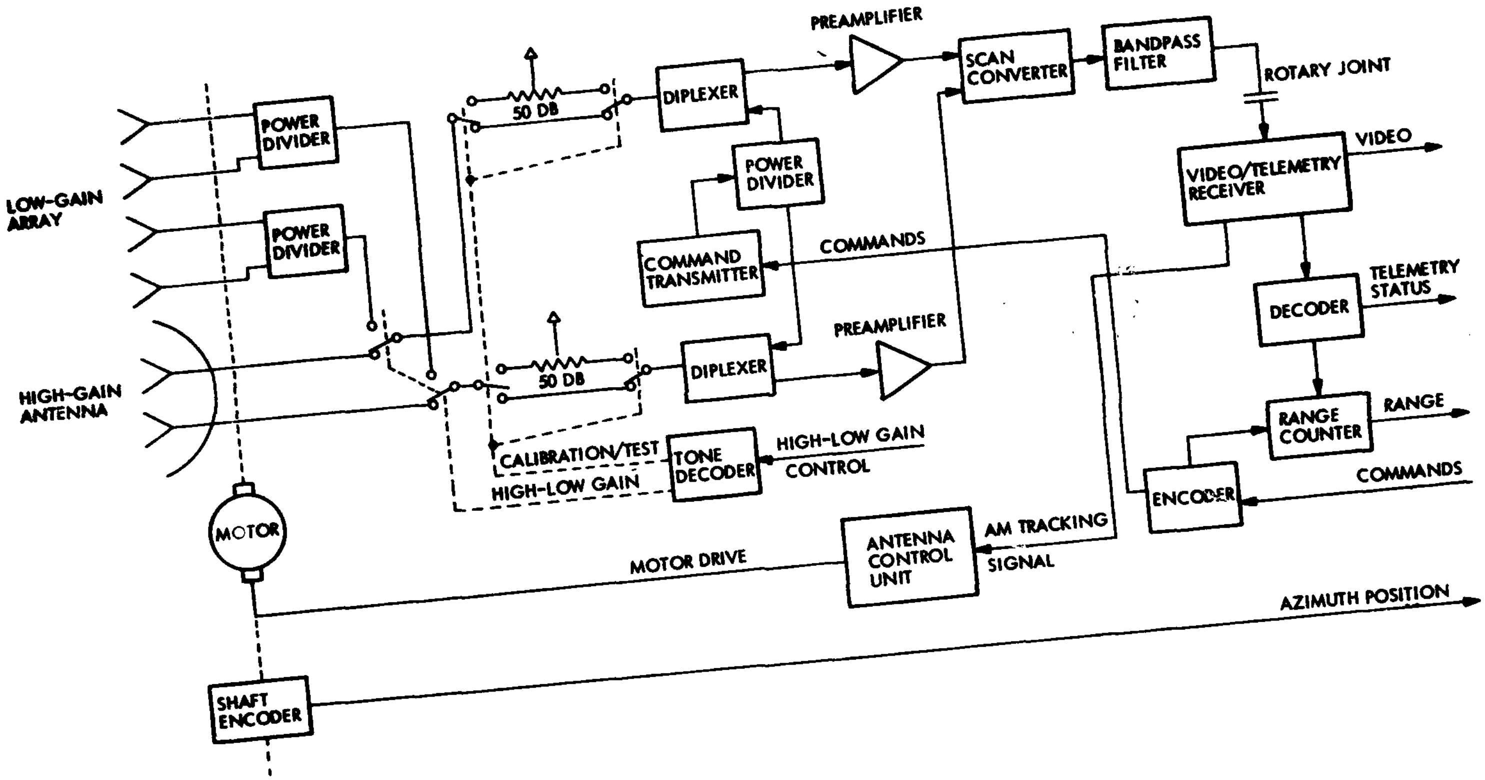


Figure 73. Block Diagram of GCS Data-Link Subsystem

The phase-modulated difference signal is then added back to the sum signal through a 12-dB directional coupler. The output of the scan converter is the received video/telemetry signal, amplitude-modulated with the direction of arrival information in the form of an error-off boresight. This information is separated in the video/telemetry receiver and processed in the antenna controller unit. The processed error signal is used in a second-order servo loop. The command transmitter uses the tracking antenna for transmitting also. This is accomplished by combining both signals in a diplexer, which provides 60 dB of isolation between transmit and receive signals. The GCS data-link subsystem provides for a prelaunch data-link integrity test. This is accomplished by switching in 50 dB of attenuation at the antenna — which simulates a 20-km range for both the uplink and the downlink.

The installation of the data-link subsystem in the GCS is shown in Figure 74. The antenna feed networks, preamplifiers, calibration networks, and command

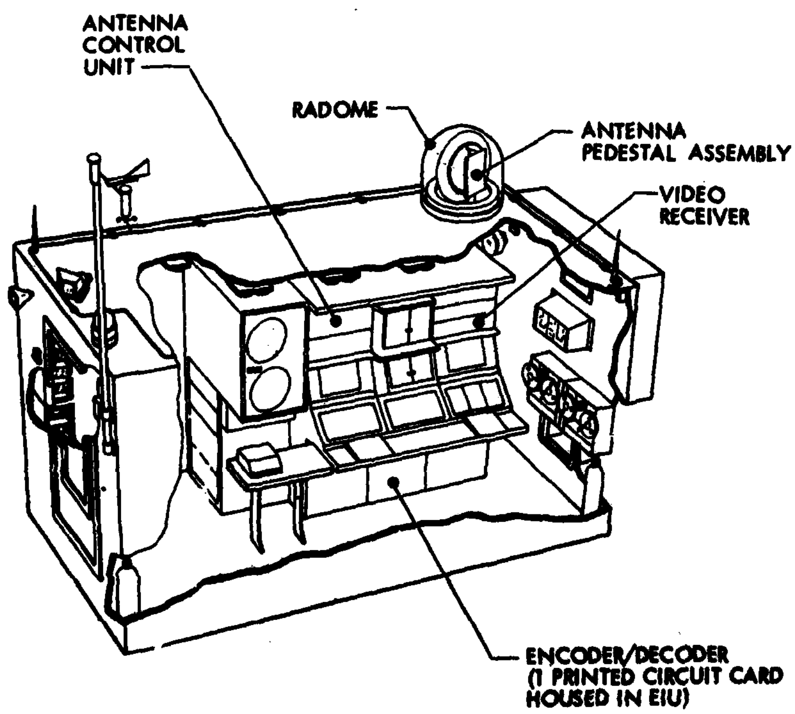


Figure 74. Installation of GCS Data-Link Subsystem

transmitter are mounted on the antenna pedestal assembly. This was done to minimize the rf transmission losses and to hold the rf rotary joint requirement to one. A blower is provided at the base of the pedestal to supply cooling air for the transmitter. The azimuth angle of the tracking antenna is provided by the shaft encoder, which has a 14-bit digital output. The antenna pedestal assembly is removable from the GCS to provide height clearance during transport of the GCS.

Size, weight, and power requirements are summarized in Table 19.

TABLE 19. GCS DATA-LINK ELEMENTS

Item	Size (in.)	Weight (lb)	Power (W)
Antenna Pedestal	42 H × 24 × 24	86	5
Antenna Control Unit	19 rack × 7	15	100
Command Transmitter	6 × 6 × 1.5	3	140
Video/Telemetry Receiver	19 rack × 5	10	20
Radome	27 diam. × 26 H	3	N/A
Encoder/Decoder	9 × 7 printed circuit board	0.75	7

The radome is a one-piece epoxy fiberglass hemisphere/cylinder. The radome provides protection of the tracking antenna from the elements. It is of electrically thin wall construction providing for low rf transmission loss and negligible boresight distortion. The radome is attached to the GCS by a Marmon retaining band at the base, providing easy access to the antenna pedestal assembly.

The GCS data-link subsystem requirements are determined from the data system requirements described in subsection 4.1.3. To close the link at over the 20-km-downrange and 10,000-ft-AGL RPV operating envelope, the ground station implemented a high-gain and low-gain antenna tracking station. Switching between the high-gain and low-gain antennas is controlled by the GCS computer, which calculates the elevation angle from the slant range data and the RPV telemetry data on RPV altitude. The switching occurs at 10.5 deg, where the effective gains of the two systems are equal (11 dB). When the RPV is determined to be above 10.5 deg, the low-gain antenna is used; below 10.5 deg, the high-gain antenna is used. Precision tracking of the RPV is performed with the high-gain antenna. The low-gain antenna, with its wide beamwidth, is susceptible to multipath transmission phenomena, which results in a noisy tracking signal. To provide adequate coverage and sensitivity for the downlink, preamplifiers are installed close to the antenna feeds – which results in a 4-dB receiver system. The major parameters of the GCS data-link elements are:

• Antenna gain	
– High	24 dBi
– Low	13 dBi
• Half-Power Beamwidth	
– Azimuth, High	7 deg
– Azimuth, Low	15 deg
– Elevation, High	-0.5 deg to +6.5 deg
– Elevation, Low	-15 deg to +65 deg
• Tracking Antenna, Slew Rate	100 deg/sec
• Tracking Antenna, Acceleration	150 deg/sec^2
• Tracking Antenna Accuracy	
– High	1 mrad
– Low	10 mrad
• Tracking Azimuth Angle Resolution	0.2 mrad
• Boresight Alignment at 10.5-deg Elevation (between high- and low-gain antennas)	±1 deg
• Receiver Noise	4 dB
• Receiver Sensitivity at Antenna Feed Point	
– Telemetry Lock	-88 dBm
– Video	-85 dBm
• Command Transmitter Power Output	10 W

Since the tracking antenna system operates in an uncontrolled environment, several user-oriented problems have been experienced in the field. These problems are associated with sidelobes of the tracking antenna system. Figure 75 shows the high-gain antenna pattern as a function of azimuth. As indicated, the first stable tracking sidelobe is down 16 dB. Other sidelobes are at 17.5 deg with the gain down 19 dB and 30 deg with the gain down 27 dB. The sidelobe in itself is not a problem. When the tracking antenna is tracking on the main beam initially and no loss of signal occurs, the antenna will stay in the main beam. At launch with the RPV on the launcher, however, the tracking antenna does not always track the RPV. The reason is the number of reflective objects close to the RPV. The tracking does not differentiate these reflective sources from the RPV direct radiation. The tracker vectorially sums all sources of radiation and tracks a virtual source, where the sum of the signals yields zero error signals. At 4.5 GHz, a wavelength is

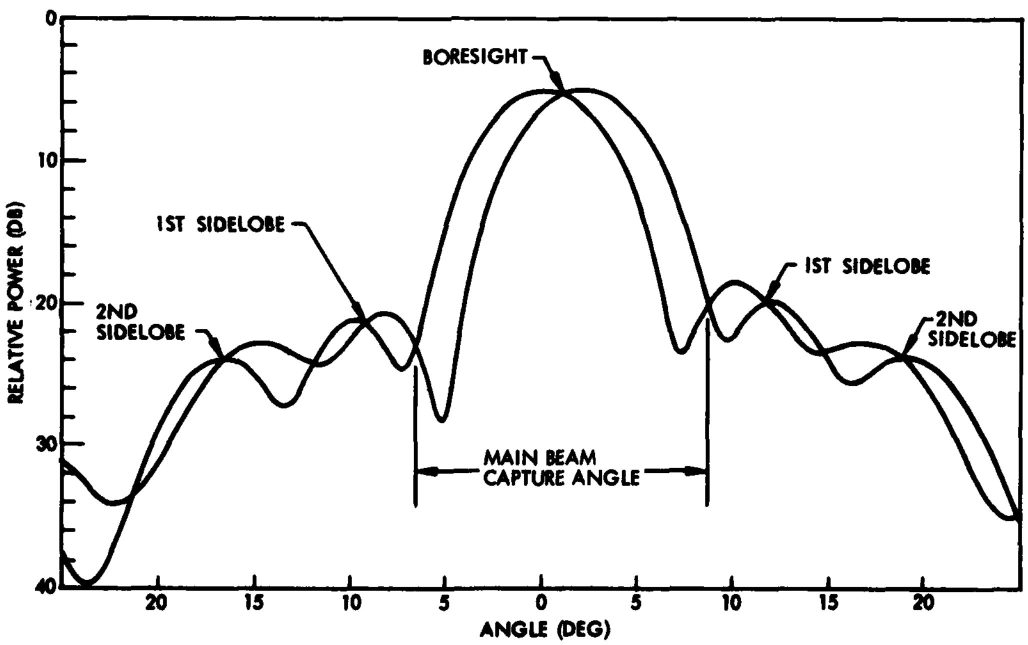


Figure 75. High-Gain Tracking Antenna, Gain Versus Azimuth Angle

approximately 6 cm; therefore, any small displacement of any reflective object will alter the position of the virtual source.

This, then, introduces a sidelobe problem, since no assurance has been provided to maintain the tracker on the main beam at launch. Procedures have been introduced to minimize the sidelobe problem. With the many launcher configurations (relative position of the launcher and other reflective sources), however, the problem has not been eliminated. The sidelobe problem does not exist when the RPV is out past 8 km, since the sidelobes are down 16 dB.

Section V
GROUND SUPPORT SYSTEM

The Aquila ground support system (GSS) consists of all the ground-based elements of the RPV system. These elements include:

- Ground control station (GCS) (truck mounted)
- Launcher (truck mounted)
- Retrieval system (trailer mounted)
- Electrical generators (trailer mounted)
- Ground support test and checkout equipment

The principal GSS elements are described in detail in the following paragraphs. Additional information, including descriptive, operational, and maintenance data are provided in Reference 14. Field testing of the GSS is discussed in Reference 15.

5.1 GSS INTERCONNECT

The GSS elements are interconnected by hardline cables providing power and communications to the various elements. Figure 76 shows a plan view of the system elements, and Table 20 lists the required external cabling by name, part number, cable length, reference designation, connector part number, location, and primary function. The reference numbers shown in the table correspond to the reference numbers on Figure 76 and are used in the following description of the system electrical interconnection.

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[14] TECHNICAL MANUAL FOR AQUILA RPV SYSTEM TECHNOLOGY DEMONSTRATOR, VOLUMES I, II, AND III, LMSC-D056906, Lockheed Missiles and Space Company, Inc., Sunnyvale, California, 10 August 1977.

[15] AQUILA RPV SYSTEM TEST REPORT, CDRL A00D, PART 8, RPV-GCS DEVELOPMENT FLIGHTS, LMSC-L028081, Lockheed Missiles and Space Company, Inc., Sunnyvale, California, October 1977.

The source of electrical power for all system operation is two GFE (government-furnished equipment) 30-kW (minimum) generators; for redundancy, either generator is capable of supplying all RPV-STD power requirements. Generator interconnect cables 1 and 2 permit load switching in the event of generator failure. One generator, designated as primary, provides three-phase ac power to the GCS via cable 3 for all functions except the GCS air conditioner, which is supplied by the alternate (backup, but on line) generator via cable 5. Intercom and emergency alarm functions are provided to the primary generator by means of the switch box through cable 4.

All power except the directly routed air conditioner power is controlled and distributed through the GCS. Cable 6 carries three-phase power and intercom and control functions to the launch system. Cable 7 provides an extension of 150 ft if operations require a greater distance between the GCS and launcher.

At the launcher, harness assembly 12 routes power to the RPV blower, air dryer, and RPV power supply. DC power from the RPV power supply is directed to the RPV control box by cable 13 and then to the RPV umbilical through cable 14.

Power for the retrieval system TV camera is supplied from the GCS by cable 8; extension cable 9 provides a 150-ft extension if required. Figure 76 shows two such cables in use, which simplify cable switching if the camera requires relocation due to a change in wind direction. Cable 15 is connected between the recovery J-box and the TV camera.

Power for the Army-supplied assembly tent is provided through cable 10. Power from the tent J-box to the Army-supplied lighting assembly is via cable 16. If weather conditions warrant, cable 17 may be used to power an Army-supplied air conditioner or heater (to condition RPV air). This cable may be connected to either the launcher or the tent J-boxes. Control of the GCS air conditioner is via cable 11 leading to the air condition control box inside the shelter.

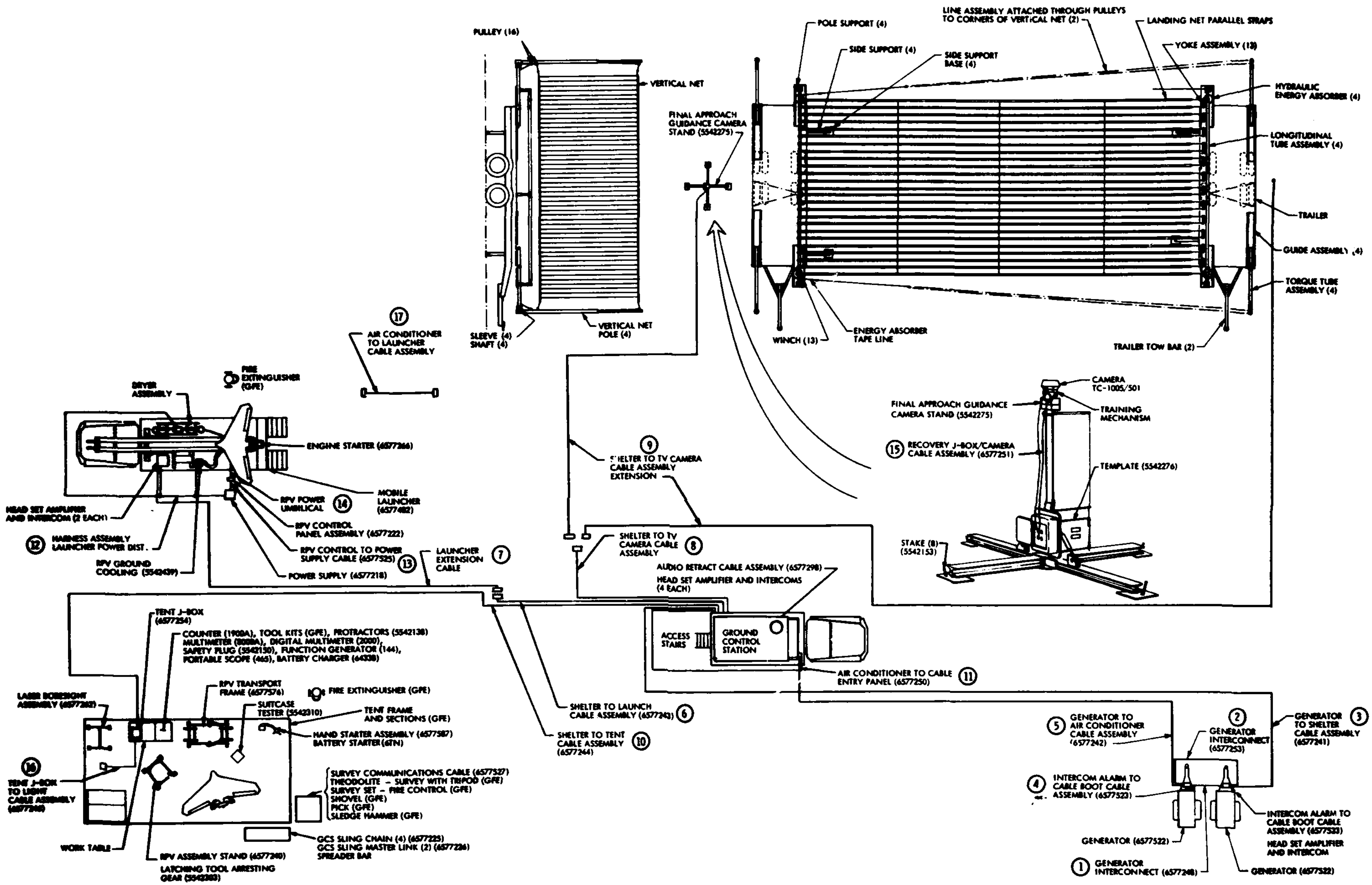


Figure 76. Aquila RPV-STD Ground Support System Components and Hookup

TABLE 20. RPV-STD INTERCONNECT CABLES AND FUNCTIONS

Ref. No.	Cable Nomenclature	Cable Part No.	Cable Length (ft)	Reference Designator	Connector Part No.	Location	Primary Function
1	Generator interconnect	6577248-501	25	GP3 BP2	MS3106F3217PX MS3106F3217PW	Primary generator Backup generator	Power interconnect between generators
2	Generator interconnect	6577253-501	25	GP2 BP3	MS3106F3217PW MS3106F3217PX	Primary generator Backup generator	Power interconnect between generators
3	Generator to shelter	6577241-501	150	GP1 GP4 SP1 SP2	MS3106F3217P MS3126F1412S MS3106F32175 MS3126F1412P	Primary generator GCS	Power and communication from generator to GCS
4	Intercom/alarm to cable boot	6577523-501	15	GJ4 GJ5	MS3120F1412P 91-856	Switch box to generator	Two required per system, intercom and emergency alarm control
5	Generator to air conditioner	6577242-501	150	BP1 SP10	MS3106F3217P MS3106F3217S	Backup generator Air conditioner	Power to air conditioning
6	Shelter to launcher	6577243-501	150	SP3 LP1	MS3106F326P MS3106F326S	GCS Launcher	Power and communications to launcher
7	Shelter to launcher extension	6577243-503	150	LPX LP1	MS3101F326P MS3106F326S	P1 of item 6 Launcher	Extension cable
8	Shelter to TV camera	6577245-501	250	SP5 RP1	DPXAMA25W334P DPXAMA25W333S	GCS Recovery J-Box	Video; communications and low-level ac power
9	Shelter to TV camera extension	6577245-503	150	RPX RP1	DMXAMA25W334P DMXAMA25W333S	RP1 on item 8 Recovery J-box	Video; communication and low-level ac power
10	Shelter to tent	6577244-501	150	SP4 TP1	MS3106F326PW MS3106F326SW	GCS Tent	Communication and power
11	Air conditioner to cable entry panel	6577250-501	25	SP7 SP8	MS3106F2033S MS3106F2033S	Air conditioner GCS	Air conditioner controls
12	Harness assembly launcher pwr. dist.	5542551-501	9	LP3 PS1	MS3106F204P MS3116F145S	Launcher pwr. box RPV power supply	AC power distribution
13	RPV control to power supply	6577525-501	5	VP1 VP6	DAMA7W2S PT06A1416P(SR)	RPV control box RPV power supply	DC power to control box
14	RPV power and control	6577249-501	20	P1-401 VP2	DBMA17W2P DBMA17W2P	RPV umbilical RPV control box	Power and control
15	Recovery J-box to camera	6577251-501	10	RP2-3 CP1	UG260B/U UG260B/U	Recovery J-box Recovery camera	Video
16	Tent J-box to lights	6577246-501	40	TL TP5-6	MS3106F2022S MS3106F2022P	Tent lights Tent J-box	AC power, single phase
17	Air conditioner to launcher	6577247-501	50	LP3/TP3 AP1	MS3106F204P MS3106F204S	Tent or launcher J-box Portable air conditioner	AC power, three phase

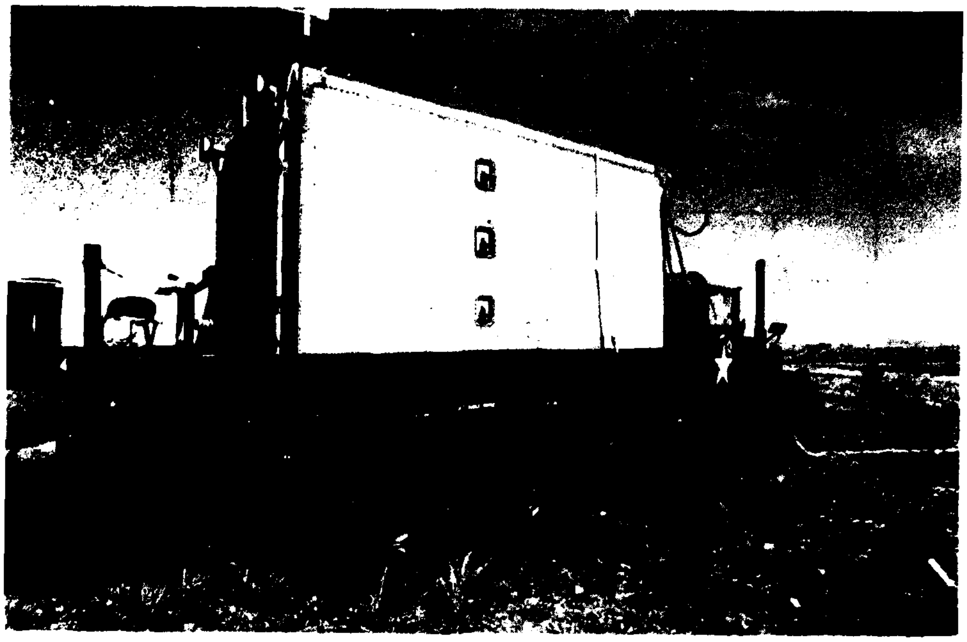
5.2 GROUND CONTROL STATION

The truck-mounted GCS, shown in Figure 77, provides a central control facility for the Aquila system and interfaces with all elements of the RPV system as shown in Figure 78. All RPV position, navigation, target location, and artillery adjustment computations are performed by the computer in the GCS.

The GCS crew consists of two operators, the RPV operator and the sensor operator. Their positions are located at a control console that provides the man-machine interface for the system and all necessary signal conditioning and routing. The RPV operator (left console position, Figure 77b) is responsible for monitoring the various RPV systems and for providing guidance mode commands. He maintains guidance control at all times with the exception of the final phase of the recovery operation, during which he transfers control to the sensor operator but retains override capability. His panel controls allow him to choose among the computer-generated flight modes or to switch over to a manual mode in which he generates vehicle heading rate, altitude, and airspeed commands. His video monitor at all times displays the RPV sensor video along with a heads-up display of RPV position, range time, and sensor attitude. Mounted in the desk top in front of him is a control panel that allows him to call up, review, and change data associated with the various programmed waypoints.

The sensor operator (right console position, Figure 77b) commands and monitors sensor operations throughout all program phases. He has a joystick that slews the video line of sight, drives an on-screen cursor for locating burst offsets from a target, and provides vehicle guidance correction commands during recovery. He also has responsibility for operation of both the video and digital magnetic tape recorders.

The heart of the GCS is the central processing computer, with peripherals, and an electronic interface unit (EIU) that routes data to and from the data link and tracking antenna, meteorological sensors, communications link, time code



a. GCS on M36 Truck

b. GCS Interior

Figure 77. Ground Control Station

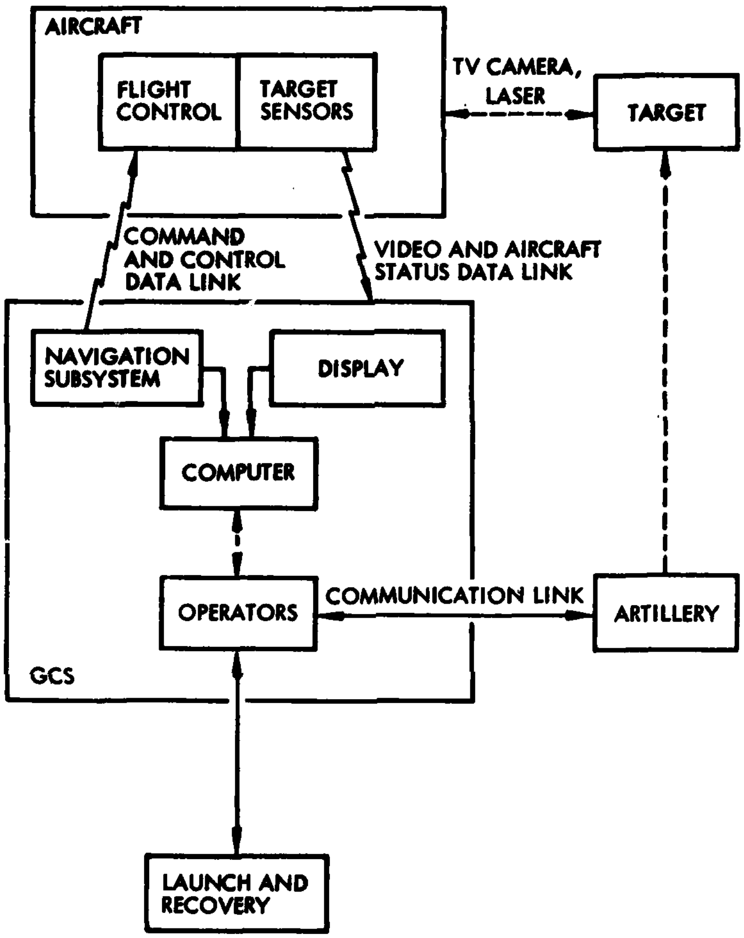


Figure 78. GCS Interfaces

generators, video recorders and monitors, x-y navigation plotters, control and display panels, and power supplies. A functional block diagram of the GCS is shown in Figure 79 and a cabling interconnect diagram is shown in Figure 80.

5.2.1 Description

The following paragraphs describe each of the components of the GCS. The various components are shown in Figure 81; the console assembly is detailed in Figure 82. The console assembly is described in the order of Figure 82; the

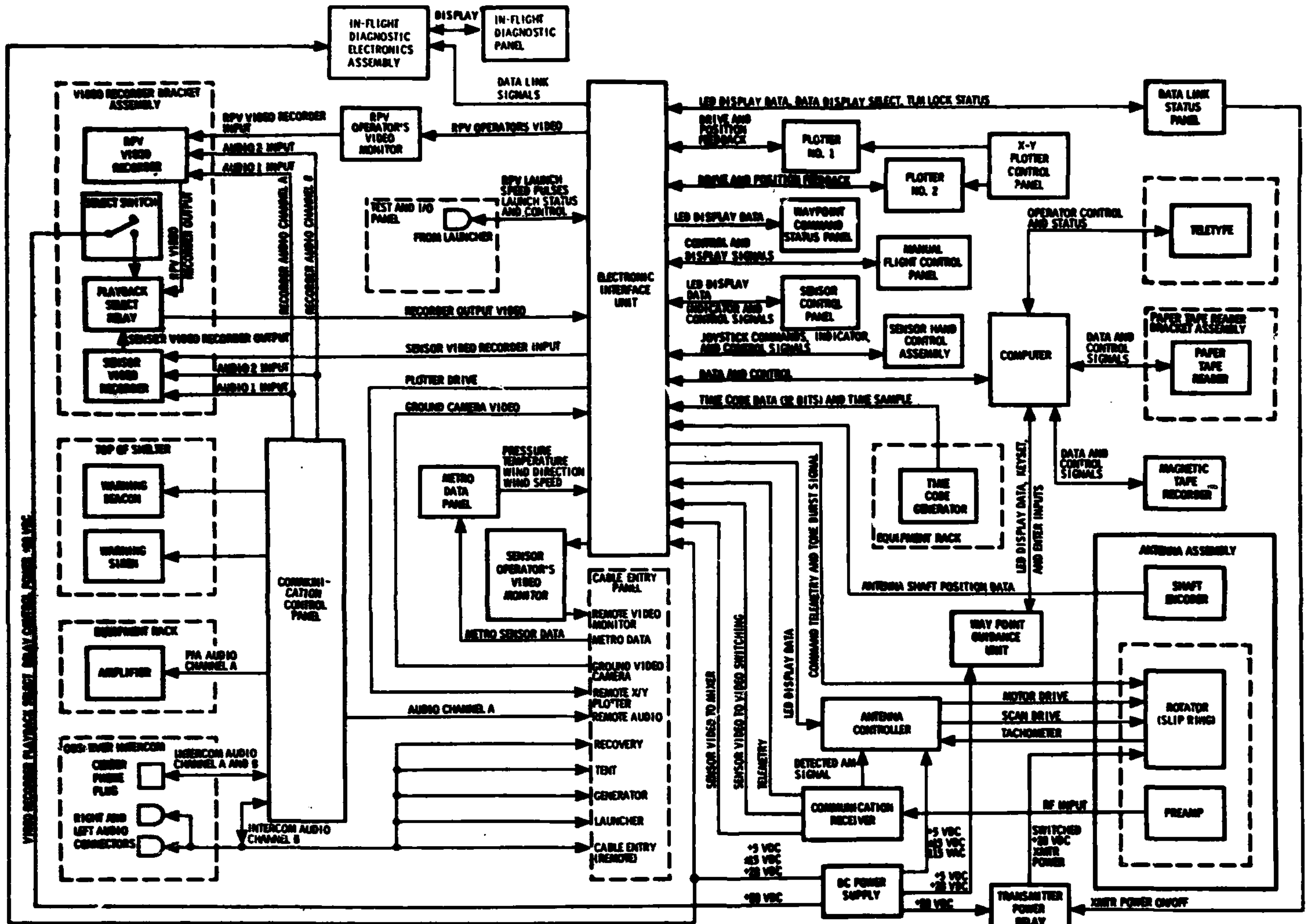


Figure 79. GCS Block Diagram

remaining components are described in clockwise order from the console as shown in Figure 81.

5.2.1.1 Console Assembly. The console provides the man-machine interface for the system and houses the major electronic assemblies and displays and controls.

Meteorological Panel. The meteorological panel, Figure 83, contains three gages that display temperature in degrees Fahrenheit, wind direction in compass degrees, and wind speed in kilometers per hour. The meters are driven by sensors mounted on a mast on the outside of the GCS. The information displayed is also digitized in the EIU and sent to the computer. The wind must be less than 37 km/h crosswind to the launch direction before the RPV is launched. The meteorological panel and associated masthead assembly are manufactured by Signet Scientific. The rack-mounted panel is 19 in. wide, 5.25 in. high, and 5.5 in. deep.

Antenna Control Panel. The antenna control panel, Figure 84, houses the electronics for the antenna assembly that is used to track the RPV. The electronics consists of a demodulator generating an azimuth error voltage, which in turn is integrated and generates a rate command to the drive electronics. Tachometer feedback is used to close the servo loop.

The control panel is operated in the manual mode for site initialization and in the automatic mode for flight. To slew the antenna, the manual mode is selected. Slew direction is controlled by the CCW/CW toggle switch and slew rate from 0 to 30 deg/sec is controlled by the MANUAL RATE INCREASE potentiometer. During automatic tracking, the tracking antenna azimuth deviation from initial orientation is indicated by the digital azimuth display and the tracking servo error in degrees is displayed on the SERVO ERROR meter.

The antenna control panel and antenna assembly are manufactured by Electro Magnetic Processes, Inc. The rack-mounted panel is 19 in. wide, 7 in. high, and 17 in. deep. The panel uses +5 Vdc at 0.5 A for the light-emitting diode

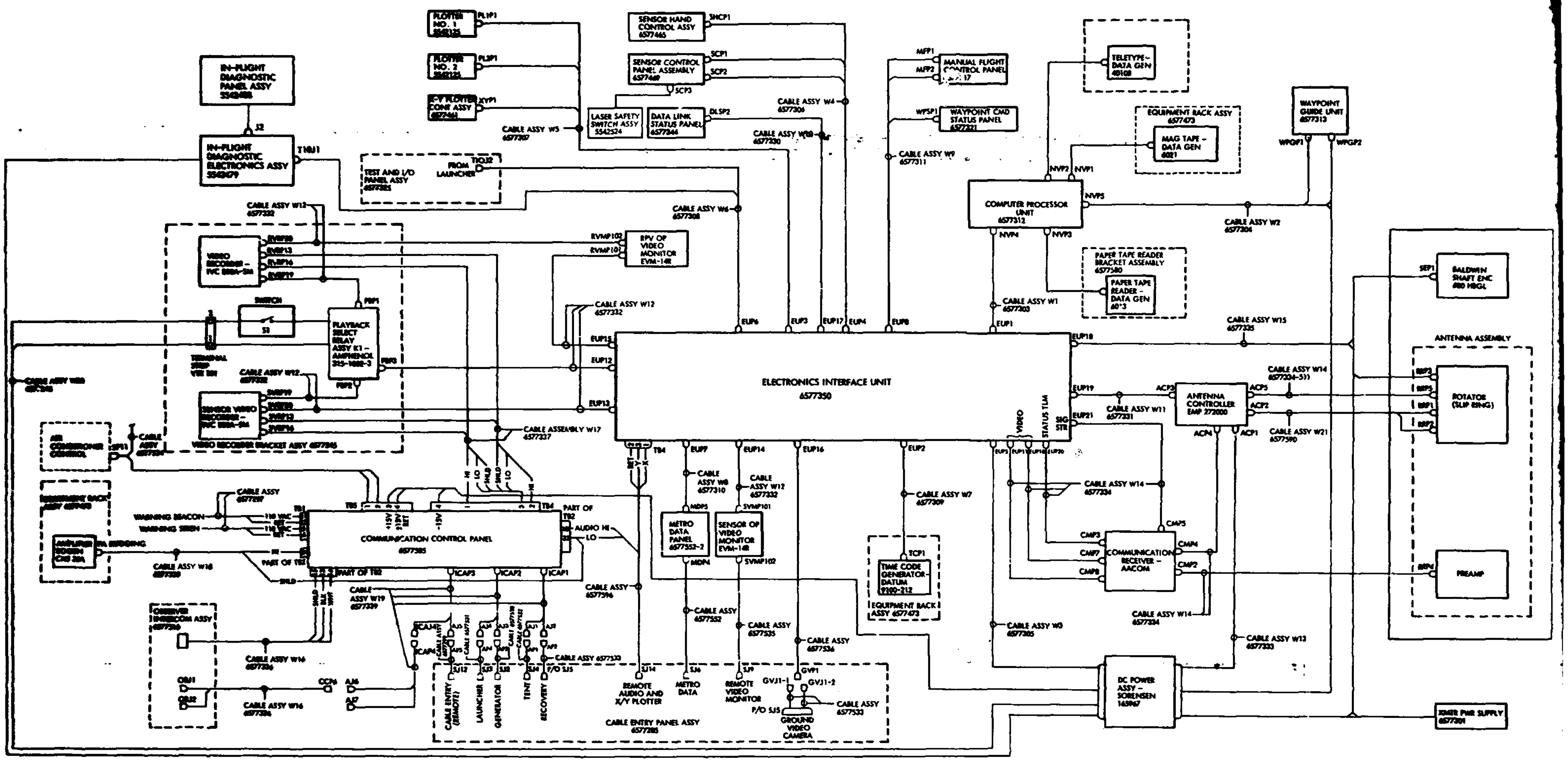


Figure 80. GCS Cabling Interconnect Diagram

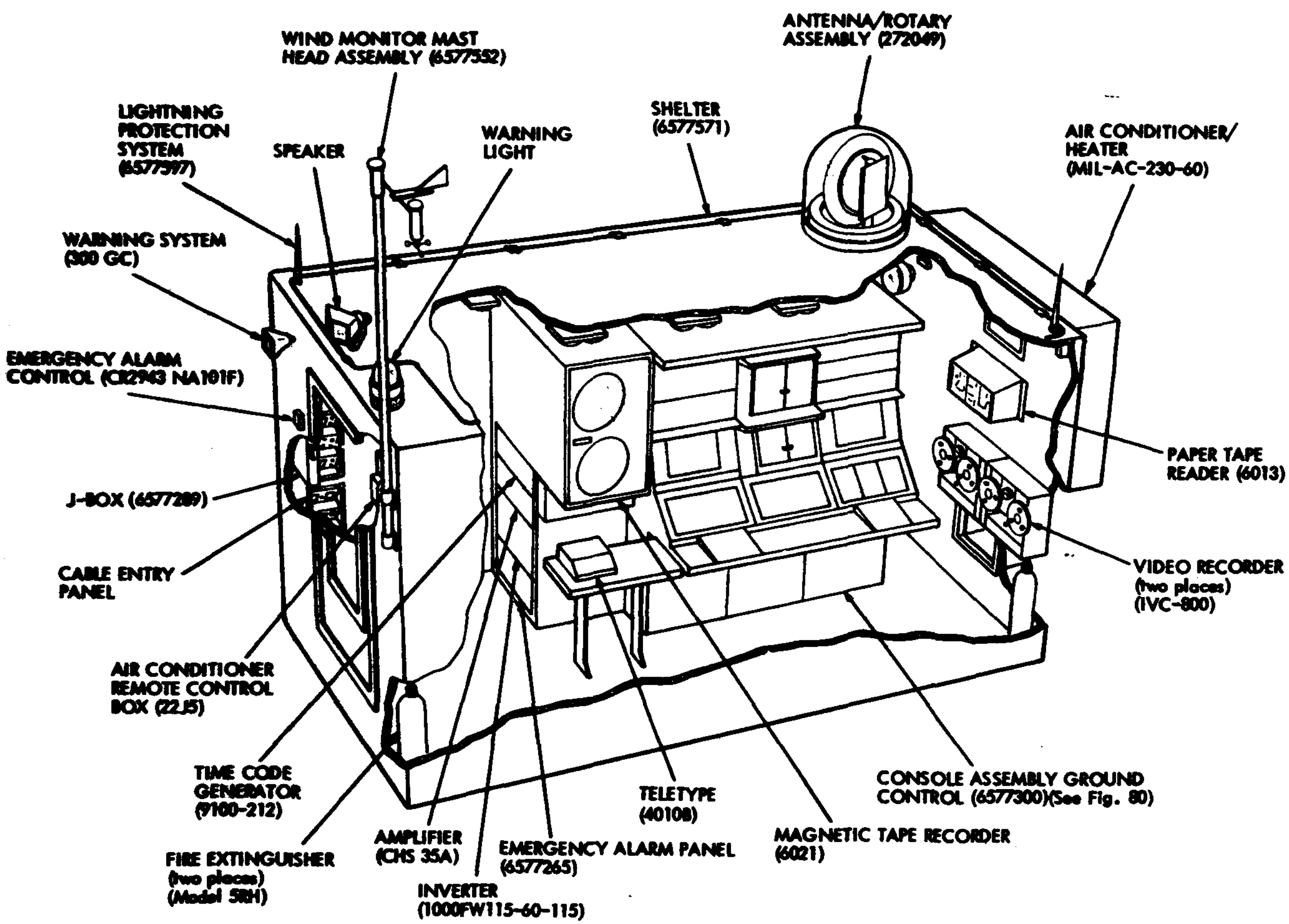
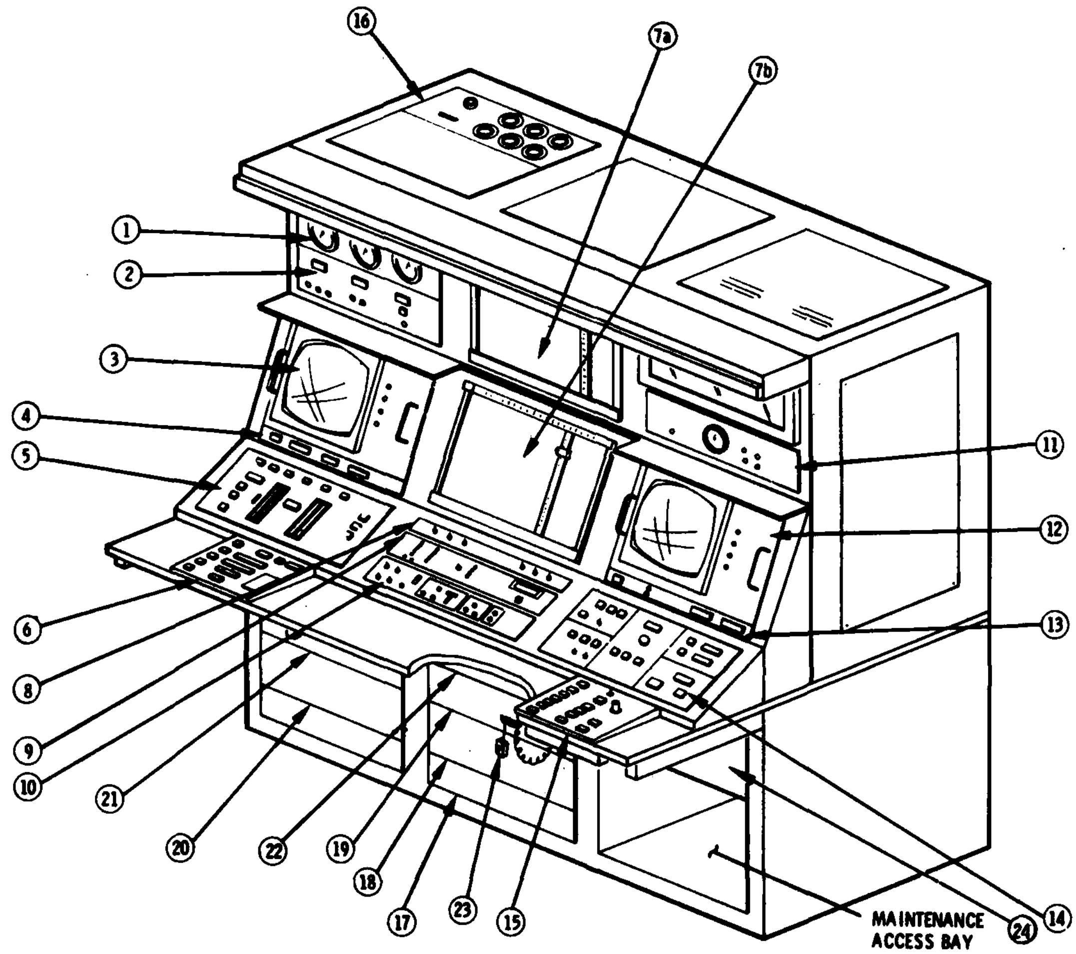


Figure 81. GCS Component Identification and Location



1 METEOROLOGICAL PANEL (6577552)
2 ANTENNA CONTROL PANEL (272003)
3 VIDEO MONITOR (EVM-14R)
4 WAYPOINT COMMAND STATUS PANEL (6577321)
5 MANUAL FLIGHT CONTROL PANEL (6577317)
6 WAYPOINT GUIDANCE PANEL (6577313)
7 X-Y PLOTTER (6577498)
8 X-Y PLOTTER CONTROL PANEL (6577461)
9 IN-FLIGHT DIAGNOSTIC PANEL (5542488)
10 INTERCOM PANEL (6577585)
11 TELEMETRY RECEIVER PANEL (AR-400C-V)
12 VIDEO MONITOR (EVM-14R)
13 DATA LINK STATUS PANEL (6577344)
14 SENSOR CONTROL PANEL (6577469)
15 SENSOR HAND CONTROL PANEL (6577465)
16 TEST AND I/O PANEL (6577325)
17 BLOWER (6577300-9)
18 ELECTRONICS INTERFACE UNIT (6577350)
19 POWER INTERFACE UNIT (6577524)
20 COMPUTER PROCESSOR UNIT (6577312)
21 POWER SUPPLY (165967)
22 IN-FLIGHT DIAGNOSTIC ELECTRONICS ASSEMBLY (5542479)
23 LASER SAFETY SWITCH (5542524)
24 INVERTER (1000FW115-60-115)

Figure 82. GCS Console Assembly Component Identification and Location

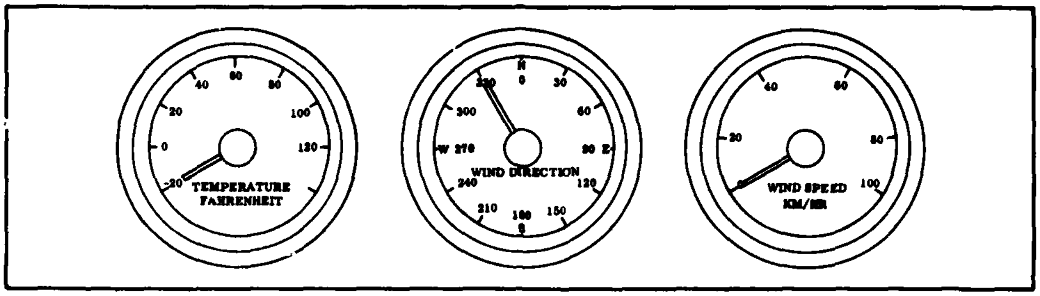


Figure 83. Meteorological Panel

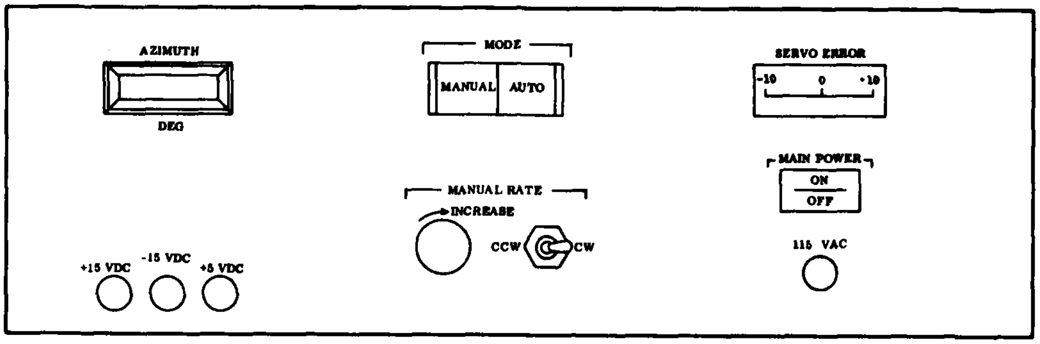


Figure 84. Antenna Control Panel

(LED) displays and ±15 Vdc at 0.12 A for the electronics. A 115-Vac input at 0.8 A is also required for generating ±30 Vdc for the drive electronics.

<u>RPV Operator Video Monitor</u>. The video monitor contains the controls and indications for video adjustments during the mission. The RPV operator's video monitor displays the real-time video received from the RPV. Superimposed on this video display are white alphanumerics on a black background generated from the vertical and horizontal video synchronization pulses and computations made from both ground information and RPV status data. These alphanumerics include time of day, RPV location in universal transverse mercator (UTM) northing and easting coordinates, line-of-sight direction and depression angle of the RPV sensor, and, with a laser designator, the location of the target in UTM coordinates and the height of the RPV above the target. Also, a blinking stall indication is displayed on the video monitor whenever the airspeed of the RPV is indicated below 74 km/h. Figure 85 shows the video monitor with the approximate location of the alphanumerics.

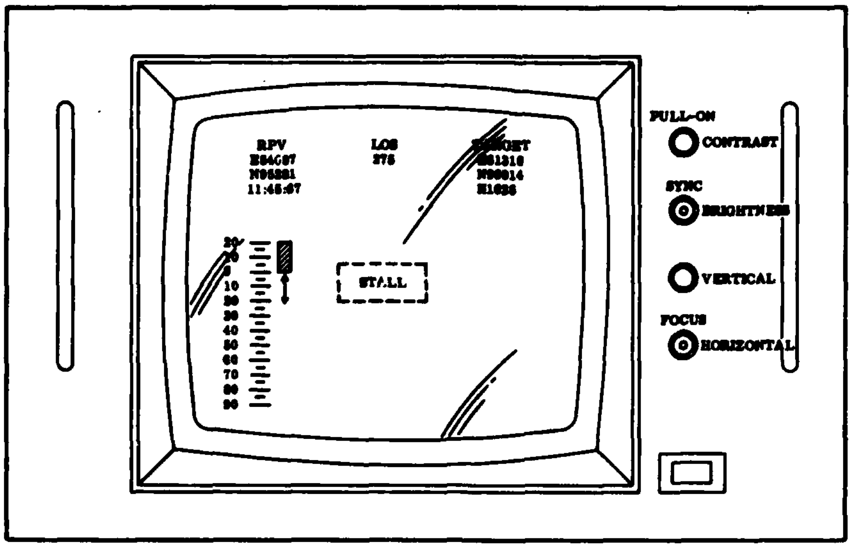


Figure 85. Video Monitor Panel (RPV Video Format)

The video monitor is a completely solid state low-cost monitor utilizing a 14-in. picture tube with a 3:4 aspect ratio. Manufactured by Electrohome, the monitor is designed to fit a standard 19-in. rack with a panel height of 12.25 in. and a depth of 11.5 in. The unit consumes 40 W at 115 Vac and weighs 39 lb.

<u>Waypoint Command Status Panel</u>. While the RPV is operating in the waypoint guidance mode, mission status is displayed on the waypoint command status panel, Figure 86. The waypoint that the RPV is approaching is indicated on a two-digit display. Present altitude command in meters, airspeed command in kilometers per hour, and mission time are also displayed.

This panel, designed and fabricated by LMSC, contains the only LED displays and interfaces directly with the EIU via parallel digital data in a binary code display (BCD) format and strobe pulses. The rack-mounted unit is 19 in. wide, 1.7 in. high, and 6 in. deep.

<u>Manual Flight Control Panel.</u> The manual flight control panel, Figure 87, contains the controls and indicators for prelaunch checkout, launch, altitude control, airspeed control, manual trim and heading control, flight mode selection,

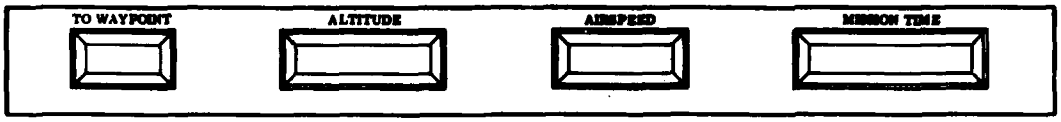


Figure 86. Waypoint Command Status Panel

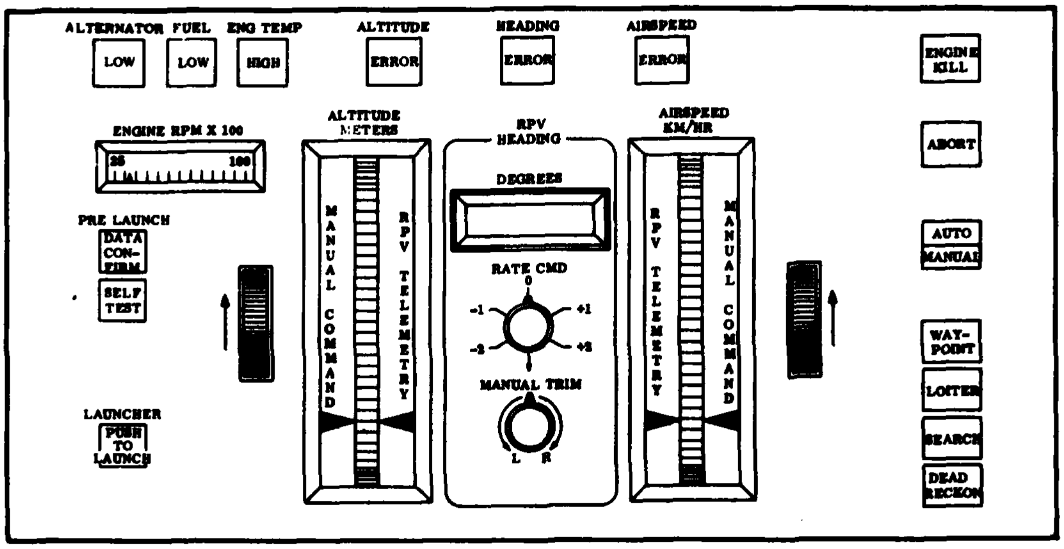


Figure 87. Manual Flight Control Panel

mission abort and engine kill, onboard operating conditions, and command response errors. For prelaunch operations, the SELF TEST switch checks the system for launch. If the low alternator output (below 24 Vdc) and fuel indicators (below approximately 2 lb) and the high engine temperature indicator (above 380° F) are off and the engine speed meter indicates sufficient rpm, the PUSH TO LAUNCH button (if lit) may be pressed to launch the vehicle.

The AUTO/MANUAL pushbutton switch selects either computer guidance (automatic) or manual control. If automatic control is selected, the guidance mode is selected by pressing the WAYPOINT, LOITER, SEARCH, or DEAD RECKON pushbutton.

RPV altitude in meters and airspeed in kilometers per hour are displayed on panel meters in all modes of control except the dead reckoning mode when downlink data are not present. If an error in altitude (> ±30 m), flightpath position (right or left > ±100 m), or airspeed (> 5 km/h) is detected during automatic mode, an amber error indicator is activated.

Manual control is effected by pressing the AUTO/MANUAL pushbutton. Altitude and airspeed are adjusted by thumbwheels adjacent to the corresponding panel meters. RPV heading is displayed on a three-digit panel indicator and is changed by rotating a trim control clockwise or counterclockwise in conjunction with the rate command, which is controlled by a six-position rotary switch. The six positions indicate zero turn rate, one and two standard rate turns (right or left), and manual rate selection.

This panel, designed and fabricated by LMSC, contains only the controls and indications and interfaces directly with the EIU via two cables. The rack-mounted unit is 19 in. wide, 8.75 in. high, and 8 in. deep.

Waypoint Guidance Panel. The waypoint guidance panel, Figure 88, displays UTM coordinates, altitude, and airspeed for each waypoint which can be entered through the waypoint guidance panel keyboard or the teletype. In addition, UTM coordinates may be entered directly from the No. 1 X-Y plotter by depressing

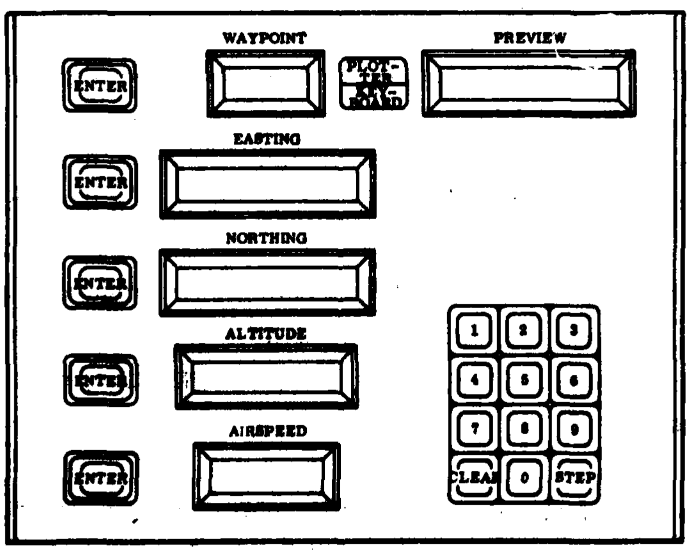


Figure 88. Waypoint Guidance Panel

the PLOTTER/KEYBOARD pushbutton. As the digits are selected on the keyboard, they are displayed on the five-digit preview display. Corrections to the display are made by pressing the CLEAR key and entering the correct data.

The waypoint number is selected first and previewed. When correct, the ENTER pushbutton adjacent to the WAYPOINT indicator is pressed and the waypoint number appears on the two-digit display. Easting and northing coordinates in meters are selected in the same manner and indicated on five-digit displays. Altitude in meters is selected and indicated on a four-digit display, and airspeed in kilometers per hour is selected and indicated on a three-digit display. The step key is used to select the next waypoint register.

This unit, designed and fabricated by LMSC, contains only the controls and indications and interfaces directly with the computer processing unit (CPU). The interface electronics are housed on a card in the CPU and furnish parallel data in a BCD format with strobe lines as the interface to the waypoint guidance panel. The unit is recessed below the top of desk top and occupies approximately 240 in.^{3}.

X-Y Plotters. The GCS console contains two X-Y plotters (Figure 89), which are used to display the navigational flightpath of the RPV. During the preflight checkout of the GCS, operational maps are placed on the X-Y plotters. During initialization, the coordinates of the four corners of the map are entered into the CPU via the teletype. Waypoints can also be entered via the plotters. During flight, the X-Y plotters will plot the flightpath of the RPV. The implementation of two plotters allows use of maps with different scales or adjacent maps with the same scale.

Analog voltages corresponding to the pen position are fed to the EIU, digitized, and supplied to the CPU. X and Y digital drive signals are derived in the CPU, converted to analog in the EIU, and fed to the plotters.

The X-Y plotters, manufactured by Hewlett Packard, have a nominal 11-in. by 17-in. active plotting surface. They are constructed of a one-piece aluminum

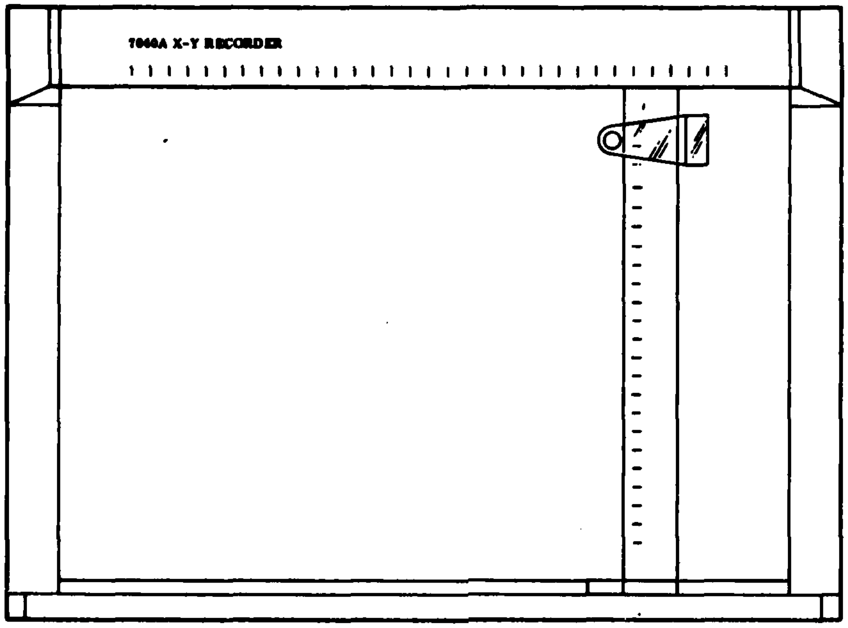


Figure 89. X-Y Plotter

casting mainframe, and equipped with an autogrip paper holddown system, and a quick-change disposable pen. The plotters consume 130 W at 115 Vac, are 19 in. wide by 14 in. high by 6.5 in. deep, rack mountable, and weigh 29 lb each.

<u>X-Y Plotter Control Panel.</u> The X-Y plotter control panel, Figure 90, controls the paper holddown system, the servo drive signals, and the recorder left position of the pen for each plotter. The rack-mounted panel, designed and fabricated by LMSC, is 19 in. wide and 1.5 in. high.

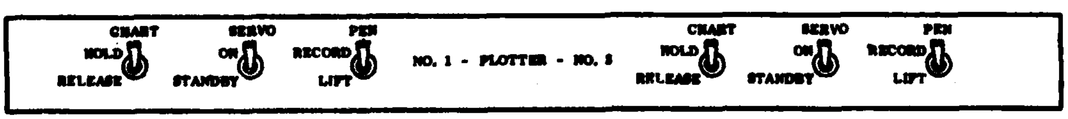


Figure 90. X-Y Plotter Control Panel

In-Flight Diagnostic Panel. The in-flight diagnostic panel, Figure 91, contains LED indicators that show flight control mode commands being sent from the GCS to the RPV, the command mode status within the RPV, data-link status, and the gain selected in the GCS tracking antenna. The panel also contains controls for testing and resetting LED displays and for selecting among eight multimeter functions to monitor console power supply output voltages and RPV receiver, battery, engine cylinder head temperature, and carburetor inlet air temperature.

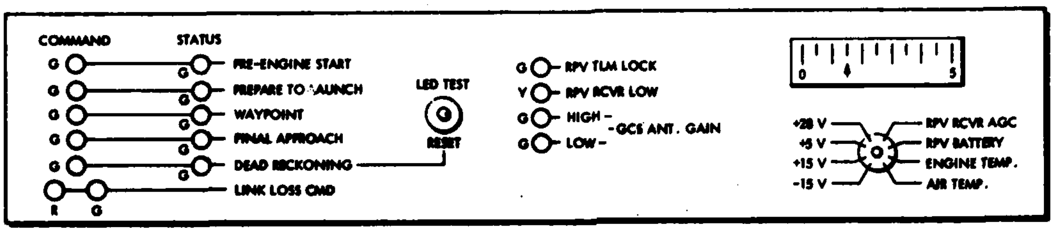


Figure 91. In-Flight Diagnostic Panel

The panel, designed and fabricated by LMSC, interfaces with the in-flight diagnostic electronics assembly. The rack-mounted panel is 19 in. wide and 3 in. high.

Interoom Panel. The intercom panel, Figure 92, is the central station for the voice communications throughout the ground system. With this panel, both operators and an instructor are able to plug in headsets and communicate with

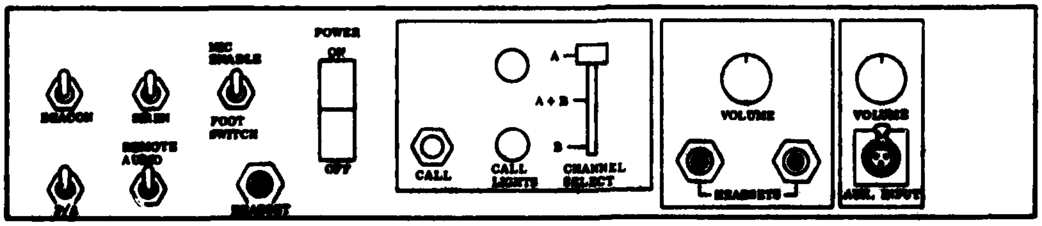


Figure 92. Intercom Panel

other ground personnel. A total of 30 headsets can be plugged into this system. Indicator lights are provided whenever a call is either coming in or going out of the GCS. Channel selection and volume control are available. This panel also gives the operator the capability to turn on the beacon, siren, and public address system.

The intercom panel was purchased from Clear Com Division of Lumiere Productions, Inc., and modified by LMSC to add the switches for the beacon, siren, public address, and foot switch control. It operates on 115 Vac with 0.5 A of current. The rack-mounted unit is 19 in. wide, 3.33 in. high, and 8 in. deep.

<u>Telemetry Receiver Panel.</u> The telemetry receiver panel, Figure 93, contains the downlink telemetry/video receiver and its controls. Manufactured by AACOM, Inc., this receiver is part of the tracking antenna system. The meter on the face of the panel is monitored for maximum signal strength while the antenna is being aligned.

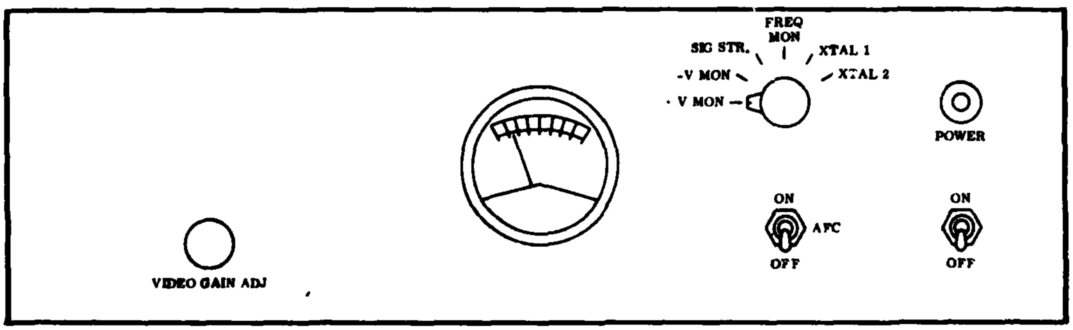


Figure 93. Telemetry Receiver Panel

<u>Sensor Operator Video Monitor.</u> The sensor operator has a video monitor identical to the RPV operator's video monitor. However, the sensor operator has the capability of displaying the real-time RPV video, a playback video stored on the recorder, or the video from the ground approach camera. Using the ground video mode, a head-on view of the approaching RPV is presented to the sensor operator. A reticle provides a centered crosshair on the operator's

display. The operator's display also presents a second crosshair that is electronically generated and controlled by the sensor operator's controls. Displacement signals are generated and transmitted to the RPV to command the RPV to fly in a direction that will cause the RPV to fly to the reference crosshair position when the controllable crosshair is placed on the RPV image. This alignment is established and maintained to force the RPV to follow the correct flightpath into the vertical net. Time of day is also included on this display. Figure 94 shows the display for the ground video camera.

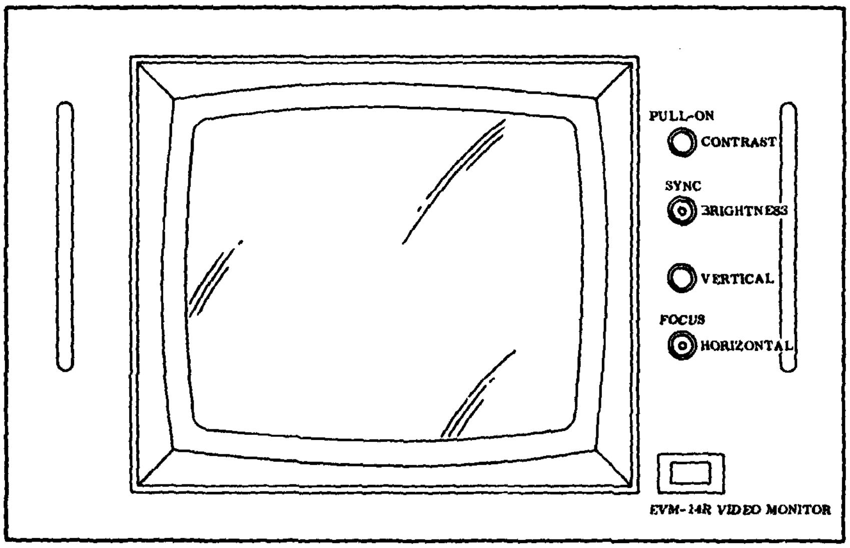


Figure 94. Video Monitor (Ground Video)

Data Link Status Panel. The data link status panel, Figure 95, is used to supply power to the uplink command transmitter and indicates the condition of the data link. The GND LOCK light, controlled by the computer, indicates that the RPV

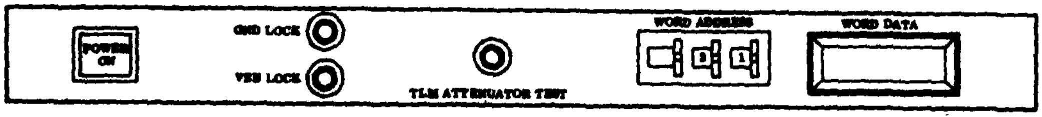


Figure 95. Data Link Status Panel

has locked onto the command link and the GCS has locked onto the downlink, and that both the computed RPV to GCS range and tracking antenna azimuth angle are within a computer controlled window (window size is a function of RPV dynamics). The VEH LOCK light indicates the RPV has locked onto the uplink transmitter.

During prelaunch, the TLM ATTENUATOR TEST switch is used to actuate rf attenuators simulating RPV ranges of approximately 20 km, thereby verifying data-link performance. During prelaunch and flight, uplink and downlink data can be displayed, in octal format, on this panel. The thumbwheels are used to select the proper telemetry channel. This panel, designed and fabricated by LMSC, interfaces with the EIU. It is rack mounted and is 19 in. wide, 1.7 in. high, and 6 in. deep.

<u>Sensor Control Panel.</u> The sensor control panel, Figure 96, contains controls and indicators for controlling the various sensor payloads used during RPV-STD program Phases I through V. They are: autotracker controls for Phases III through V, laser controls for Phases IV and V, artillery offset controls for

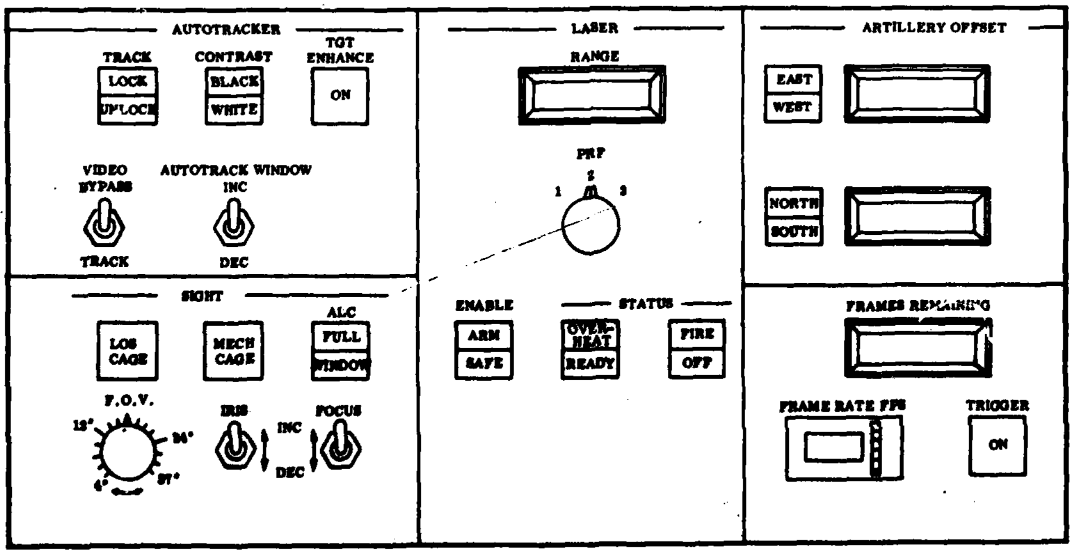


Figure 96. Sensor Control Panel

Phase IV, 35-mm camera controls for Phase II, and sight controls for the Phases I through V TV camera.

The automatic target tracking mode, used in Phases III through V, is selected by an AUTO TRACK ENABLE pushbutton on the sensor hand control panel; the status of that pushbutton is displayed by the sensor control panel TRACK LOCK/UNLOCK indicator. The target is manually located by the sensor operator with the AUTO TRACK ENABLE switch in the off condition. When the AUTO TRACK ENABLE switch is pressed, the payload camera automatically tracks the centroid of the target. When the tracker is actually locked onto the target, a 1-in.-long horizontal bar, from the RPV TV sensor, appears in the lower lefthand corner of the TV screen; this is the only indication that the tracker is in fact locked on.

Video contrast within the track window can be changed from a normal black and white image to a negative image by pressing the CONTRAST switch. Further contrast control is effected by pressing the TGT ENHANCE pushbutton that increases the picture contrast in the track window. The size of the window is controlled by the AUTOTRACK WINDOW spring-loaded toggle switch that increases or decreases the window area.

The video camera normally passes the video signals through the autotracker. In the event of a malfunction, the VIDEO BYPASS/TRACK switch can be used to bypass the video around the autotracker.

Laser rangefinder controls are used in Phases IV and V. The laser is enabled by the ENABLE ARM/SAFE pushbutton switch and the status is indicated on the OVERHEAT/READY indicator. The pulse repetition frequency is selected by the three-position PRF rotary switch. During operation, transmission is verified by the FIRE/OFF indicator, and the vehicle-to-target range is displayed in meters on the four-digit RANGE indicator. The laser is fired by the LASER FIRE switch on the senser control panel.

For Phase IV, artillery offset is displayed on two three-digit displays, accompanied by an EAST/WEST and a NORTH/SOUTH indicator to indicate, in coordinates, the displacement between the target and the burst.

The 35-mm camera controls are used in Phase II. The frame rate is selected by the FRAME RATE FPS thumbwheel/indicator switch in frames per second. The three-digit FRAMES REMAINING display indicates the number of frames remaining. The camera is controlled by the TRIGGER ON pushbutton that triggers the camera at the selected frame rate.

The LOS CAGE control is used for Phases III through V; all others are used in Phases I through V. The RPV TV camera can be caged in two positions. The MECH CAGE pushbutton points the video camera forward at a depressed angle of 6 deg. The LOS CAGE pushbutton electrically locks the video camera in its present position.

Full-screen or window (center 10 percent of screen) automatic level controls are activated by the ALC pushbutton. Video camera brightness and contrast are kept in balance over the entire screen or within a central window area. Video camera field of view is continuously adjustable for 4 deg to 37 deg by the FOV control. Manual light level control over the entire field of view is adjusted by the spring-loaded IRIS toggle switch that increases or decreases the filter density, and returns to the center position when released. The spring-loaded FOCUS toggle switch adjusts camera focus (not used in Phases IV and V).

This panel, designed and fabricated by LMSC, is 19 in. wide by 8.75 in. high by 8 in. deep, rack mounted, and interfaces directly with the EIU. Voltages required are +5 Vdc for the LED displays and +28 Vdc for the indicator lamps.

Sensor Hand Control Panel. The sensor hand control panel is shown in Figure 97. The PAYLOAD ON pushbutton switch applies power to the RPV sensor gimbals, autotracker, and laser. The approach camera or RPV camera selection is made by the VIDEO SELECT GROUND/VIDEO pushbutton, and displayed

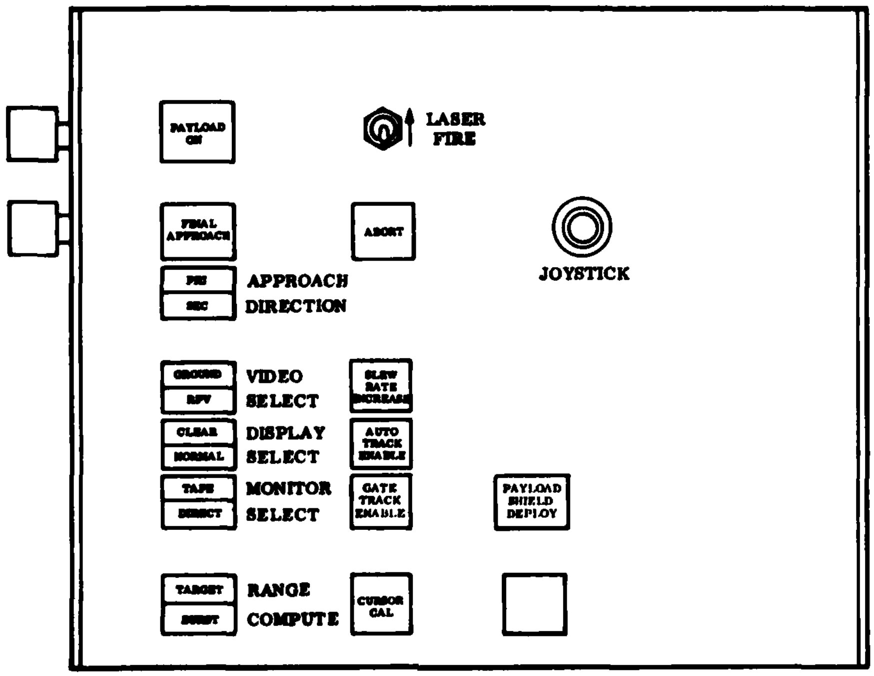


Figure 97. Sensor Hand Control Panel

on the sensor operator's TV monitor. Superimposed alphanumeric information and symbols (heads-up display) may be cleared from the screen by pressing the DISPLAY SELECT NORMAL/CLEAR pushbutton. In addition, the video tape replay may be viewed by selecting the tape position of the MONITOR SELECT TAPE/DIRECT pushbutton. The DISPLAY SELECT and MONITOR SELECT pushbuttons are effective only when the RPV video is selected.

For Phases IV and V, the LASER FIRE switch fires the laser rangefinder/designator in conjunction with the controls and indicators on the sensor control panel. For retrieval and Phase IV, the cursor is calibrated by centering the cursor on top of the reticle (or the crosshair) with the joystick and pressing the CURSOR CAL pushbutton. The offset range is computed by positioning the reticle on the target and pressing the AUTO TRACK ENABLE pushbutton. The cursor is then positioned with the joystick by the sensor operator on the burst and the BURST function is selected by pressing the RANGE COMPUTE pushbutton for computation. Offset information is calculated and displayed on the ARTILLERY OFFSET section of the sensor control panel when the laser is fired again. The two control knobs on the left side of the panel zero the cursor elevation and azimuth drift rates on the sensor operator's TV monitor with the joystick in neutral.

FINAL APPROACH, APPROACH DIRECTION, and ABORT controls are used in conjunction with the joystick to retrieve the RPV. Pressing the FINAL APPROACH pushbutton ends waypoint guidance, initiates the computer guidance and RPV flight controls approach modes, places the RPV tracking under sensor operator control, and deploys the payload protector. (The payload protector can also be deployed by pressing the PAYLOAD SHIELD DEPLOY pushbutton.) The APPROACH DIRECTION pushbutton selects the primary or secondary landing direction. If the wind has shifted during the mission, necessitating landing in the opposite direction, the ground TV camera must be switched to the opposite end of the retrieval system, the opposite vertical net erected, and the PRI/SEC pushbutton selected. In the event the approach is not satisfactory, pressing the ABORT pushbutton will cause the RPV to pull up and circle for another attempt. During retrieval, the joystick controls the cursor on the TV monitor that the sensor operator uses to track the RPV. By comparing the location of the tracking cursor with the center of the glideslope, the ground station computer calculates the steering error and sends correcting commands to the RPV autopilot. The sensor operator continues to track the RPV with the cursor until retrieval is accomplished.

The panel, designed and fabricated by LMSC, interfaces directly with the EIU. It is recessed below the table top and occupies 400 $in.^3$.

<u>Test and I/O Panel.</u> A connector panel on top of the test and input/output (I/O) console is used to supply data between the launcher and EIU. These data include the launch signal, launcher speed pulses, and launcher status.

Blower. The blower cools the console interior electronics.

EIU. The EIU, designed and fabricated by LMSC, houses all the interface electronics required between the vendor components and subassemblies and the displays and controls. This unit consists of 27 plug-in printed circuit boards (6.5 in. by 7.5 in.) plus two AACOM, Inc. data link boards. The unit occupies 4,075 in.^{3}. A drawing of the EIU is shown in Figure 98.

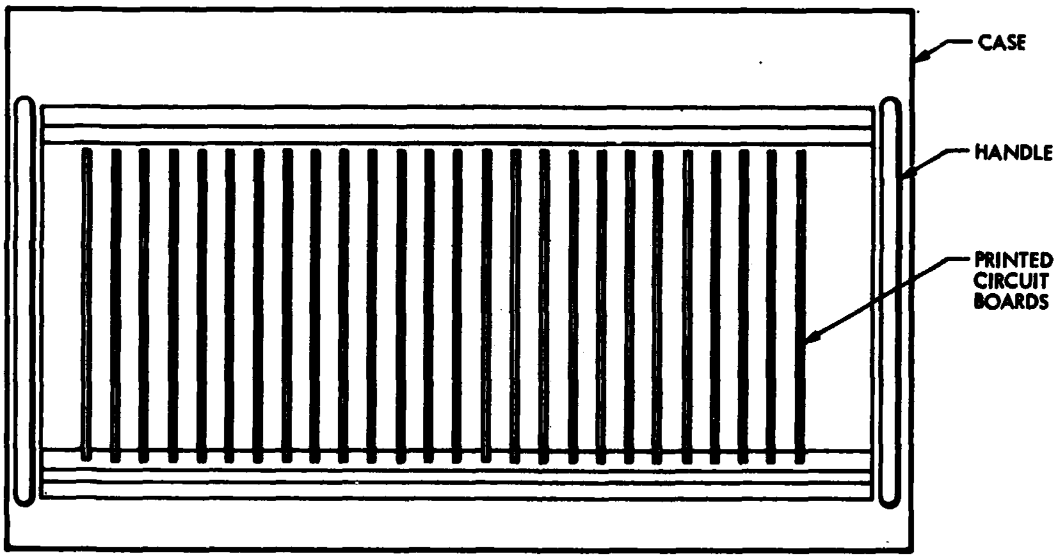


Figure 98. Electronics Interface Unit

Power Interface Unit. The power interface unit, designed and fabricated by LMSC, is used to switch on the console power and the power to the shelter accessories, such as lighting. A 25-A circuit breaker is used for the console power and a 15-A circuit breaker for the accessories. Power outlets are also available on the face of the panel. The panel is rack mounted and is 19 in. wide and 3.5 in. high.

CPU. The Data General Nova 2 general-purpose computer performs real-time calculations utilizing floating point arithmetic and data processing for the RPV-STD system. The computer communicates directly with the paper tape reader, magnetic tape recorder, teletype, and waypoint guidance unit. Access to all other active units in the GCS and launcher is provided through the EIU. A photograph of the CPU is shown in Figure 99.

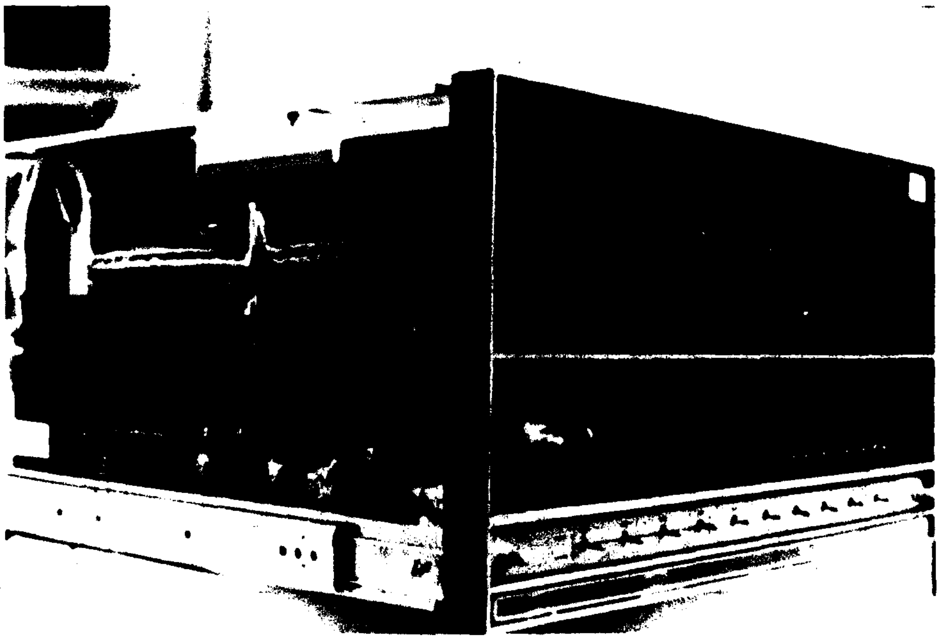


Figure 99. Computer Processing Unit

The basic computer programming is read into the 16,000-word memory in 16-bit binary words from either the paper tape reader or the magnetic tape unit. Information regarding site initialization, mission planning, and prelaunch data is provided to the computer via the teletype, waypoint guidance unit, or the X-Y plotters through the EIU.

During a mission, the computer senses the tracking antenna azimuth and data-link range indicators to determine actual RPV position, compares this position with the programmed flightpath, and issues corrective commands through the data link to the RPV. Throughout the mission, the computer provides signals to the X-Y plotters that plot RPV position, monitors the vehicle sensors for vehicle status changes, and provides updated data for displays or for the sensor control panel, waypoint status panel, manual flight control panel, and the antenna control panel. At discrete intervals, the computer also provides comprehensive flight data to the magnetic tape recorder for a permanent flight record.

The CPU has front panel displays and controls. In this way, the operator is able to enter words into the computer, to load program in memory, to start the program, and to examine the contents of any memory location. This serves as an added troubleshooting tool which is not used during flight.

Power Supply. The power supply assembly, purchased from Sorenson, supplies the regulated dc power for the complete console. Operating off 115 Vac, the following voltages are supplied with regulation and current capability:

+5 Vdc ± 0.05% at 36 A
+15 Vdc ± 0.1% at 2.8 A
-15 Vdc ± 0.1% at 2.8 A
+28 Vdc ± 0.1% at 11 A

These supplies have shutoff capability when overloaded.

In-Flight Diagnostic Electronics Assembly. The electronics assembly, designed and fabricated by LMSC, is used in conjunction with the in-flight diagnostic panel. Interfacing with the EIU, the in-flight diagnostic electronic assembly receives both the command and status data and generates the drivers for the LED displays. In addition, the electronics decommutates status data to display RPV receiver AGC, RPV battery voltage, engine cylinder head temperature, and carburetor inlet air temperature. The electronics are contained on a 14.5-in. by 8.5-in. printed circuit card and housed in a rack-mounted 19-in.-wide by 3.5-in.-high chassis.

Laser Safety Switch. A laser safety switch was added to the console to serve as an additional safety precaution to the firing of the laser. This switch must be held down whenever the laser is to be fired.

Inverter. The inverter, manufactured by Topaz, provides a frequency-regulated 117-Vac, 60-Hz output power from a 117-Vac input with varying frequency, such as from a generator or auxiliary power unit. This unit supplies power to the two video tape recorders. The unit is located under the sensor operator's desk top.

5.2.1.2 Magnetic Tape Recorder. The nine-track digital tape recorder, manufactured by Data General, is used in the playback mode to program the Nova 2 computer and in the record mode to record uplink and downlink data for system performance analysis. The controls on the recorder allow the operator to (1) load the tape that draws the tape into the vacuum column and advances it to the beginning of the tape, (2) place the recorder on line for computer control, and (3) rewind the tape at high speed.

5.2.1.3 Teletype. The model KSR 33 teletype is comprised of a keyboard unit and a typing unit controlled by a Nova 2 computer. The computer program instructs the operator to enter specific data in a sequence required by the computer. A photograph of the teletype is shown in Figure 100.

With the LOCAL/OFF/LINE switch in the LOCAL position, the keyboard and typing units are tied directly together and the teletype operates as a typewriter. With the switch in the LINE position, the Nova 2 controls the keyboard and typing units individually. Under computer control, the typing unit provides a hard copy of the program data while the computer instructions are entered via the keyboard. Data communications between the computer and teletype are by 11-bit coded words containing the standard 8-bit ASCII information code. For example, when data are transmitted to computer via keyboard, the computer will respond by printing data on the typewriter if the computer is operating and programmed properly.

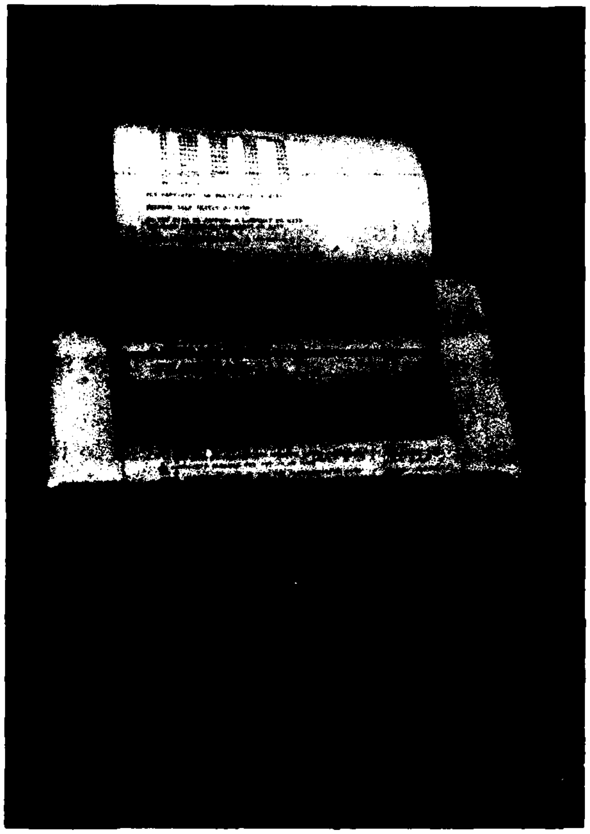


Figure 100. Teletype

5.2.1.4 Emergency Alarm Panel. The alarm panel is located on the auxiliary equipment rack and is shown in Figure 101. The two switch indicators must be activated in the correct sequence to avoid inadvertent alarm system activation. Pressing the EMERGENCY READY switch indicator enables the alarm switches in the tent, GCS panel, launcher control box, and generator J-box, and lights the indicator green if all the cables are connected and the switches are off.

While the EMERGENCY READY indicator is green, pressing the ALARM ON switch indicator will enable the alarm siren circuit. The indicator will light red. The alarm will sound if any of the alarm switches is pressed, any of the intersite signal cables becomes disconnected, or if the EMERGENCY READY

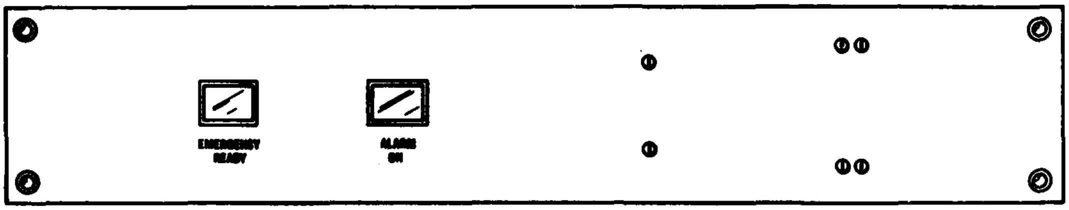


Figure 101. Emergency Alarm Panel

switch is pressed a second time (before turning the ALARM ON switch off). This panel, designed and manufactured by LMSC, is 19 in. long and 3.5 in. high.

5.2.1.5 Inverter. This second inverter is identical to the one used for the video recorders. This one, however, is used to supply regulated output power to the computer and is located in the auxiliary equipment rack.

5.2.1.6 Amplifier. The power amplifier is a 35-W Bogen public address amplifier and is located on the auxiliary equipment rack. The amplifier controls the emergency siren and the loudspeaker on the GCS roof.

5.2.1.7 Fire Extinguishers. Two model 5RH fire extinguishers are located in the shelter.

5.2.1.8 Time Code Generator. The time code generator, Figure 102, is located on the auxiliary equipment rack. During the computer site initialization, the generator is turned on and set to Greenwich mean time. Using the thumbwheel, the most significant digit (day of the month) is selected and entered into the appropriate display position. The succeeding digits are entered in sequence. When the correct second is entered, the START pushbutton is pressed.

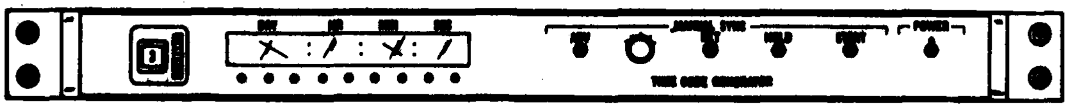


Figure 102. Time Code Generator Panel

The time code generator output is visible on the front panel display and is applied to the computer as a time reference for the tape recorders. The time reference is also used to calculate flight time for the video monitor heads-up display and the mission time display on the waypoint command status panel. The unit is manufactured by Datum.

5.2.1.9 Air Conditioner Remote Control Box. An air conditioner remote control box, Figure 103, contains a thermostat and an air conditioning function selector which is used to regulate the temperature of the shelter. An hour-meter records operating time. This unit is manufactured by Ellis and Watts.

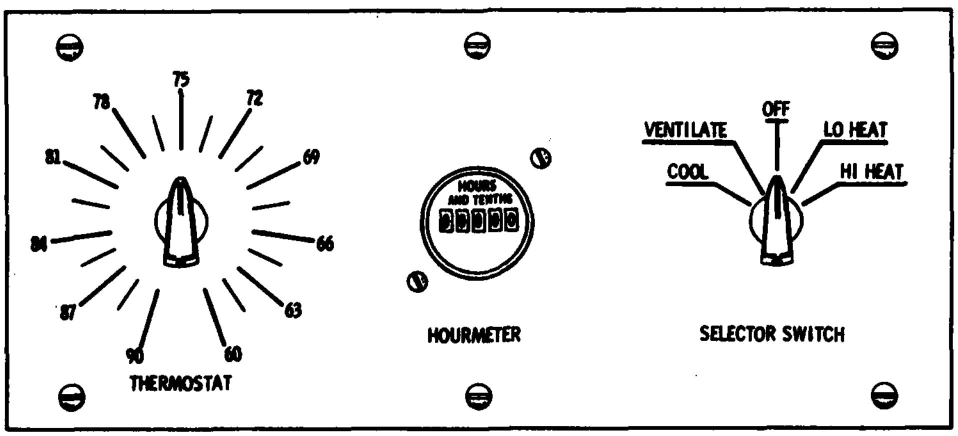


Figure 103. Air Conditioner Remote Control Panel

5.2.1.10 Cable Entry Panel. This panel is used to interface the shelter with the rest of the ground system. Communication lines between the GCS and launcher, generators, and recovery system are routed through this panel. Spare lines are also provided. Other interfaces routed through this panel are the ground video camera signals at the recovery site, remote video monitor output, weather data, and remote audio and X-Y plotter outputs available as spares.

5.2.1.11 J-Box. The J-box controls all the site ac power except that for the air conditioner. This box contains the main circuit breaker (200 A per phase) and 19 other circuit breakers for GSS power.

5.2.1.12 Emergency Alarm Control. This control, manufactured by Federal Signal Co., is an external control for activating the warning siren.

5.2.1.13 Warning System. This system, assembled by LMSC, consists of a warning siren that can be sounded (if activated) by the emergency alarm panel in the GCS, or by emergency alarm control external to the GCS, or by the alarm switches at the remote sites. This siren can be controlled from the communication panel during prelaunch checks.

5.2.1.14 Lightning Protection System. This system, designed and fabricated by LMSC, consists of lightning arrestor rods on top of the GCS, connected by no. 4 AWG wire which is routed along the wall of the GCS, and attached to a 5/8-in. copperweld pipe 8 ft in the ground.

5.2.1.15 Speaker System. The speaker system, manufactured by Cobraflex, consists of two speakers used for the outdoor communication system. The speakers are driven from the Bogen 35-W amplifier.

5.2.1.16 Wind Monitor Mast Head Assembly. This assembly, manufactured by Signet Scientific, includes the sensors for monitoring wind direction and speed and outdoor temperature. The sensor outputs are fed to the meteorological panel. This assembly sits on an extendable/retractable mast on top of the GCS. A photograph of the wind monitor mast is shown in Figure 104.

5.2.1.17 Warning Light. The warning light, manufactured by Federal Signal Co., consists of a beacon mounted on the top of the GCS. During a flight when the beacon is turned on, it is rotating and flashing. The emergency alarm system can also turn on this beacon.

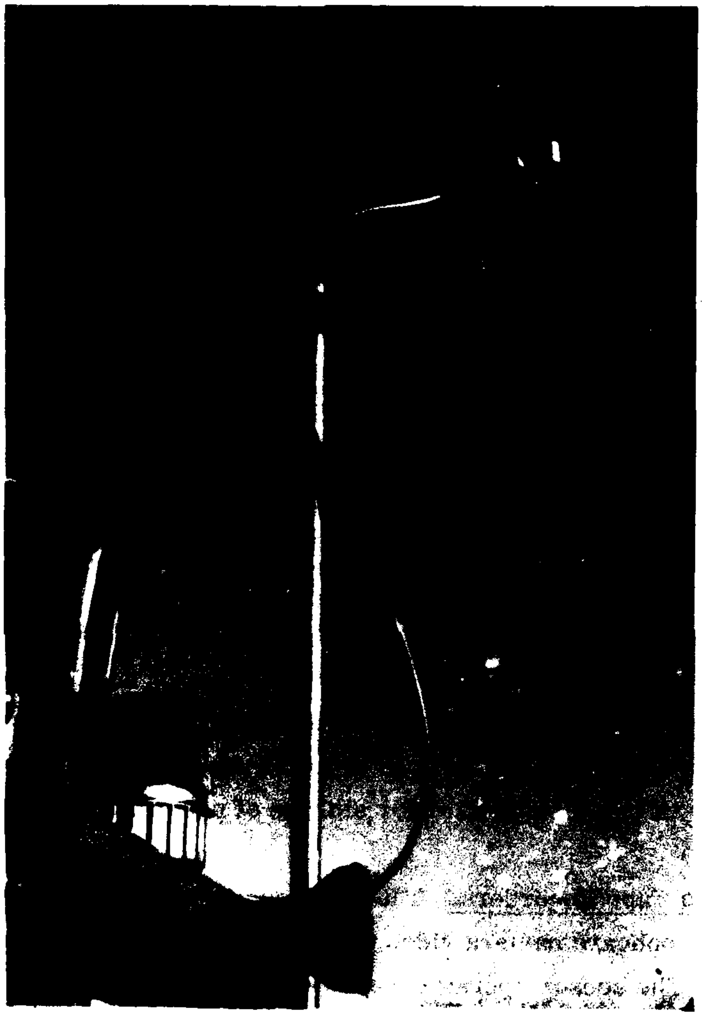


Figure 104. Wind Monitor Mast Head Assembly

5.2.1.18 Shelter. The shelter is a basic Craig Systems S-280 shelter and was modified by LMSC. The modifications included inlet and outlet holes and mounting brackets for the air conditioner, the addition of a side panel for installing the console and for gaining access behind the console during checkout, and attaching support structures for installing the tracking antenna, warning light, speaker, mast, siren, communication lines, light fixtures, J-box, teletype, console, auxiliary console, digital tape recorder, video recorder, and paper tape unit. The shelter is 138 in. long, 81.5 in. wide, and 74.5 in. high.

5.2.1.19 Antenna/Rotary Assembly. The antenna/rotary assembly, manufactured by EMP, provides a means for automatically tracking the RPV. The assembly consists of a radome, low-gain and high-gain receive/transmit antennas, gimbals, tachometer, and rotary joint assembly with slip rings, command transmitter, and rf components. A detailed functional and interface description of the tracking system is presented in subsection 5.1.2.

5.2.1.20 Air Conditioner/Heater. The MIL-AC-230-60 air conditioner/heater, manufactured by Ellis and Watts, is capable of providing 36,000 Btu/hr maximum cooling capacity with an ambient temperature of 125° F. It also is capable of supplying 25,000 Btu/hr heat capacity. This unit is electric motor driven, air cooled, automatic, and self-contained. It operates off of 115/208-V, 3-phase, 60-Hz power.

5.2.1.21 Paper Tape Reader. The 300 character per second tape reader, manufactured by Data General, is used to load a diagnostic program into the GCS computer. It can also be used for storage of programs or data.

5.2.1.22 Video Tape Recorders. The two video tape recorders are used to record the RPV onboard camera video signal superimposed with the added alphanumeric data. The sensor operator has an option to record the ground camera video instead. In addition, the sensor operator has the capability of playback from his video recorder to his monitor. Audio data from the intercom channels are also recorded for data analysis following the flight.

The video recorders, one of which is shown in Figure 105, are high-performance helical-scan, fully transistorized industry devices manufactured by International Video Corporation (IVC). These recorders provide both record and reproduce functions and are remotely controllable. Each has replay capability with slow and stop motion. The recorders feature a 5.0-MHz bandwidth and a 44-dB

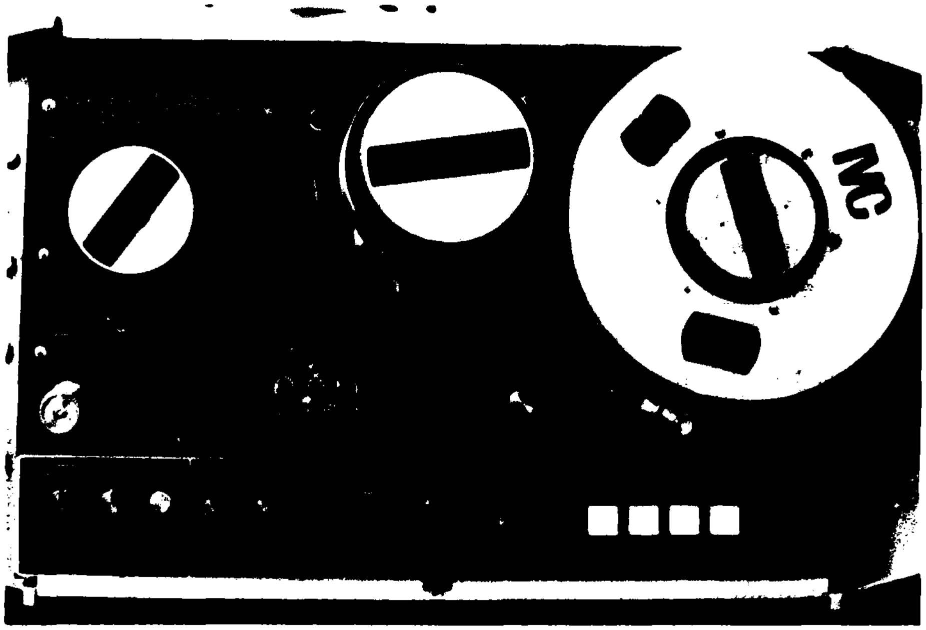


Figure 105. Video Recorder

signal-to-noise ratio for video plus two channels of recording for audio range signals. Each scan of the video head records one field of video. For the nominal 30 sec of instant replay, tests have shown that the tape recorder will rewind and ready itself within 4 sec. The recorders provide 1 hour of recording time on an 8-in. reel with a horizontal resolution in excess of 400 lines.

5.2.2 Requirements and Capabilities

To meet the requirements set forth in the contract Description/Specification, the GCS is housed in a mobile shelter equipped with air conditioning and heating units, and contains the following equipment and subsystems:

- A computer that monitors pertinent RPV and sensor parameters in order to control the flight of the RPV and to compute target UTM coordinates and height above sea level. The computer also provides fire correction displacements in meters. These locations and corrections are accomplished within 2 sec of data input. The target location computations are initiated by the receipt of laser range data; the fire correction computation is initiated by the operator marking the burst location on the display. Burst-to-target accuracy for fire correction is 25 m CEP.

- Controls that include autopilot and other flight commands, preprogrammed flight commands, launch and recovery control, TV commands, autotracker commands, laser commands, and controls to transfer burst location from TV monitor to fire adjustment computation subsystem.
- Displays that include two TV monitors (one for real-time display and one for playback); pan and tilt position of RPV TV; sensor field of view; computed target coordinates; fire correction; laser range; RPV altitude, heading, and airspeed; and engine rpm, temperature, and fuel quantity.
- Recording capability to record TV imagery for instant playback of 30-sec segments and for replay of the entire flight recording, and stop action capability wherein the operator can freeze any frame viewed from the instant replay recorder.
- Ground portion of the data link and command and control for the RPV system.

The following paragraphs discuss the capabilities of the GCS and the compliance with the requirements.

5.2.2.1 Functional Interfaces. The heart of the GCS is the CPU and the EIU which routes data to and from the data link and tracking antenna, meteorological sensors, communications link, time code generator, video recorders and monitors, X-Y navigation plotters, and controls and displays. The following paragraphs show the interfaces between all portions of the GCS for each functional mode. The modules shown refer to the EIU printed circuit boards, and block diagrams accompany each function.

RPV Range Counter (Figure 106). The range from the GCS to the RPV is computed by measuring the delay between the uplink and the downlink clocks. On request from the CPU, range counter output is fed to the CPU. These data, along with the antenna azimuth data, are used to determine RPV position in UTM coordinates.

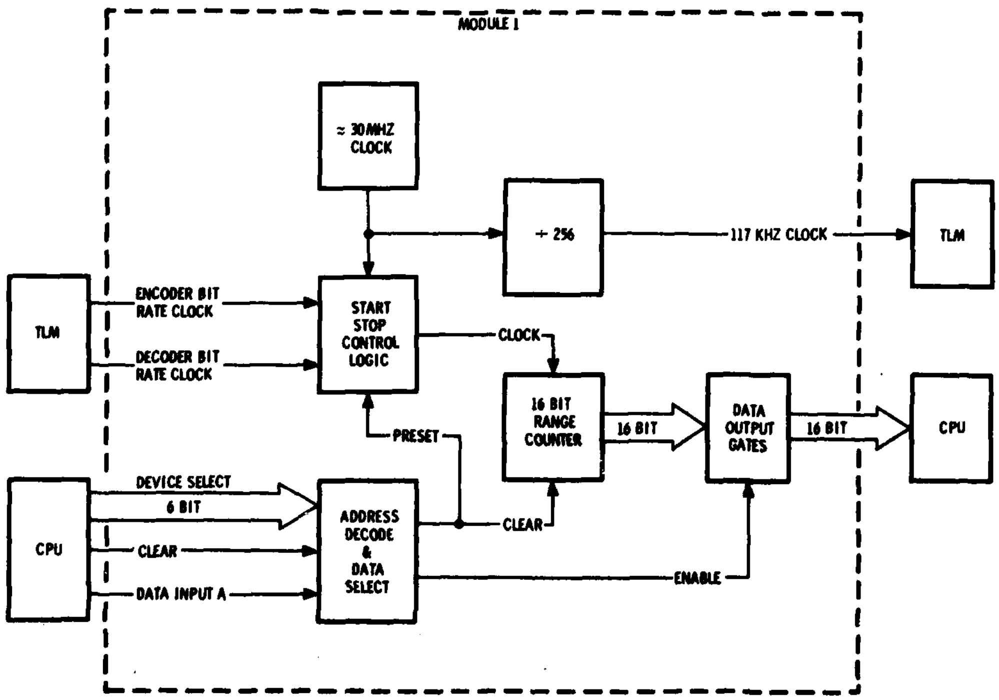


Figure 106. RPV Range Counter

X-Y Plotter Drive (Figure 107). To plot the position of the RPV, the CPU compares the calculated position of the RPV with the initialization corner points of the plotter, thereby deriving the plotter X-Y signals. These signals are 10-bit words that are converted to analog drive signals.

Auto/Manual Command Select (Figure 108). The airspeed, altitude, and heading rate commands are computed in the CPU for the automatic mode, output as 10-bit words, and converted to analog. Manual commands are available from

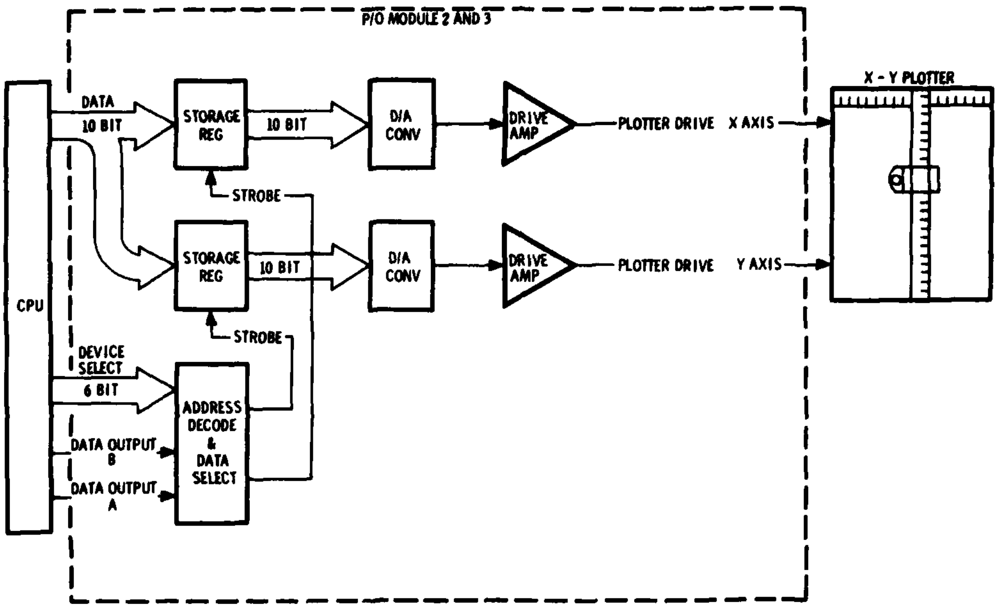


Figure 107. X-Y Plotter Drive

the manual flight control panel. Selection of either mode determines the commands to be sent to the RPV.

CPU-Generated Displays (Figures 109 and 110). Display data, RPV status, and target information are contained in the CPU and, by proper decoding, can be made available to the appropriate display, as indicated in Figures 109 and 110.

Time Code Generator to CPU (Figure 111). The time code generator output, available as a 32-bit word, is inserted into the computer as 2- to 16-bit words. These data are available for storing on the magnetic tape and for video display.

Sensor Slew Command (Figure 112). The sensor hand control joystick derives the sensor slewing commands transmitted to the RPV. Input to the cursor generating circuitry is also made available for approach guidance.

Analog-to-Digital Converter (Figure 113). Analog input, such as wind direction and speed, air temperature, and the pen position on each plotter, are

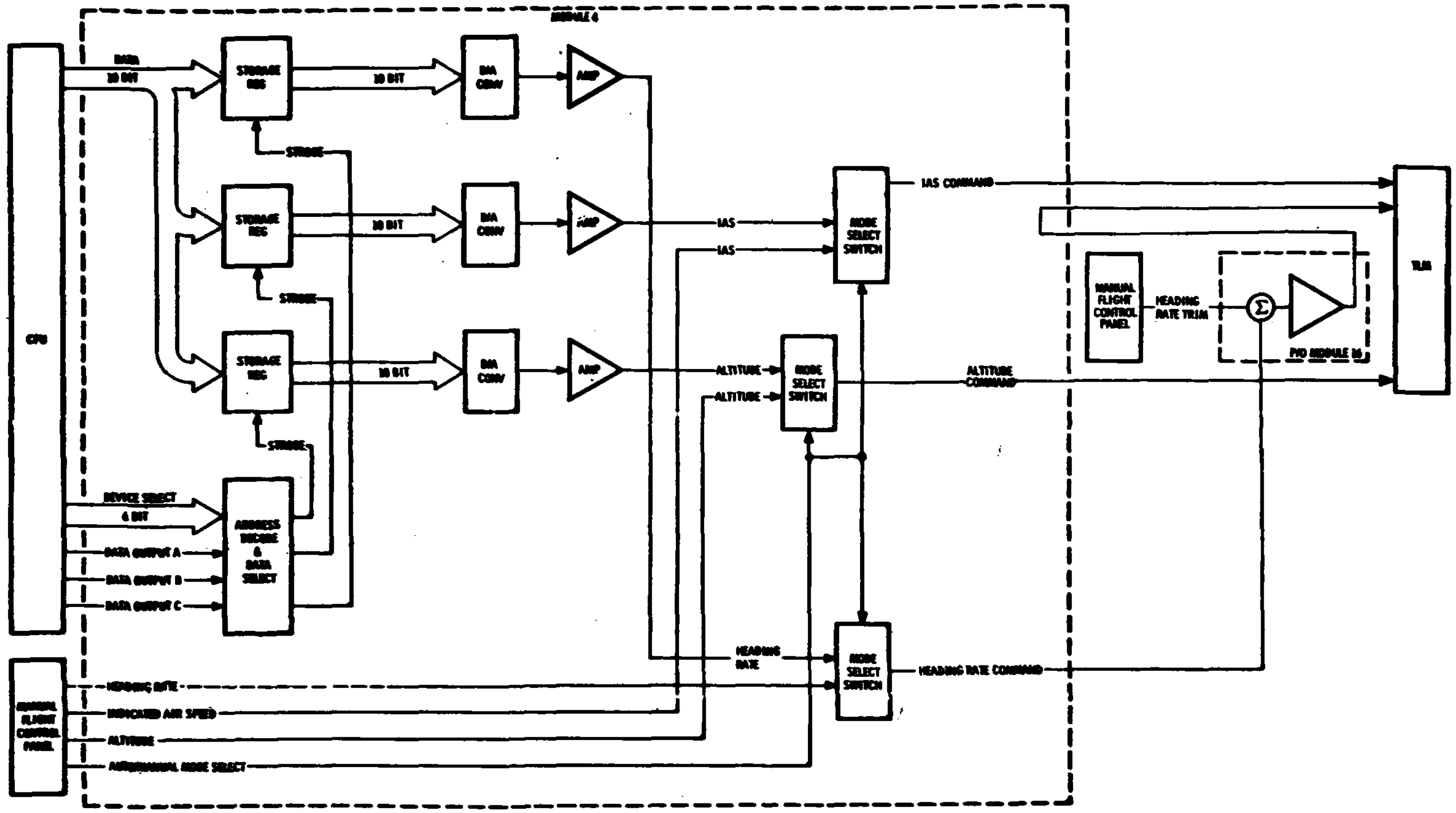


Figure 108. Auto/Manual Command Select

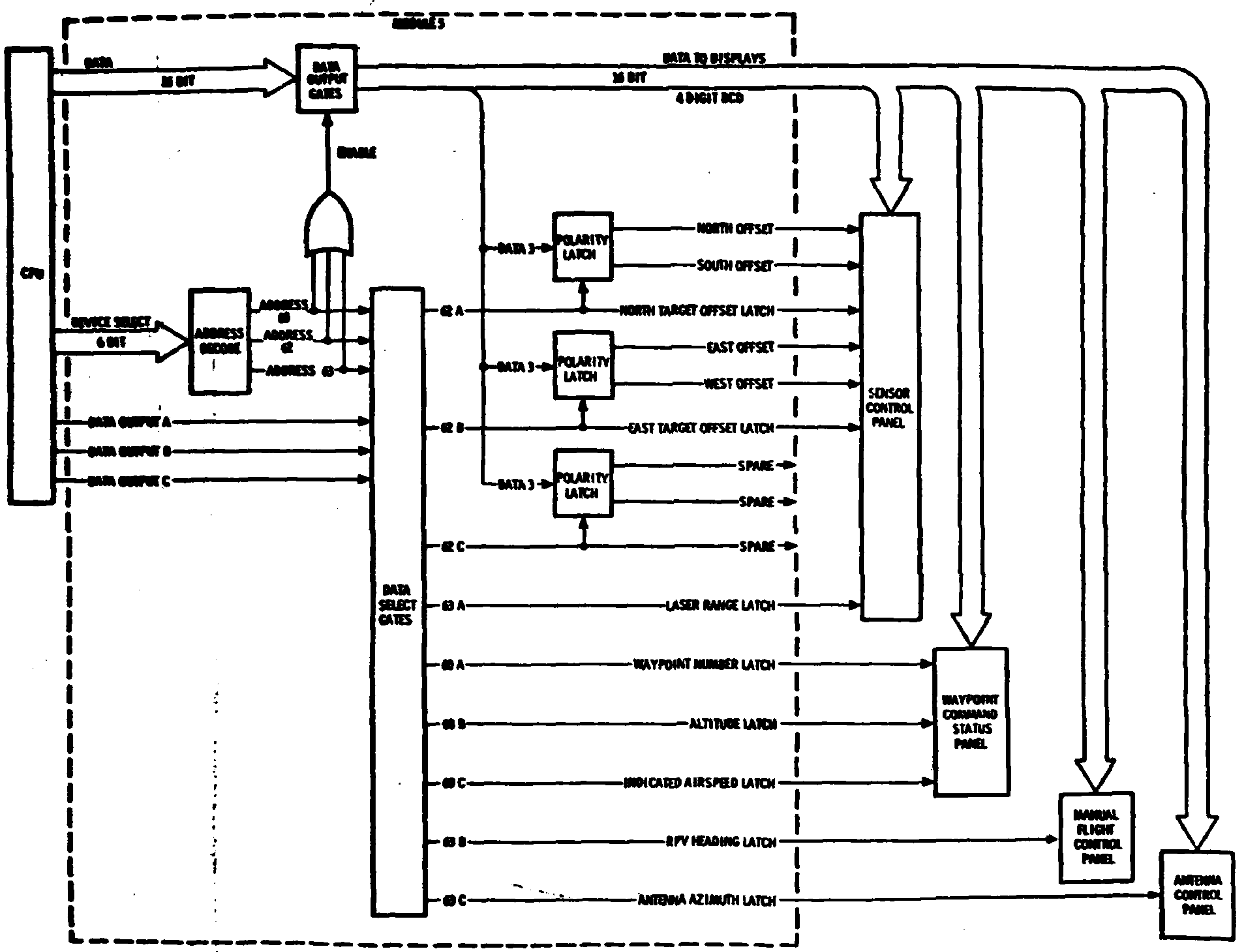


Figure 109. CPU-Generated Displays

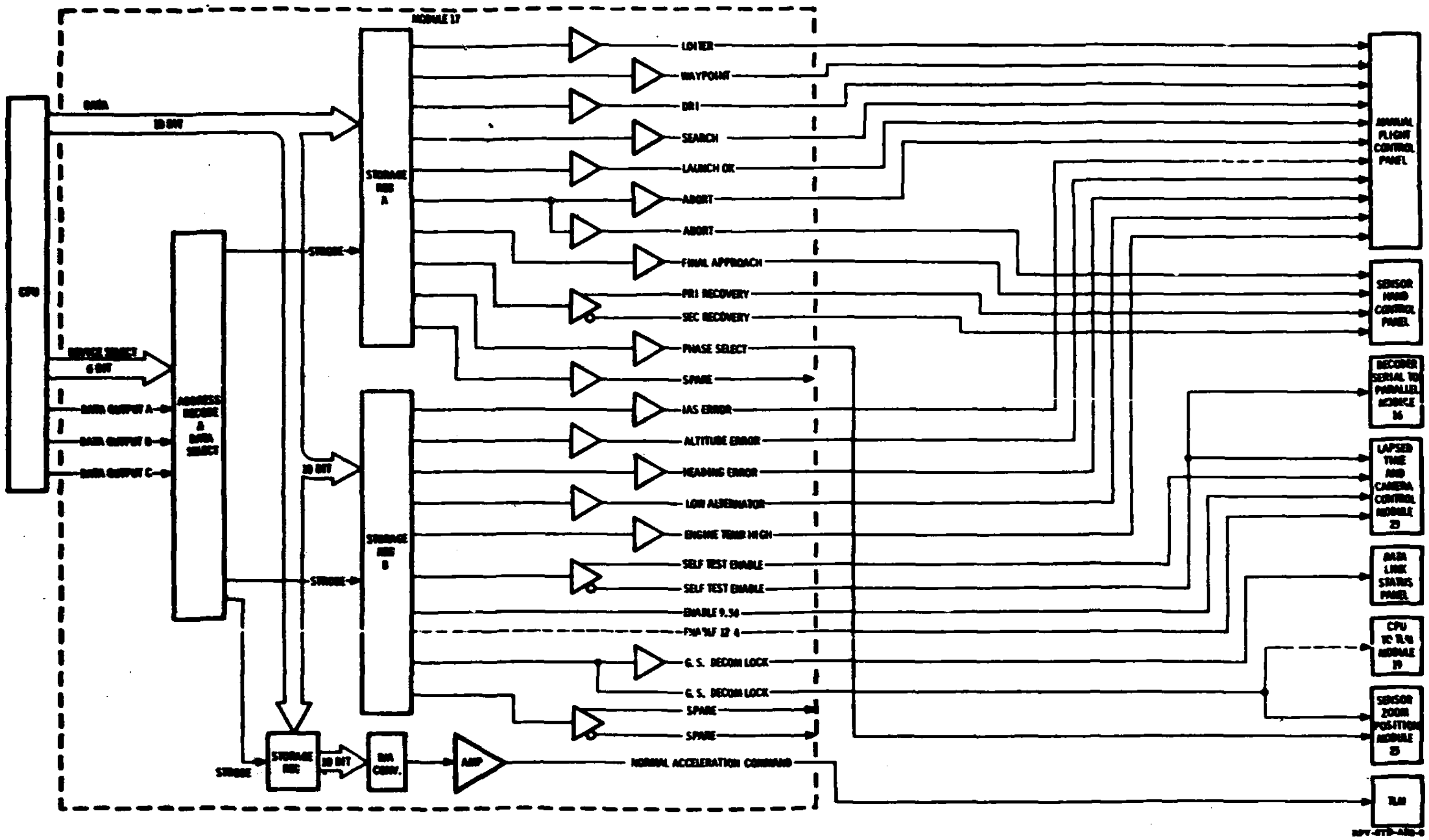


Figure 110. CPU-Generated Discretes

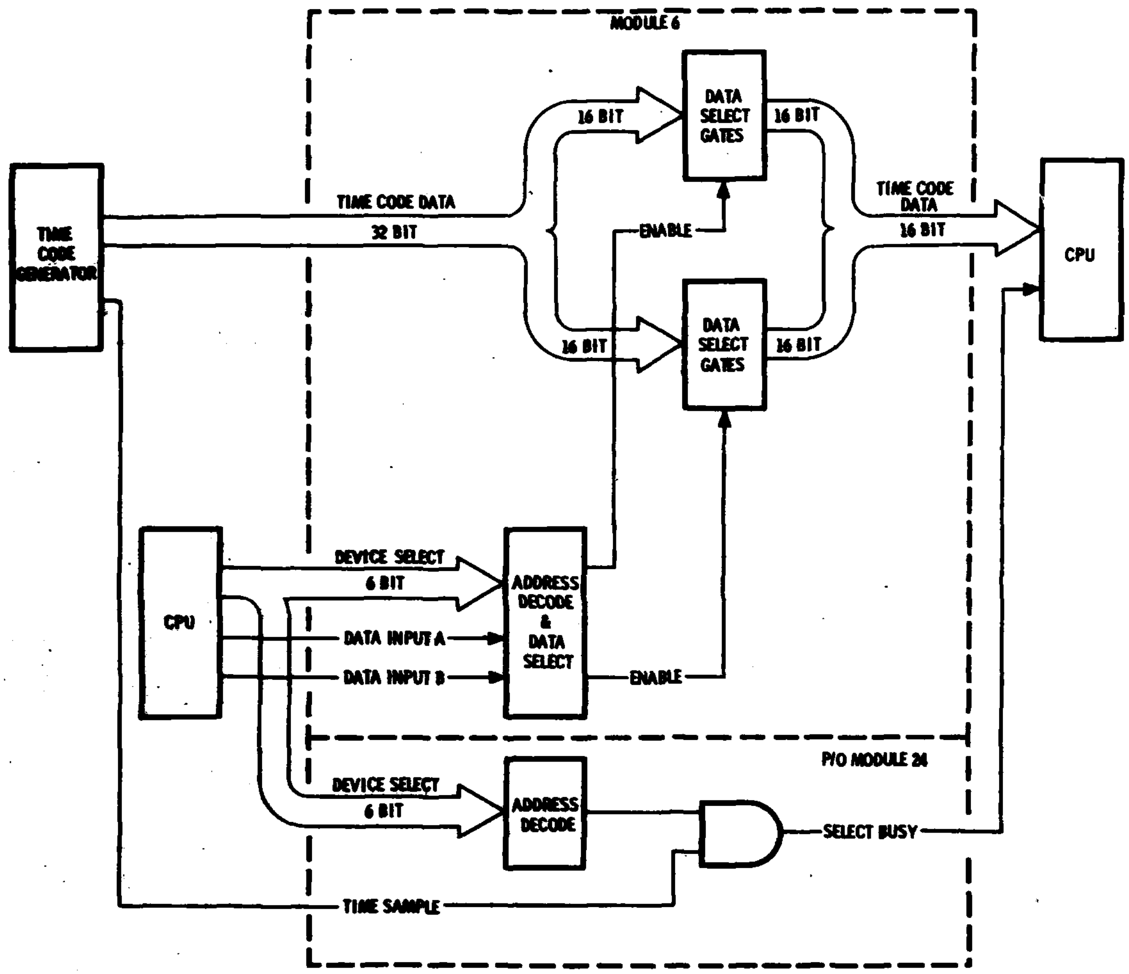


Figure 111. Time Code Generator Circuit to CPU

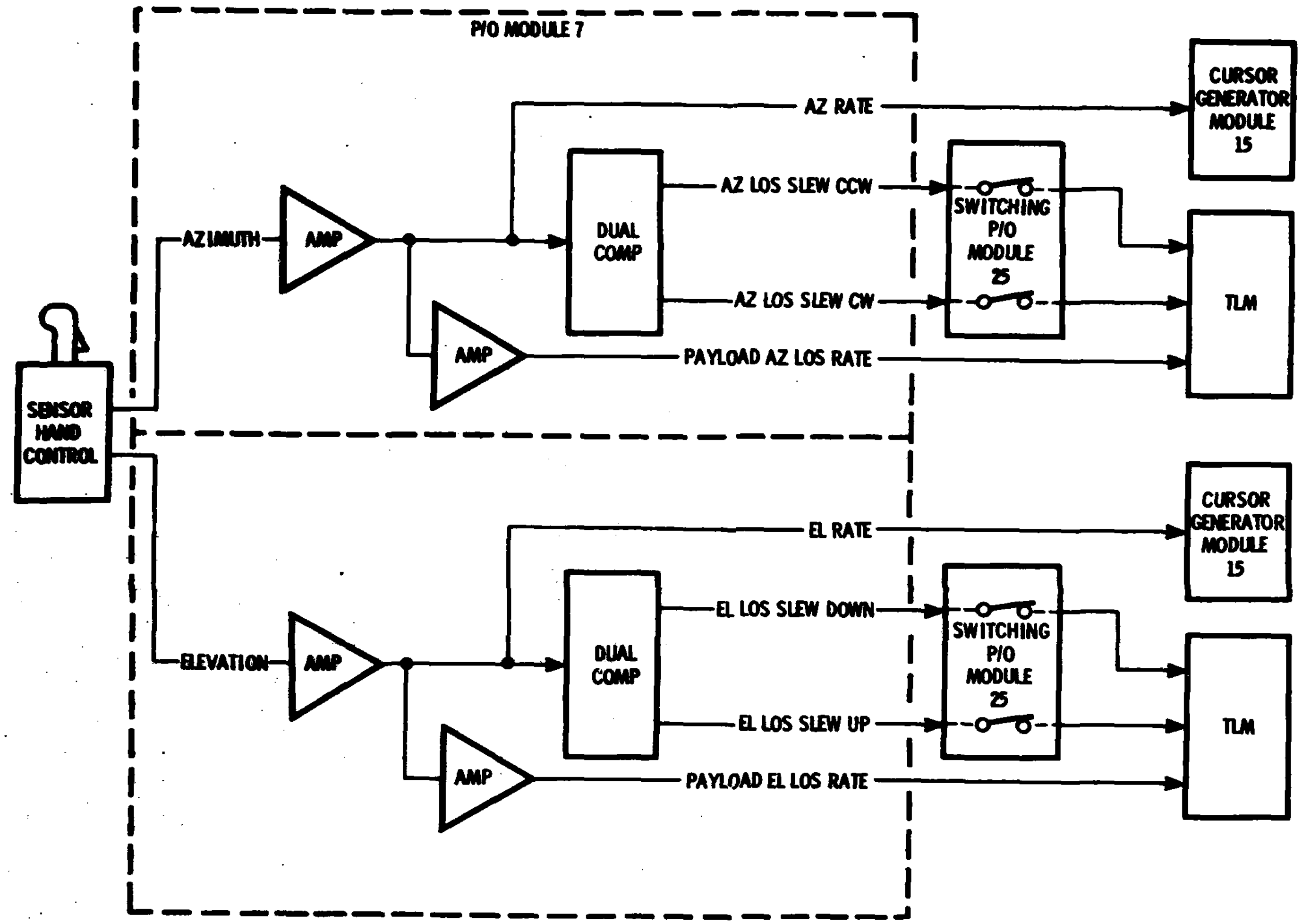


Figure 112. Sensor Slew Command

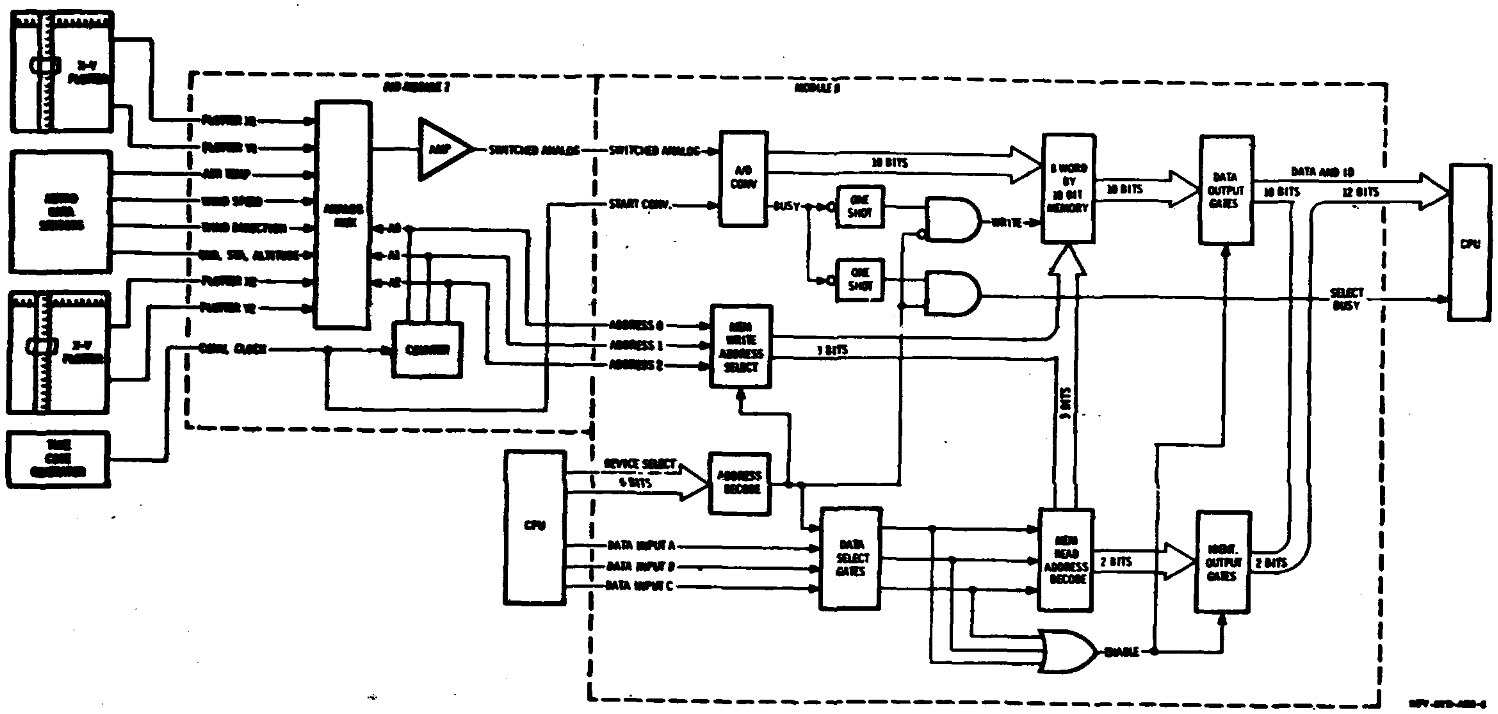


Figure 113. Analog-to-Digital Converter

multiplexed and converted to digital words. These words are available to the CPU upon request, for computations, criteria, or recording.

Telemetry Decoder (Figure 114). Certain telemetry downlink serial data must be decoded in the proper address format, converted to parallel, and converted to analog for display. Other data remain as digital data.

Telemetry to CPU (Figure 115). Certain telemetry downlink data must be made available to the CPU upon request. Using the frame sync, the proper telemetry data are picked off the data stream and sent to the CPU.

CPU to Telemetry (Figure 116). Command uplink data must be made available to the command transmitter. Upon request by the CPU, these data are placed in the proper uplink data stream position.

Data Link Status (Figure 117). Callup of any uplink or downlink data can be displayed in octal form. Under valid telemetry lock, sensor and RPV status can be displayed.

Telemetry Discrete Switching (Figure 118). Due to the limited numbers of uplink channels, sensor commands change function depending upon sensor used. Selection of the sensor phase (configuration) establishes the appropriate discrete logic.

Switch Interrupt Processing (Figure 119). The CPU operates on an interrupt principle. When data are to be entered, an interrupt request is asked. If the CPU is not busy, it is honored and the data are entered into CPU.

Lapsed-Time Counter and Camera Frame Rate Control (Figure 120). Counters are required to determine and display mission time and to keep track of the Phase II camera frames taken. A 5-bit word is required to select the frame rate of the Phase II sensor.

Video Interconnect and Switch (Figure 121). RPV video data are continuously displayed on the RPV operator's video monitor and stored on his video recorder. The sensor operator has the capability of storing RPV video or ground camera video and of displaying real-time or playback video or ground camera video.

Control Circuits (Figure 122). Tone generators are required to terminate the RPV dead reckoning mode and to switch from high to low antenna gain. To reduce power, LED displays are alternately turned on and off.

Antenna Azimuth Buffer (Figure 123). The antenna azimuth position is available to the CPU from a 14-bit shaft encoder. A strobe pulse is provided when required to generate a position reading.

5.2.2.2 Operational Capabilities. The following is a discussion of the major capabilities of the GCS and its relationship to the complete RPV system.

Automatic Tracking System. The automatic tracking system, located on the GCS, provides a means for automatically tracking the RPV. The system, with its block diagram shown in Figure 124, is comprised of high- and low-gain receive/transmit antennas, an upper antenna mount, a lower antenna mount, an antenna controller, and a video receiver. Evolution of the tracking system is reported in Reference 16.

The antennas consist of four helical low-gain antennas, and a 25-in. parabolic dish fed by two dipoles, forming the high-gain antenna. The upper antenna mount contains the circuitry to process the receive and transmit signals. The low-gain antennas are operated in pairs through power dividers such that pair AB can be lobe-switched with pair CD. In a similar manner, when the high-gain antenna is selected by the high-low switch, dipole E is lobe-switched with

[16] AQUILA RPV SYSTEM TEST REPORT, CDRL A00D, PART 9, GCS TRACKING ANTENNA, LMSC-L028081, Lockheed Missiles and Space Company, Inc., Sunnyvale, California, September 1977.

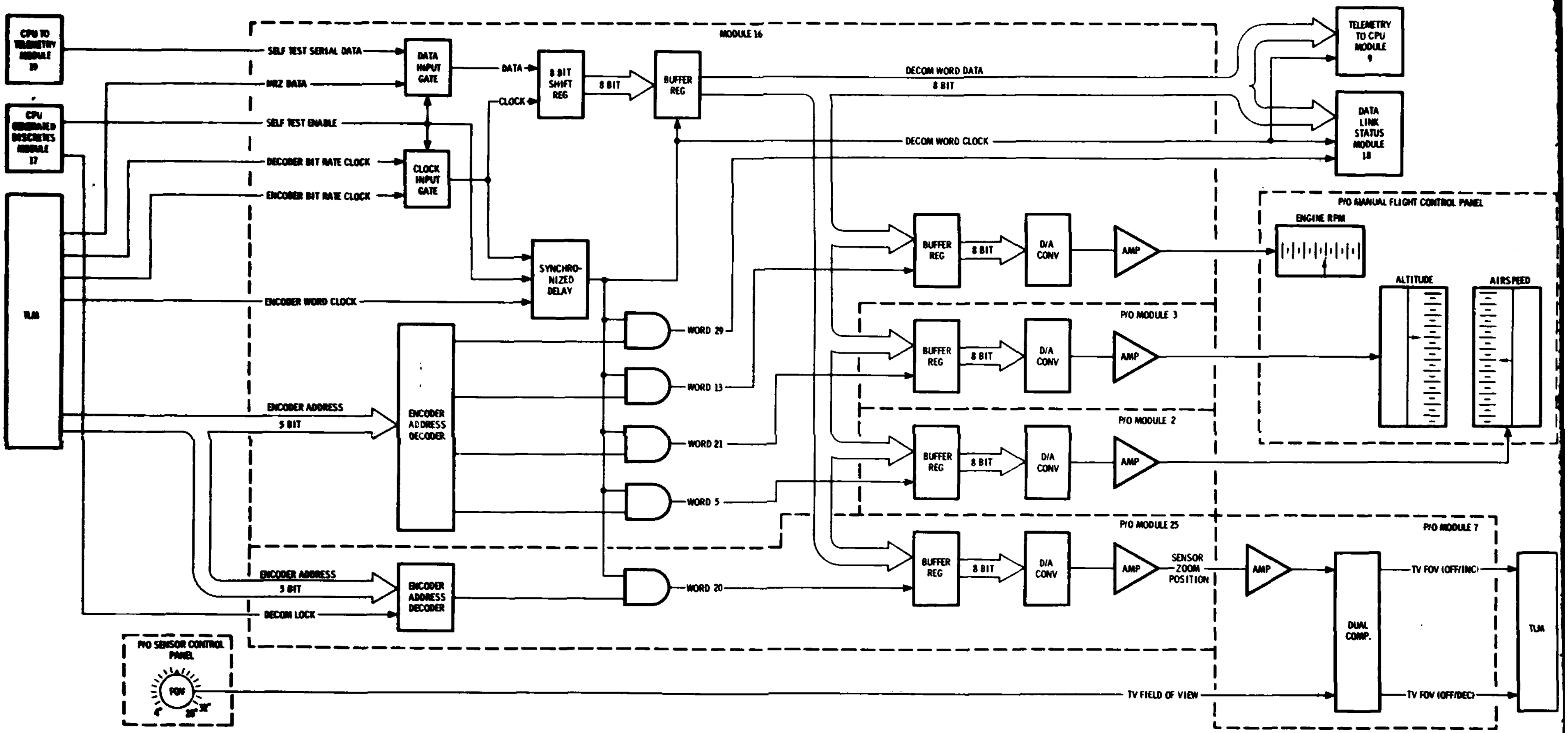


Figure 114. Telemetry Decoder Serial-to-Parallel Converter, and Digital-to-Analog Converters

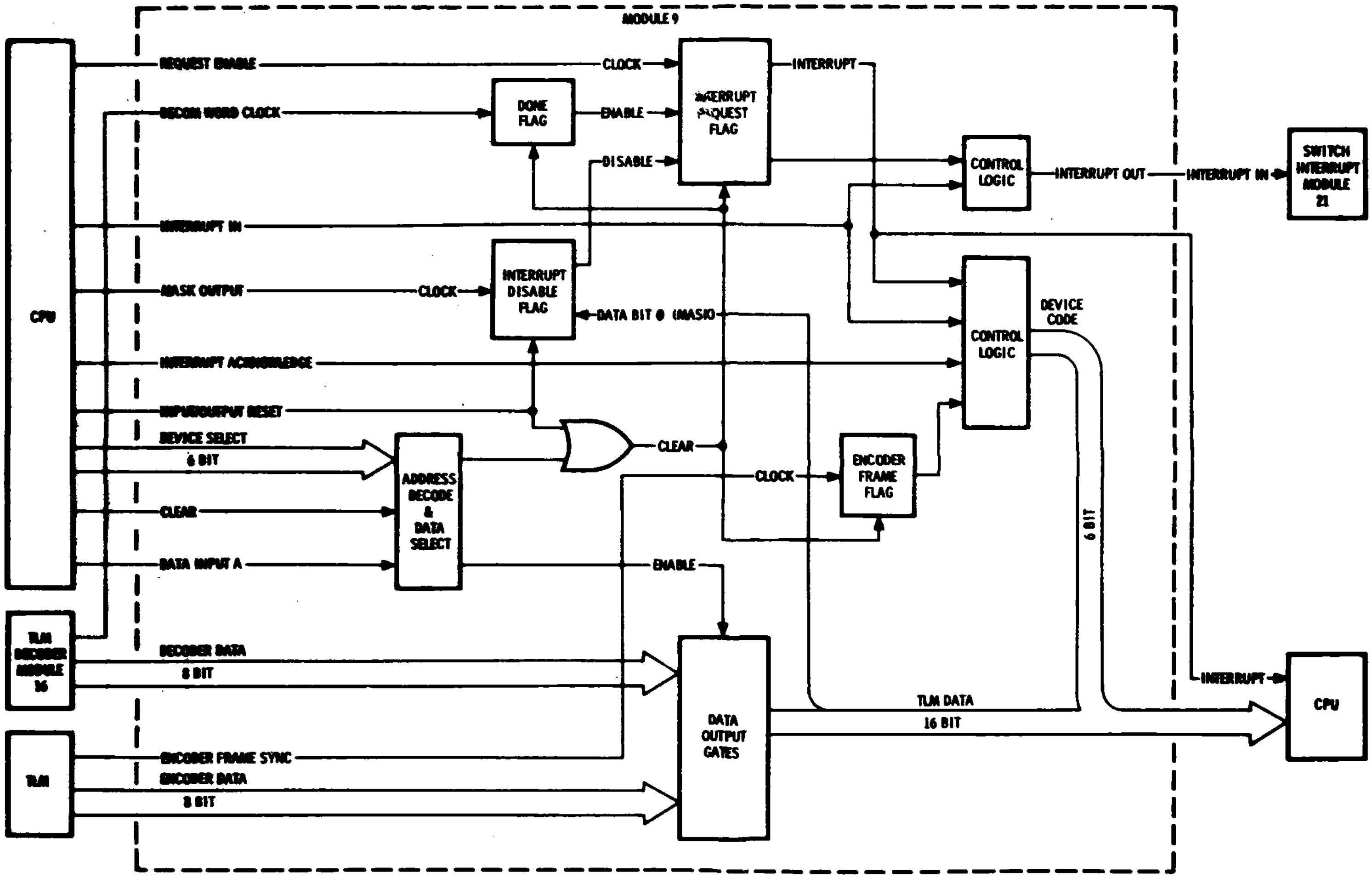


Figure 115. Telemetry Circuit to CPU

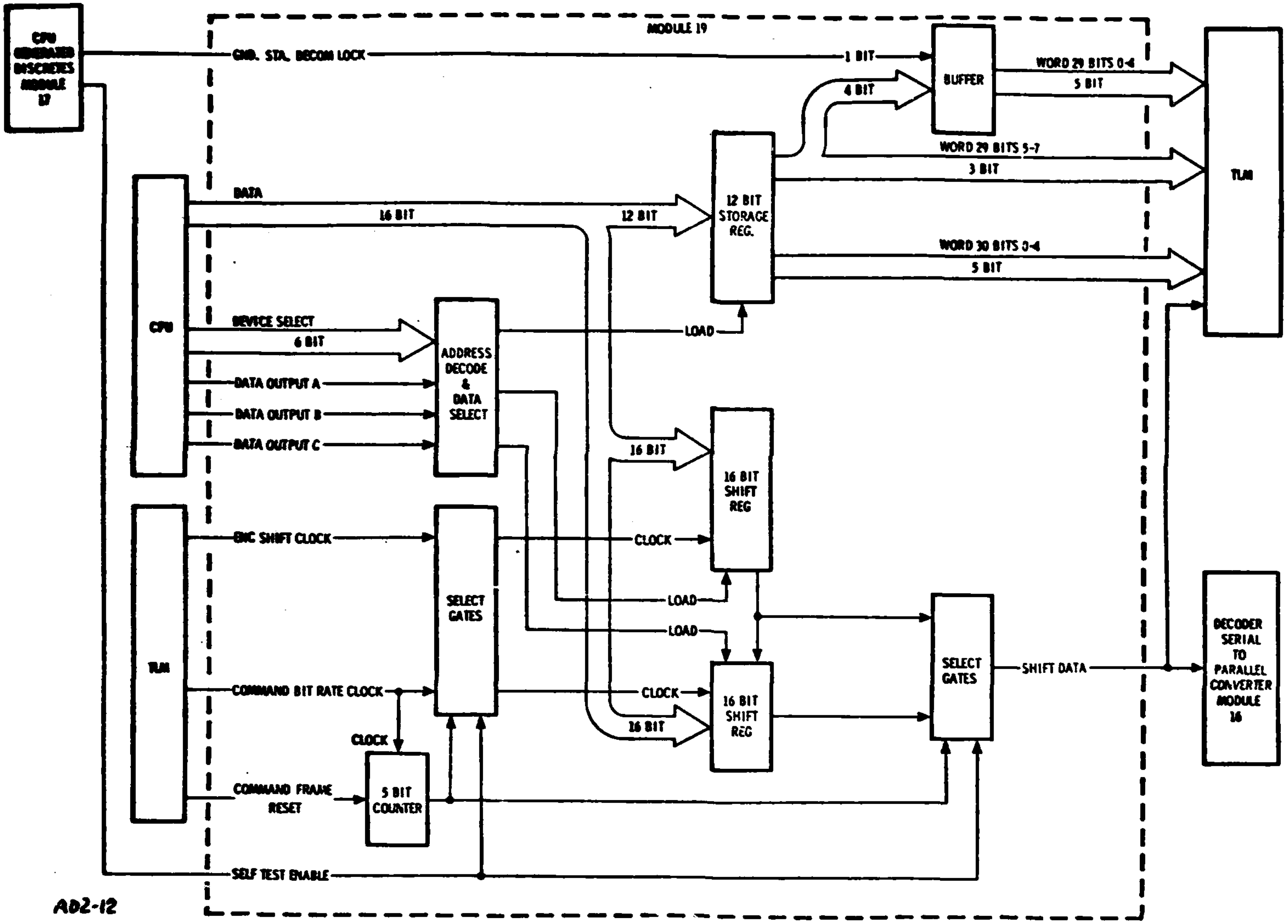


Figure 116. CPU Circuit to Telemetry

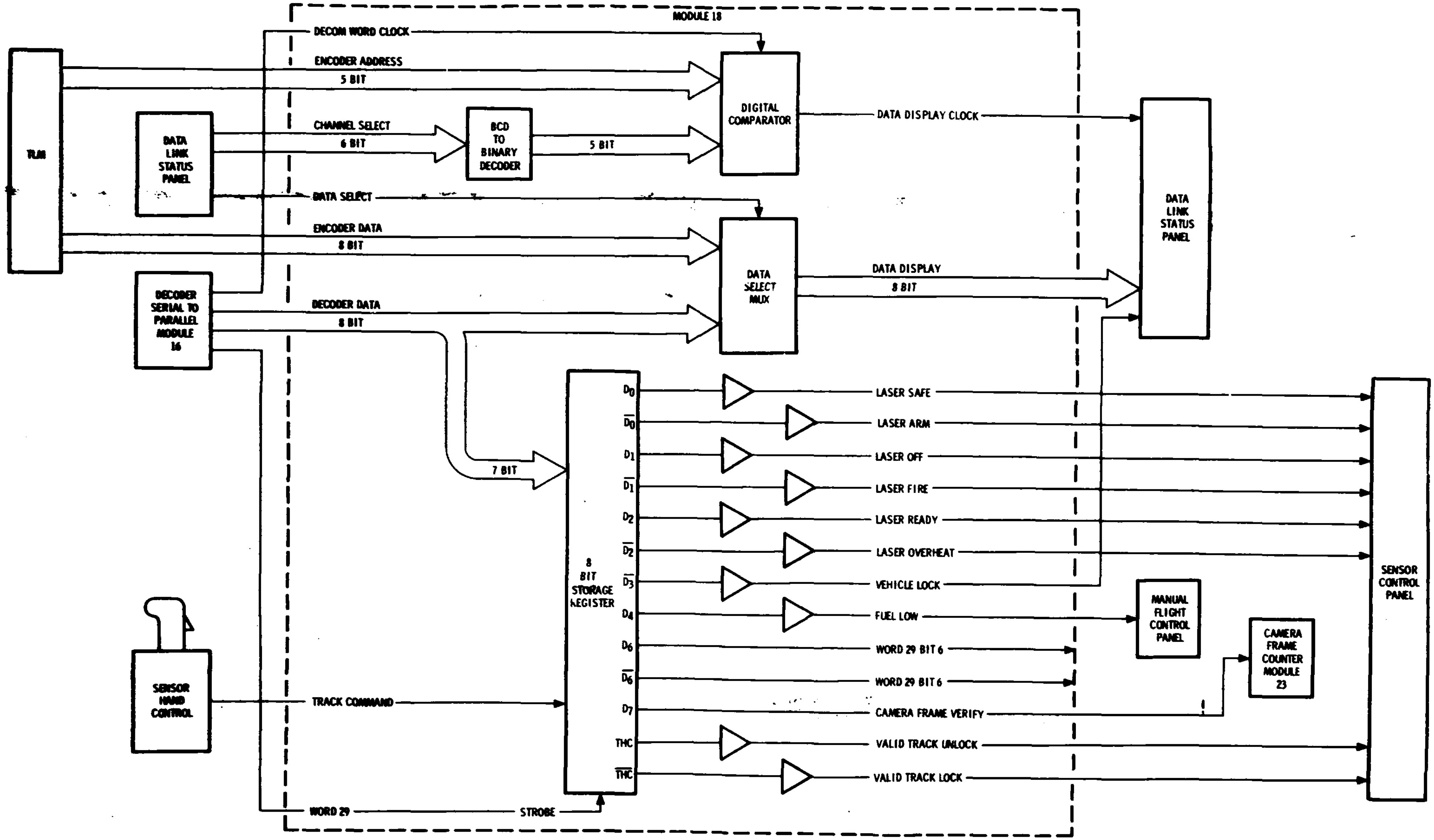


Figure 117. Data Link Status

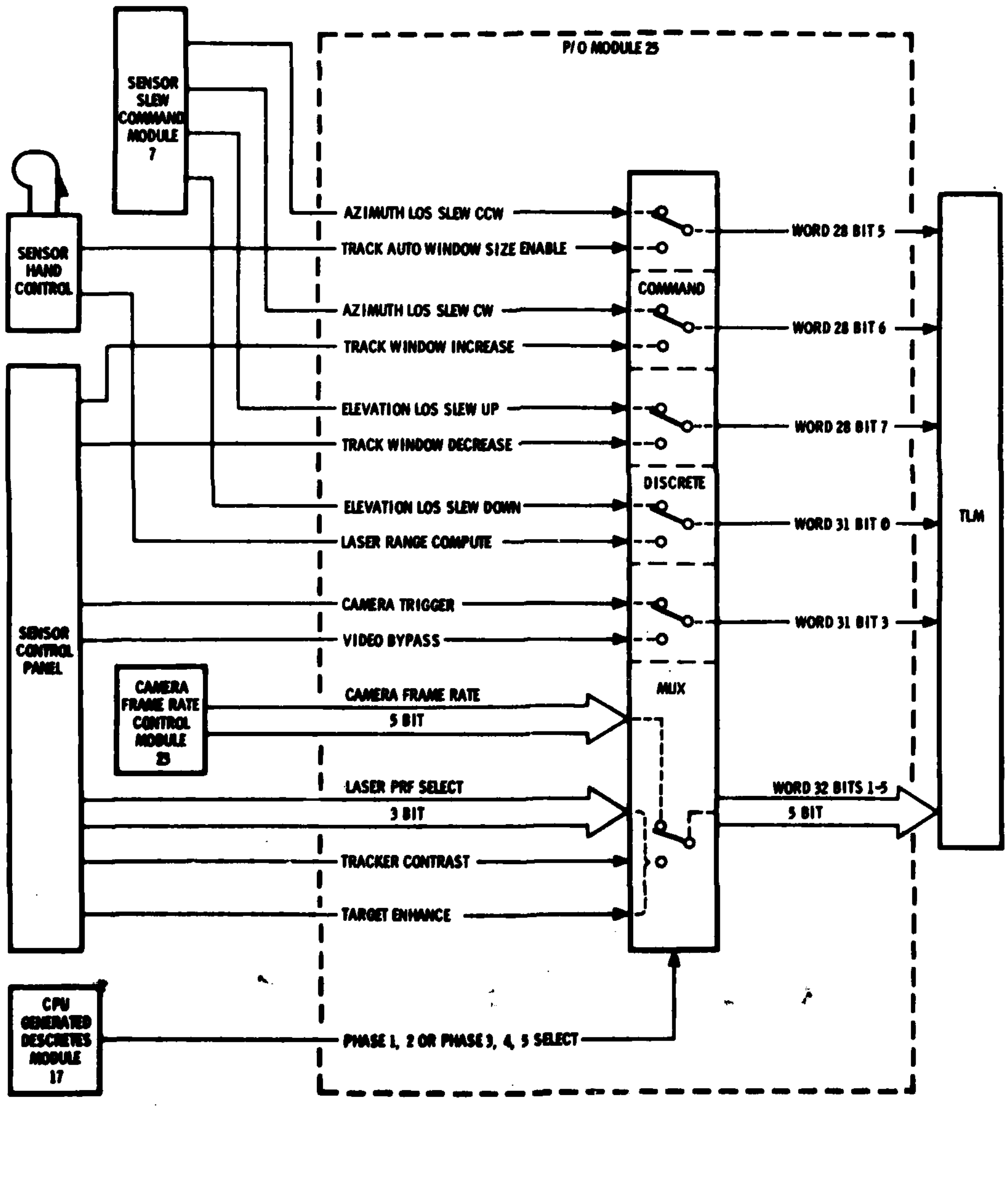


Figure 118. Telemetry Discrete Switching

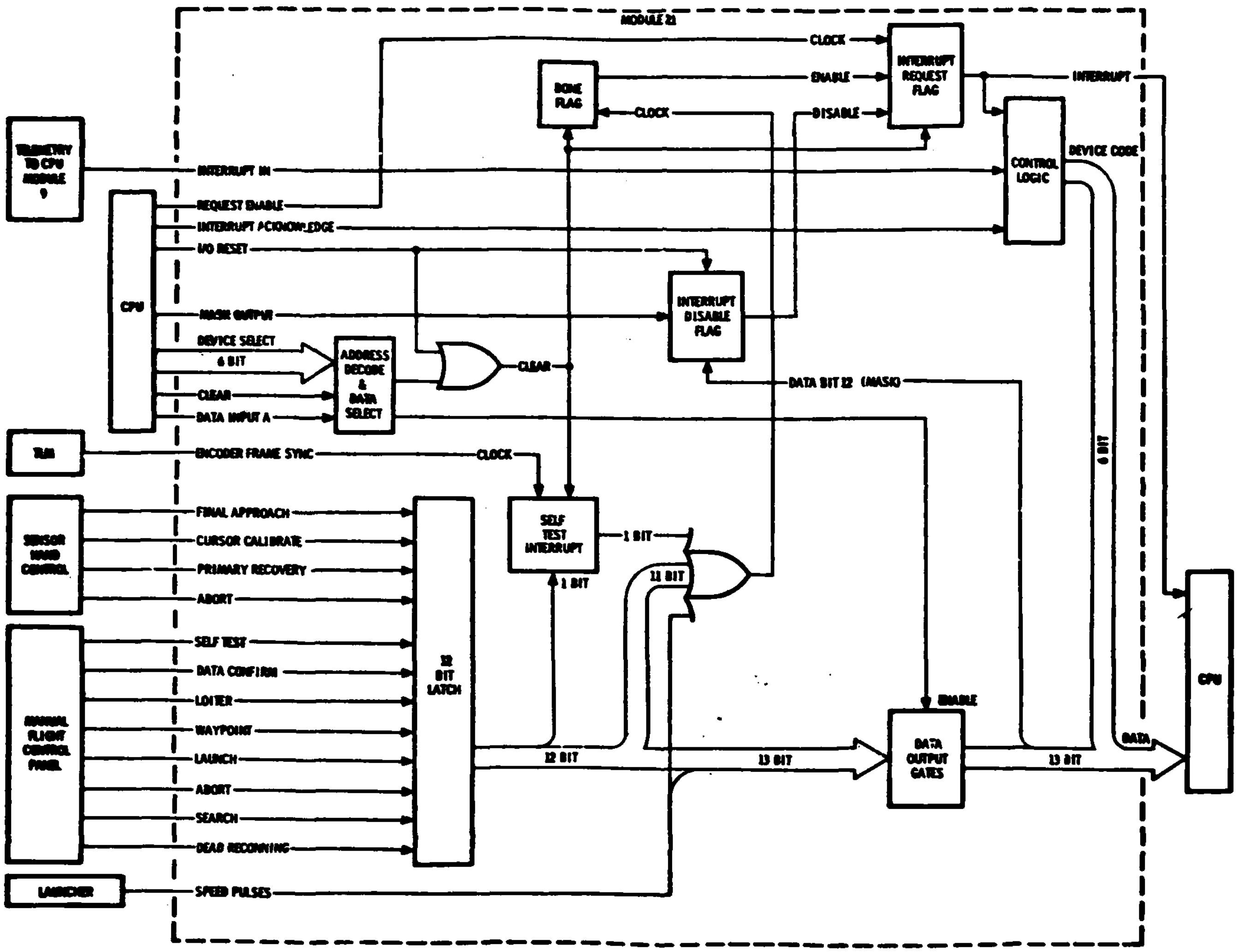


Figure 119. Switch Interrupt Processing

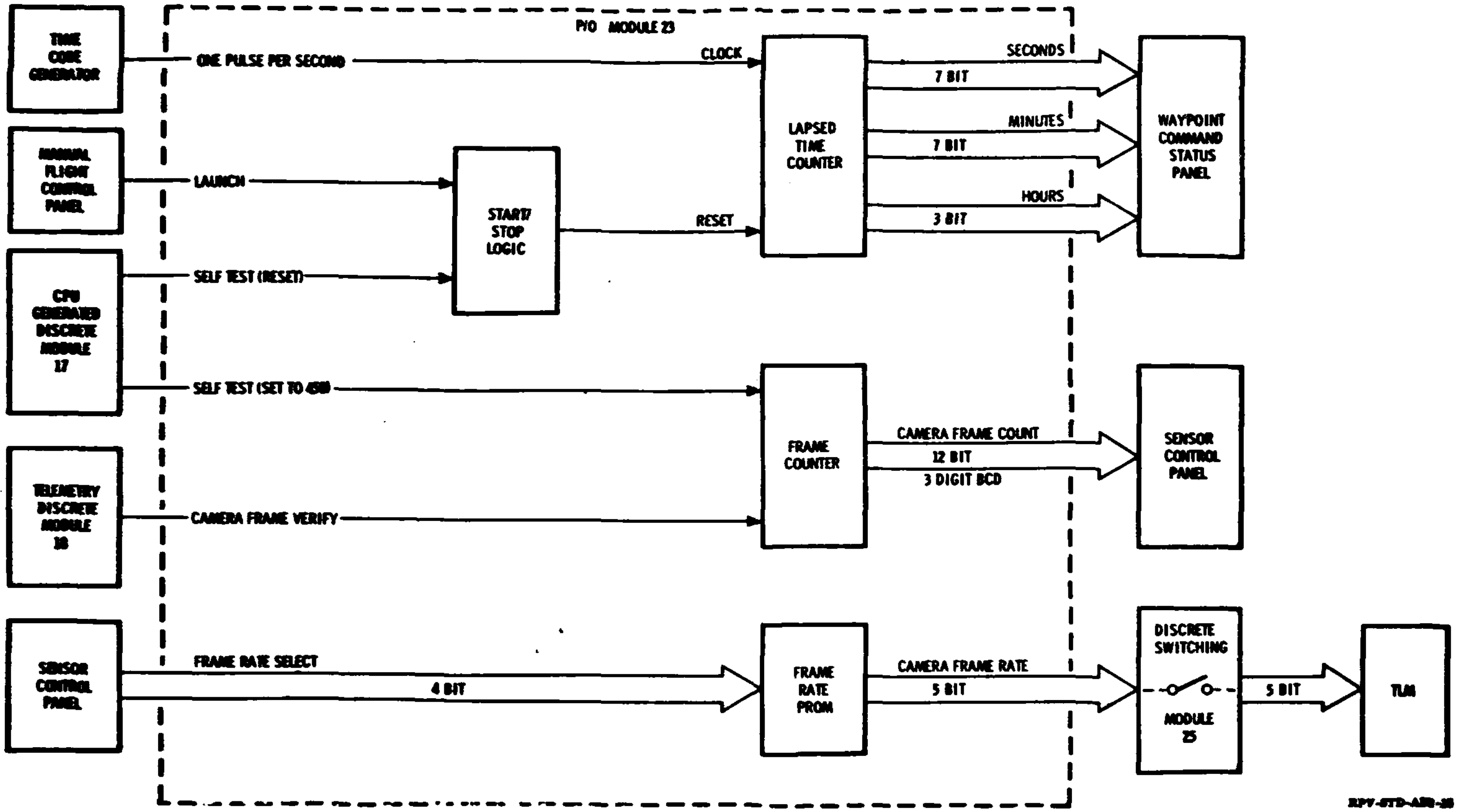


Figure 120. Lapsed Time Counter and Camera Frame Rate Control

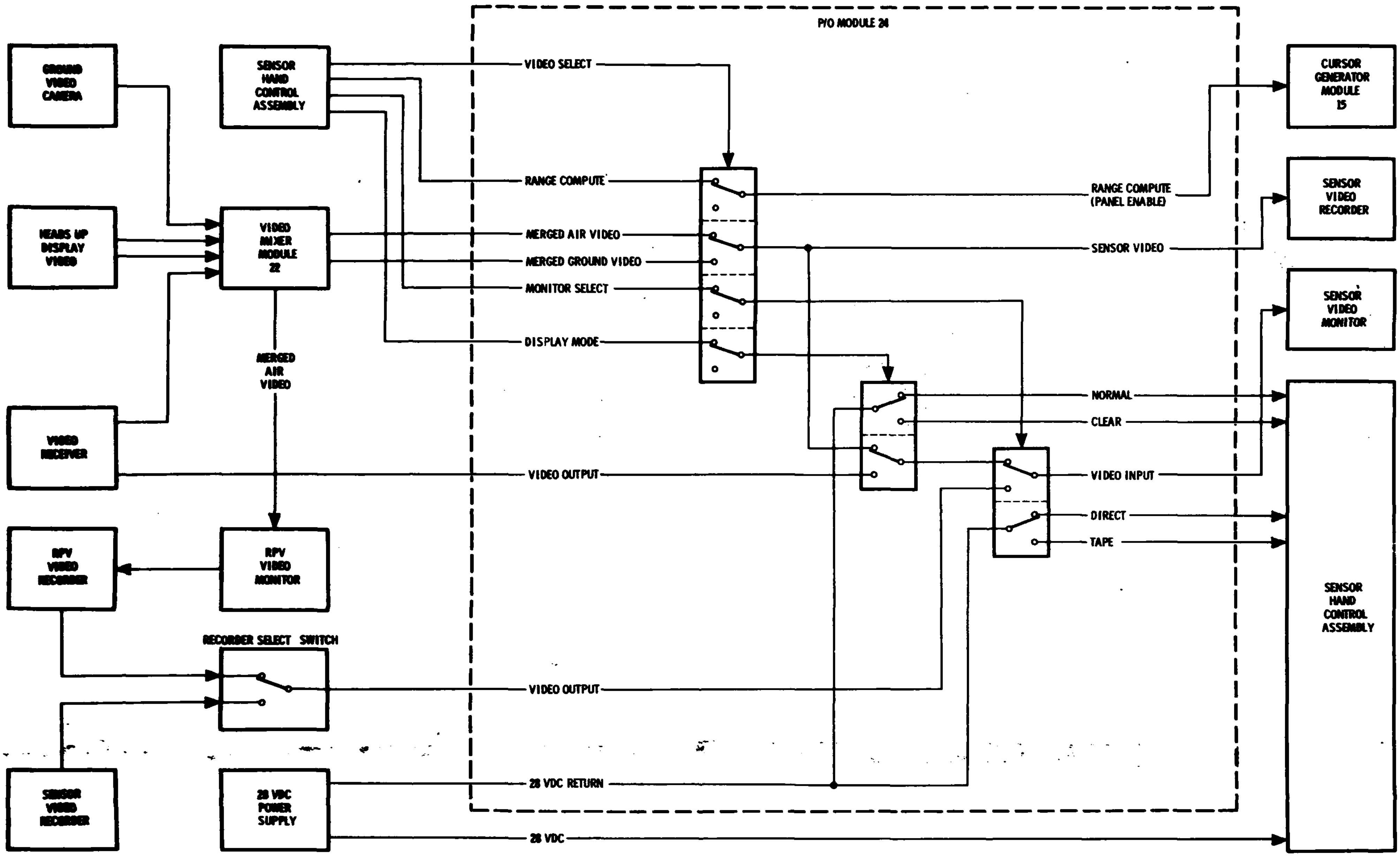


Figure 121. Video Interconnect and Switching

[redacted]

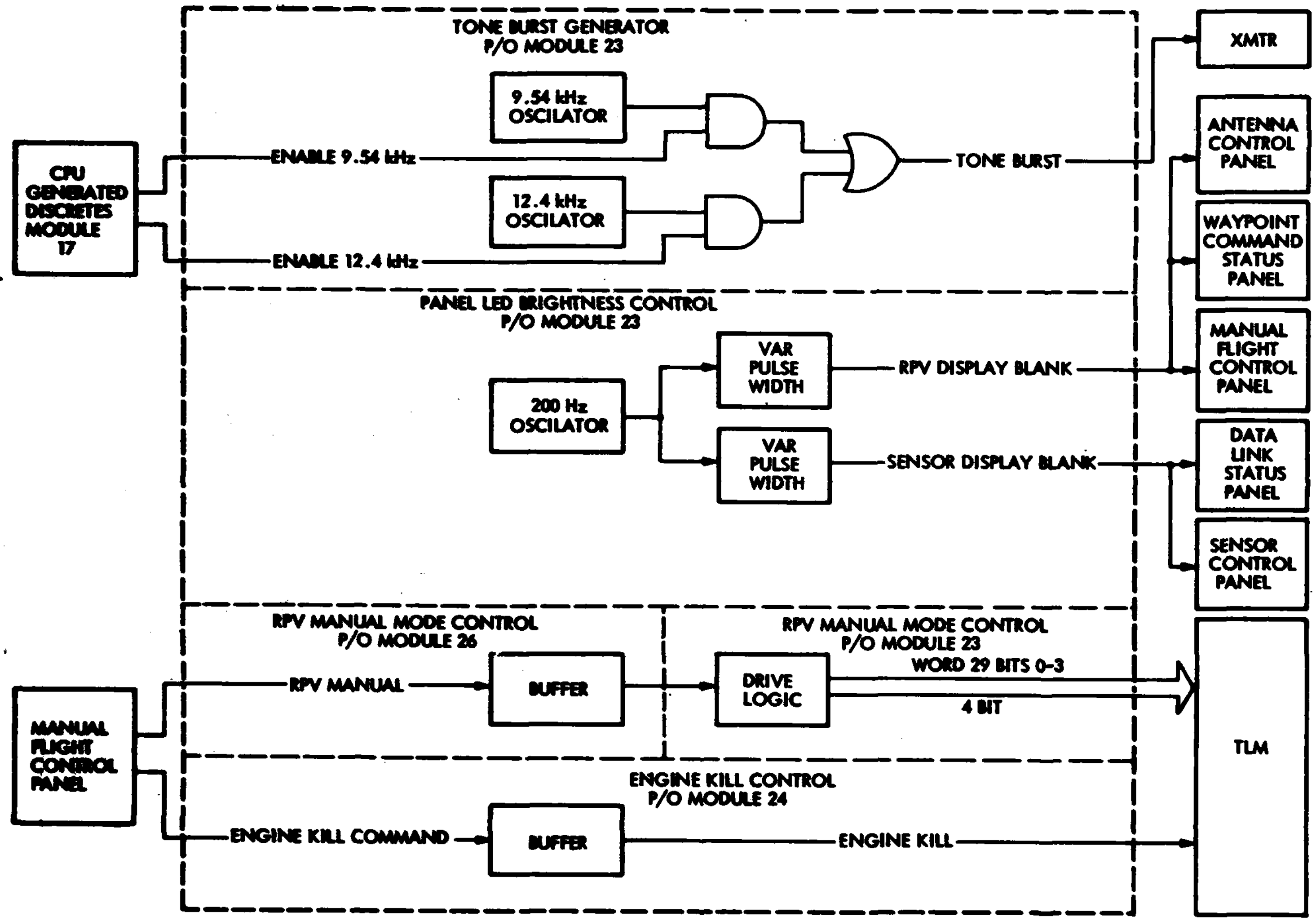


Figure 122. Control Circuits

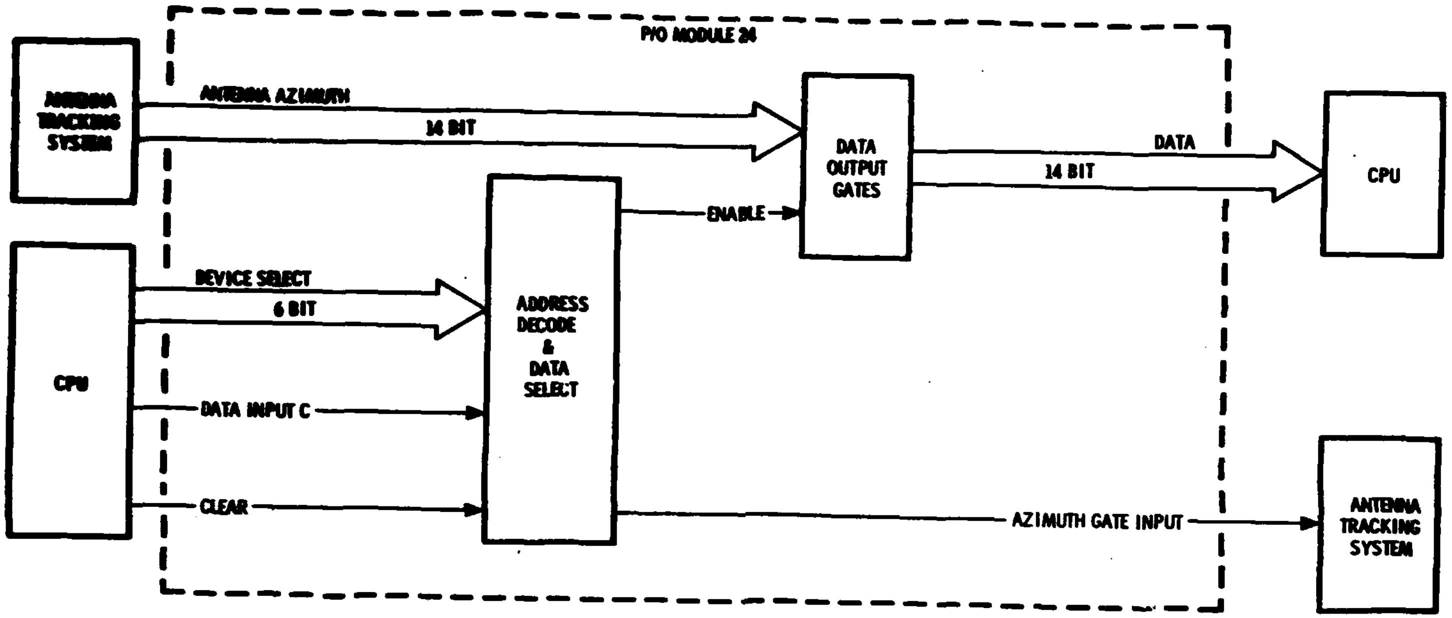


Figure 123. Antenna Azimuth Buffer

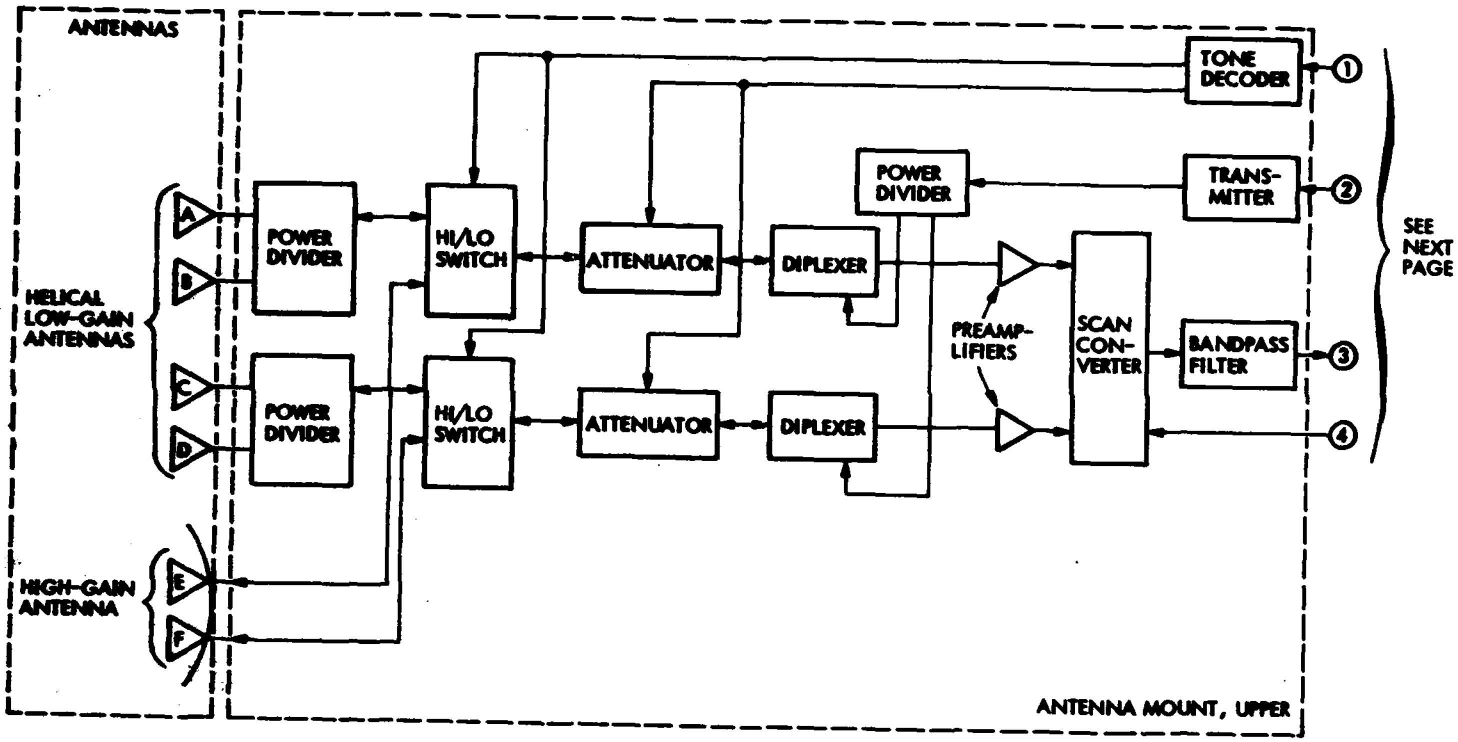


Figure 124. Automatic Tracking System

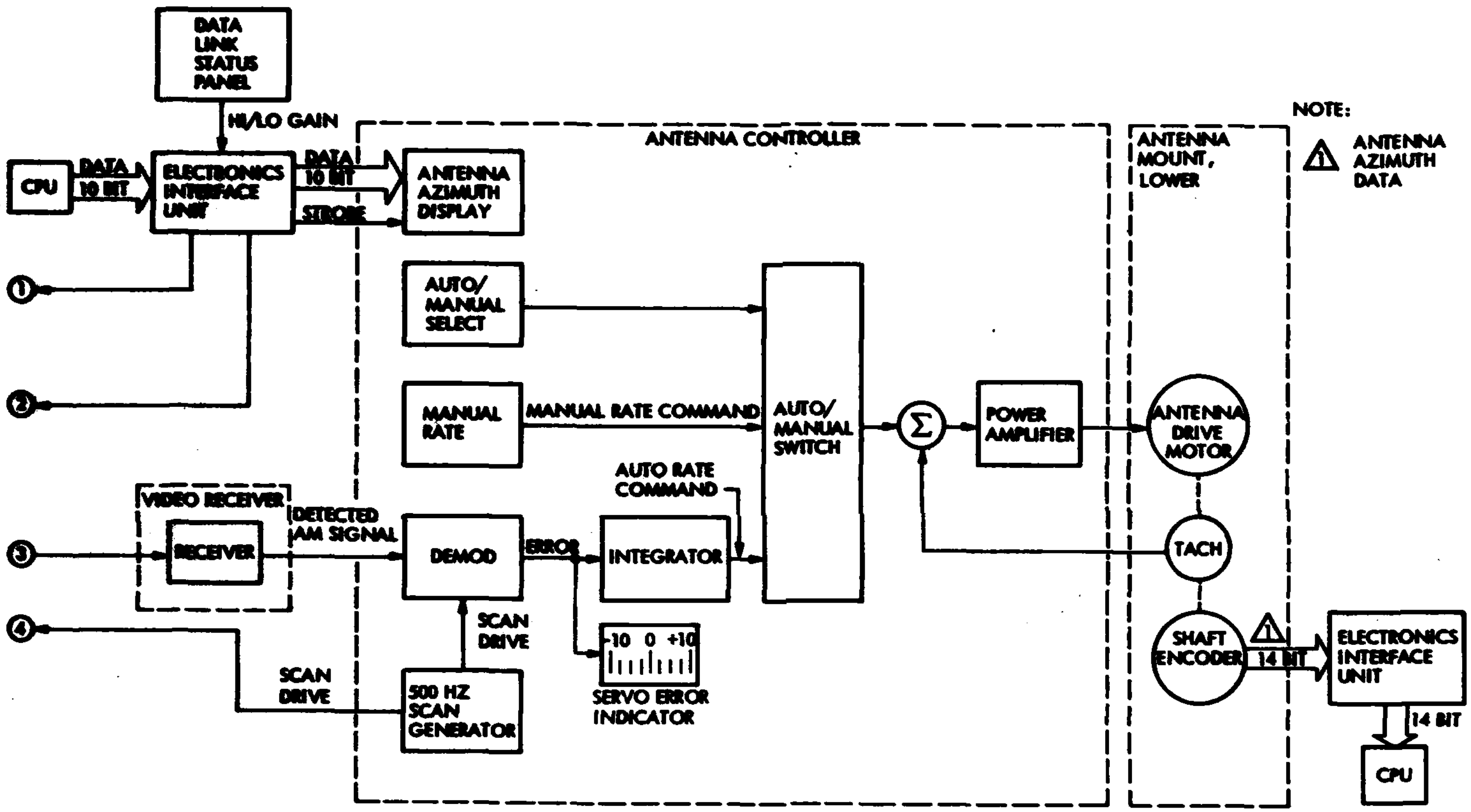


Figure 124. (Continued)

dipole F. The high-low switches are controlled by a tone decoder, which is controlled by a tone from the EIU selected by the computer as a function of RPV range and elevation angle. The tone decoder also controls two in-line attenuators that simulate the maximum range signal strength to and from the RPV during prelaunch checkout. The control tone for this operation is selected by the high-low gain switch on the data link status panel. Transmitted or received signals are switched by the diplexers. If the signals are transmitted, they come from a power divider fed by the 10-W transmitter. The transmitter is modulated by command signals from the EIU. If the signals are received, they pass through the diplexers and are preamplified. The scan converter switches back and forth between the preamplified signals at a 500-Hz rate generated by a scan generator in the antenna controller. The converter output, which is the sum of these two signals, is sent through a bandpass filter to the video receiver.

The video receiver produces three outputs: video, telemetry, and AM. The antenna controller receives the AM signal and compares it in a demodulator with the scan drive signal used to switch the scan converter in the upper antenna mount. Any amplitude variation in the AM signal indicates that the RPV is off the antenna axis since one of the receive antennas is receiving a stronger signal than the other. The phase difference between the AM signal and the scan drive signal indicates the direction off axis; the amplitude indicates how far. This error signal is displayed on the SERVO ERROR indicator on the antenna control panel. The signal is also processed by an integrator that generates an auto rate command whose amplitude is a function of the error signal. This command is applied to an auto/manual switch within the antenna controller which is selected by the MODE switch on the antenna control panel. A manual rate command can also be generated and is adjusted by the MANUAL RATE controls on the antenna control panel. The output of the auto/manual switch is applied to a summing amplifier which compares the selected rate command with the actual rate of the antennas as sensed by a tachometer on the antenna drive shaft. The resulting signal is applied to a power amplifier that drives the antenna drive motor.

The tachometer, antenna drive motor, and a 14-bit shaft encoder are mounted on a common shaft in the lower antenna mount that drives the antenna in the upper antenna mount. The 14 bits of parallel data generated by the shaft encoder represent the antenna azimuth relative to the GCS. These data are processed by the EIU and sent to the computer. The computer corrects the data for magnetic variation and GCS orientation and outputs 10 bits of data representing the antenna azimuth relative to grid north. These data are processed by the EIU and sent to the three-digit AZIMUTH display on the antenna control panel.

5.3 LAUNCHER

The launch system for the XMQM-105 Aquila RPV, as originally proposed by LMSC for Army use, employs a linear pneumatic launcher. The system is pictured in Figure 125. The launch system is a mobile, self-contained (except for electric power) system that supports RPV preflight checkout as well as providing the required launch velocity at a prescribed vehicle attitude. The evolution of the launch system is documented in Reference 17 and summarized in Volume II of this report.

The launcher is shown in Figure 126. The launcher system is designed to meet the prime objectives of (1) Army field use from unprepared sites, (2) mobility provided by truck-mounted components, and (3) operational ease of handling in tactical situations.

The launcher-to-RPV interfaces can be segregated into three areas: RPV to shuttle, RPV umbilical and quick disconnect, and RPV ground cooling duct. The interface between RPV and shuttle consists of five points, Figure 127: two mid-wing support rest pads, two aft-wing thrust fittings, and the skeg keeper. The umbilical interface is established in the RPV starboard side along BL 9.22. Ground cooling for the RPV is supplied via a duct in the left-side forward wing

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[17] AQUILA RPV SYSTEM TEST REPORT, CDRL A00D, PART 10, LAUNCHER DEVELOPMENT, LMSC-L028081, Lockheed Missiles and Space Company, Inc., Sunnyvale, California, September 1977.

Figure 125. Aquila Launcher Assembly

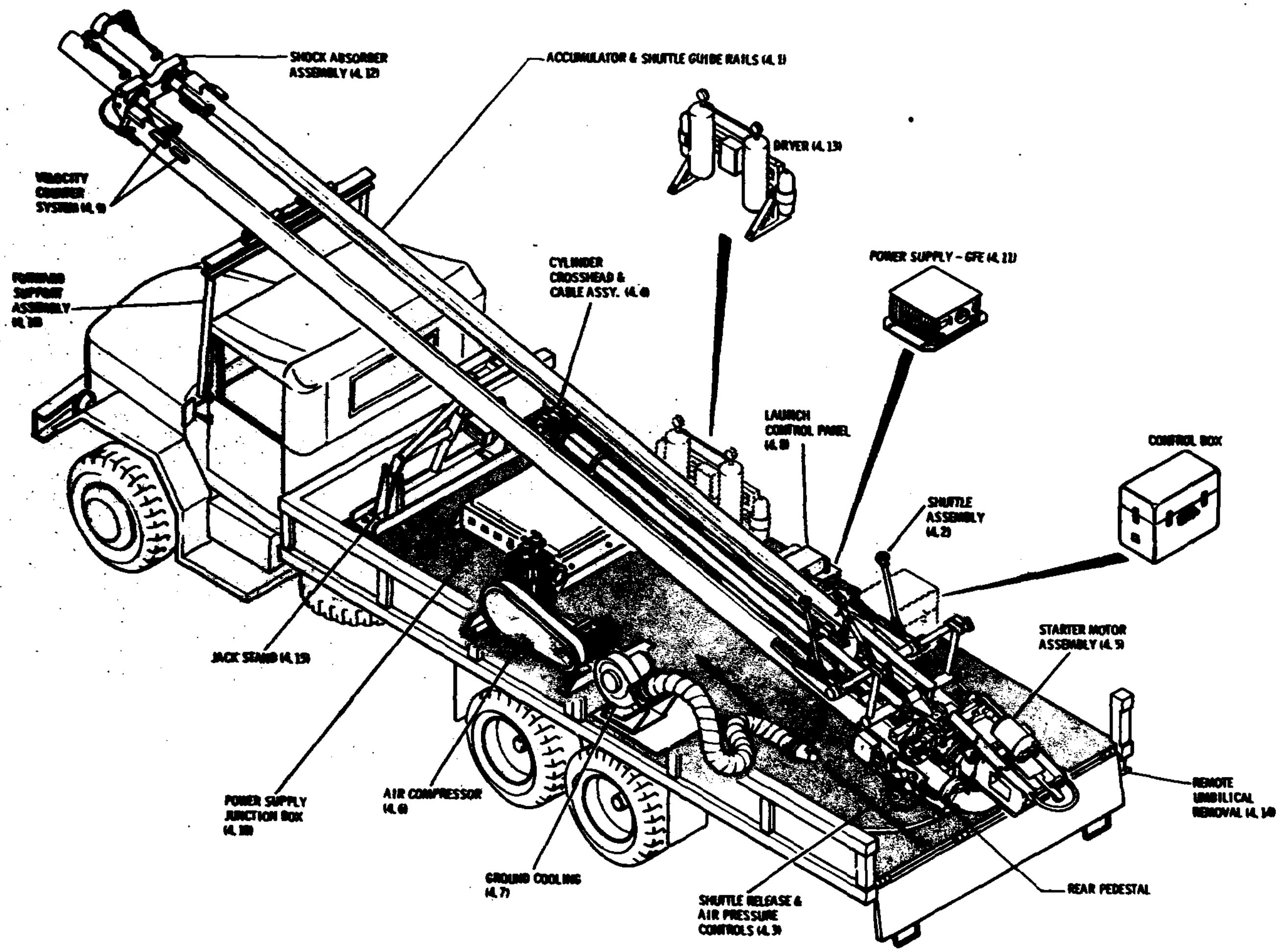


Figure 126. Launcher Assembly, Details

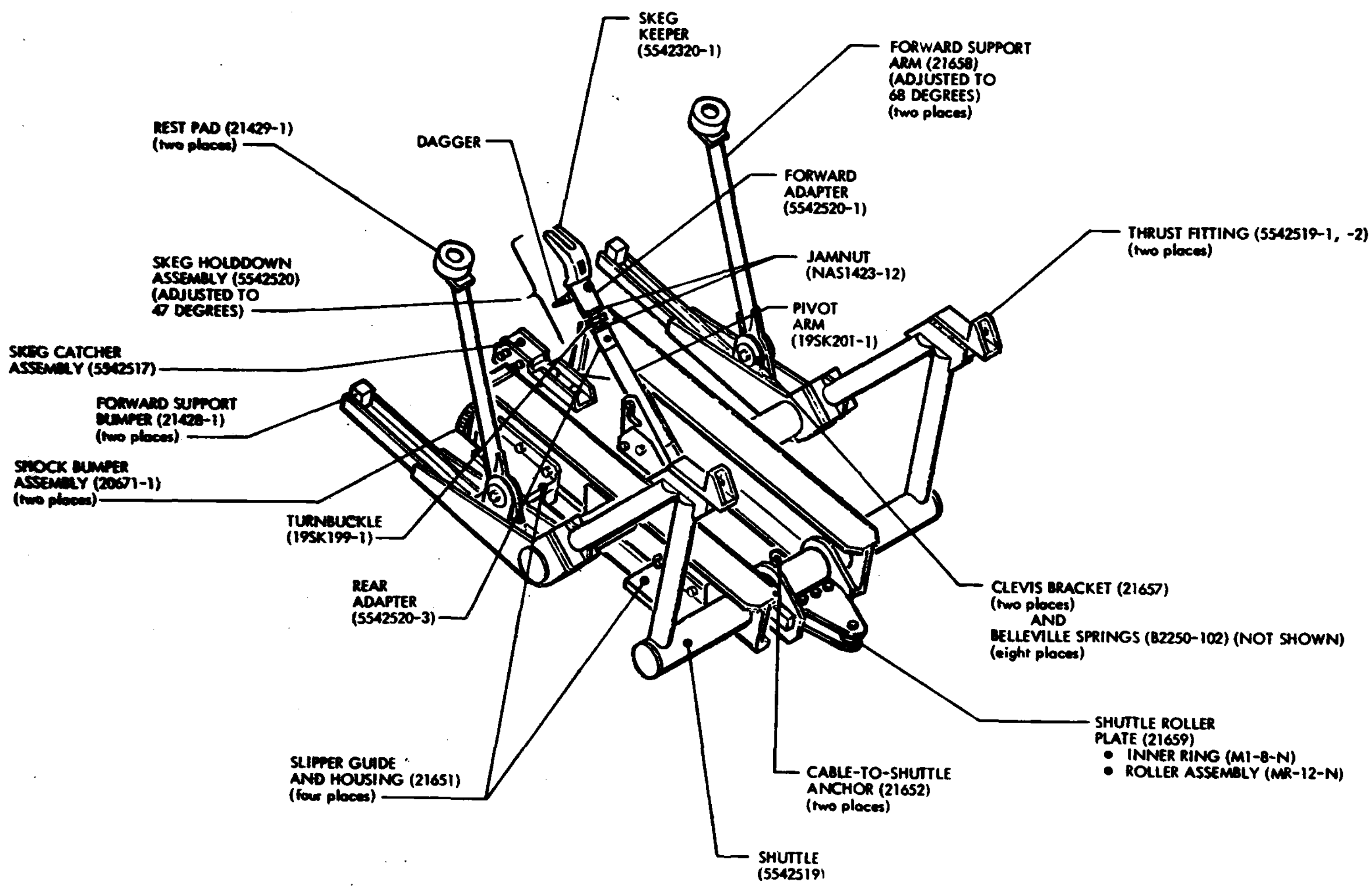


Figure 127. Launcher Shuttle Assembly

root. The ground mating half is contoured to provide easy removal just prior to launch.

The major launcher system components, as shown in Figure 126, are as follows:

- Accumulator and shuttle guide rails
- RPV shuttle assembly
- Shuttle release and air pressure controls
- Piston and cable assembly
- Starter motor assembly
- Air compressor
- Ground cooling
- Launch control panel
- Velocity counter system
- Power supply junction box
- Power supply (GFE)
- Shock absorber assembly
- Dryer
- Remote umbilical removal
- Jack stand
- Forward support assembly

5.3.1 System Description

The launch system is described in the following paragraphs. The subsystems are discussed in the order listed above.

5.3.1.1 Accumulators and Guide Rails. The launcher pressure accumulators serve as guide rails for the launch shuttle and RPV. The accumulator and guide rail structure consists of two 5-in.-diameter aluminum extrusions approximately 20 ft in length. The accumulator volume is sufficiently large so that essentially constant force is maintained on the piston stroke multiplier. Thus the RPV sees a constant g force during the launch cycle. The accumulator extrusion provides two sets of guide rails; the upper set guides the shuttle and the lower set functions as guides for the piston and crosshead assembly. The piston and crosshead assembly are connected to the (outer) accumulator cylinders by a manifold section at the rear of the launcher.

5.3.1.2 RPV Shuttle Assembly. The shuttle assembly is shown in Figure 127. This design features stiffness, light weight, and high reliability. The shuttle unit weight is 85 lb. The shuttle absorbs loads into the two main I-beams with torsional stiffening provided by transverse and vertical tubular members. An additional improvement to the aft wing interface is provided by two hard points that interface to the thrust fitting.

The RPV is prevented from prerelease by shear rivets at the thrust fittings and by the skeg keeper. The combined shear force for the two shear rivets is approximately 150 lb. At the end of the launch stroke, the forward momentum of the RPV shears the rivets, allowing the RPV to move forward, free of the shuttle assembly, as the shuttle assembly is decelerated. As the RPV moves forward, the skeg holddown assembly is released from the RPV skeg and the skeg holddown assembly rotates forward due to inertial forces. Another feature is the dagger and a block of neoprene, which prevents any rebound of the skeg holddown assembly, avoiding collision with the RPV duct. The forward support arms are set to an angle of 68 deg by a movable bolt under the arms, then adjusted for a breakaway force of 100 lb. The breakaway force is established by friction using belleville spring washers at the arm pivot end. Variation of the RPV skeg placement is compensated for in the turnbuckle adjustment of the skeg holddown assembly, which is locked in place by two jam nuts.

The shuttle rides on the upper flanges of the accumulator extrusions. The graphite-impregnated slipper guides provide containment and low friction between the shuttle and the accumulator flanges.

5.3.1.3 Shuttle Release and Air Pressure Controls. Control of the shuttle release latch assembly is derived from accumulator air pressure applied through an air pressure regulator operating in a range of 65 to 120 psig. The regulator supplies air to a solenoid-operated four-way valve. When activated by 28 Vdc, the solenoid valve operates the air cylinder and shuttle release latch on the latch assembly, which disengages the shuttle from the battery position (see Figure 128).

Accumulator pressure is sensed by a pressure transducer and commands compressor shutoff when a given preset pressure value on the control box pressure select dial is exceeded. Blowdown of the piston cylinder is accomplished remotely using the solenoid pressure release valve located beneath the ball valve. Manual blowdown can also be accomplished at this valve if required. Total system blowdown requires only that the ball valve be [illegible] during piston decompression.

In order to preclude improper pressurization of the main cylinder, the manual ball valve is provided with a solenoid-activated air-actuated safety pin. The solenoid remains deactivated unless the shuttle-in-position limit switch senses the shuttle is in battery, thus assuring the shuttle release latch can engage the shuttle roller plate when commanded closed, and the latch-closed limit switch senses full extension of the air cylinder rod end, which assures the shuttle release latch is fully closed.

A small shock absorber mounted on the latch assembly retards operation of the latch. The result is to slow the pressure onset to the shuttle and limit the maximum force applied to the RPV to about 6 g.

A manual safety pin protects the system from premature activation in case of a failure in the pressurization and safety interlock systems. The pin locks directly into the latch hook and prevents any movement of latch and shuttle until manually retracted. The position of this pin is sensed by a limit switch and monitored by a light in the control box.

The J-box assembly is a junction point for safety interlock wiring, control wiring, and instrumentation wiring and is provided with a protected switch that can retract and extend the latch provided no pressure is sensed by the monitor pressure switch (bottom of ball valve).

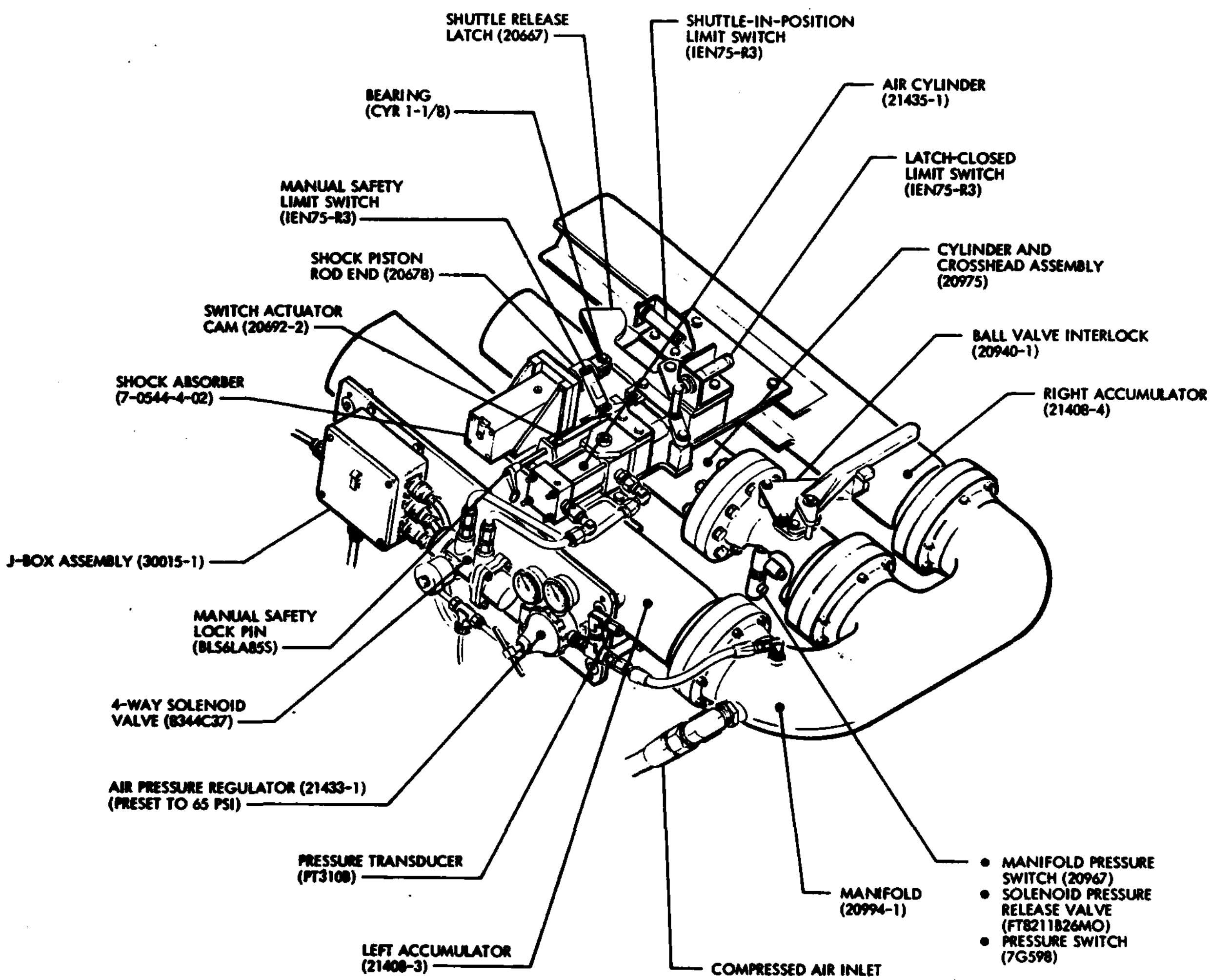


Figure 128. Launcher Shuttle Release and Air Pressure Controls

5.3.1.4 Cylinder and Crosshead Assembly. The cylinder and crosshead assembly provides the launch stroke to the shuttle and RPV when commanded. See Figure 129. The assembly mounts between the two accumulator tubes, the base of the cylinder being bolted directly to the manual ball valve. Mounted to the head of the piston tube is a crosshead consisting of two aluminum and Teflon guide assemblies and two cable sheaves.

The sheaves and launch cable geometrically provide a 2-to-1 shuttle launch ratio. The piston travels approximately 10 ft and is capable of reaching a maximum velocity of approximately 30 knots. The 2-to-1 ratio causes the shuttle to travel twice the distance for the same time thus producing a maximum launch velocity of 60 knots. The guide assemblies support and position the piston during the launch stroke. The guide sliding on the center accumulator guide rails provides vertical and lateral piston tube and cable sheave stability.

The cylinder containing the piston and protruding crosshead is a 5-in. by 13-ft aluminum pressure vessel. The cylinder serves as a carriage for the piston and, together with the piston cup seal, provides containment of accumulator air pressure applied to the piston.

The piston assembly consist of a 4-in.-diameter by 14-ft-long aluminum tube. The piston tube is hollow and is drilled and tapped along the walls to accept mounting hardware. At the forward end is the crosshead assembly secured by an O-ring sealed aluminum plug, and at the aft end are another O-ring, cup seal, and support hardware. Two relief valves set for 1 psig relieve and vent air trapped between piston and cylinder and provide indication of cup seal leakage.

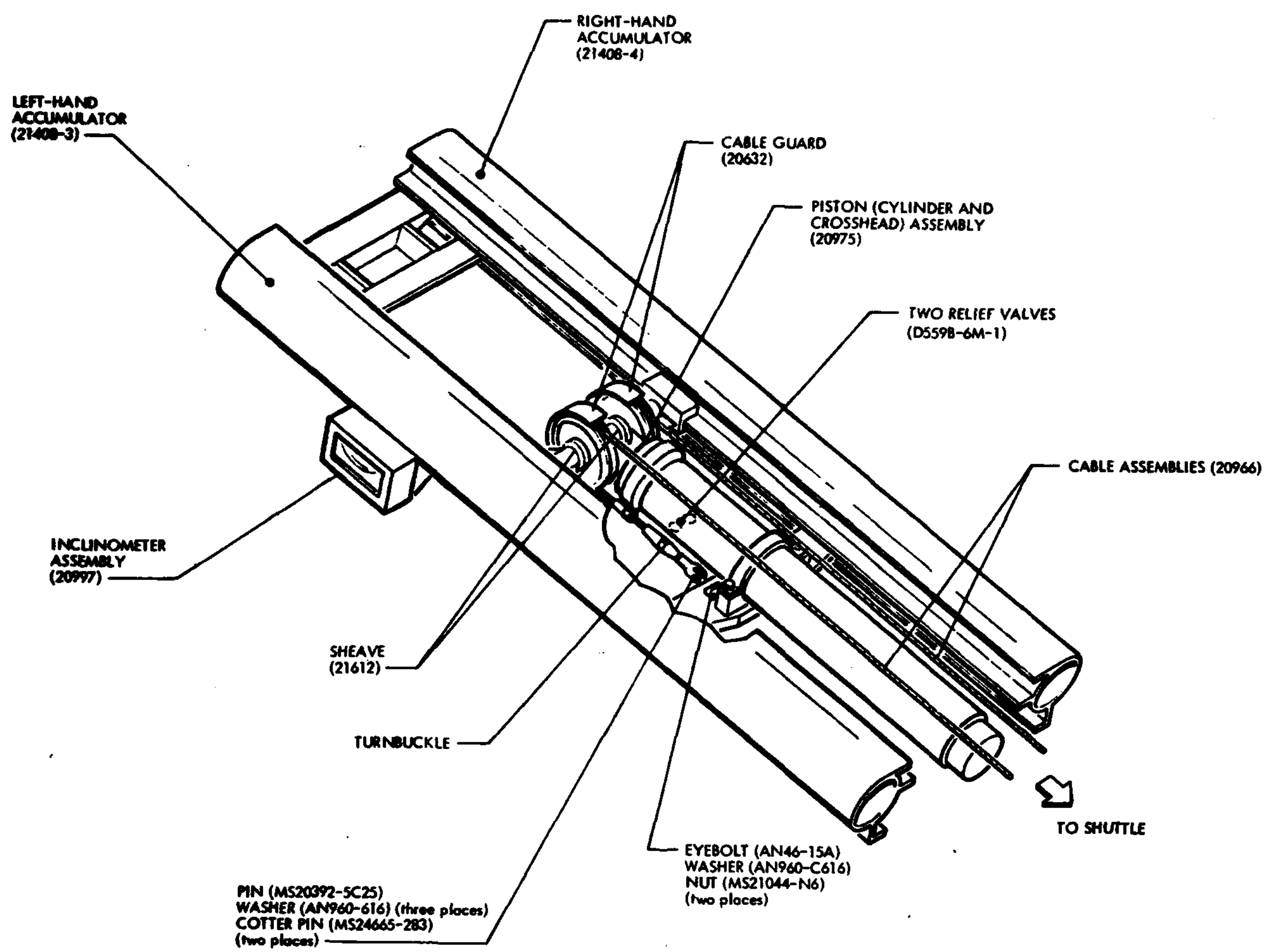


Figure 129. Cylinder and Crosshead Assembly

5.3.1.5 Starter Motor Assembly. The starter motor assembly (Figure 130) provides for remote (control box) starting of the RPV engine and remote-control retract after confirmed engine start. The starter base is located on the platform welded to the manifold at the rear of the launcher. The starter tray base mounts to the starter base at an inclination of 5 deg to the launcher guide rails. A jackscrew adjustment provides vernier adjustment to correct for small variations in RPV dimensions. The starter motor, polyclutch, and starter shaft and its supporting pillow blocks constitute a movable assembly, which is manually inserted into the mating engine receptacle.

When the proper engagement distance is achieved, the movable tray locks into the engaged position and can then be released by solenoid activation commanded from the control box. The polyclutch is a unidirectional friction clutch, which engages only when rotated in a clockwise (as viewed from the rear) direction and will freewheel when engine rpm exceeds the starter motor rpm.

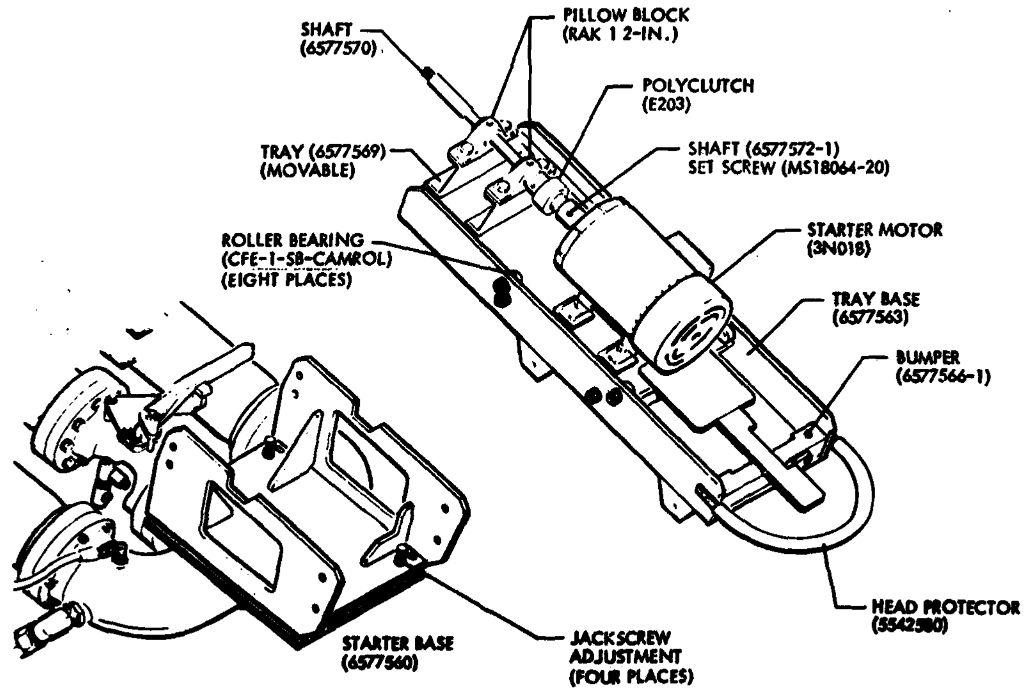


Figure 130. Starter Motor Assembly

The starter motor is a 1.5-hp three-phase, 208-V, ac motor rotating at 1,725 rpm. The motor is a totally enclosed heavy-duty unit providing 350-percent starting torque.

When engine start is complete, the movable tray is retracted by a remote command from the control box. The tray slides rearward and is stopped by a rubber bumper assembly. To prevent rebound of the tray and starter shaft back into the RPV, a latch is engaged. Finally, a head protection ring is installed to provide a safe area in the vicinity immediately to the rear of the launcher. Figure 131 is a schematic drawing of the starter system showing the major elements.

5.3.1.6 Air Compressor. The air compressor is a commercially available heavy-duty unit capable of supplying pressures to 500 psig at 35 cfm. The compressor is driven by an environmentally protected 5-hp, three-phase, 208-V, ac motor. The compressor is a two-stage Quincy Model 325, with a

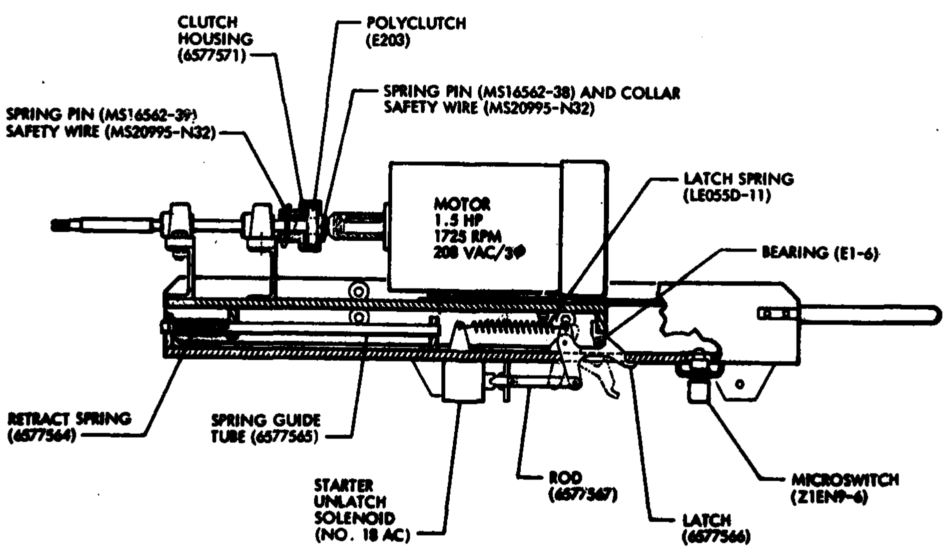


Figure 131. Schematic Drawing of Starter Motor Assembly

safety valve installed in the head providing compressor protection in the event an obstruction blocks the passages in the head between high- and low-pressure stages. When the proper accumulator air pressure is attained as sensed by the pressure transducer, located on the air pressure control panel, the compressor head is unloaded and the unit idles until commanded to resume pressurization. The compressor is mounted to the truck bed by two aluminum L-sections, which distribute the compressor load to the truck bed.

5.3.1.7 Ground Cooling. The ground cooling system provides forced-air cooling (Figure 132) to the RPV electronics and engine during ground operations and is removed manually just before RPV launch. The system consists of a high-pressure blower, spiratube K duct, rubber floor base mat for a pole support fixture, and an RPV inlet assembly, which mates to the RPV wing root air inlet opening.

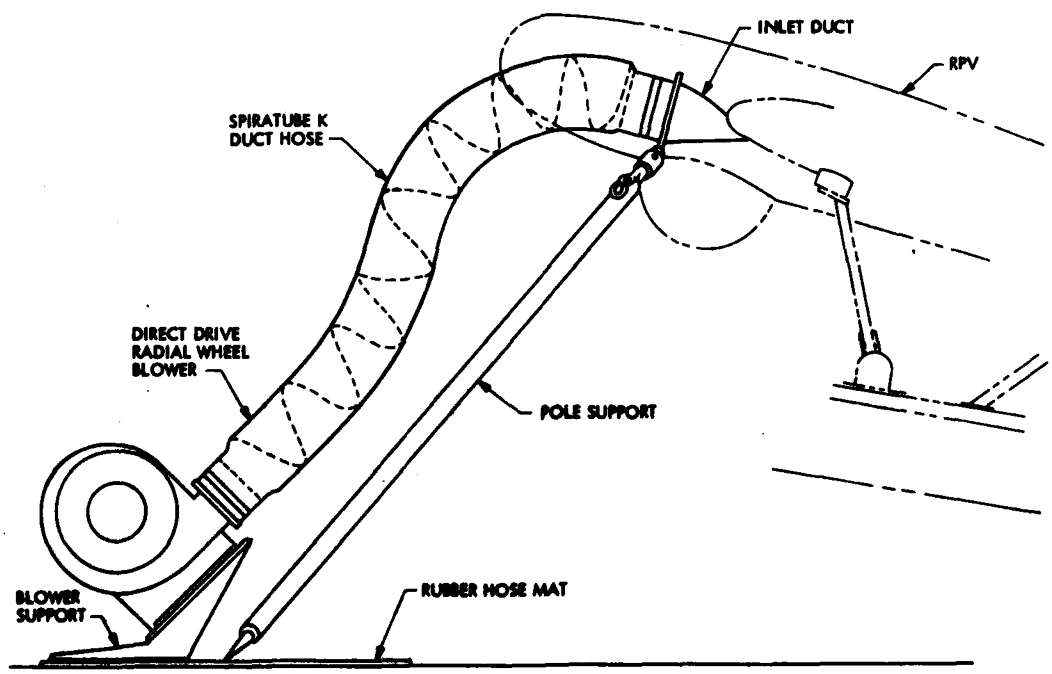


Figure 132. Ground Cooling System

The blower is a 1/3-hp direct-drive radial-blade unit capable of supplying 475 cfm at 2 in. of water. The blower is fastened to a support stand, which rests on the rubber base pad together with the inlet support pole.

5.3.1.8 Launch Control Panel. The launch control panel provides remote controls for launcher operation, status and malfunction indications, launcher ready signal to the GCS, and RPV manual launch capability.

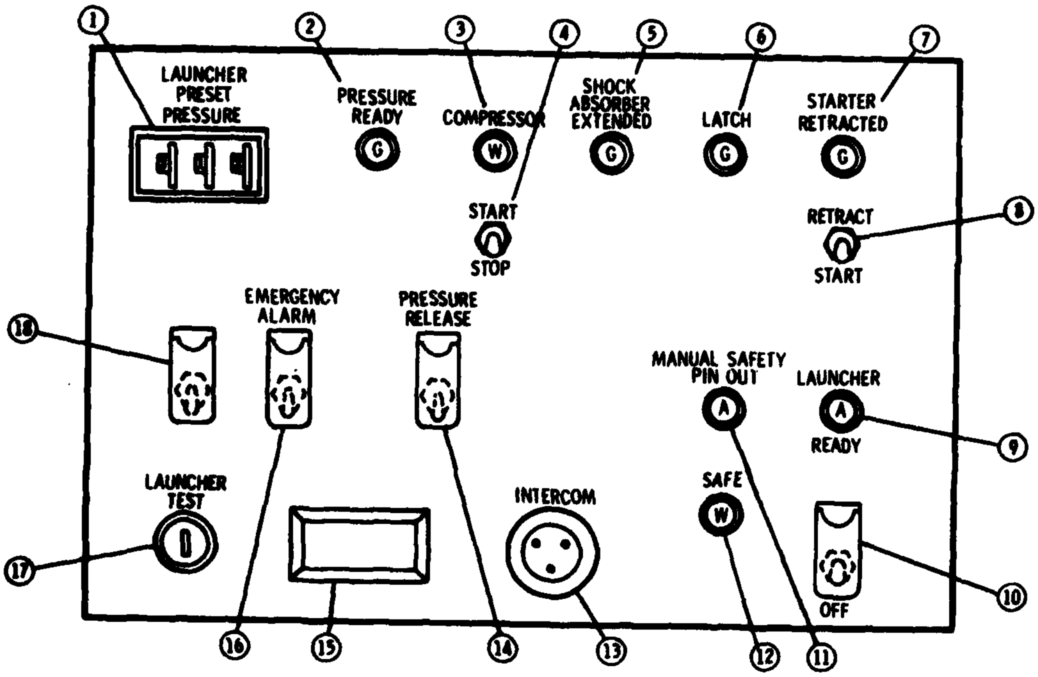
Figure 133 shows the location of the control panel indicators and switch controls. The LAUNCHER PRESET PRESSURE thumbwheel switch permits selection of accumulator pressure up to 500 psig on 10-psig increments. The actual pressure is monitored by the pressure gage at the pressure regulator. When the pressure transducer at the accumulator senses the preset pressure, the compressor is commanded to the standby mode and the PRESSURE READY light (green) is on.

The compressor power is controlled by means of the compressor START STOP switch; once turned on, the compressor may be pressurizing the accumulator tubes or may be in the bypass mode, depending on the position of the preset dial and the current accumulator pressure. Power-on is indicated by a white light.

The SHOCK ABSORBER EXTENDED light (green) indicates that the required 65 psig of air is being applied to the shock absorbers.

The starter RETRACT/START switch is a momentary three-position center off switch that permits application of three-phase power to the starter motor (down position) and retract of the starter motor tray (up position). The retract position is indicated by a green light.

The position of the manual safety pin is indicated by an amber light in the armed or open position and by a white light for the safe or closed position.



CODE

1	LAUNCHER PRESET PRESSURE THUMBWHEEL SWITCH
2	PRESSURE READY INDICATOR (GREEN)
3	COMPRESSOR INDICATOR (WHITE)
4	START/STOP TOGGLE SWITCH
5	SHOCK ABSORBER EXTENDED INDICATOR (GREEN)
6	LATCH INDICATOR (GREEN)
7	STARTER RETRACTED INDICATOR (GREEN)
8	RETRACT/START TOGGLE SWITCH
9	LAUNCHER READY INDICATOR (AMBER)
10	LAUNCHER READY TOGGLE SWITCH (COVERED)
11	MANUAL SAFETY PIN OUT INDICATOR (AMBER)
12	SAFE INDICATOR (WHITE)
13	INTERCOM
14	PRESSURE RELEASE TOGGLE SWITCH (COVERED)
15	VELOCITY INDICATOR
16	EMERGENCY ALARM TOGGLE SWITCH (COVERED)
17	LAUNCHER TEST KEY SWITCH
18	LAUNCHER TEST TOGGLE SWITCH (COVERED)

Figure 133. Launcher Operator Panel, Controls and Indicators

A protected PRESSURE RELEASE switch vents all pressure applied to the cylinder and piston assembly. Blowdown of accumulator pressure is accomplished by opening the manual ball valve and activating the PRESSURE RELEASE switch.

The protected EMERGENCY ALARM switch activates a general warning emergency alarm in the GCS.

The protected LAUNCHER TEST switch and enabling-key switch provides a means of manually launching the RPV from the control box and a means of test-firing the shuttle to confirm operational readiness.

The velocity counter provides a number readout proportional to final launch velocity. Velocity can be found by dividing 29,600 by the number obtained on the launch velocity readout.

The LAUNCHER READY light indicates system readiness; no launch can occur until the logic for this light is satisfied and the LAUNCHER READY switch is placed in the up position.

The intercom plug provides for voice communication between major system elements.

In order to ensure proper launch of the RPV, the various control and safety functions are interlocked by relays located in the control box. Three conditions for launch and test are met in the demonstration launch system: (1) RPV launch via the ground station computer, (2) shuttle-only firing, and (3) return of shuttle to the battery position, including cycling of the latch mechanism. The launch interlock controls are shown schematically in Figure 134.

The requirement for launch requires proper launch pressure (relay K5), verified by the gage; safety pin removed (relay K1); pressure applied to the shock

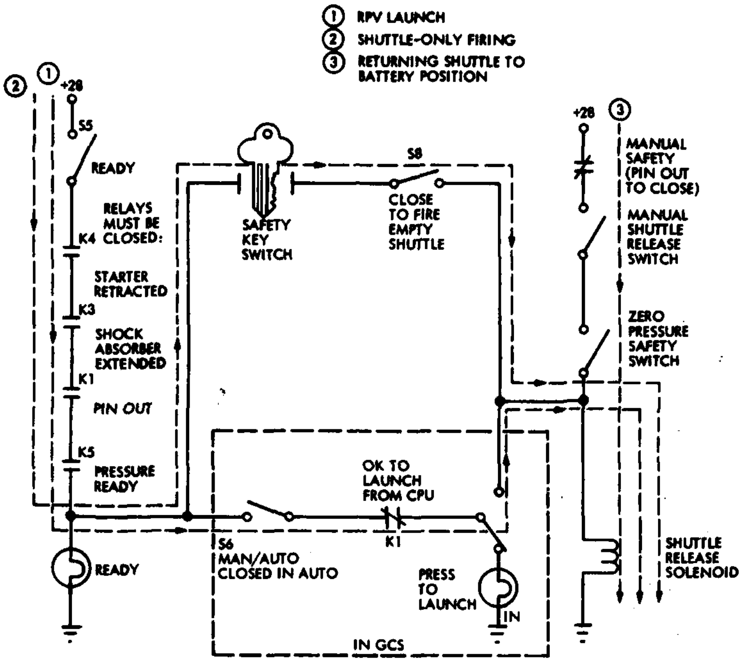


Figure 134. Launch Interlocks

absorber (relay K3); starter retracted after engine start (relay K4) and after visual verification by the cognizant launch personnel that all safety and interlock conditions have been met; and closure of the permissive launcher-ready switch (S5). If all the aforementioned conditions prevail, RPV launch or shuttle firing is possible from either the GCS or from the control panel. In order to operate the latch that locks the shuttle into the battery position, three conditions must be met: (1) the manual safety pin has been released; (2) zero pressure has been sensed in the piston; and (3) the manual shuttle-release switch has been activated.

8.3.1.9 Velocity Counter System. Determination of the RPV terminal launch velocity is desirable to prevent any launcher system degradation that would permit final launch speed to approach RPV stall speed. Launch velocity is also a valuable diagnostic tool to assess aircraft performance and assist in failure analysis.

The velocity measurement system used on the launcher consists of two magnetic pickups located on the left-side accumulator tubes near the end of the launch stroke and a magnet mounted on the port-side slipper guide of the crosshead assembly (Figure 135). The velocity counters are positioned 6 in. apart and so located that, when the crosshead magnet has passed over the second counter, the shuttle and RPV are close to the shock-absorber cylinder rods. In the piston cylinder, 6 in. of travel corresponds to 1 ft of shuttle motion, and the time interval between the two velocity-counter pulses provides a close approximation of the RPV instantaneous launch velocity.

The electronic pulses from the velocity counters are processed in the control box with a count proportional to time being displayed on the control panel LED

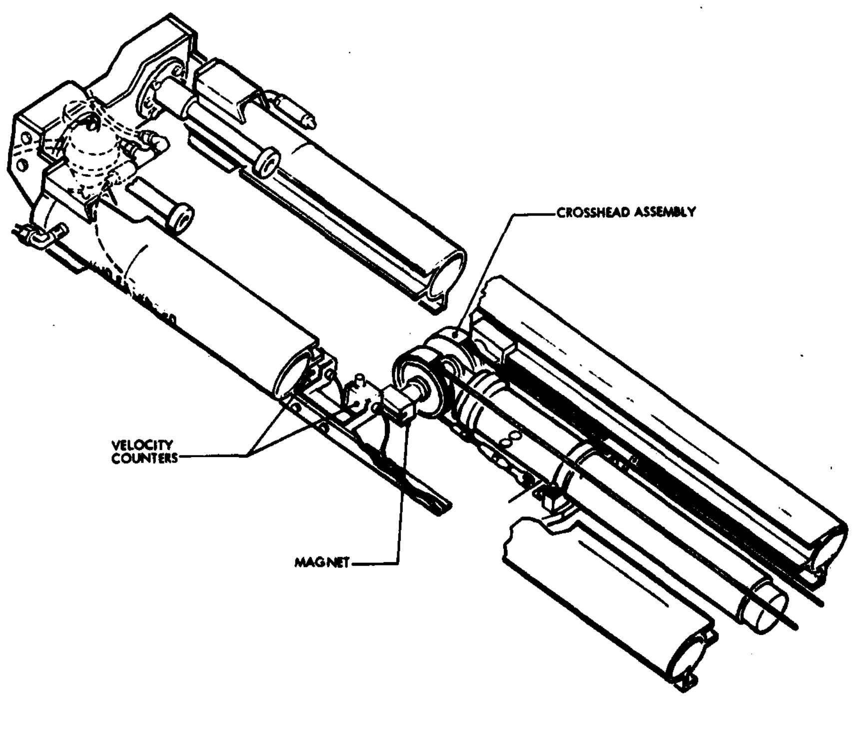


Figure 135. Velocity Counter Sensors

counter. To convert time to velocity the number 29,600 is divided by the observed count, providing velocity in knots.

5.3.1.10 Power-Supply Junction Box. The power-supply junction box, a major interconnect box between launcher functional electrical systems, is the electrical interface between launcher-related items and the ground control station. The junction box (Figure 136) is located at the front of the truck bed just forward of the jack-stand assembly. The J-box contains a 28-Vdc power supply, two magnetic contactors, several control relays, and interface wiring. The 28-Vdc power supply is the source of dc control power used in relay interlock circuits, solenoid-operated valves, the velocity sensor, and indicator lamps. Three-phase power to the compressor and RPV starter motors is controlled by two magnetic contactors with thermal overload sensors that sense excessive current or low-phase voltage, thereby removing all power from the area of malfunction. The contactors can be manually reset after the power-loss diagnostics are completed. The box is waterproof and weatherproof with dust seals between body and hinged lid.

5.3.1.11 Power Supply. The power supply is mounted on the truck bed (Figure 136) and provides power to the RPV before engine start. The unit is a

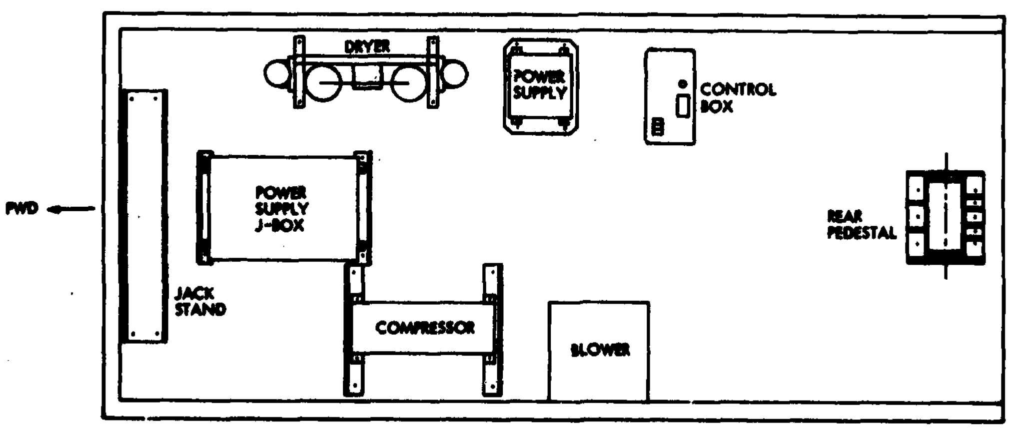


Figure 136. M36 Truck Bed, Plan View

Government-furnished Digiac PP6241U capable of providing 28 Vdc at 240 A. The supply operates from 110 Vac supplied from the power-supply junction box. The unit is a completely waterproof, rugged, militarized power supply weighing 98 lb.

5.3.1.12 Shock Absorber Assembly. Shuttle arrestment is provided by two air-over hydraulic shock absorbers mounted on the forward end of the launcher assembly. The shock absorbers are factory adjusted to provide optimum performance for launch speeds in the range of 45 to 55 knots. Each shock absorber is 5 in. in diameter with a 21-in. body extending from the forward end of the launcher. The internal bore is 2 in., with a 1.25-in. rod extending 16 in. from the body. Air is supplied at 65 psig through a 5,000-psig check valve to augment the hydraulic shuttle arrestment. Maximum working capacity of each shock absorber is 100,000 in.-lb.

5.3.1.13 Dryer Assembly. The dryer consists of dual regenerative desiccant towers. The air dryer is connected in series with the air compressor so that air entering the launcher accumulators is dry, thereby reducing maintenance requirements on the launcher seals, valves, etc. The dryer (shown schematically in Figure 137) contains two desiccant towers, a timer, valves, and filters. During launcher pressurization, the dryer is turned off. Air from the compressor at about 300 psig flows through normally open valves through the desiccant towers, where it is dried, and then to the postfilter and the launcher accumulators. The pressurization sequence takes about 10 min; the desiccant towers take about 4 hours to saturate without regeneration. The desiccant beds are regenerated by operating timer-controlled solenoid valves to direct the air flow through one tower then the other, changing from one to the other every 2.5 min. The compressor is set to 100 psig during the regeneration period.

Air at 100 psig and 35 cfm flows from the compressor, through the prefilter, through the on-line desiccant tower, where it is dried, and to the shuttle valve.

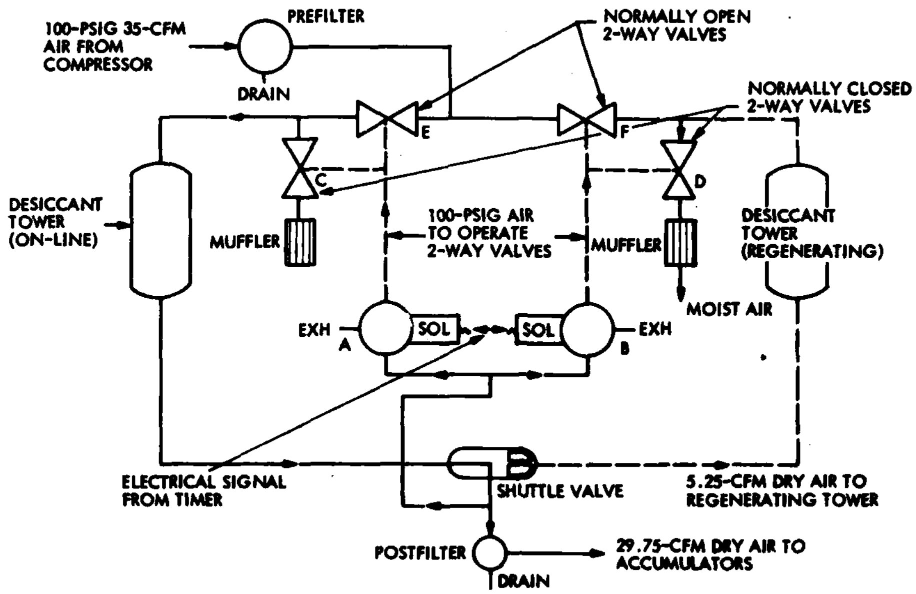


Figure 137. Schematic Drawing of Dryer

At the shuttle valve, 29.75 cfm are diverted to the postfilter and launcher manifold, and the remaining 5.25 cfm of dry air are sent to the regenerating tower; moisture is removed from the desiccant bed and is carried out through valve D in Figure 137. When the accumulator pressure reaches 100 psig, the compressor shuts off and the pressure bleeds down through whichever tower is regenerating. When the pressure falls to about 90 psig, the compressor turns on again. Figure 136 shows the location of dryer as mounted on the M36 truck.

5.3.1.14 Remote Umbilical Removal. The RPV umbilical cable (Figure 138) is removed just before launch by a lanyard leading down through the truck bed and to the right rear corner of the M36 truck. The lanyard passes just outside the right-hand accumulator tube, runs through a friction-reducing fairlead and two externally mounted eyebolts, and terminates in a handle. Maximum disconnect force at the RPV umbilical connector is 20 lb, but friction losses increase the required force at the lanyard handle to about 50 lb.

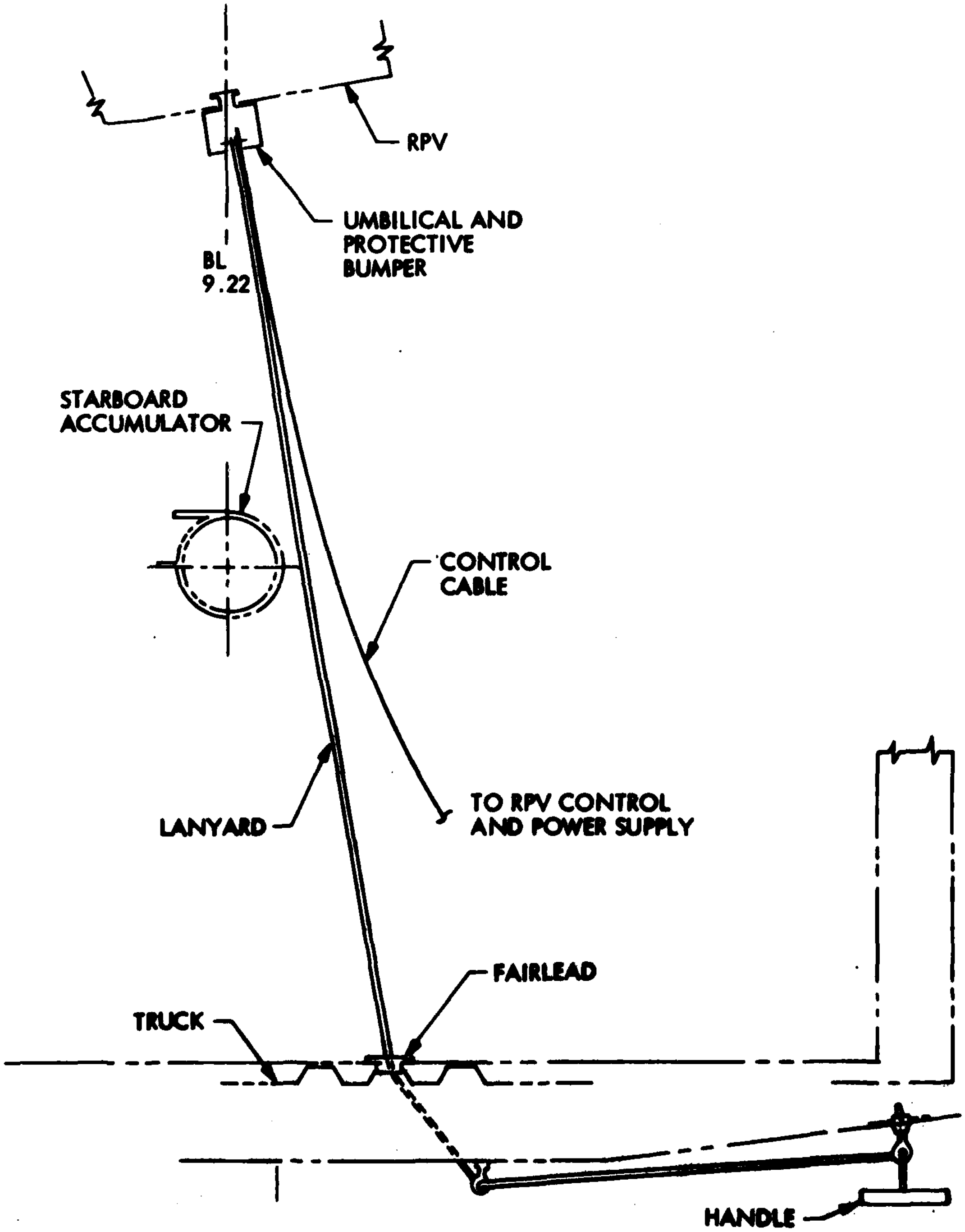


Figure 138. Remote Umbilical Removal

5.3.1.15 Jack Stand. The jack stand provides a simple reliable hand crank for adjustment of launch angle in the range of 10 to 20 deg and supports the basic launcher assembly. An inclinometer is provided to give visual confirmation of the guide-rail angle. The installed assembly is shown in Figure 126.

5.3.1.16 Forward Support Assembly. The forward support assembly provides longitudinal support to the accumulator tube during transit between operational sites. Once a launch site has been selected, the forward support wing nuts are loosened and the entire unit is pivoted onto the truck hood. The assembly (Figure 126) is designed to avoid interference with the vision of driver or observers.

5.3.2 Requirements

The requirements for the launcher system are as follows:

- No more than two people required for setup, teardown, and system operations
- Minimum time and skill for all operations
- Minimum observables during launch operations
- Launch system common to all phases of the program

Design parameters selected and proposed to meet these requirements are compared with the final characteristics in Table 21. A review of the system parameters shows that only the increase of launcher weight is significant; all other specified parameters were essentially met.

In order to increase launcher life, decrease maintenance, decrease field mobility reaction time, and provide for prelaunch conditioning of the RPV, the launcher system was augmented by the following truck-mounted ancillary equipment: RPV ground cooling, RPV remote umbilical, RPV power supply and control, and pneumatic air dryer. The final launcher configuration is shown in Figure 126.

...ISON OF FINAL LAUNCHER SPECIFICATIONS WITH ...NE

...em	Baseline	Final (√ = Unchanged)
... subsystem type	Pneumatic launcher	√
...ication	Army RPV vehicle	√
...unch payload	RPV System Technology Demonstrator Program Phases I through V	√
RPV description:		
• Weight (including fuel)	120 lb maximum	146.5 lb max.
• Length	72 in. nominal	74 in.
• Wing span	143 in. nominal	148 in.
• Propeller shroud diam	22 in. nominal	22 in.
Launch speed	44 knots nominal	41 knots
Maximum acceleration	6 g axial	√
Launch elevation angle	0 to 20 deg max.	10 to 20 deg
Launch bearing angle	Adjustable (±45 deg to track axis)	360 deg (truck)
Launch shuttle retraction	Manual	√
Holdback	Latch mechanism	√
Cradle	4-point RPV support	5-point
Holddown	Pin-release mechanism	Keeper
Length of stroke	18 ft nominal	20 ft
Launcher length	24 ft maximum	30 ft
Deceleration	Compression spring system	Hydraulic absorber
Air pressure, operating	300 psi maximum	300 psi nominal
Launch crew	Two persons (maximum)	(four to load RPV)
Launch crew skills	Minimum related MOS desirable	√
Total weight, assembled launcher	300 lb max.	2,000 lb
Ambient winds	20 knots, gusts to 30 knots	35-knot gusts
Max. altitude atmospheric launch condition	4,000 ft MSL at 95° F	4,580 ft at 95° F
Power supply	Compressed air	√
Instrumentation & control system	Display console	√
...de of RPV engine start	Retractable electric or manual	Electric

5.3.3 Performance

Launcher performance has been confirmed by test for launch velocities to 60 knots and vehicle weights up to 200 lb. The theoretical accumulator pressure required to launch the RPV can be closely approximated by an expression in which pressure is linearly proportional to the weight and to an exponential power of the velocity. The required relation to within a constant is then:

$$P = C, WV^{\alpha} \qquad (1)$$

where

P = initial launch pressure

V = RPV launch velocity

W = system weight

α = exponent approaching a value of 2

C = constant of proportionality

Similarly, the theoretical maximum acceleration loads can be approximated by a term linearly proportional to weight and to an exponential power of the acceleration. When the acceleration is expressed in multiples of gravitational force at the earth surface (g), the required equation is:

$$P = C_2 Wg^{\beta} \qquad (2)$$

where

P = initial launch pressure

g = acceleration parameter

W = system weight

β = exponent approaching a value of 1

C_2 = constant of proportionality

Experimental data were first obtained by controlled factory testing and then augmented by field use data. Figure 139 plots RPV weight versus launch velocity with the required pressure as a parameter. When the plot is used, the 6-g restriction for acceleration should be maintained; hence, the launch velocity selected should not exceed 52 knots.

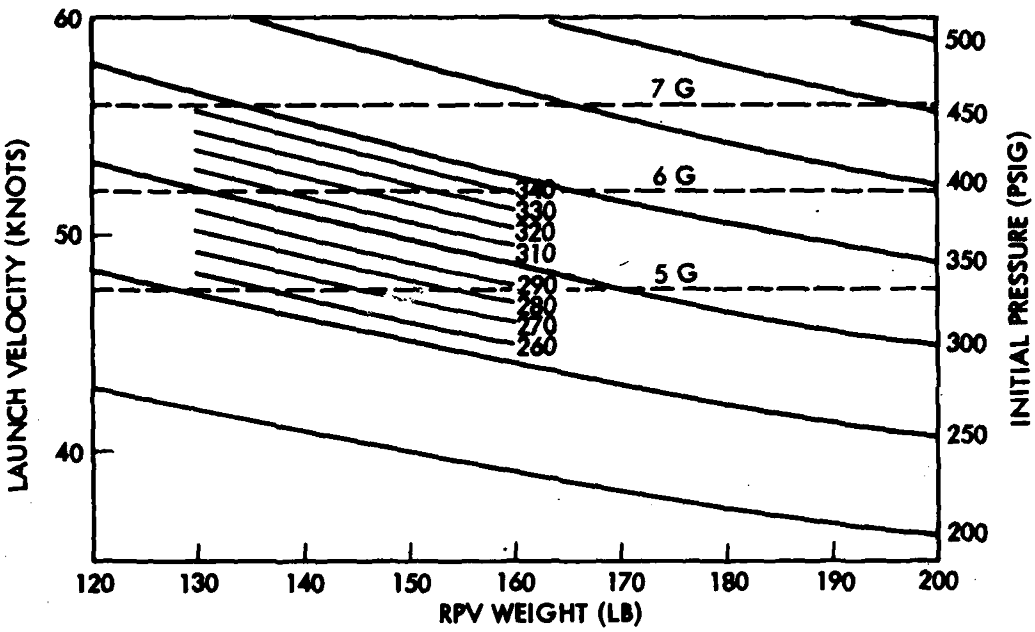


Figure 139. RPV Launch Velocity, Variation With Weight and Pressure

The acceleration loads can be found by Equation 2, but a more direct method is found when experimentally determined g values for various shuttle weights and launch velocity are plotted versus the kinematic values for linear acceleration. Figure 140 is such a plot of data from Aquila and from other programs that use pneumatic catapults. The straight line is the theoretical, linear acceleration; the data points reflect experimental data. As can be seen, the linear acceleration approximation holds very closely for a wide range of data. Thus, the g values of Figure 139 are those for an ideal linearly accelerated RPV.

Although it is desirable to have the launcher small and compact, the launch stroke required to restrict the RPV acceleration loads to 6 g for a given launch velocity can be calculated from the expression for ideal kinematic acceleration:

$$L = 0.00739 V^2 \quad (3)$$

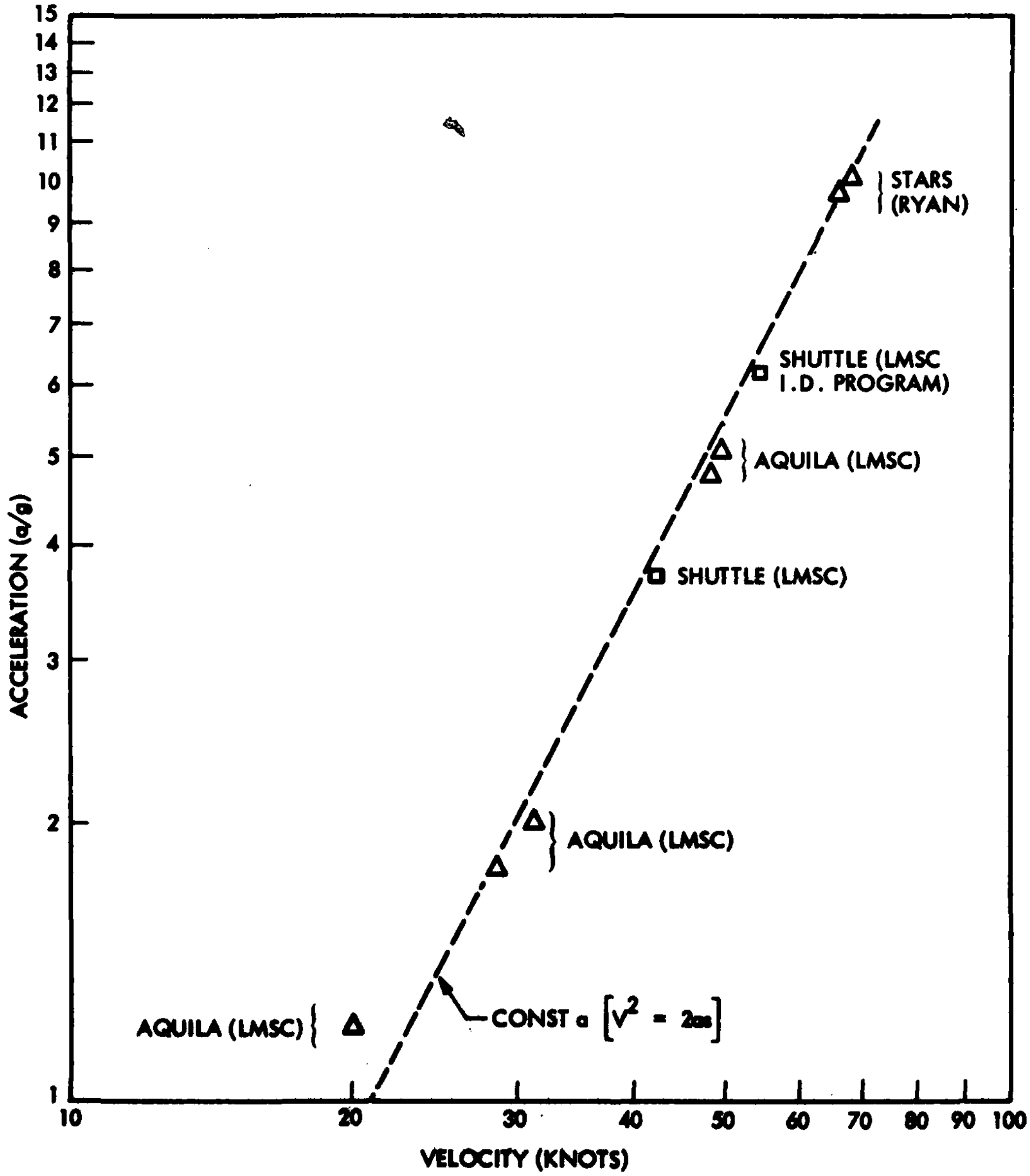


Figure 140. Launch Data, Theoretical and Actual

where

L = launch stroke (ft)

V = launch velocity (knots)

For a 52-knot launch velocity, the required length is 19.98 ft. For a 49-knot launch, the required length is 17.75 ft. Increasing the permissible g levels and decreasing the launch velocity result in a shorter required launch stroke.

5.3.4 Conclusions

The linear pneumatic system has been developed into a reliable launch system for the Aquila RPV. The system provides prelaunch conditioning to the vehicle and proper inclination and attitude during launch. The system is limited to truck use in its current mounting and has proved mobile in limited field use. The current system is mounted on an M36 2.5-ton, long-bed truck. Current geometry provides some overhang, which limits mobility.

5.4 RETRIEVAL SYSTEM

The retrieval system (Figure 141) consists of two trailer-mounted vertical arrester nets, a horizontal landing net connected between the two trailers, and a ground video camera. The trailers are positioned approximately 18 m (60 ft) apart and at right angles to the prevailing wind; the horizontal net is connected between the trailers; and the vertical nets are raised. The horizontal net stretches 2 ft above the trailer bed; this clearance prevents the RPV from striking the ground when it lands in the net. Shortly before retrieval, the upwind net is lowered, and nylon lines connected to the corners of the raised net are attached to nylon straps that are wound around tape-reel, hydraulic energy absorbers on the opposite trailers.

The system is capable of safe RPV retrieval in a headwind or crosswind of 37 km/hr (20 knots). The vertical barrier absorbs and dissipates the flight

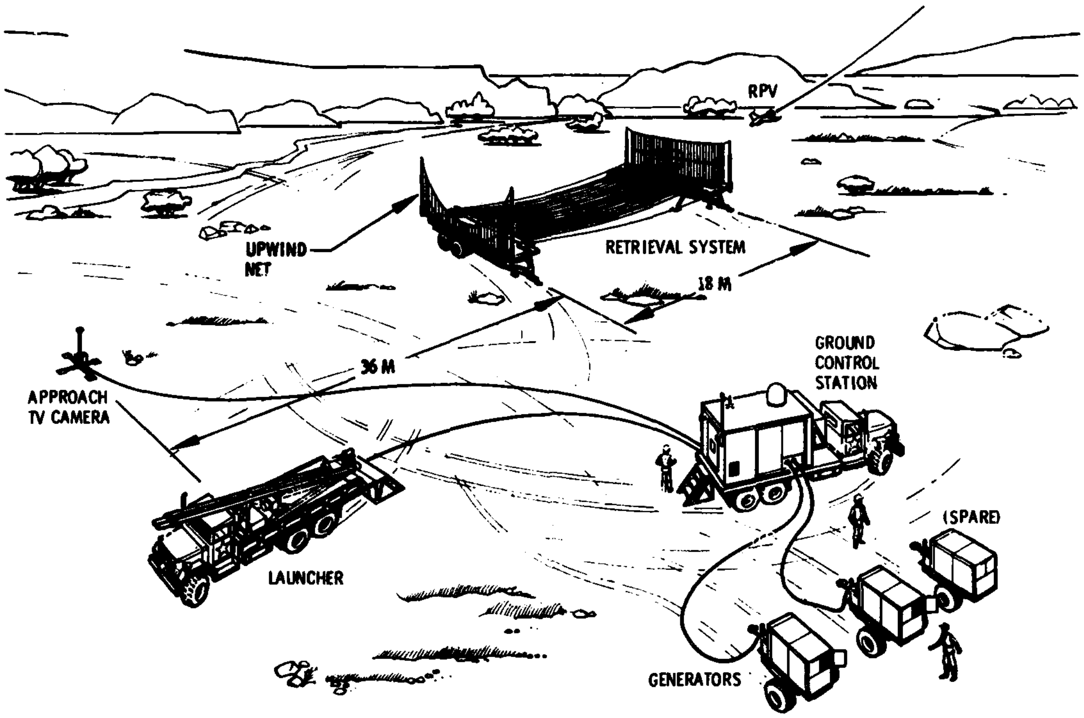


Figure 141. Aquila RPV Retrieval System

kinetic energy while maintaining deceleration within the 6-g load limit. The setup is described in Volume III of Reference 17. System capabilities are discussed further in Reference 5. The development of the system is set forth in Reference 18.

The dimensions of the horizontal landing net (25 ft wide and 60 ft long) are compatible with the vertical barrier (15 by 35 ft) and provide the desired RPV deceleration characteristics within the structural load limits of the Aquila RPV. The characteristics of the system are listed in Table 22.

[18] Sterbenz, William H., AQUILA RPV SYSTEM TEST REPORT, CDRL A00D, PART 6, RETRIEVAL SYSTEM DEVELOPMENT, LMSC-L028081, Lockheed Missiles and Space Company, Inc., Sunnyvale, California, 30 June 1977.

TABLE 22. RETRIEVAL SYSTEM CHARACTERISTICS

Parameter	Value or Method
Retrieval system type	Vertical barrier net, horizontal landing net
Engagement velocity	70 to 96 km/hr (38 to 52 knots) ground speed, low approach angle
Energy dissipater fluid	Hydraulic brake, automatic transmission fluid
RPV runout impact distance	13.5 m (45 ft)
Vertical barrier net energy dissipater tape	Nylon, 7,257-kg (16,000-lb) load strength, each
Vertical barrier net overall dimensions	10.6 m (35 ft) wide, 4.6 m (15 ft) high
Retrieval window	6.2 m (21 ft) wide, 3.6 m (12 ft) high
Horizontal net	Low-rebound, longitudinal Dacron straps
Strap size	28.6 mm (1-1/8 in.) wide, 3.175 mm (1/8 in.) thick
Capture loads	6 g vertical, 6 g axial maximum
Horizontal landing net overall dimensions	18.1 m (60 ft) long by 7.6 m (25 ft) wide
Retrieval crew	Two (minimum)
Ambient winds	37 km/hr (20 knots), gusts to 64 km/hr (35 knots)
Instrumentation and control system	Passive

The retrieval assembly is mounted on two standard Army M345 trailers. Each trailer acts as the base for the vertical arrester nets and serves as the attach points to which the ends of the horizontal landing net are connected.

The video camera is positioned on the centerline of and 36 m (120 ft) downwind of the center of the horizontal net. The height and tilt angle of the camera are adjusted to define the flight approach path leading into the center of the upwind vertical net and down a 4-deg glide path.

5.4.1 Description

Figure 142 presents a drawing of the vertical barrier retrieval system. As shown in Figure 143, each vertical barrier net supported between two vertical poles is connected by nylon lines from its four corners through pulleys to two rotary hydraulic energy absorbers. The energy absorber assembly (Figure 144) consists of a hydraulic-fluid-filled housing with two sets of eight stator vanes fixed to the top and bottom of the housing. Nine rotary vanes attached to the rotor shaft are located in the space between the upper and lower sets of stator vanes. The rotor shaft is driven by a tape reel on which a roll of high-strength nylon tape is stored. When the RPV engages the vertical barrier net (Figures 145a and b), the nylon tape connected to the vertical barrier pays out and the desired arresting force is provided by the hydraulic-fluid vortex motion induced by the rotor. Once the kinetic energy of the RPV has been absorbed by the vertical net, the RPV's potential energy is absorbed by the horizontal landing net. Figure 145c shows the RPV on the horizontal net just before its removal.

The entire retrieval assembly is mounted on two standard Army M345 trailers. The assembly is designed so that field setup and strikedown can be accomplished by four men in 1 hour and 0.5 hour, respectively. Structural elements of the assembly consist of telescopic poles and torque tube assemblies, which form the support frame for the vertical nets. The telescoping pole assemblies consist of two 2024 aluminum 12-ft-long cylinders. The lower pole is 5 in. in diameter with 0.50-in. wall thickness; the upper pole is 4 in. in diameter with 0.50-in. wall thickness. The overall length of the assembled unit is approximately 19 ft. The longitudinal tube assemblies bolted to each trailer form the supporting members for the horizontal landing net and the four hydraulic energy absorbers. The poles are constructed of 6061 aluminum alloy with 5.0-in. outside diameter and 0.25-in. wall thickness.

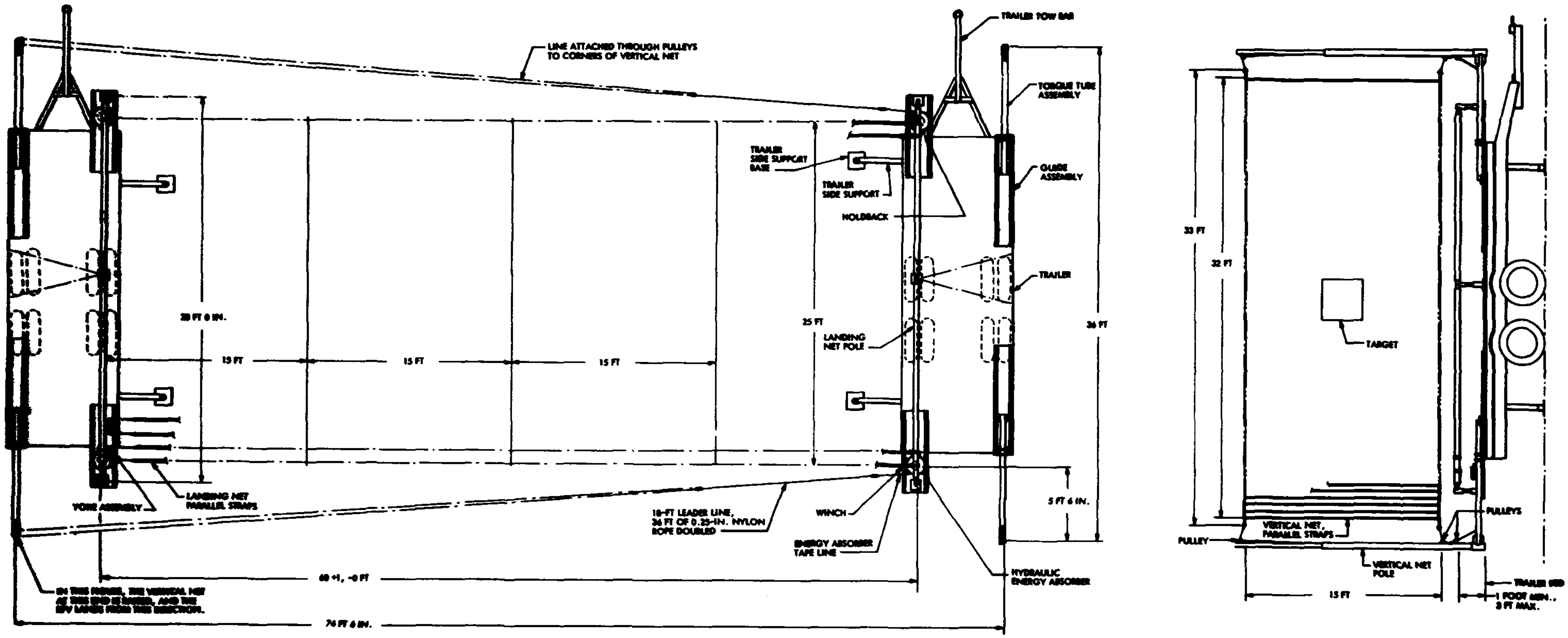


Figure 142. Vertical Barrier System

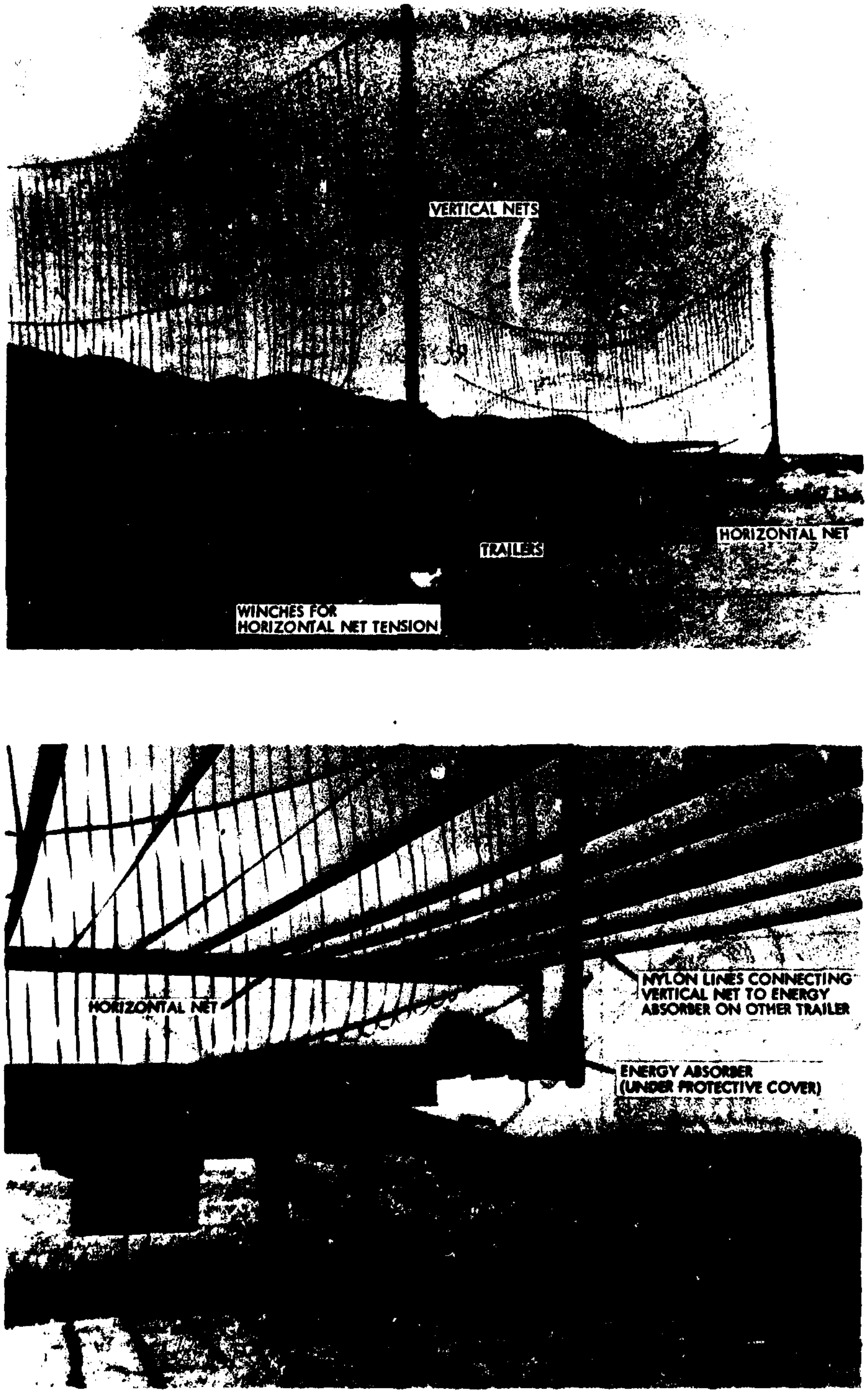
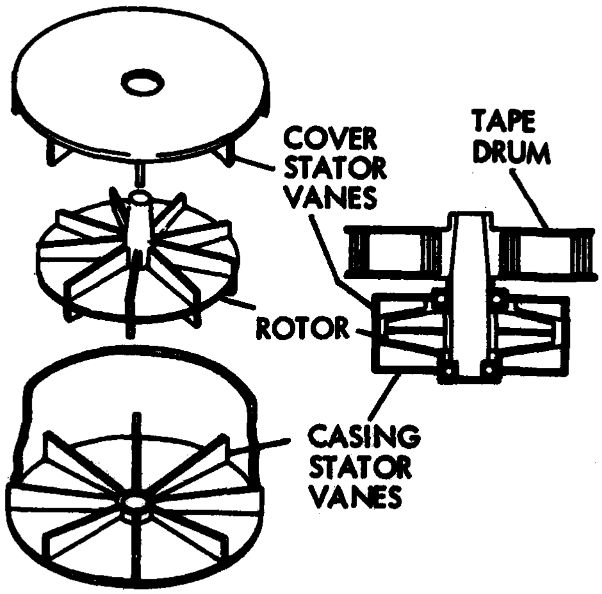
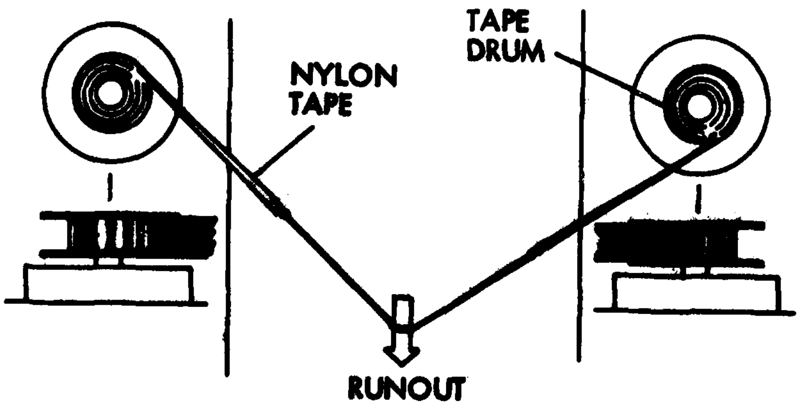


Figure 143. Retrieval System Details



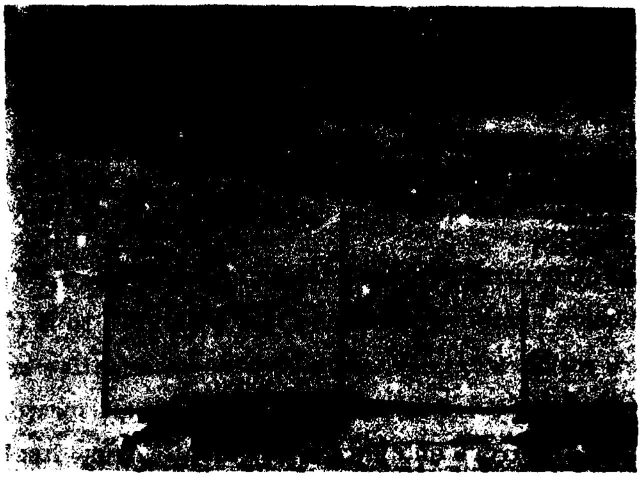
a. Energy Absorber

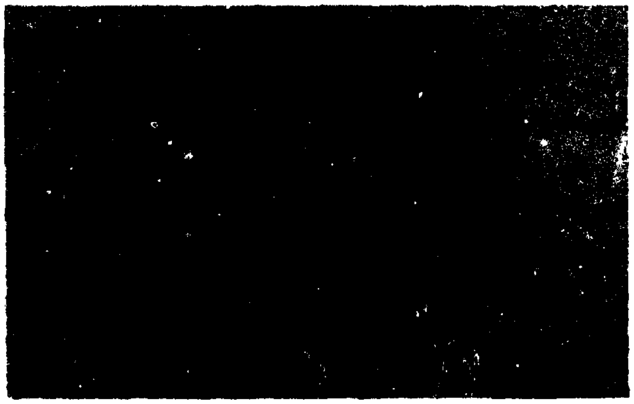


b. System Operation

Figure 144. Energy Absorber and System Operation

a. Approach





b. Capture

c. Removal From Horizontal Net

Figure 145. RPV Retrieval

To stabilize the entire assembly when erected, and to facilitate retrieval operations, each trailer is modified to accept two side support assemblies. These are pinned to the bottom of the trailer, and a jackscrew at each support is installed to provide the required adjustment.

The flying and structural characteristics of the Aquila RPV-STD and its final approach guidance system determined that a barrier 15 ft (4.6 m) vertically and 35 ft (10.6 m) horizontally would provide an effective retrieval window of 12 ft by 21 ft (3.6 m by 6.2 m), providing ample safe margins for the wing span and propeller shroud outside the retrieval window itself. The vertical net consists of 66 vertical nylon ribbons which are 0.5 in. (12.7 mm) wide and 0.0625 in. (1.58 mm) thick. The equal spacing of these ribbons is maintained by the upper horizontal strap, midline ribbon spacing strap, and lower horizontal positioning strap. The midline strap provides a margin of safety so that the RPV cannot penetrate the vertical barrier during retrieval operations.

The horizontal RPV landing net has a width of 25 ft (7.6 m) and a length of 60 ft (18.1 m). The horizontal landing net consists of 13 dacron straps (26 lines) 1.125 in. (28.6 mm) wide and 0.125 in. (3.175 mm) thick. Equal spacing of these lines is maintained by their attachment to the two landing net poles rigidly attached to the trailer. The tension adjustment is applied to each strap by means of the winch mount assembly. A torque of 10 ft-lb on the winch provides the proper strap tension to prevent ground impact of the RPV during recovery and keeps vertical loads below 6 g.

The Aquila RPV recovery system uses a video camera that looks up the 4-deg glide slope at a point where the RPV will transition from waypoint guidance to terminal guidance. This video information is displayed on the sensor operator's monitor in the GCS and is also recorded on tape for analysis and record.

The ground camera system used is an RCA Model TC 1005/501 video camera with a 1-in. silicon vidicon tube and a motorized auto iris. An f/1.8 lens with a 75-mm focal length provides a field of view of 9.8 deg (horizontal) by 7.3 deg (vertical).

To eliminate the problem of vertical net scintillation in the video as the wind rotates the vertical straps, and to improve the contrast of the RPV against the sky, an ultraviolet filter is placed over the video lens. The filter used is a 200-Å bandpass filter centered at 3,900 Å with a transmissivity of approximately 75 percent.

Once the retrieval system was fully operational and using the semiautomatic guidance mode, the precision and reliability of the system were very high. Some anomalies occurred in the altitude of the outer marker because of altitude system errors. However, these were adjusted by reprogramming that waypoint. Once the RPV approach was set up properly, the LMSC test team recovered every RPV on the first pass. The 1-σ miss distance demonstrated was 1.6 ft lateral and 0.8 ft vertical from the distribution centroid of the net impact points. The centroid was 0.33 ft to the right and 0.07 ft high from the video line-of-sight intersection with the center of the net (looking from the ground camera position).

5.4.2 Requirements and Capabilities

Requirements and goals of the retrieval system, as identified at the beginning of the program, include:

- Minimum observability
- Operation from unprepared sites
- Transport on standard Army ground vehicles
- Two-man operating team
- Minimum time and skills for operation
- Reliable RPV recovery

Difficulty in evolving a reliable recovery system led to the compromises of some of these goals. The system fielded was oversized to ensure reliability in recovery. The resulting ground signature is large, but potentially subject to concealment by camouflage techniques. The system operates well from unprepared sites if clearance criteria are observed in site selection. The system is portable and is transported on the two M345 trailers. The system can be operated with a two-man team. Minimum set-up times were not established during field testing. Recycle time with two men is approximately 0.5 hour. The system is operated by E3-level personnel. With over 100 successful recoveries (and 100-percent recovery success upon system engagement) the system reliability is indeed high. The tight pattern of vertical barrier impact points indicates the potential for reduced size of retrieval system and improvement for operations in a tactical environment.

5.5 ELECTRICAL GENERATORS

Electric power for the RPV-STD system is supplied from Government-furnished diesel electric generators rated at either 30 or 45 kW. These generators were mounted by LMSC on Government-furnished utility trailers, generally designed to accommodate either generator. LMSC has provided specific mounting hardware for the 45-kW units; the 30-kW units were delivered on their respective trailers. Table 23 shows the trailer type and associated generator as delivered to the Army.

In addition to having the generators mounted on trailers, a power control switch box has been designed and installed on four trailers. The switch box provides auxiliary fusing and permits transfer of electric loads between generators in case of a generator failure. Nominally, one generator provides the GCS air-conditioning loads and another supplies all other electric power for

TABLE 23. AQUILA GENERATOR TRAILER ASSEMBLIES

Item	Generator Model, Power, and Manufacturer		
	JHD W45A (45 kW) FSN 6115-075-9122 Hollingsworth Diesel	450 (45 kW) FSN 6115-840-8258 Consolidated Diesel	CE-301-AW/WK1 (30 kW) FSN 6115-077-8600 Hol-Gar Diesel
Utility Trailer, Two-Wheel M200A 1, 2-1/2 ton (FSN 2330-331-2307)	4	1	
Utility Trailer, Four-Wheel Tandem 1A002M67 (FSN not available)			2
Utility Trailer, Model T52 (FSN not available)		1	
Switch Box (LMSC)	2		2

the GCS and the launch and recovery systems. Two of the trailer-mounted generator assemblies are shown in Figure 146.

5.5.1 Detail of Generators and Trailers

The following subsections provide characteristics for the generators and trailers used in the Aquila RPV-STD programs. Estimated maximum peak power required for the ground support system is approximately 17 kW. Significantly larger generators were used (1) because they were more readily available as GFE, (2) they provided margin against unexpected power drains, and (3) they provided auxiliary power for test observation vans, and test equipment not directly associated with the system.

5.5.1.1 John R. Hollingsworth Model JHDW45A Diesel Generator Set. The Hollingsworth Model JHDW45A generator set is a portable, skid-mounted,

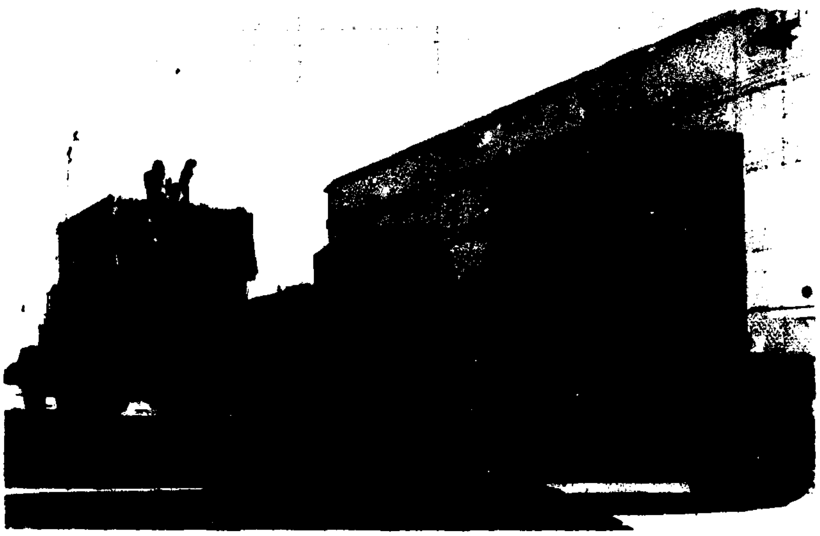


Figure 146. Trailer-Mounted Electrical Generators

winterized, self-contained unit. It is provided with the controls, instruments, and accessories necessary for operation as a single unit and for operation in parallel with other generator sets. This generator set can be connected to deliver three-phase four-wire, 120/208-V, 240/416-V, or 120-V, three-phase, three-wire, 60-cycle alternating current (ac). The ac generator is directly driven by a six-cylinder diesel engine. Engine speed is regulated by an electric governing system. All operating controls and major components are readily accessible through hinged doors mounted on the housing. A lifting eye is located on top of the lifting frame. Towing eyes are provided at each end of the skid frame. An auxiliary fuel hose is stowed on the left side of the generator set. A paralleling cable is stowed in the tool box. The winterization equipment consists of an engine heater and an ether primer.

The Continental Model TD427 diesel engine is a liquid-cooled, six-cylinder, valve-in-head, four-stroke-cycle, full diesel engine. It is rated at 83 hp at 1,800 rpm, and 75 hp at 1,500 rpm. When operated under full load, the engine speed is governed at 1,800 rpm. An altitude compensator is provided in the air intake system to maintain engine power at altitudes up to 8,000 ft above sea level. The engine has a 24-V, negative grounded electrical system with two 12-V batteries and a battery-charging system including alternator, rectifier, and voltage regulator. The engine is equipped with a primary fuel filter, two secondary fuel filters, two identical lubricating oil filters, and an air cleaner. Coolant is circulated through the engine by a water pump. Safety devices are provided to stop the engine automatically in case of high coolant temperature, low oil pressure, low fuel level, or overspeed. An Electric Machinery Model 631454G generator is used.

5.5.1.2 Hol-Gar Model CE-301-AC/WK1 Diesel Generator Set. The Hol-Gar Model CE-301-AC/WK1 generator set is a precise-power, fully winterized 30-kW, 60-cycle, single- and three-phase unit, convertible to a 25-kW, 50-cycle unit. It is completely enclosed with a sheet metal housing. Doors are provided for easy access to the generator set components. The instruments and controls necessary for the proper operation of the generator set are located on the instrument panel at the rear of the unit.

Many physical features of this generator set are similar to those of the Hollingsworth model, including towing eyes, auxiliary fuel hose, and engine heater. The engine is a three-cylinder diesel, Model 5033-7101, made by Detroit Diesel Engine Division of General Motors Corporation. The generator is a Westinghouse, style 653J044G01, with voltage options of 120/208, and 240/416. Voltage of 60 Hz is provided at 1,800 rpm and is maintained within 4 percent of rated voltage throughout the load range.

5.5.1.3 Consolidated Model 4150 Diesel Generator Set. The Consolidated diesel generator set, Model 4150-0009, is a self-contained, skid-mounted unit. It is powered by a six-cylinder, valve-in-head, four-cycle, full diesel engine, which is connected to the generator by a disk coupling. The necessary controls and instruments for single or parallel operation, and for operation of the winterization equipment, are located on the instrument control panel. Accessories are accessible through hinged side and rear doors. The generator is equipped with a lifting link located in the center of the housing roof. Towing holes are located at each corner of the skid frame to facilitate easy movement.

The physical features of this generator set are similar to those of the two already described. A Continental TB427 six-cylinder diesel engine is used (the same as that used in the Hollingsworth set). The generator provides voltages of 120 delta, 120/208, and 240/416.

5.5.1.4 2.5-Ton, Two-Wheel Generator Trailer, Chassis M200A1. This 2.5-ton, two-wheel generator trailer chassis consists of a frame onto which are secured two generator mounting support assemblies and two step-jack assemblies. This trailer has a retractable landing leg in front and step jacks in the rear. Extending downward from the rear of the frame is a retractable landing leg assembly used for support of the front end or nose of the chassis when uncoupled. It is equipped with a conventional tubular trailer axle with dual wheels and a spring suspension. A lunette is located at the front end of the frame for attachment to a vehicle equipped with a drawbar or towing pintle.

The trailer chassis can be towed over prepared roads with loads of 6,200 lb at a maximum speed of 55 mph and over unimproved roads, trails, and open rolling terrain with loads to 6,200 lb at a maximum speed of 30 mph. It will ford hard-bottom water crossings to any depth that can be negotiated by the towing vehicle.

The trailer chassis is towed by the 2.5-ton 6-by-6 cargo truck M35 or similar vehicle.

5.6 GROUND SUPPORT, TEST, AND CHECKOUT EQUIPMENT

Ground support equipment (GSE) for the Aquila RPV involves a number of unique items that required specific design, and in some cases development, to accommodate the unique requirements associated with an RPV system. These requirements include RPV handling, RPV assembly, RPV checkout, RPV fueling, engine starting, RPV power-up, and RPV subsystem testing. In addition, certain standard instruments and tools were required for conventional surveying and electrical checkout activities and for maintenance and assembly. The following paragraphs briefly describe this special Aquila ground support, test, and checkout equipment. Additional information is provided in Reference 18.

5.6.1 RPV Assembly and Handling Equipment

Supporting the RPV during assembly and checkout, and moving the assembled RPV to the launcher, require special fixtures. This requirement arises primarily because RPV elements such as the payload dome and antenna must be protected, and because the RPV has no landing gear of its own.

5.6.1.1 RPV Assembly Stand. The assembly stand is constructed simply from welded aluminum angle, industrial casters, and clamps, as shown in Figure 147. The frame serves as an assembly stand both during manufacture and in field operations. Four rubber pads are provided to support the RPV at its hard points near the wing root. Assembly clamps are provided in conjunction with the rear supports to secure the RPV to the stand. In addition, an adjustable over-center locking clamp arrangement is provided to engage and hold the RPV by its launch skeg. By proper bracing of this lock mechanism to react thrust loads, and by proper anchoring of the stand (sandbagging the wheels), the stand is also used as an engine run-up stand.

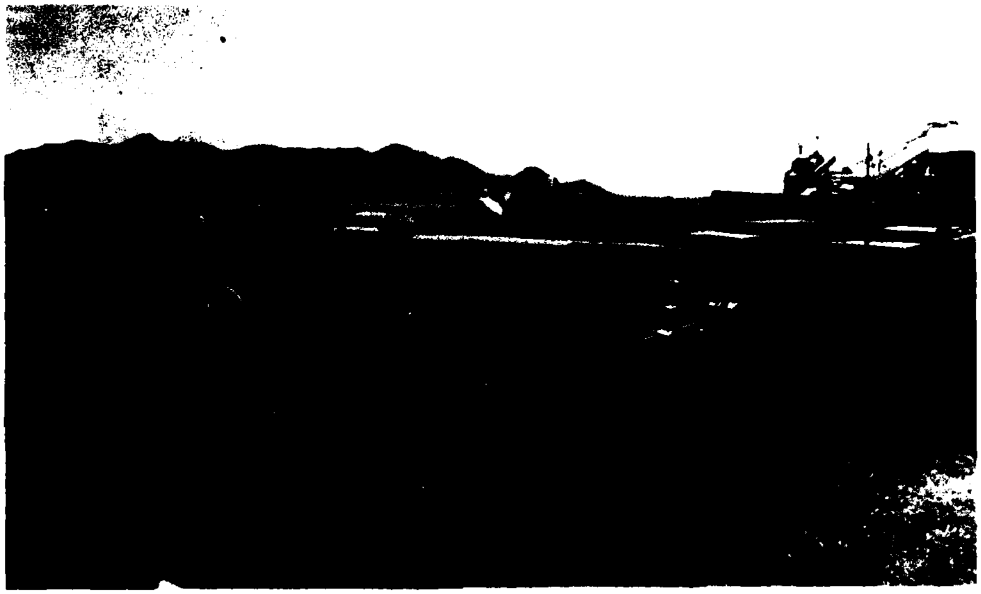
5.6.1.2 RPV Handling Frame. The RPV handling frame consists of a pipe and tube frame and is used to move the RPV from the workstand to the launcher. The equipment splits in half so that it can be easily moved into position around the RPV when on the assembly stand and is then bolted together and attached to the airframe with nylon straps. Two carrying handles at each end of the frame allow two men to carry the plane easily, one walking in front of the plane and one behind. Figure 148 shows the RPV being put on the frame and transferred from the workstand to the launcher. In this case, there is a man at each corner of the frame so that the RPV can be carried up the steps at the end of the launcher. The four-man carry was typically used during the field testing. The frame is constructed so as to permit the RPV to be set down on the ground without loading any component of the RPV such as the payload dome or duct.

5.6.1.3 Mounting Steps. Metal steps are provided for personnel access to the launcher truck bed on either side of the rear of the launcher. These steps, shown in Figure 148, permit access to the launcher and its subsystems, and allow personnel to ascend to the launcher shuttle while carrying an RPV. A similar set of steps with hand rails is provided for the ground-station truck bed to allow personnel access to the ground station.

a. Assembly Application

b. Field Application

Figure 147. Aquila Assembly Stand



a. Lifting RPV From Workstand

b. Carrying RPV up to Launcher Shuttle

Figure 148. RPV Carrying Frame

5.6.2 Equipment for RPV Preparation, Checkout, and Test

The Aquila RPV must be checked out quickly under field conditions. This requires both special and standard test units. These are described in the following paragraphs. Additional description and application data are provided in Reference 17.

5.6.2.1 RPV Power Supply and Control Panel. Ground power (28 Vdc) for test and operation is provided by a rugged DIGIAC PP62241U power supply and is selectively distributed by an RPV ground control box specially designed by LMSC for the Aquila system. Both units and the RPV umbilical power cord are shown mounted to a carrying board in Figure 149. The system is powered by 110-V 60-Hz alternating current. The carrying board permits transporting the system from the checkout area to the launcher. Figure 150 shows the RPV control box panel and designates the various controls and switches. The primary

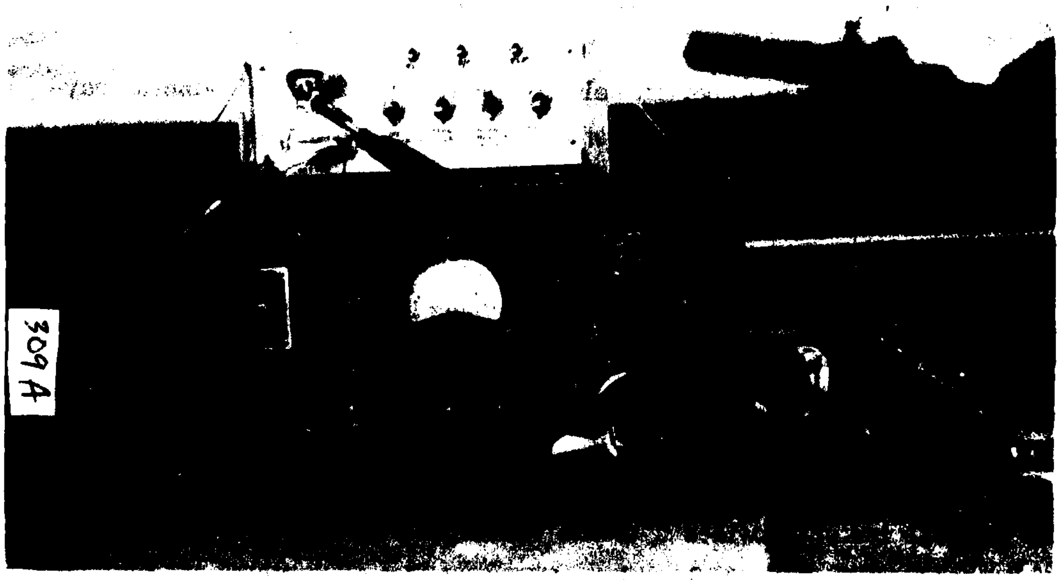
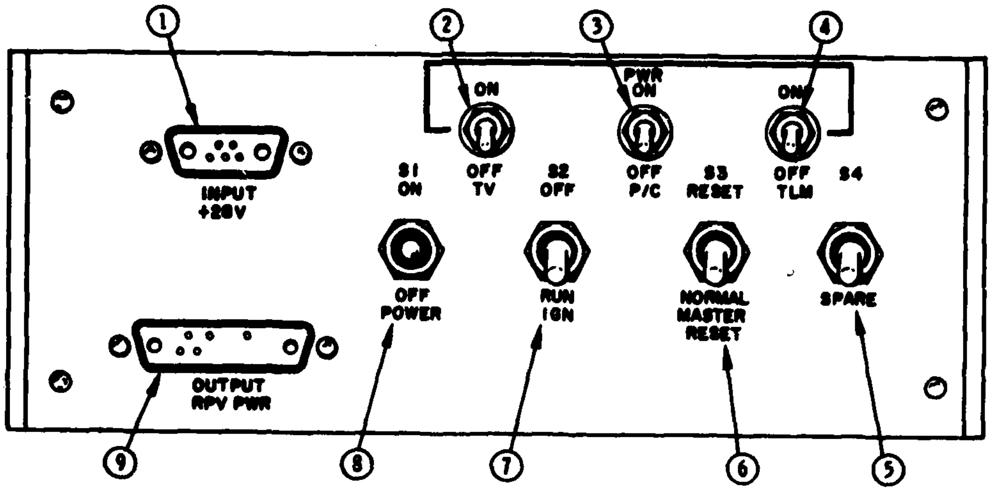


Figure 149. RPV Power Supply and Control Panel



CODE			
1	INPUT +28-V RECEPTACLE	5	SPARE SWITCH
2	TV ON/OFF SWITCH	6	MASTER RESET
3	PAYLOAD/CAMERA ON/OFF SWITCH	7	IGNITION OFF/RUN SWITCH
4	TELEMETRY ON/OFF SWITCH	8	POWER ON/OFF SWITCH
		9	OUTPUT RPV POWER

Figure 150. RPV Control Panel, Controls and Receptacles

function of the design is to permit selective power-up of the TV camera, payload gimbals and film camera, airborne transmitter, autopilot reset, engine kill, and RPV power relay. This selectivity aids in checkout and troubleshooting.

5.6.2.2 Suitcase Tester. This test unit derives its name from its installation in an aluminum suitcase for transportation in the rugged field environment. The unit is manufactured by METRO DATA of Norman, Oklahoma. The unit is pictured in Figure 151.

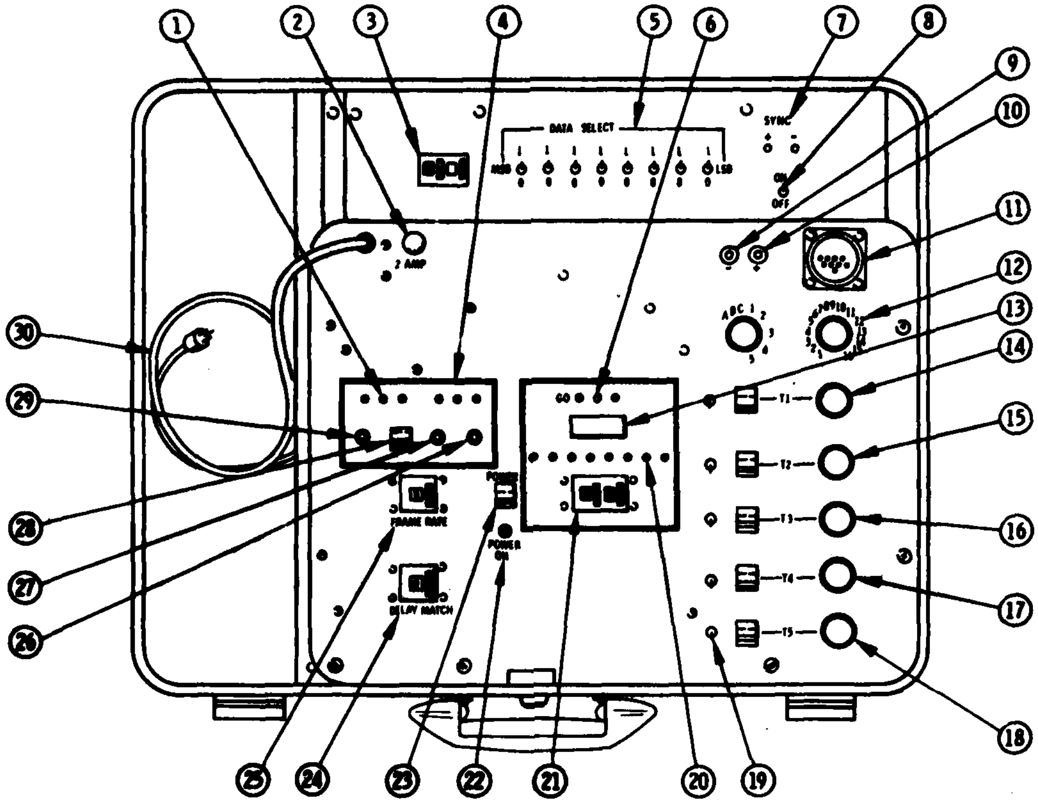
The suitcase tester provides a means for ground testing of the RPV, at the assembly area or on the launcher, to ensure that all systems are functioning properly. The tester sends commands to the RPV and verifies proper

Figure 151. Suitcase Tester

responses to the commands. The digital command signals are transmitted to the RPV via the uplink. The digital downlink data are checked against preset parameters in the tester for a go or no-go condition.

Figure 152 describes the controls and indicators on the tester console. There are three programmable read-only memories (PROMs) in the tester, each of which contains a command memory, an upper-response-limit memory, and a lower-response-limit memory. With each PROM, the three memories are connected on a common address bus so that, when a specific command is programmed, the corresponding upper limit and lower limit will be programmed at the same time. Each PROM is programmed to contain eight 32-word frames in each of its three memories. The tester incorporates automatic and manual provisions for testing the RPV.

Details of the RPV checkout procedures and use of the suitcase tester are defined in Reference 17.



CODE

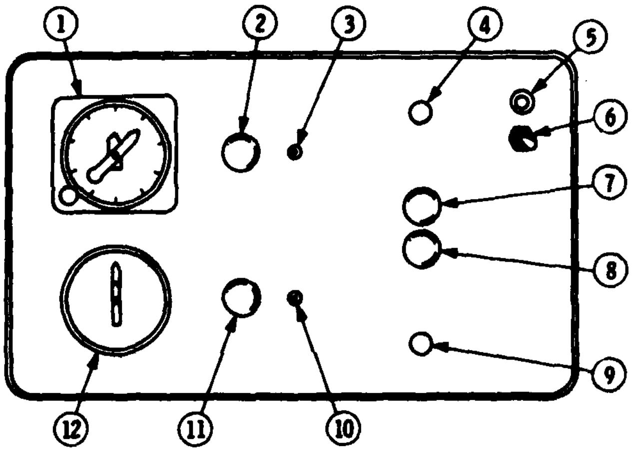
1	PROM INDICATORS	19	T1 THROUGH T5 TOGGLE SWITCHES
2	2-A FUSE	19A	LINK LOSS DOWN
3	CWS WORD SELECT		HE UP
4	FRAME INDICATORS		AE UP
5	DATA-SELECT TOGGLE SWITCHES		AL UP
6	ERROR (YELLOW) INDICATOR		PE UP
	ERROR-ON-DISPLAY (YELLOW) INDICATOR	20	DWS WORD SELECT (8 INDICATORS)
	GO (GREEN) INDICATOR	21	DWS WORD SELECT
7	SYNC TEST JACK	22	POWER-ON INDICATOR
8	CUE TOGGLE SWITCH, ON/OFF	23	POWER TOGGLE SWITCH
9	TEST JACK - (NEGATIVE)	24	DELAY-MATCH (SINGLE-DIGIT) THUMBWHEEL SWITCH
10	TEST JACK + (POSITIVE)	25	FRAME RATE (SINGLE-DIGIT) THUMBWHEEL SWITCH
11	CONNECTOR PLUG	26	MASTER-CLEAR PUSHBUTTON SWITCH
11A	ROTARY SWITCH	27	ADVANCE PUSHBUTTON SWITCH
12	ROTARY SWITCH	28	DYNAMIC/STATIC TOGGLE SWITCH
13	LEDs	29	DR-CLEAR PUSHBUTTON SWITCH
14	LAS_n POTENTIOMETER	30	POWER CABLE
15	h_m POTENTIOMETER	(Upper right corner of panel)	S-SCOPE JACK, PCM DOWN
16	A_n POTENTIOMETER		C-SCOPE JACK, PCM UP
17	$\dot{\eta}$ POTENTIOMETER		
18	RPM POTENTIOMETER		

Figure 152. Suitcase Tester, Controls and Indicators

5.6.2.3 Air-Data Test Set (ADTS). As an augmentation to the suitcase tester, the air-data test set provides a calibrated air pressure source for checking the accuracy of the altitude and airspeed transducers in the RPV. The unit was fabricated by LMSC for Aquila field testing. The panel of the unit is shown in Figure 153. The static and dynamic pressure controls permit input through tubes and sealed fittings into the RPV static and pitot pressure parts. Corresponding responses from the autopilot are monitored by the suitcase tester and a digital multimeter. The setup for this test is shown in Figure 154, which also depicts an alternate test procedure using a U-tube water manometer and rolling clip to create known pressures at the pitot and static tubes.

5.6.2.4 Elevon Protractors (Deflection Angle Markers). Elevon protractors, fabricated of thin-gage aluminum sheet, are provided to aid in RPV checkout. These protractors indicate elevon position as the suitcase tester activates the various RPV responses. The protractor units clip to the outboard end of the elevon cutout. The units do not restrict elevon motion. Adjustment is provided to calibrate (match) the zero indication with the zero deflection position.

5.6.2.5 RPV Fueling System. The RPV bladder fuel tank requires a special fueling system to inject the RPV fuel efficiently and leave no air residue or bubble. The system, fabricated by LMSC, comprises a fuel tank, a sight glass for determining the amount of fuel in the tank, valves for regulating the direction of fuel flow (out of or into the system), and two hand pumps, one for pumping fuel into the RPV fuel cell, and the other for withdrawing fuel from the RPV fuel cell and pumping it into the fueling system. The system is shown in Figure 155. The defueling pump can also be used to purge the RPV fuel cell of entrained air. The system is designed so that, when the RPV fuel cell is filled completely or partially, no air is trapped within it to cause engine hesitation or failure; also, the operator can determine exactly how much usable fuel has been transferred into the RPV fuel cell by comparing beginning and final readings on the sight glass.



CODE

1	ALTITUDE INDICATOR
2	ALTITUDE GATE VALVE
3	STATIC HOSE
4	STATIC PRESSURE BLEED VALVE
5	POWER CORD (110 VAC, 60 HZ)
6	ON/OFF TOGGLE SWITCH
7	STATIC PRESSURE COURSE CONTROL
8	DYNAMIC PRESSURE COURSE CONTROL
9	DYNAMIC PRESSURE BLEED VALVE
10	DYNAMIC HOSE
11	AIRSPEED GATE VALVE
12	AIRSPEED INDICATOR

Figure 153. Air-Data Test Set, Controls and Indicators

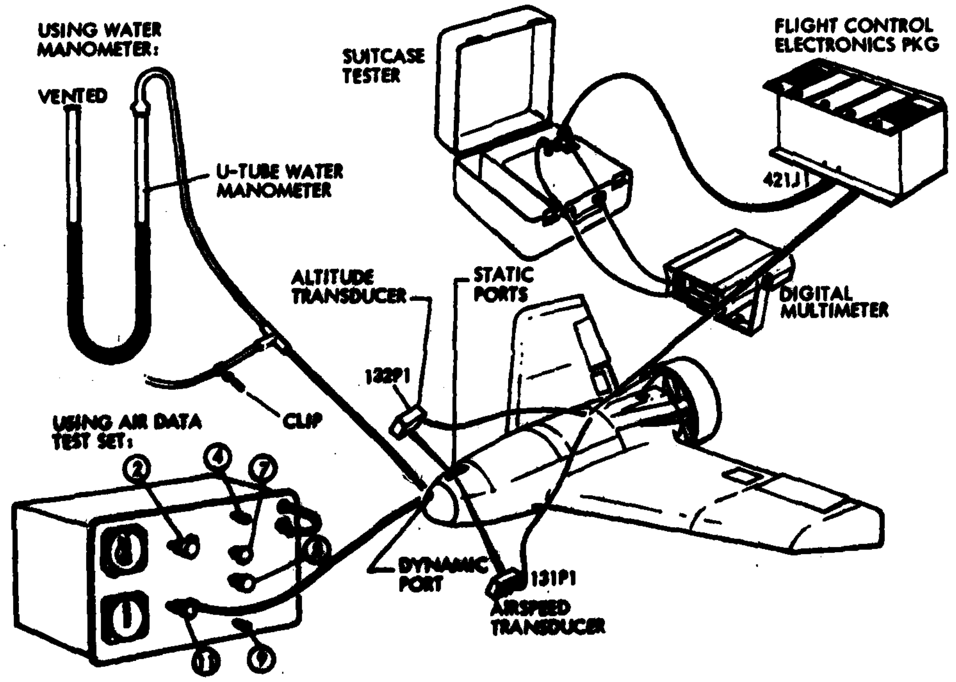


Figure 154. Connections for Checkout of Air-Data System

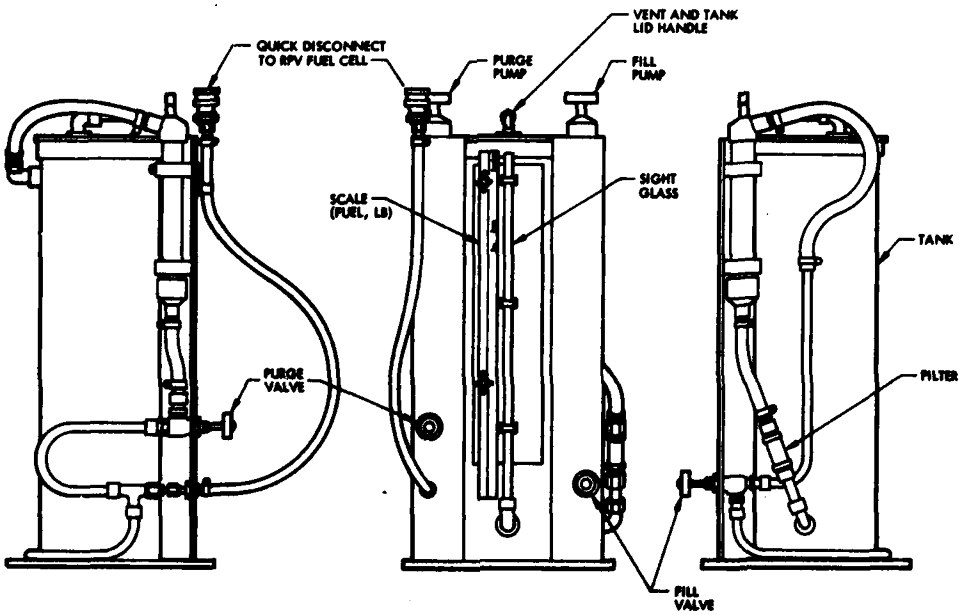


Figure 155. RPV Fueling System

5.6.2.6 Engine Starter (Hand-Held). RPV checkout operations require starting the engine before placement of the RPV on the launcher, where the automatic starter can be used. Consequently, a hand-held starter assembly was constructed. The starter power unit, made by R&D Enterprises, is shown in Figure 156. The unit is basically an automotive starter unit and relay mounted to a hand-held frame. The unit is completed by the addition of a unidirectional Bendix drive and shaft.

This arrangement prevents the torque from a started engine from overdriving the starter motor. The drive shaft is slotted to mate with the pinned cylinder in the propeller hub. A standard 12-V car or truck battery is used to power the unit.

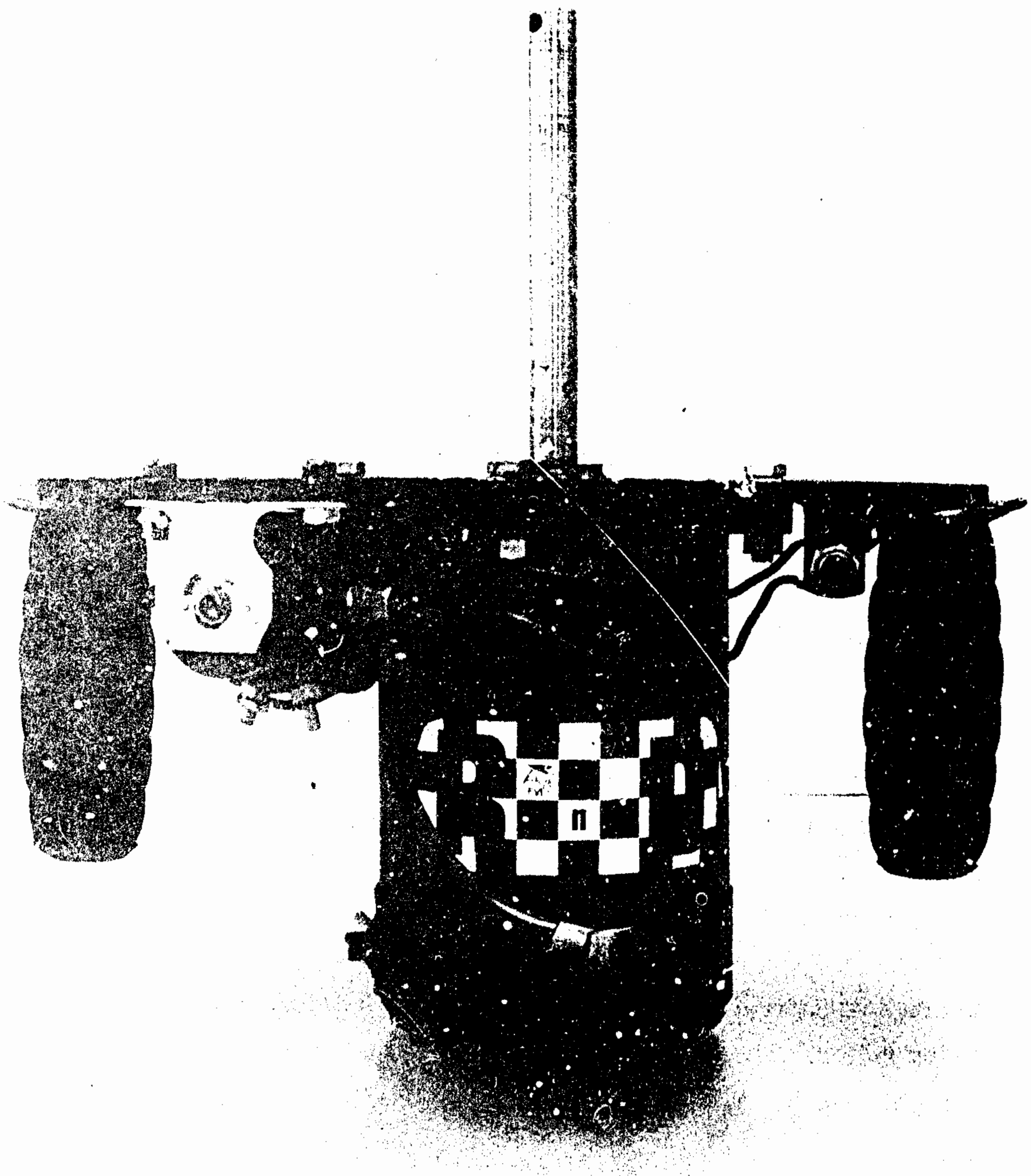


Figure 156. Engine Starter Power Unit

5.6.3 Standard Equipment and Tools (Government-Furnished)

In support of site setup, equipment maintenance, RPV/GSS checkout, and assembly and site safety, standard Government-furnished equipment is provided. This equipment is listed in Table 24.

TABLE 24. STANDARD GOVERNMENT-FURNISHED EQUIPMENT AND TOOLS

Item	Federal Stock Number
Tool Kit, Shelter	5180-00-987-9796
Tool Kit, Electronic	4935-00-532-9112
Tool Kit, Instrument	5180-00-699-5273
Pump, Hand	4930-00-276-0087
Shovel, Hand	5120-00-222-4505
Pick, Digging	5120-00-187-8679
Hammer, Sledge	5120-00-243-2957
Survey Set, 5th Order, Service	As required
Theodolite, Survey	6675-00-232-8972
Extinguisher, Hand	4210-00-202-7858
Extinguisher, Wheeled	4210-00-203-0341

Section VI

SITE GEOMETRY AND SELECTION

An Aquila operational site contains all of the elements necessary to support flight operations in a field environment. All system components are mobile and/or portable; the entire system can be transported using two M36 and two M35 Army trucks, and the trailers for the recovery system and the generators. No site preparation is normally required prior to site setup, with the exception of an existing benchmark or one laid in from other benchmarks and the clearing of possible flight obstructions.

6.1 SITE GEOMETRY

The Aquila system requires a site that is approximately 108 by 72 m, is reasonably level, and varies in elevation no more than approximately 6 m boundary to boundary. The launch and recovery corridor should be oriented into the prevailing wind when practicable, and must be clear of obstructions as described in subsection 6.2. Clearance must exist for the 4-deg descent angle and climb-out angle dictated by RPV weight and density altitude. The site is composed of the following basic elements:

- Ground control station (GCS)
- Launcher
- Retrieval system
- Assembly tent (optional)
- Generators
- Fuel storage area
- Grid reference benchmark

The orientations of these elements are interdependent. Layout restrictions imposed by individual elements are described in subsection 6.2. A typical site layout is illustrated in Figure 157.

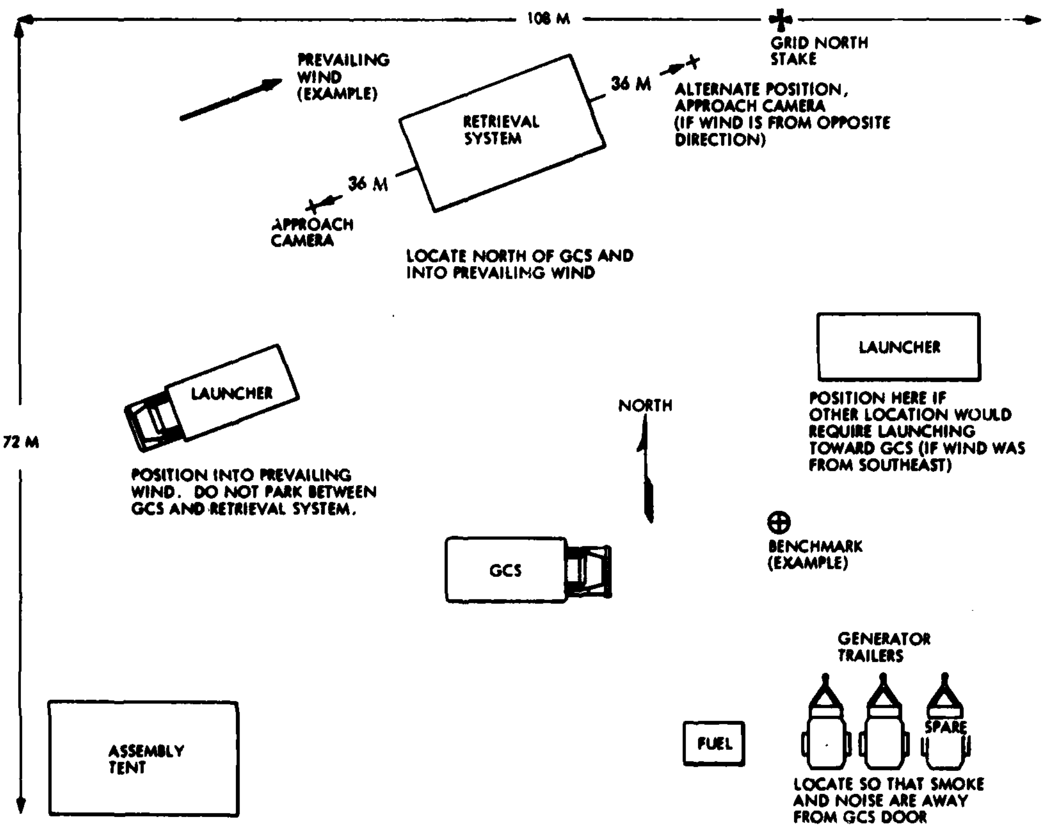


Figure 157. Site Layout (Typical)

5.2 SITE DESCRIPTION/SELECTION

Due to the number of variables in the site selection process, it is difficult to specify briefly the requirements for an acceptable site. Terrain, foliage, ground elevation, and climate all influence the choice of the site location. The Aquila system is designed to permit flexible operation over wide operating limits, and exceeding these limits during flight operations will not "fail" the system. However, system operation from nonoptimum (i.e., non-flat) ground sites, such as at the foot of bluffs, or on hillsides, may affect total system flexibility (i.e., sector of operation) and/or mission capability; the ultimate selection of a site must therefore consider the overall objective of the flights.

6.2.1 Site Selection and Arrangement

General site selection and arrangement are determined with regard to the following requirements: site density altitude, command and control line of sight, launch and recovery corridors, system layout, and mission.

6.2.1.1 Site Density Altitude. The Aquila RPV is designed for use at or below a rated service ceiling of 12,000 ft. This value is equated to density altitude, which can be computed by correcting pressure altitude for nonstandard temperature variation. Although often close to absolute or "tapeline" altitude, density altitude is highly dependent on temperature. Figure 158 contains a graph for computing density altitude given pressure altitude and temperature.

RPV rate of climb after launch is inversely related to density altitude. Therefore, operating sites should not be selected in areas where ground elevation and temperature combine to create launch conditions at density altitudes in excess of 8,000 ft. At density altitudes above this value, RPV climb performance is not adequate to permit safe launch and recovery operations.

6.2.1.2 Command and Control Line of Sight. The command uplink and status downlink frequencies used in the Aquila system (4,861 MHz and 4,530 MHz, respectively) allow RPV command and control under line-of-sight conditions only. The single exception to this requirement would occur when the dead-reckoning flight mode (see subsection 3.4.4, Vol. II) is made available for flights behind obstructions such as hills or mountains.

For launch and recovery, clear, unobstructed line of sight between the RPV and GCS is mandatory; therefore, the site should be selected to provide a clear line of sight to the airspace over the entire area to be overflown. The GCS should be located clear of terrain obstructions and as high as system layout restrictions outlined in subsection 6.2.1.4 allow. GCS operation near conductive structures (e.g., high-tension towers and cyclone fences) should be avoided to prevent command and control link shielding or beam distortion.

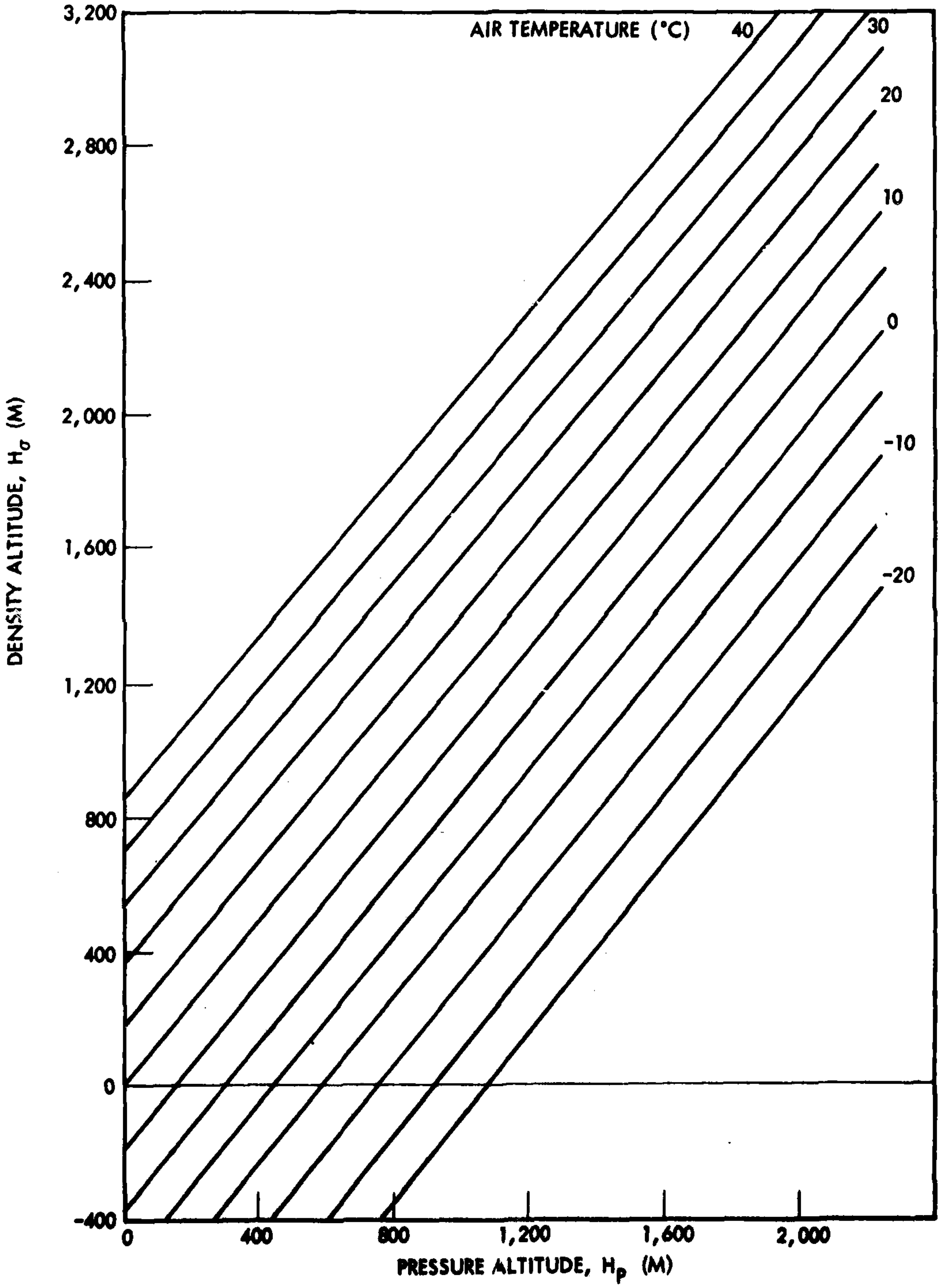


Figure 158. Density Altitude Determination

6.2.1.3 Launch and Recovery Corridors. The Aquila RPV was designed for balanced launch and recovery performance. Since nominal climb and recovery approach angles are the same, similar terrain restrictions apply to both launch and recovery. The Aquila RPV has demonstrated a launch and recovery flightpath of 4 deg above the horizon. To ensure sufficient terrain clearance during launch and recovery, there should be no obstructions (1) higher than 1 m for a distance of 100 m, (2) higher than 2 m for a distance of 300 m, and (3) higher than a 2-deg slope above the 2-m height from 300 m to 1,000 m within 45 deg of each side of the projected centerline (Reference 17, Vol. III, and Reference 5). In areas where this is impractical, operation is still possible if a corridor at least 25 m wide and 1,000 m long along the centerline can be cleared as described.

6.2.1.4 Site Layout Requirements. Once a relatively level, accessible location has been selected that satisfies the above requirements, the site is laid out as follows.

Retrieval system. The retrieval system consists of two trailer-mounted vertical nets with a horizontal landing net strung between them, and a final-approach video camera assembly with two camera stands. The vertical nets are mounted on two M345 trailers which are fully mobile until the system is erected. The horizontal net should be positioned into the prevailing wind if possible (but no more than 40 deg off). If obstructions cannot be removed because of their type or lack of time, the horizontal net should be oriented in the direction of the fewest obstructions. Obstructions are defined as objects higher than 2 deg above the horizon for a distance of 1,000 m from the center of the net.

Only the upwind vertical net is raised; the downwind net is assembled but not raised. If the wind is from the opposite direction when the RPV returns, the net that had been at the downwind end is raised and the other net is lowered. The approach camera position is also reversed.

The nets should be located on a reasonably smooth area so excessive blocking will not be necessary to level the trailers. Also, all bushes, rocks, etc., must be removed from the area beneath the horizontal landing net to prevent RPV damage on retrieval.

When the location of the retrieval system has been selected, a stake is placed in the ground at the center of the desired net location. Additional stakes are used to mark the locations of the approach camera stands after their positions have been calculated. A 30-m surveyor's tape is provided for this purpose. An approach camera stand is positioned at each end of the horizontal net and on its centerline, with the distance from the center of the net to each stand determined by the formula:

$$D = 45 - (L/2) \tag{4}$$

where D is the distance in meters from the center of the horizontal net to the camera stand, and L is the horizontal net strap length in meters. This adjustment is necessary to maintain a fixed relationship between the vertical nets and the camera stands.

The camera stands must be adjusted to position the camera body approximately 1.5 m above the ground. On uneven ground it may be necessary to raise or lower the camera support until it is approximately even with the bed of the nearest trailer. To prevent obstruction of the approach path, the camera support should not extend above the bed of the nearest trailer. For a rapid visual check of camera stand alignment, an observer at one stand should be able to see the top of the other stand centered over the alignment targets mounted on each trailer. The approach camera assembly is mounted on the camera stand used for the primary recovery direction (the upwind stand) and is centered on the approach slope, looking through the vertical nets, using procedures contained in Reference 17, Vol III.

The approach camera stands are connected to the GCS using three cables, one 6577245-501 and two 6577245-503. The -503 cables, each 45 m in length, are connected to the approach camera stand J-boxes, and are then routed along the side of the recovery net facing the GCS. The -501 cable is connected to the GCS, and the other end is positioned next to the two mating ends of the -503 cables. The alternate final approach camera location is selected by moving the camera assembly to the other stand, connecting the appropriate -503 cable to the -501 cable, and aligning the camera to the new recovery slope. Detailed descriptions of the erection and alignment of the retrieval system are contained in Reference 17, Vol. III.

Launcher. Primary and secondary launcher positions are selected to provide a level platform for the launcher, and to permit use of the same flight corridors required by the retrieval system. Once the launcher positions are selected, they should be staked and surveyed. During launch operations, the launcher must be positioned over the survey stake to ensure a proper prelaunch initialization. The launcher is connected to the GCS using the 45-m cable 6577243-501. If additional length is required, a 45-m extension cable is provided.

The launcher should be positioned into the wind as much as conditions allow; however, the launcher must not be positioned so as to launch over other elements of the site, or toward ground obstructions not in accordance with subsection 6.2.1.3. Specific launcher elevation angles and launch pressures are described in subsection 5.2.

Ground Control Station. The GCS is the central component of the Aquila site. Since all power and control cables are routed through the GCS, its location is critical to the operation of the system. The following considerations should be followed in placement of the GCS:

- Attitude. The GCS should be located in a relatively flat area with easy access to all system components. The parking direction is not critical. For unobstructed tracking, the GCS must be leveled to within ± 3.0 deg, both laterally and longitudinally. At greater angles, insufficient clearance exists within the tracking antenna radome to permit antenna rotation. This requirement is best attained by placing an inclinometer on the floor of the GCS, and moving the truck as required. In areas where no adequate level location is available, jacking one side of the vehicle, digging away ground, or letting some air out of the tires may be necessary. Once the proper location is selected, the truck parking brake is set, the wheels are blocked, and the lightning protection system is installed.

- Retrieval System Orientation. The GCS should be located from 15 to 75 m from the center of the retrieval system, on a line as perpendicular to the planned recovery path as conditions allow. The maximum distance of 75 m is determined by the length of the ground camera cable. The requirement for perpendicularity and the 15-m minimum spacing are necessitated by the tracking antenna slew rate limit of 30 deg/sec. RPV flight close to the tracking antenna could cause loss of track if the antenna slew rate is exceeded.
- Launcher to GCS Orientation. The GCS must be located from 15 to 90 m away from the launcher. Maximum distance is determined by launcher cable length; the minimum distance is controlled by tracking antenna slew rate limits. Additionally, the tracking antenna should not be elevated more than 2.0 deg above the RPV when mounted on the launcher to avoid tracking antenna pattern nulls that could cause loss of link or failure to lockup the data link for checkout.
- Tracking Antenna Line of Sight. The GCS-mounted tracking antenna must have a clear line of sight that covers all anticipated types of missions to be flown, with the exception of dead reckoning legs.

Assembly Tent. The assembly tent is an optional item. When an assembly tent is used with the Aquila system, it should be located within 45 m of the GCS. The location must provide access to the launcher and retrieval net to allow hand carry of the RPV to and from those areas. The tent should not be installed within the launch and retrieval corridor.

A tent J-box is provided that connects to the GCS using a 76-m cable (6577244-501). The J-box is mounted in the tent and provides 120-Vac 60-Hz power, and an interphone station for communication with other site elements.

Fuel Storage. The fuel storage area must be located a safe distance away from all other elements of the ground system. Access to the assembly tent area is required to support flight operations. Current Army directives regulating the storage and handling of aviation gasoline and diesel fuel govern the methods of storage authorized.

Generators. Two 30-kW diesel generators (Hol-Gar, Model CE-301-AC/WK1 or equivalent) provide all required site power. For mobility, these units are mounted on Army T52 utility trailers. The generators should be positioned downwind as far as practical from the GCS to minimize noise and eliminate fume hazards. The maximum distance is 45 m due to cable length. The generators are connected to the GCS using two parallel 45-m cables (6577241 and 6577242). The two generators are interconnected using a 7.6-m cable (6577253). Specific requirements for generator grounding and operations are covered in the applicable generator operator's manual and in Reference 17, Vol. III.

Grid Reference Benchmark. Each site to be used for flight operations must be provided with a grid reference benchmark. The benchmark must provide the following information:

(1) UTM grid northing: ±0.1 m
(2) UTM grid easting: ±0.1 m
(3) Benchmark elevation: ±0.1 m
(4) UTM grid north bearing: ± 1 mradian

The benchmark must be located in an area contiguous to the site, with unrestricted fields of view to the GCS, retrieval system, and launcher. Also, the benchmark should be located between 10 and 50 m from the GCS tracking antenna to facilitate antenna alignment.

The UTM grid north reference should be provided by positioning a target stake approximately 20 m from the benchmark and in an area where it is visible. If no target stake can be provided, a small landmark, located more than 2 km away, can be referenced from the benchmark if repeatable ±1.0 mradian bearing accuracy is attained.

Once the benchmark is surveyed, the Government-furnished theodolite is set up over the benchmark and aligned to grid north. Grid bearing and distance from the benchmark to the launcher stakes and retrieval net stake are measured using the theodolite and surveyor's tape. The distance between the benchmark and GCS tracking antenna is also measured. These values are recorded for later entry into the computer during site initialization. Use of the theodolite for antenna azimuth alignment and recovery bearing determination is described in Section VII.

6.2.1.5 Mission Requirements. As stated earlier, the requirements for site selection have been established to provide optimum field operating conditions. Mission requirements may dictate variance from the site selection parameters stated above. The field test results obtained to date demonstrate that the current Aquila system can be successfully operated under nonoptimum site conditions. Since mission considerations must take precedence during military operations, it is therefore necessary to accept less than optimum site selection criteria at times when the tactical situation warrants the attendant risk.

6.3 PROGRAM REQUIREMENTS AND CAPABILITIES

The requirements for the Aquila demonstration program that relate to the site selection and geometry are as follows:

- Launch and retrieval of the RPVs must be accomplished from unprepared sites.
- Insofar as feasible, all ground support equipment required for transportation, loading, unloading, servicing, or a source of power at the user level shall be standard items of equipment listed in SB 700-20.
- Ground transportability requirements shall be compatible with existing conventional Army ground vehicles.

6.3.1 Demonstrated System Capabilities

During the period from January 1976 to December 1977, LMSC and Army personnel conducted almost 150 flights of the Aquila RPV from three different operating sites at Fort Huachuca, Arizona. These operations were conducted using site selection and preparation procedures as outlined above. All components of the ground site are currently transportable using existing Army ground vehicles. These successful flight tests demonstrated the compliance of the ground site selection and layout criteria with the Army requirements for an operable RPV system that is compatible with existing Army support equipment.

Section VII
SYSTEM OPERATION

This section describes the man-machine interface required to enable the hardware to perform the RPV missions in a safe and efficient manner. This section also highlights the overall operational capabilities designed for the Aquila system and describes briefly the development of these capabilities.

7.1 OPERATIONAL SCENARIO

From the inception of RPV-STD program, Aquila was considered not simply a flight vehicle, but rather an entire weapon system. Beginning early in the preliminary design phase, functional flow analyses of the entire system were conducted to identify and study the interrelated actions required between components of the system and with their human operators. Scenarios were developed to establish the functions required for mission performance, and to ensure that the system had the desired flexibility to meet or exceed all of the required operational capabilities. Direct outputs of these studies were:

- Types and numbers of personnel required for system operation
- Number, type, and placement of operator controls and displays
- Functional assignments for personnel
- Plans and procedures for a sequenced flow of events from arrival at the unprepared site, through flight operations, to departure from the site

The following scenario summarizes the activities required for a typical Phase V target designation mission.

7.1.1 Site Setup Design

The Aquila system is to arrive at the preselected, unprepared site on several M35 and M36 trucks and trailers. The site elements are located in the proper operating relationship to each other, the system components are unpacked and erected, and the location of the key site components are surveyed in relation to the benchmark. When all of the site cabling is completed and site power is on, the site is fully operational and is ready for RPV assembly and checkout.

7.1.2 RPV Assembly and Checkout

RPVs are uncrated, inspected, and assembled in the assembly tent. The required payload is installed, and all electronic assemblies are connected and secured. The assembled RPV is connected to the portable RPV system test set (suitcase tester), and all mechanical and electronic flight readiness checks are completed. If the RPV passes all of these checks, only the rf data link and engine remain to be checked prior to launch.

7.1.3 Mission Planning

While the RPV is being assembled and tested, the pilot and sensor operator are planning the mission. Using the mission requirements as a guide, they decide on the route to be flown, including the altitudes and airspeeds required for maximum mission performance, as well as terrain and climate. Once the mission profile is established, the crew enters the waypoint parameters on a waypoint programming form for review by the site commander. This form is used later to preprogram the computer prior to launch.

7.1.4 Prelaunch Preparation

When the mission has been reviewed and approved by the site commander and the RPV assembly checks are complete, site prelaunch preparations begin. The launcher and retrieval system are checked and prepared for operation, and the RPV is mated to the launcher. Inside the ground control station (GCS), all ground electronics are tested. Data for the planned flight are entered into the computer via a short series of interactive programs that "prompt" the system operators for the information required by the computer to control and monitor the flight. The system checkout is also computer aided, including a system self-test.

7.1.5 Launch

At the completion of the GCS ground system checks, the RPV ground power is turned on and a full data link is established with the GCS. At this time the final RPV and GCS control checks are accomplished by the GCS operators and by the computer. The engine is started, and the RPV changes to internal power. As in previous checkout phases, the computer steps the operators through the final check with instructions and queries on the teletype. The computer automatically compares critical subsystem performance against programmed go/no-go criteria. The computer verifies acceptable performance for the operators and identifies anomalous situations for resolution or override. The pilot reviews the status of the vehicle and fires the launcher. The RPV is now airborne.

7.1.6 Cruise and Navigation

The RPV, now commanded by the ground computer, automatically climbs to the preset altitude and begins to fly to the first programmed waypoint. From this time in the mission until the final approach for retrieval is initiated, the RPV requires little human intervention. The vehicle will proceed from waypoint to waypoint, automatically changing altitude, airspeed, and heading to fly the mission profile planned prior to launch.

The GCS operators monitor the flight's progress on their displays. If a change to the preprogrammed flight plan is desired, the RPV pilot, at his discretion, may reprogram the computer with a new flight plan, or command the RPV autopilot directly with real-time manual flight commands. This combination of preprogrammed, reprogrammed, and manual command modes provides the Aquila system with a degree of mission flexibility sufficient to meet almost any tactical situation occurring while in flight.

As changes in wind velocity and direction cause the RPV to drift off the programmed course, the computer senses the drift offset and commands changes in the RPV heading to bring the vehicle back on track.

7.1.7 Search and Loiter

When the target area is entered, the RPV pilot may command SEARCH. At this time the RPV will leave the preset ground track and begin to fly one of the preprogrammed search patterns. These patterns allow the RPV to fully cover the ground area of interest. At the same time, the sensor operator is controlling the RPV's stabilized video payload in an effort to locate one of the mission targets. As soon as a target is detected, the sensor operator uses the payload laser ranger to fix the range to the target. The computer then computes the target's universal transverse mercator (UTM) position. When the pilot commands LOITER, the RPV is flown in a circular pattern by the computer so that it will remain in the immediate vicinity of the target. For a Phase V designation mission, the RPV site then contacts a Copperhead laser guided projectile battery and forwards the coordinates of the target to them, requesting fire support. When the battery is ready to fire a round, the RPV site is informed, and the sensor operator locks onto the target, activating the laser designator. The target is now illuminated for the laser homing warhead. The battery fires, and, immediately after weapon impact, the RPV sensor operator confirms the weapon's effectiveness. The RPV operators are now free to locate other targets, or to return the RPV to the recovery area as the mission dictates. The RPV returns to the ground site in a manner similar to the outbound flight legs.

7.1.8 Recovery

The computer returns the RPV to the site via a waypoint designated as the initial fix. From this point in the flight until initiation of final approach, all flight commands are generated by the computer. After the RPV reaches the initial fix, it descends along a preprogrammed path that has been selected to provide maximum terrain clearance in this critical flight phase. When the RPV attains the outer marker (waypoint where final approach is initiated), it is normally 1 km from the vertical retrieval net and 75 m above the ground.

7.1.9 Final Approach

The final approach path, or glide slope, is defined by a final-approach video camera on the ground which looks up, through the center of the vertical net, at a 4-deg angle. The sensor operator monitors the ground video display beginning with the RPV's descent from the initial fix. When the RPV is located on the ground video display, the sensor operator, using a joystick, places a video cursor on the RPV image and commands final approach as the vehicle passes the outer marker. With the RPV in final approach, the sensor operator continues to track the incoming image. Using signals generated by the cursor, the computer provides guidance signals to the RPV that will keep it centered on the glide slope. When the RPV is captured by the vertical net and falls into the horizontal net, the flight is completed.

7.1.10 Recycle

Immediately after the flight, the RPV is returned to the assembly area where it can be recycled for the next mission. The checks performed on the RPV at this time are similar to those used during initial assembly and checkout.

Due to the variations that are possible in the tactical situation, mission objectives, and RPV payloads, this scenario is only representative of the many options that may be flown. To explain the operational capabilities more fully, a detailed description of the system operating modes is presented below.

7.2 DETAILED OPERATION

Detailed system operation is best described as it relates to the personnel involved in the operation of the system. The basic tactical crew consists of the following assignments:

- RPV pilot
- Sensor operator
- RPV assembler/crew chief
- Launcher and retrieval system operator
- Site commander
- Generator operator

During Aquila flight test operations conducted to date at both Crows Landing Navy Auxiliary Landing Field, California, and at Fort Huachuca, Arizona, no attempt was made to operate the system with a minimum operational crew. Additionally, the use of nondeliverable test and measurement equipment along with the range operations requirements necessitated the use of larger operations crews. The system operation for a defined crew position is no different for a tactical demonstration than for a flight test program. The responsibilities of the various positions are described in the following paragraphs.

7.2.1 RPV Pilot

The RPV pilot has prime responsibility for the operation and safety of the RPV during flight operations. This responsibility begins during mission planning where the pilot plots the proposed flightpath of the RPV on a standard 1:50,000 or 1:100,000 scale military chart. Flight altitudes are chosen to provide line-of-sight RPV coverage and ample height above the terrain. System operator manuals and system capabilities documents are provided to assist in this function.

The pilot is also responsible for data entry into the computer. Using the teletype console located to the left of his position, the pilot enters the data required by the computer during site setup, premission setup, self test, and launch. To assist the pilot with this task, preprinted forms are used to prepare the data in the correct format for computer use.

At times when the GCS has control of the RPV, the pilot must monitor the status of the RPV. Warning lights are provided for fuel low, alternator low, and engine temperature high. Additional displays provide altitude, airspeed, and heading, as well as a continuous video sensor display and an X-Y plotter for present RPV position.

During flight the pilot may control the RPV operating modes through use of the manual flight control panel. This panel permits selection of the computer-controlled flight modes: waypoint, loiter, search, and dead reckoning (when available), in addition to a manual real-time flight mode that provides direct control of altitude, airspeed, and heading rate.

Prior to, or during the flight, the pilot may program waypoints into the computer using the waypoint guidance panel. A display is provided to exhibit the RPV commands currently stored in the waypoint register which the RPV will respond to when in any of the "automatic" computer-controlled modes.

In the event of an in-flight emergency, the pilot is responsible for a rapid analysis of the emergency, and he must apply corrective action when such action is possible. A comp[illegible]te understanding of the system as well as evaluation of all status indications are necessary to identify the required corrective action. An in-flight diagnostic panel located on the center console provides additional status information that the pilot may require at these times.

7.2.2 Sensor Operator

The sensor operator's prime function is control of the RPV sensor payload during flight. The sensor control panel provides him with all the sensor controls necessary to accomplish the mission objective. Depending on the mission to be flown, the sensor operator performs the following tasks:

- Real-Time Reconnaissance. Using either a stabilized or unstabilized video camera, the sensor operator detects, identifies, and locates the position of enemy battlefield elements. Video camera controls are provided for iris, focus, and zoom. The camera is pointed using a joystick hand control on the sensor hand control assembly mounted in front of the operator.
- Photographic Reconnaissance. The sensor operator remotely controls the use of a 35-mm miniature panoramic camera that provides high-resolution photographic imagery for postflight interpretation. The only camera controls available to the operator are camera power and frame rate.
- Artillery Adjustment. Using a stabilized video camera and payload-mounted laser ranger, the sensor operator locates targets for fire support missions and provides the UTM coordinates of the targets to an artillery battery. To assist in tracking the target after it has been located, the sensor operator controls a video autotracker which locks onto the target image and drives the payload gimbals as required to keep the target centered on the video display. When the sensor operator ranges on the target using the laser, the computer calculates the target's UTM coordinates, and displays them on the sensor control panel. As artillery rounds impact near the target, the sensor operator places a movable video cursor on the burst point, and commands BURST OFFSET. The computer is then to calculate the grid burst offset coordinates for relay to the artillery battery. All laser controls, ARM, FIRE, and PRF (pulse repetition frequency), are controlled from the sensor operator's position. (As indicated in Section 3.5.2.4, the burst offset measurement formulation/software were not complete in time for evaluation.)

- Target Designation. This mission requires the same payload and controls as the artillery adjustment mission. However, the sensor operator tracks the target, sending the UTM coordinates to the artillery battery, then continuously designating the target with the laser to provide illumination for the laser-seeking warhead.

The sensor operator is also responsible for the retrieval of the RPV. Using the sensor hand control assembly, he selects the recovery direction of the vehicle, controls the final approach camera, and commands final approach while tracking the RPV on the video monitor with a movable cursor controlled by his joystick.

At his position in the GCS, the sensor operator also controls the two video recorders, the data link status panel, and the telemetry receiver panel. During mission planning, prelaunch checkout, and flight operations, he assists the pilot as required with the safe operation of the system.

7.2.3 RPV Assembler/Crew Chief

The crew chief is responsible for the assembly and checkout of the RPV. To perform this function he requires the suitcase tester, an assembly stand, and a set of standard mechanic's tools. The suitcase tester provides him with controls that simulate the GCS in order to operate the RPV and assist with checkout or troubleshooting procedures. During site setup, he performs the site survey functions and assists in the initialization of the GCS tracking antenna. For these functions, a standard field survey set and a theodolite are provided.

7.2.4 Launcher and Retrieval System Operators

The launcher and retrieval system operators are responsible for the setup and checkout of the retrieval system and for the operation of the launcher. Prior to launch they perform preventive maintenance and checkout of the launcher.

During launch the launcher pneumatic system is controlled, using the launcher operator panel mounted in a case near the launcher. The actual RPV launch is activated remotely from the GCS. For recovery operations, the operators are responsible for the correct alignment and tensioning of the retrieval net assembly, and for correct positioning of the final approach video camera.

7.2.5 Site Commander

The site commander is responsible for the total operation of the ground site and for the safe, efficient completion of mission objectives. Since his responsibilities are nontechnical in nature, they are subject only to Army requirements and will not be expanded upon here.

7.2.6 Generator Operator

The generator operator is responsible for maintenance of the site generators. During flight operations his duty station is at the generator interphone panel, where he monitors the progress of the flight and stands by to perform energency generator switching, or repair. Additional duties include general site maintenance and assistance with preflight site preparations.

7.2.7 Crew Training

The crew duties described above were included in an LMSC/Army Training Program conducted at LMSC and at Fort Huachuca. Instruction included one week of classroom training on system description, operation, and limitations for all students and a second week of classroom training on operation, organization-level maintenance, and emergency procedures for each of the major components (launchers, retrievers, ground control stations, and RPVs). Two weeks of additional on-the-job training (OJT) at Fort Huachuca was scheduled, but since training was subordinated to the engineering and test validation program and schedule, most trainees were able to receive three to eight weeks of low-intensity OJT. In any event, this training proved to be sufficient for subsequent flight operations using Army personnel. Certificates were awarded to Army personnel for successful completion of the various training courses as well as on-the-job training (OJT) and demonstration of skill qualification under the Aquila program. Army personnel trained in the maintenance, operation, and evaluation of the Aquila system (see Table 25) exceeded the originally planned delivery requirements because of (1) the added number of students assigned by the Army, (2) the refresher training for 21 students made necessary by schedule stretchout resulting from redesign, and (3) the certification program. More than 90 successful flights were made by the 30 contractor-trained and certified Army operations and maintenance personnel during the reported period. (By time of publication of this report, the Army flight crews had subsequently completed another 60 successful flights in a continuing series of additional flight tests.)

Special hardware for a recovery system trainer-simulator that was made on a related contract (DAAJ02-75-C-0055) was installed in the ground control systems consoles. This trainer-simulator provided an image of an incoming RPV on the sensor operator's TV screen, allowing him to practice RPV recovery techniques and procedures without risking an aircraft.

TABLE 25. ARMY PERSONNEL PROVIDED AQUILA TRAINING

Type of Aquila Training	Classroom Students Original Requirement	Classroom Students Delivered
A-Team Operators/Maintainers	17	21
B-Team Operators/Maintainers	16	31
Advanced Sensors Operation/Maintenance	9[a]	23[a]
Evaluators	10	11
Classroom Spaces Occupied (Total)	52[a]	86[a]
Personnel Trained in One or More Skills	43	63
Personnel Enrolled in OJT	33	44
Personnel Completing Certification	(not mentioned)	30

(a) These numbers include students previously given A or B team training and subsequently trained in two or more of the five sensor types.

7.3 REQUIREMENTS AND CAPABILITIES

System operational requirements are those that transcend individual component requirements or specifications. Often such requirements are unstated or implied. The specific requirements and capabilities of the airborne system are covered in Section 3; this subsection discusses the overall system-related requirements and the capabilities demonstrated during the flight test program. The RPV-STD program description stressed the following points relating to system operation: minimum personnel required, minimum skill level, simplicity of operation, no site preparation, and minimum time required for operation. The problem of developing a sophisticated RPV system that would be simple to operate using minimum skills was successfully overcome through use of a digital computer that controls many of the aspects of system operation.

7.3.1 Computer Software

The computer software (i.e., programs) allows the system to perform many complex tasks in a very short period of time with minimal operator assistance. The programs provide the following functions: site setup, premission setup, trainer-simulator, self-test, launch, waypoint navigation, status displays, target location, burst offset, recovery guidance, and postflight. A detailed description of these functions demonstrates the degree of simplification achieved.

7.3.1.1 Site Setup. Ranges and bearings from the benchmark to key site elements are entered into the computer along with data on local magnetic variation and the recovery bearing. The site setup program then calculates the UTM coordinates of the GCS, launcher, retrieval system, and outer marker waypoints. The computer also initializes the Baldwin digital shaft encoder on the GCS tracking antenna to provide antenna bearing data referenced to grid north. All of these data are stored in nonvolatile core memory that only requires updating for site relocation. To assist in site setup, a form is provided to record the required data. This form is presented in Figure 159.

01	BENCHMARK EASTING		(M)
02	BENCHMARK NORTHING		(M)
03	BENCHMARK ELEVATION		(M)
04	GRID BEARING TO ANTENNA		(DEG)
05	DISTANCE TO ANTENNA		(M)
06	GRID BEARING TO RECOVERY NET		(DEG)
07	DISTANCE TO RECOVERY NET		(M)
08	ANTENNA CORRECTION FACTOR	SIGN	(DEG)
09	ANTENNA ELEVATION ANGLE	SIGN	(DEG)
10	THEODOLITE HEIGHT		(M)
11	GRID BEARING OF PRIMARY APPROACH PATH		(DEG)
12	LOCAL MAGNETIC VARIATION	SIGN	(DEG)

Figure 159. Site Setup Data

7.3.1.2 Premission Setup. The premission setup program initializes the computer with the data required for the next mission. The first data entered are for historical purposes, i.e., date, mission number, and RPV number. These are followed by a request for meteorological data, which would be required for the legs of a dead reckoning operation. The program then initializes the charts used on both X-Y plotters to permit real-time RPV position display. Finally, the computer accepts the waypoint data. Up to 50 waypoints may be programmed for inflight navigation. Each waypoint is entered as a data word: waypoint number, UTM easting, UTM northing, altitude, and airspeed. The UTM coordinates identify the location of the waypoint. The altitude and airspeed values are the commands that will be transmitted to the RPV while flying to that waypoint. Waypoint planning sheets are used during mission planning to record these data for entry into the computer. The waypoint planning sheet is shown in Figure 160.

7.3.1.3 Trainer-Simulator. The trainer-simulator program, along with a simulator modification assembly, allows the ground crew to simulate a mission in real time once it has been programmed as described above. This program presents moving X-Y plotter displays and realistic RPV status indications, and allows full use of the search, loiter, dead reckoning, and waypoint reprogramming capabilities of the system for crew training or for simulation. For retrieval simulation, the program generates a pseudoretrieval display for the final approach video camera system, which allows operators to realistically practice retrieval techniques.

7.3.1.4 Self Test. The self-test program exercises all computer-generated displays within the GCS. The self-test is accomplished in approximately 8 min, during which time the pilot and sensor operator verify that the displays and indicators perform properly.

7.3.1.5 Launch. The launch program systematically steps through a series of computer-assisted checks of the RPV flight control system and engine prior to enabling the launch circuits within the GCS. By providing written prompts to the pilot via the teletype, the computer first measures the

DATE:__________ MISSION NO.__________ SYSTEM NO.__________

WP NO.	UTM COORDINATES		ALTITUDE (M)	AIRSPEED (KM/H)
	EASTING	NORTHING		
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				

NOTES: (1) ANY WAYPOINT WITH AIRSPEED OF 000 IS CONSIDERED UNDEFINED AND IS SKIPPED.

(2) WAYPOINTS 00-49 ARE USED FOR THE WAYPOINT GUIDANCE MODE.

(3) WAYPOINTS 50-53 ARE USED FOR THE DEAD RECKONING MODE.

Figure 160. Waypoint Planning Sheet

zero rate bias values of the RPV yaw/roll rate gyro and asks the pilot for a proceed instruction if the value is beyond preset limits. The program then cycles the autopilot heading rate loop through a series of six preset commands. If either of the two elevon displacements is found to be out of limits, the computer will again ask if the pilot wants to proceed. When the RPV engine has been started, the program will monitor engine temperature until it passes a preset value. At this time the computer will command zero altitude (idle rpm). If the idle rpm is within limits, the computer will command maximum altitude (full rpm). When full rpm is attained, the computer will measure this value and, if it is within acceptable limits, the computer will again command zero altitude and measure the speed at which the engine responds to the command. If any of the engine tests were out of limits, the computer will inform the pilot of the failure and query him to find out if he wishes to proceed. If all engine tests were within limits, the computer will command maximum rpm and stand by for the pilot to launch the RPV.

7.3.1.6 Waypoint Navigation. Immediately after launch the computer enters the waypoint navigation program. At this time the altitude and airspeed stored in the computer for the first waypoint are transmitted to the RPV. Using conventional rectangular coordinates, the computer generates the formula for a line connecting two points, the launch point and the next waypoint. Converting the range and bearing of the RPV from polar coordinates to the same rectangular coordinate system described above, the computer calculates the UTM coordinates of the RPV, in meters, and displays these coordinates on the video monitor. The computer also calculates the distance, D, in meters between the current position and the desired ground track line, measured perpendicular to the line. Figure 161 diagrams the "sense" of a typical D value. This value D is used in the following equation to generate RPV heading rate commands, $\dot{H}_c$, that will steer the RPV over the desired ground track:

$$\dot{H}_c = \left\{ \left[\left(K_D \cdot D \right)_{LIM} + \left(K_{\dot{D}} \cdot \dot{D} \right)_{LIM} \right]_{LIM} + \int \left[\left(K_{D1} \cdot D \right)_{LIM} dt \right]_{LIM} \right\}_{LIM} \tag{5}$$

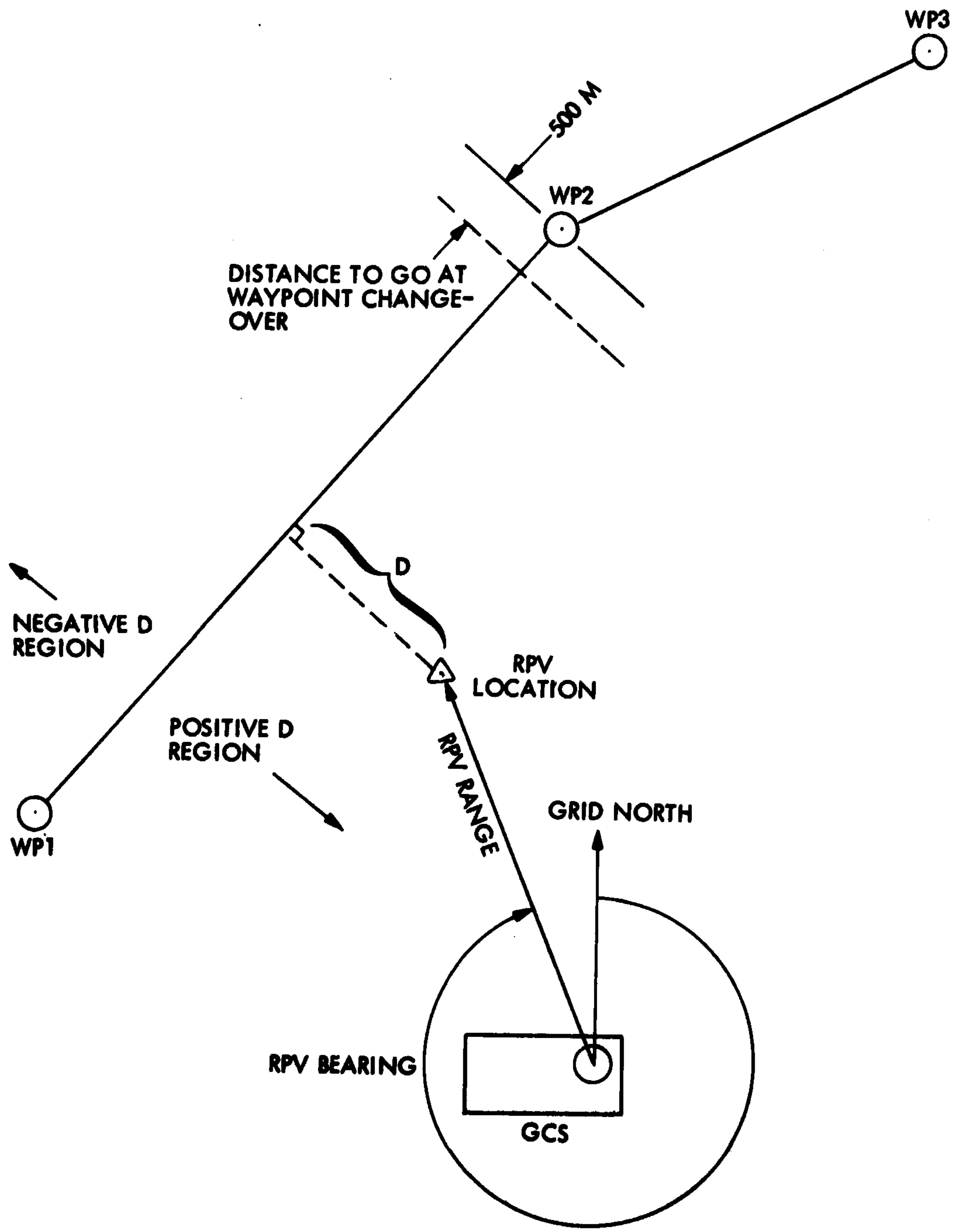


Figure 161. Waypoint Guidance

The above equation is simplified for discussion purposes. The actual value of D used during flight is corrected for indicated airspeed to equalize system response over wide variations in airspeed. $\dot{D}$ is the derivative of D, and K_D, $K_{\dot{D}}$, and K_{D1} are gain constants. The integral term is used to "wash out" bias errors in the yaw/roll rate gyro used in the RPV. This term is zeroed for 60 sec after the RPV turns to a new waypoint, or at times when the calculated value of D is greater than 100 m. The various limit values, LIM, are provided to prevent those terms from overdriving the system due to discontinuities in the flightpath at the various waypoints. As the RPV approaches within 500 m of the next waypoint, the computer will switch waypoints, and the next leg will begin. Typical tracking accuracy attained during the field test operations to date are in the order of ± 100 m from track.

Search and loiter are also included in the waypoint program. The guidance equations for both are similar to the waypoint equation described above, and are as follows:

$$\ell = -0.75\left[\frac{60}{IAS_c}(L_o - L)\right]_{LIM\pm30} + \frac{60}{IAS_c}(L_o - L) \qquad (6)$$

$$n = -0.5\left[\frac{60}{IAS}(L_o - L)\right]_{LIM\pm30} + \frac{60}{IAS_c}(L_o - L) \qquad (7)$$

$$H_o = \left[IAS_c \cdot 360/(L_o \cdot 2\pi)\right]_{LIM} \qquad (8)$$

where

- L = RPV distance to loiter point
- L_o = 500 + (K · ΔT)
- ΔT = time since loiter button was pushed

$$\dot{H}_c = \left\{ \left[\left(K_D \cdot \ell \right)_{LIM} + \left(K_{DR} \cdot \bar{\dot{n}} \right)_{LIM} \right]_{LIM} + H_o + \left[\int \left(K_{D1} \cdot D \right)_{LIM} dt \right]_{LIM} \right\}_{LIM} \qquad (9)$$

During loiter, $K \cdot \Delta T$ is forced to zero to ensure a loiter radius of 500 m.

To initiate either the loiter or the search pattern, loiter or search is commanded. If loiter is being flown, the computer will command a right turn onto a circular track with a 500-m radius around the point where the RPV was located when the command was given. The RPV will remain in this pattern until another flight mode is selected.

If search is being flown, the RPV has several options: spiral search, moving box, and squared S. A visual representation of these patterns is shown in Figure 162. The computer will command the RPV to fly a variation of one of these basic search patterns any time the search mode is selected. The exact pattern flown is determined by the values entered in waypoint registers 60 through 69 prior to launch. If no data are entered in these registers, the RPV will fly the "default" spiral search pattern using a modified loiter equation as shown above. If appropriate data are entered in registers 60 through 69, the computer interprets the data in the northing and easting columns to be offset distances to be flown alongside of or across track, and the RPV will fly a pattern similar to type b or c, as shown in Figure 162. Once another flight mode

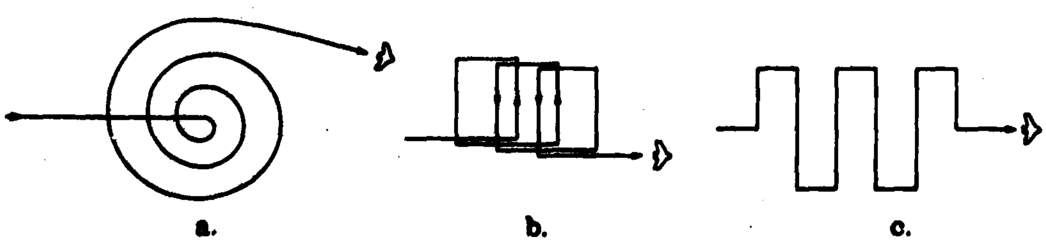


Figure 162. Search Patterns

command is initiated, the RPV will depart the search pattern and proceed to execute the new command.

Due to the many variations possible in the search, loiter, and waypoint modes, Reference 17, Vol. I, Appendix A, "Waypoint Guidance," should be referred to for detailed information on this subject.

7.3.1.7 Status Displays. The status display program continuously monitors the RPV downlink and converts the status data into a usable format, which is routed to the various console displays within the GCS.

7.3.1.8 Target Location. The target location program calculates the actual ground UTM location of the target through a series of geometric coordinate transformations using known and measured system parameters. The following data are required to calculate the target position:

- GCS antenna coordinate, northing
- GCS antenna coordinate, easting
- RPV altitude, alt
- RPV grid bearing from tracking antenna, az
- RPV range from tracking antenna, range
- Three-axis magnetometer output, X_s, Y_s, Z_s
- RPV pitch angle, θ
- RPV roll angle, ϕ
- Laser azimuth relative to RPV, ψ_s
- Laser declination relative to RPV, θ_s
- Laser range to target, R_T

Northing and easting coordinates are calculated by the computer as part of the site setup program. The location of the RPV is calculated by measuring alt, az, and range. Once the RPV position has been calculated, the target location is determined adding the RPV-to-target northing, N_T, and easting, E_T, components to the RPV northing and easting components. N_T and E_T are calculated as follows:

$$\psi = \tan^{-1}\left[\frac{\cos\phi\, Y_s + \sin\phi\, Z_s}{\cos\theta\, X_s + \sin\theta\sin\phi\, Y_s - \sin\theta\cos\phi\, Z_s}\right] \quad (10)$$

$$N_T = R_T\Big[\cos\psi\cos\theta\cos\theta_s\cos\psi_s - \sin\psi\cos\phi\cos\phi_s\sin\psi_s + \cos\psi\sin\theta\sin\phi\cos\theta_s\sin\psi_s - \sin\psi\sin\phi\sin\theta_s - \cos\psi\sin\theta\cos\phi\sin\theta_s\Big] \quad (11)$$

$$E_T = R_T\Big[\sin\psi\cos\theta\cos\theta_s\cos\psi_s + \cos\psi\cos\phi\cos\theta_s\sin\psi_s + \cos\psi\sin\phi\sin\theta_s + \sin\psi\sin\theta\sin\phi\cos\theta_s\sin\psi_s - \sin\psi\sin\theta\cos\phi\sin\theta_s\Big] \quad (12)$$

Target altitude, H_T, is calculated in a similar manner using the following equation:

$$H_T = R_T\Big[-\sin\theta\cos\theta_s\cos\psi_s + \cos\theta\sin\phi\cos\theta_s\sin\phi_s - \cos\theta\cos\phi\sin\theta_s\Big] \quad (13)$$

A circular error of probability (CEP) goal of 100 m and a 50-percent-probability altitude accuracy goal of 75 m were assigned for target location accuracy at target ranges of 20 km from the GCS and 2 km from the RPV using a laser comounted with the stabilized video camera. Table 14 summarizes the contractor flight test results.

7.3.1.9 Artillery Offset. The artillery offset calculation uses the same formula as the target location program, but with some additions. The initial target coordinates are calculated and stored in the computer, and, when the artillery burst is detected, a movable cursor is placed over the burst. The position of this cursor is measured, relative to the target, on the video monitor in both horizontal, ΔH, and vertical, ΔV, directions. These values, along with the payload camera optical lens focal length, F, in counts, are used to calculate pseudo sensor position angles θ_s' and ψ_s' and pseudo laser range values R_T'.

$$\theta_s' = (\Delta V)(2.178 \times 10^{-6})(F') + \theta_s \tag{14}$$

$$\psi_s' = (\Delta H)(2.904 \times 10^{-6})(F') + \psi_s \tag{15}$$

$$R_T' = \frac{R_T \sqrt{\left(1 + \theta_s^2\right)\left(1 + \psi_s^2\right)}}{1 - (\theta_s - \theta_s')\cot\theta_s'} \tag{16}$$

where

$$F' = F + 75 \quad \text{if} \quad F < 75$$
$$F' = 2F \quad \text{if} \quad F \geq 75$$

The pseudo position and range values are substituted into the original target location equation, and the location of the burst is calculated. Subtracting the burst location from the target location, the computer provides burst offset data to the display panel.

Army specifications call for burst offset data to be calculated to an accuracy of ± 25 m. Test data indicated inconsistent performance which was subsequently traced to an erroneous formulation in the software. The design performance of the system should meet the 25-m requirement after correction of the formulation.

7.3.1.10 Final Approach. During final approach, the computer measures video cursor displacement of the RPV in both horizontal, ΔH_R, and vertical, ΔV_R, planes. Using these values along with range from the ground recovery camera to the net, R_R, the computer calculates the horizontal, D_H, and vertical, D_V, displacements of the RPV from the retrieval glide slope:

$$\dot{H}_c = \left\{ \left[\left(K_D \cdot D\right)_{LIM} + \left(K_{\dot{D}} \cdot \dot{D}\right)_{LIM} \right]_{LIM} + \left[\int \left(K_{D1} \cdot D\right)_{LIM} dt + \dot{H}_{c_{bias}} \right]_{LIM} \right\}_{LIM} \quad (17)$$

Horizontal displacements are corrected by using D_H in place of D in an equation of the type used for waypoint guidance. The gains and limits are changed to permit rapid vehicle response for offset from the desired track. In the vertical plane, the following equation is used to generate a vertical velocity command, $\dot{Z}_c$, which is transmitted to the RPV:

$$\dot{Z}_c = \left[K_Z \left(d + db\right) \lambda_Z\right]_{LIM} \quad (18)$$

Both commands, $\dot{H}_c$ and $\dot{Z}_c$, are used by the RPV from initiation of final approach through impact with the vertical net. Flight test data to date indicate a 1-sigma miss distance (from the center of the net) of 0.6 m, well within the acceptable recovery envelope.

7.3.1.11 Post Mission. The post-mission program prints photographic camera frame information on flights in which the 35-mm mini-pan film camera is used. Also printed are launcher interrupt times from which time of launch and launch velocity can be calculated.

Section VIII
CONCLUSIONS

The Aquila RPV system has provided the U.S. Army with hands-on RPV experience in field exercises that became routine. The testing accomplished by LMSC and the Army supports the following conclusions:

- Current technology, when applied in a suitable development program, can produce a highly effective Army tactical RPV system.
- A tactical RPV system will greatly enhance Army artillery effectiveness through improved battlefield surveillance, target detection, target recognition, target location, fire correction, and target designation.
- A tactical RPV system could be compatible with and complementary to existing and near-future Army equipment and operations.
- A tactical RPV system should include the following operational features: (1) mobility equivalent to artillery batteries using conventional Army ground vehicles; (2) operation from unprepared sites; (3) capability of rapid deployment, short cycle time, and rapid relocation; and (4) operability with a small crew of enlisted personnel (E3 to E6) requiring minimal training.

From 1 December 1975 through November 1977 the Aquila system completed 149 flights — 35 were conducted by Lockheed personnel, 114 by Army teams at Fort Huachuca. During the Army test program an average flight rate of one per day was achieved by Army enlisted personnel. Two flights per day were achieved on occasion and once three flights were accomplished in one day. On occasion, the same RPV was used with less than 1 hour turnaround time.

The contractor and the Army have experienced minimal flight hardware losses. A summary of flights and losses is shown in Table 26. Clearly, the high (50 percent) loss rate experienced during the early test period, before the introduction of the vertical ribbon barrier (VRB) retrieval system, was almost entirely eliminated after the retrieval system change. Army testing, as of the date of completion of the TRADOC tests, shows only an 8-percent loss rate due to hardware problems, for an overall program loss rate of only 9 percent attributable to hardware problems. Since the VRB retrieval system was implemented (completing the system evolution) in September 1976, 117 flights were conducted, of which 110 were successfully recovered. Two of the seven losses were attributed to human error. For this period, therefore, the overall loss rate was 6 percent, and the loss rate due to hardware problems was only 4.27 percent. This flight test record represents a successful achievement unprecedented in the history of RPV development.

TABLE 26. SUMMARY OF FLIGHTS AND LOSSES

Test Segment	Total of System Validation Flights	System Validation Flights Before VRB	LMSC Flights After VRB	Army Flights With VRB	Total Program Flights As of 21 Oct 77	Total Program Flights With VRB
Total Flights	65	14	51	66	131	117
Total Losses	8	7	1	6	14	7
Human Error Losses	1	–	1	1	2	2
Hardware-Problem Losses	7	7	0	5	12	5
Hardware-Problem Loss Ratio	11%	50%	0%	8%	9%	4.27%

During the flight operations, the usefulness of RPVs in conducting surveillance, target acquisition, target recognition, and target designation in the field environment was examined. The Aquila system technology demonstrator has clearly demonstrated the operational utility of RPV systems through the successful integration of airframe, propulsion, sensor, command and control, navigation, data link, launch, and recovery technologies.

More specific conclusions will certainly result from the Army field tests. At this point in the assessment, however, trends that are developing and preliminary findings can be discussed. Tables 27 through 30 summarize the conclusions relative to the characteristics of the Aquila System. Discussion of the tables follows.

8.1 REMOTELY PILOTED VEHICLE

The Aquila RPV provides the flight performance necessary to conduct effective field operations without climb, descent, and transit times distracting significantly from the time for targeting functions. This was the basic objective of the Army requirements (Table 27), an objective that was based on Army experience in previous programs. Performance goals most significant to mission capability were essentially met by Aquila as demonstrated by flight tests. Maximum speed, weight, and time-to-climb performance capabilities are below the specifications for Aquila as shown in Table 27, but did not distract from system operations. Further testing and evaluation by the Army will be necessary to study factors such as tactics and vulnerability to fully determine required performance capabilities for a tactical RPV system.

Guidance and control specifications shown in Table 27 were fully provided and demonstrated with the Aquila RPV. Even the dead reckoning hardware was demonstrated, but a circuit anomaly in the autopilot made reacquisition erratic after the mode was changed. A minor change in the autopilot to correct the

TABLE 27. AQUILA RPV CAPABILITIES

Parameter	Specification	Capability	Method of Validation
RPV			
Cruise airspeed range (KEAS)	75 to 120	36 to 90	Flight test (flight 61) plus wind tunnel data and analysis
Gross weight (lb)	120 (max.)	146 (max.)	Actual weight
Payload weight (lb)	30 (min.)	39.95	Actual Phase IV and V sensor weight
Endurance (hours)	3 desired, 1.5 min.	3.4 (max.)	Flights 61 and 65 (plus analysis)
Maximum cruise altitude (ft MSL)	12,000	12,000	Flight 58
Time to climb: SL to 10,000 ft (min)	15 (max.)	28 at 143 lb	Analytical derivation from flight test data
Typical operating altitude (ft AGL)	2,000		
Operating radius (km)	15 to 20	≈24	Army flights
Structural design load factor (g)	6	>6	Analysis
Takeoff and landing conditions	4,000 ft MSL at 95°F	4,560 ft MSL at 99°F	Flight 56
Winds (knots)	20, gusts to 35	20, gusts to 35	Flight data plus simulation
Guidance and Control			
Flightpath control	Preprogrammable	Waypoint guidance (100 waypoints)	Flight tests
Operating modes	Operator override	Manual/automatic	Field test demonstrations
Pilot skills/operation	Nonpilot skill level	Nonpilot operators	Field tests
Link-loss reaction	Maneuver to reacquire	Automatic maneuver sequence	Field tests
Non-LOS operation	Autonomous RPV operation (three legs)	Flown, full capability not available	Hardware demonstration in flight (mode unavailable, pending minor adjustment)

anomaly was deferred to permit continuation of more critical flight tests. The dead reckoning mode is not available pending that design change.

8.2 DATA LINK AND COMMAND AND CONTROL

Requirements and characteristics of the data link and command and control system are given in Table 28. Overall performance of the data link was good; however, some aspects proved troublesome. The single-axis tracking antenna produced apparent range errors due to shifts in antenna polarization induced by RPV motion. The resulting snaking motion of the RPV degraded targeting capability with the unstabilized video sensor. Hardware and/or software fixes could alleviate this problem. Another problem concerned the fixed vertical position of the tracking antenna lobe which required a switchable broad and narrow beam option to provide necessary coverage. The imprecise tracking of the broad beam sometimes produced oscillatory deviations in the RPV flightpath. The situation was "tolerated" in order to continue with the flight tests, but would require resolution for a tactical system.

8.3 GROUND SUPPORT SYSTEM

Table 29 compares the characteristics of the Aquila ground support systems with the program requirements and goals. The modified shelter proved acceptable for a wide range of climatic conditions. Console controls were acceptable, as were the displays provided. Tape and video recorders and the computer provided excellent postmission data, but proved somewhat sensitive to temperature variations. More rugged militarized units would be required for a tactical system.

After finalization of the shuttle-to-RPV interface, the launcher performed with high reliability. The vertical barrier retrieval system also performed with high reliability, as previously discussed.

TABLE 28. AQUILA DATA LINK AND COMMAND AND CONTROL CAPABILITIES

Parameter	Requirement	Capability	Method of Validation
Data Link Capability (TV)	20 km at ≥ 2,000-ft alt.	20 km at ≥ 2,000-ft alt.	Ground and flight tests (flight 38)
Command and Control Capability	20 km at ≥ 1,000-ft alt.	20 km at ≥ 1,000-ft alt.	Ground and flight tests (flight 40)
Fail-Safe Link-Loss Signal	Detect loss, indicate to autopilot	Uplink detection, automatic link-loss command, GCS signal-strength indication	Ground and flight tests
Telemetry	RPV/sensor status and target parameters	Video plus 32 telemetry words	Data adequacy in flight tests
Radio Frequency	Compatability with test ranges	4.861-GHz uplink 4.530-GHz downlink	Field tests (no rf interference)
Interference	Protection against friendly inadvertent interference	Barker code protection	Field test, no known loss due to interference
Tracking	Auto/manual tracking, accurate RPV position	Hi/lo gain tracking, RPV position to 20 m (some "masking")	Field tests (comparison with tracking radar AN/FPS-16)

TABLE 29. AQUILA GROUND SUPPORT SYSTEM CAPABILITIES

Parameter	Requirement	Capability	Method of Validation
Ground Control Station			
Mobility	Suitable mobile shelter	M36 truck-mounted S-280 shelter	Field tests
Air conditioning and heat	Conditioned for crew	Conditioned for crew, trainees, and observers	
Console controls	Autopilot and flight commands	Manual flight control panel	Field tests at Fort Huachuca
	Preprogrammed flight commands	Waypoint guidance panel	
	Launch and recovery control	Launch command and recovery display	
	Sensor controls	Sensor and hand control panels	
	Autotracker commands	Antenna control panel	
	Laser commands	Safety switch and arm-fire control	
	Burst location	Cursor on tracked scene	
Displays	Two TV monitors	Two TV monitors	
	Pan and tilt position of TV	Alphanumeric video display	
	RPV altitude, heading, airspeed, engine rpm and temperature	Panel gages plus over-temperature warning	
	Sensor FOV, target coordinates, fire correction, laser range	Video alphanumeric display plus console gages	
Recording	TV imagery, 30-sec instant replay plus stop action	Dual recorders for continuous recording plus replay and recovery recording	
	Data tape (digital)	All mission, flight, command, and telemetry recorded for the entire flight	
Computer	Compute target location	Target coordinates	
	Compute burst displacement (±25 m)	Unavailable pending correction of formulation	
	Navigation	Waypoint, search, recovery diagnostics, go/no-go criteria	

TABLE 29. (Continued)

Parameter	Requirement	Capability	Method of Validation
Launcher			
Site preparation	Unprepared site	Minimal preparation, selected as free of obstructions	Three site operations at Fort Huachuca
Size	Minimum	30-ft length	-
Transportability	Standard Army vehicles	Mounted on M36 truck	Field tests
Operation time and skill	Two people, minimum	Two E3 personnel, minimum setup and recycle time not established	-
Observables	Minimum during operation	No flash or smoke with launch-prominent profile, could be camouflaged	Field observations
Retrieval System			
Site preparation	Unprepared site	Local brush and rocks cleared, site selected as free of obstructions	Three site operations at Fort Huachuca
Size	Minimum	Over-sized for reliability	Field tests
Transportability	Standard Army vehicles	Mounted on M345 trailers	Field tests
Operation time and skill	Two people, minimum	Minimum setup and recycle time not established	
Observables	Minimum during operation	No flash or smoke, but large plan and profile, could be camouflaged	Field observations

8.4 NAVIGATION AND TARGETING

Table 30 compares the Aquila characteristics with program requirements and goals. Overall performance was excellent. Degradation of target detection and recognition with the unstabilized TV is the only major deviation. Several factors, including data-link-induced RPV oscillation, degradation of resolution on a recorded video tape, and limited sensor operator experience at the time the data were taken make this assessment preliminary at best and highly conservative. Improvement is expected with further experience and evaluation using the monitor directly instead of video tape. With the limited data analysis, other system targeting performance parameters appear to be fully acceptable for demonstrating the potential for tactical RPV systems and for evolving design requirements for those systems.

TABLE 30. NAVIGATION AND TARGETING CAPABILITIES

Parameter	Requirement	Actual Capability	Method of Validation
RPV Altitude for Targeting (ft AGL)	2,000	2,000	Design analysis
RPV Range for Targeting (km)	2 to 20	2 to 20	Field Tests
Phase I – Unstabilized Video			
Target detection slant range (m)	Tank on road, 3,000, 50% probability	1,618 (avg.)	Limited video tape analysis
	Tank in field, 1,500, 50% probability	No data available	-
Target recognition slant range (m)	Tank, road/field, 1,000, 50% probability	940	Limited video tape analysis
Phase II – 35-mm Panoramic Camera			
Resolution (ft)	Standard photoreconnaissance	1.6 at 2,000 ft	Standard camera spec.
Film capacity	225 ft	225 ft thin-base film	
Selection and control	Maximum	Frame rate, shutter speed	Field and flight tests (standard reconnaissance camera
Phases III, IV, V – Stabilized Video			
Target detection slant range (m)	Tank on road, 5,000, 50% probability	Mean = 4,845 m, max = 8,014 m	Field tests (limited flight data)
	Tank in field, 2,500, 50% probability	Mean = 2,282 m, max = 3,371 m	Field tests (limited flight data)
Target recognition slant range	Tank, road/field, 2,200, 50% probability	Mean = 1,747 m, max = 3,233 m	Field tests (limited flight data)
Phase IV – Laser Rangefinder			
Target location: UTM coord. (m)	100 CEP at 20 km	253	Flight 65
Altitude (m)	75, 50% probability	71	Flight 65
Burst offset accuracy (m)	25 CEP	Not demonstrated	-
Phase V – Laser Designator			
Designation duration	20 sec at 4,000 ft, 95°F	1 min at 20 pps, continuous at 1 pps	Laboratory tests
Recycle time	2 min	3 min	Laboratory tests
Dwell on target (2.3 m by 2.3 m, high contrast)	95% of time, 2,500-m slant range	All observed hits on target	Field tests

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