NASA-CR-172583

(NASA-CR-172583) MISSION ANALYSIS OF SOLAR POWERED AIRCRAFT Final Report (Lockheed Missiles and Space Co.) 54 p HC A04/MF A01 N85-31072
CSCL 22A Unclas
G3/12 21760

Lockheed Missiles & Space Company, Inc.
SUNNYVALE, CALIFORNIA

NASA Contractor Report 172583

Mission Analysis of Solar Powered Aircraft

David W. Hall, David A. Watson, Robert P. Tuttle and Stanley A. Hall
Lockheed Missiles and Space Company, Inc.
Sunnyvale, California

Contract NAS1-16975
July 30, 1985

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

This report presents a preliminary analysis of a solar high altitude powered platform (HAPP) applied to a hypothetical mission. The Agricultural Research Service of The United States Department of Agriculture supplied preliminary details of a mission to be flown over southern Arizona. Given the mission scenario, a time line of events was constructed and the vehicle's response to mission requirements was estimated.

A solar remotely piloted high altitude powered platform (HAPP RPV) configuration analyzed in previous studies was assumed for this analysis, but it is not optimum for the mission. A smaller aircraft could be designed to fly this much less demanding mission.

Conclusions and recommendations are presented which point to the need for development of a system simulator. This valuable research and development tool could be used throughout the development of a solar HAPP to assess interactions of power train, airframe, meteorological, and mission parameters. This simulator could be used later during operations to assist in solving problems as has been done with ground simulators for space missions.

INTRODUCTION

This is the third in a series of studies of solar powered aircraft. The first (Ref. 1) examined the feasibility of solar powered aircraft and focused on identifying critical technologies which must be developed further if solar powered aircraft are to become a reality. The comprehensive methodology developed during the first study established the feasibility of solar powered aircraft for certain missions.

The second study (Ref. 2) examined various structural schemes and identified critical structural technologies which must be developed. The present study emphasizes the overall concept of mission operations of a solar HAPP. The main product is a preliminary mission time line that identifies events which must take place to accomplish an entire mission. The events in the time line and evaluation of interfaces, data and control links, and peripheral equipment provide insight into operation of the generic class of high altitude long endurance aircraft.

This report is organized along the lines followed in conducting the study. A brief review of previous related work following this introduction, describes the Solar HAPP including a functional arrangement of subsystems and overall system performance. There follows a description of the mission postulated by the Agricultural Research Service of the U S Department of Agriculture A discussion of mission operations is included

A mission time line is presented, showing the time interval for each event and identifying equipment and personnel required. Critical mission/payload/vehicle interfaces, including data and control links, are discussed. A brief estimate of peripheral equipment requirements is presented. The report concludes with discussions of state-of-the-art considerations, conclusions and recommendations

Two appendices are attached. The first addresses the feasibility of adapting several currently available, conventionally powered aircraft to perform a mission for a brief period of time. The second presents the performance capabilities of several currently available, or soon to be available, sensors which could be used for surveillance missions of the type modelled in this study.

A Short Story

It's 3:50 AM in Palestine, Texas, on May 21, 1992. A ten-minute warning prior to launch of the world's first operational solar powered reconnaissance aircraft, Lockheed's ER-3, **Solarstar I**, has just been given.

The day prior to launch, the ER-3 fuel cell reactant tanks were loaded with hydrogen and oxygen--energy for the coming night's flight. This fuel cell charge cycle gave the ground controllers an opportunity to complete a thorough preflight check of the power train and other aircraft systems. Problems crept in, of course, but the countdown allowed for their resolution and several last minute adjustments.

The flight plan has been filed with the FAA for a climb corridor to the west from Palestine with a NOTAMed (Notice to Airmen) temporary restricted area 9.3 kilometers (5 nautical miles) wide and 185.4 km (100 nmi) long for 4 hours tonight. During this time the vehicle will climb to its operational altitude of 20 km (65 600 feet). All that is required now to activate the flight plan is a call to the nearest FAA facility. They, in turn, will notify each of the air traffic control (ATC) facilities affected during the climbout through 18.3 km (60 000 ft). Fort Worth Center will watch the transit and will hand off to Phoenix Center who will monitor

Solarstar I during its mission even though the vehicle will be above their jurisdictional limit at 18.3 km (60 000 ft). **Solarstar I** will also be carefully watched by military controllers who will interface on a daily basis with USDA during the mission. In keeping with the FAA's concern that the climb through 5.6 km (18 500 feet) be watched by an airborne command pilot in visual contact with **Solarstar I**, two jet-powered Caproni sailplanes are preflighted and available for the coming night's work.

The ER-3, dubbed **Solarstar I** in a corporation-wide naming competition earlier in the year, is strapped to its takeoff dolly just prior to launch. As final checks are completed, flight plan approval arrives for a launch at 4:00:00 AM. Precisely on time, **Solarstar I** starts its takeoff roll behind a truck. Its propeller is held fixed as the aircraft moves forward on its dolly. When speed reaches about 6 meters per second (20 feet per second), the straps are released and the ER-3 lifts off from its takeoff dolly. **Solarstar I** points its nose upward 22° and climbs to an altitude of about 21 meters (70 feet) on its instrumented towline. A command is given and the 10 m (32.8 ft) propeller begins turning at 140 revolutions per minute. After a quick check of motor status, the towline is dropped.

Solarstar I is on its way, continuing its climb at a 22° angle at 2.2 mps (440 feet per minute). Because its power train is electric, it will sustain this climb rate throughout most of the next three hours. Reciprocating and turbine engines take ambient air onboard for power generation. Electric motors are not dependent on outside air for power and, therefore, their power output during a climb is only affected by lowering Reynolds numbers at the propeller.

Day # 1. It's 4:05 AM CDT, and the flight plan has been activated by Chase 1 which has the command pilot aboard. Both Chase 1 and Chase 2 have joined formation with **Solarstar I**, and the three graceful birds soar into the night sky, only the noise of the Caproni's jet engines breaking the silence. Climb continues to 5.6 km (18 500 ft) some 27.5 km (17.1 statute miles) downrange within the first 40 minutes of the mission.

4:42:03 AM CDT. FAA air traffic control has shifted from Palestine Flight Service to Fort Worth Center Low and now shifts to Fort Worth Center High. As ATC transfer is made, the Capronis break formation and orbit at 5.6 kilometers (18 500 feet) while **Solarstar I** continues its climb to cruise altitude. The Caproni pilots can relax a bit now after keeping formation with **Solarstar I** during the last 40 minutes. Their workload has been quite high because of the difference in climb performance of the two aircraft types. **Solarstar I** now climbs alone into positive control airspace. It is a quiet night and Fort Worth High doesn't have much traffic to reroute. Ground crews are monitoring motor power, temperature, shaft rotation speed, and gearbox temperature. Fuel cell output power and reactant usage rates are also being closely monitored to verify fuel cell efficiency and to assure that **Solarstar I** doesn't use too much "fuel" prior to sunrise. Ground crews are also monitoring telemetered airspeed, attitude, and structural deflection angles and rates along the wingspan Ground track information is provided via the Global Positioning System (GPS) and inertial navigation to enable an estimate of winds aloft These accurately measured, real-time wind data are part of the payoff to FAA for their participation

5:05:45 AM CDT. "Trans World 568, this is Fort Worth High. Please turn right to one-two-zero for traffic spacing. Traffic 1 O'Clock at 10 miles and climbing." "Fort Worth High, TW568. Roger turn to one-two-zero. Traffic in sight passing through flight level three-five-zero now " "Roger, TW568. Resume original heading after passing traffic."

6:15:10 AM CDT. The RPV command pilot on the ground at Palestine calls Fort Worth Center: "Fort Worth High, **Solarstar I**. Passing through flight level six-zero-zero. Request frequency change. Good day." "**Solarstar I**, Fort Worth High. Frequency change approved to Continental Control Area. Good day and good luck."

6:28:48 AM CDT. **Solarstar I** is now 156 km (97 mi) west of Palestine, Texas, and has just leveled off at its cruise altitude of 20 km and cruise speed of 27 mps (52.5 knots) on course to Phoenix. The sun will rise in an hour and **Solarstar I** will automatically raise its wingtip solar collectors as power simultaneously increases.

9:27:36 PM CDT. Sunset was at 7:30 PM at 20 km (65 600 ft) altitude when **Solarstar I** resumed its nighttime configuration and decreased power to its nighttime cruise setting. **Solarstar I** is now over Tombstone, Arizona, after about 16 hours at cruise altitude. Distance covered was 1636 km (1016 miles) for an average zero-wind speed of 26 mps (50.6 kts). **Solarstar I** turns northwest toward Tucson. The distance of 111 km (69 mi) will be covered in 1 hour and 8 minutes and **Solarstar I** will be turned right again to head for Phoenix 282 km (175 mi) away.

Day # 2. It's now 7:28 AM MDT. **Solarstar I** has been in its nighttime configuration since sunset. Ground controllers again activate the pivot mechanisms at each wingtip and cautiously watch structural deflection indicators and power output to assure that everything is functioning smoothly. Cruise power is slowly increased almost 40 % more than the nighttime value as the outboard lifting portions of the wing are rotated vertical to catch the sun's rays.

7:30 AM MDT. The sun is rising on **Solarstar I** as its subsystems checkouts are completed after the nighttime loiter over Phoenix. It turns southwest toward Tucson as its solar cells begin collecting solar energy. The payload has been switched on just prior to sunrise and now begins painting a multi-colored swath on monitors at the centrally located control station. All systems look nominal and **Solarstar I** now begins earning its keep . . .

The foregoing narrative illustrates some of the operational considerations which have been investigated in detail in this study. This analysis is concerned with the application of a previously designed solar HAPP to a specific mission. Included is a time line, a discussion of critical mission/vehicle interfaces, possible failure modes, conclusions, and recommendations for further study. This study has also addressed the suitability of currently available space-qualified hardware to perform a hypothetical USDA mission. Included also is a brief summary of the feasibility of currently available, conventionally powered platforms to perform this mission for shorter periods than the two months required for the solar mission.

SOLAR HAPP SYSTEM DESCRIPTION

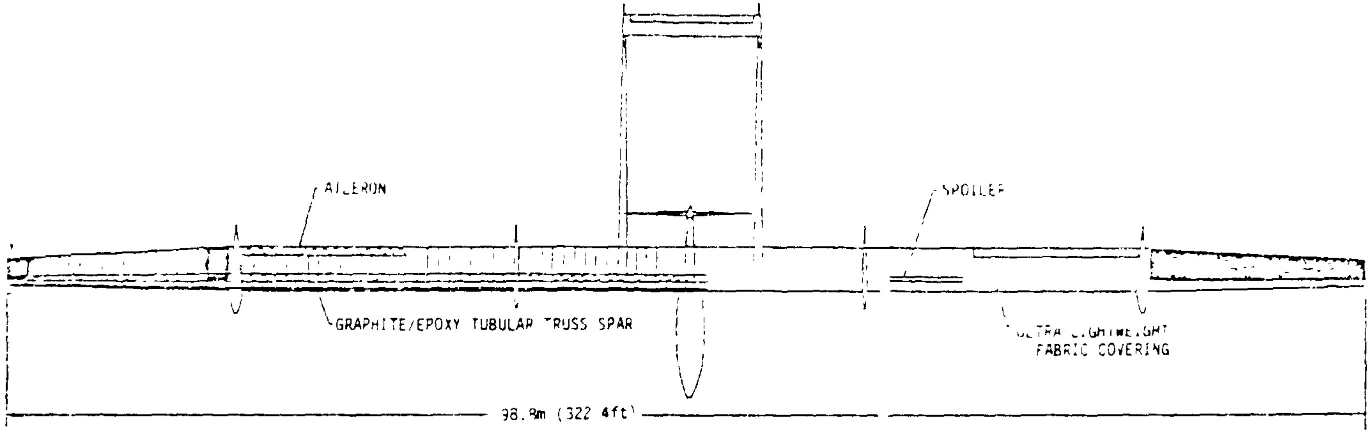
The baseline airplane and subsystem configurations for this analysis are described in detail in references 1 & 2. Figure 1 presents a general arrangement of the baseline vehicle used for this study. It represents the Mk.21 configuration which was structurally analyzed in reference 2. This aircraft was nominally designed to fly for one year at 20 km (65 600 ft) over the Great Central Valley of California with a 110 kg (243 lb_f) payload

Functional Identification of Subsystems

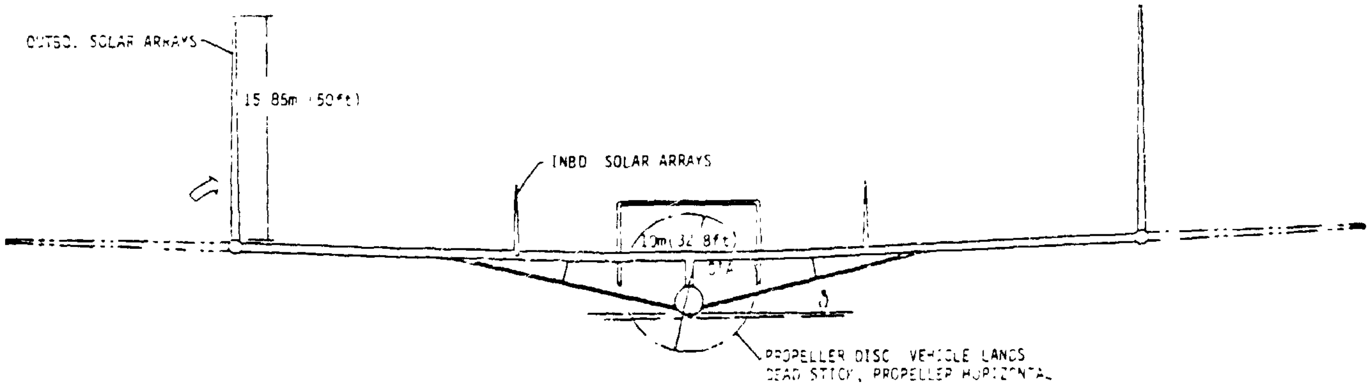
For this analysis, onboard equipment is identified by its relation to one or more of five subsystems or functions:

1. Energy collection and storage subsystem comprising solar cells, electrolyzer, reactant storage, fuel cell, and power conditioner and associated controls (Figures 2 and 3).
2. Rotating components including motor, gearbox and propeller (Figures 2 and 3). Items 1 and 2 together comprise the complete power train.
3. Autopilot and system monitor including electronics and actuators necessary for flight control and system monitoring functions.
4. Navigation subsystem.

5. Payload, sensors and equipment necessary to process and transmit mission data to ground stations.



NIGHTTIME CONFIGURATION
TIPS DOWN



DAYTIME CONFIGURATION
TIPS UP

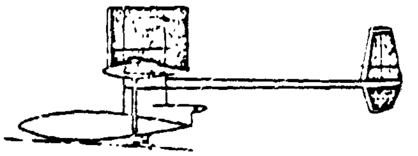


FIGURE 1. BASELINE SOLAR PHOTOVOLTAIC HIGH ALTITUDE POWERED PLATFORM (from reference 2).

This assignment of functions will simplify discussion of interfaces which follows. In later studies, when the airplane and subsystem configurations are refined, systematic functional analyses can be performed which may result in a different functional arrangement. At this time, data transfer and interfaces within the designated functions are not identified or discussed. Also, interfaces with the power bus or power conditioning are not discussed.

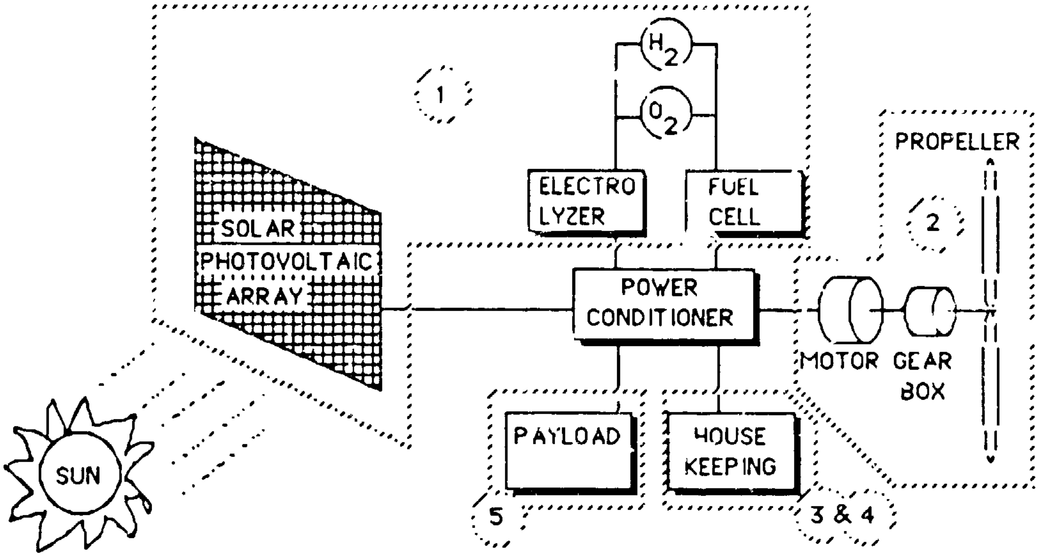


FIGURE 2. SOLAR HIGH ALTITUDE POWERED PLATFORM POWER TRAIN.

Ground equipment is divided into two groups. The first is the system monitor and control made up of equipment required for launch, mission control, mission system monitoring and recovery. The second is the data subsystem which comprises equipment and software required to receive and process data from the airplane to prepare it for display and/or interrogation. Power train details are shown in Figure 3. The functional arrangement of power train components is shown is Figure 4.

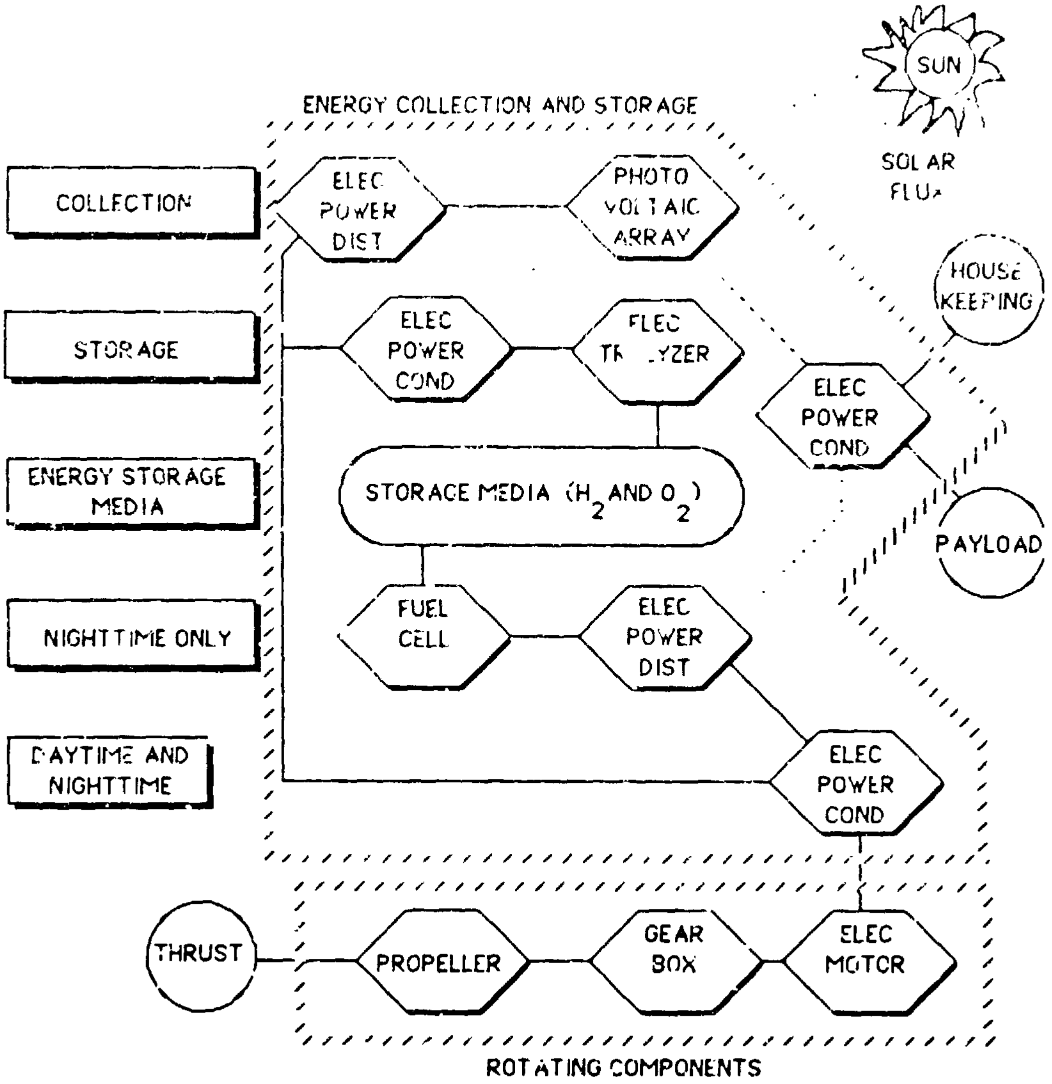


FIGURE 3. ENERGY COLLECTION, STORAGE, AND ROTATING COMPONENTS SUBSYSTEMS OF A SOLAR HIGH ALTITUDE POWERED PLATFORM POWER TRAIN.

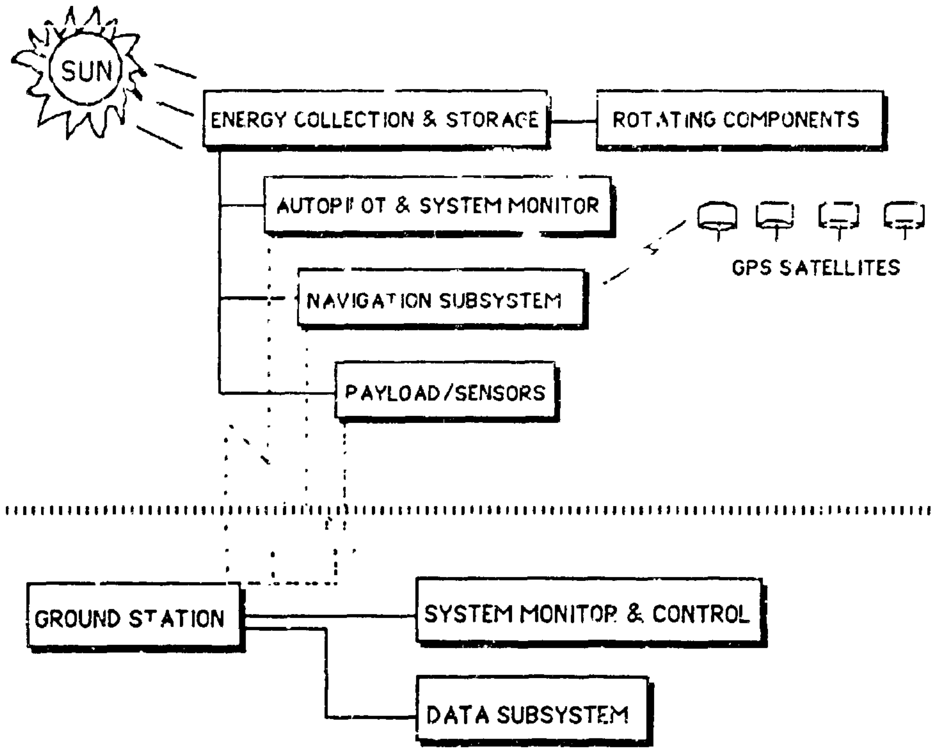


FIGURE 4. HIGH ALTITUDE POWERED PLATFORM SUBSYSTEM FUNCTIONAL ARRANGEMENT.

System Performance

The overall efficiency of the solar power train from the collection of solar flux to the propeller is about 5.6 % as itemized in Table 1 below. A complete discussion of the factors affecting performance of each of the power train components is given in reference 1.

System Design Features

Airplane performance is given in Table 2 below. The data are extracted from reference 1. The solar HAPP has a fly-by-wire control system and a longitudinally fixed center of gravity (c.g.), although c.g. varies vertically from daytime to nighttime configurations. Primary navigation will be through the use of the Global Positioning System (GPS), and no provision will be made for onboard data processing or data storage.

TABLE 1. POWER TRAIN SYSTEM EFFICIENCY.

ITEM	EFFICIENCY
Solar Array Peak Efficiency at Altitude	14.5 %
Power Conditioner	92.0
Electrolyzer Reactant Storage Fuel Cell	56.0
Motor/Controller/Gearbox	87.0
Propeller	86.0
Overall Efficiency	5.6 %

TABLE 2. SOLAR HIGH ALTITUDE POWERED PLATFORM FLIGHT CHARACTERISTICS (FROM REF. 1).

AIRPLANE PERFORMANCE	
CRUISE SPEED	52 KNOTS
ALTITUDE	65600 FEET
CRUISE POWER	13 HORSEPOWER
GLIDE RATIO	
WINGTIPS UP	24
WINGTIPS DOWN	30
CLIMB PERFORMANCE	
WINGTIPS UP	400 FEET PER MINUTE @ 52.5 KNOTS
WINGTIPS DOWN	440 FEET PER MINUTE @ 42.8 KNOTS
STALL SPEED AT SEA LEVEL	9.7 KNOTS WINGTIPS DOWN
MANEUVERABILITY	
MINIMUM TURN RADIUS	5 WINGSPANS
BANK ANGLE	3.7 DEGREES
LANDING PERFORMANCE	
FINAL GLIDE PATH	1.9 DEGREES
LANDING ROLL TO FULL STOP	60 FEET

MISSION DESCRIPTION

The hypothetical mission requirement specified by the U.S. Department of Agriculture is to acquire surface data with a multi-spectral radiometric scanner along a ground track from an experimental farm at

Maricopa, Arizona, to Tucson, then southeast to Mt. Wrightson, via Tucson, and east to Tombstone, Arizona. The HAPP will then turn around and re-trace the course to Maricopa via Tucson The HAPP will fly back and forth over this route, as shown in Figure 5, for 60 days, from May 21st to July 20th

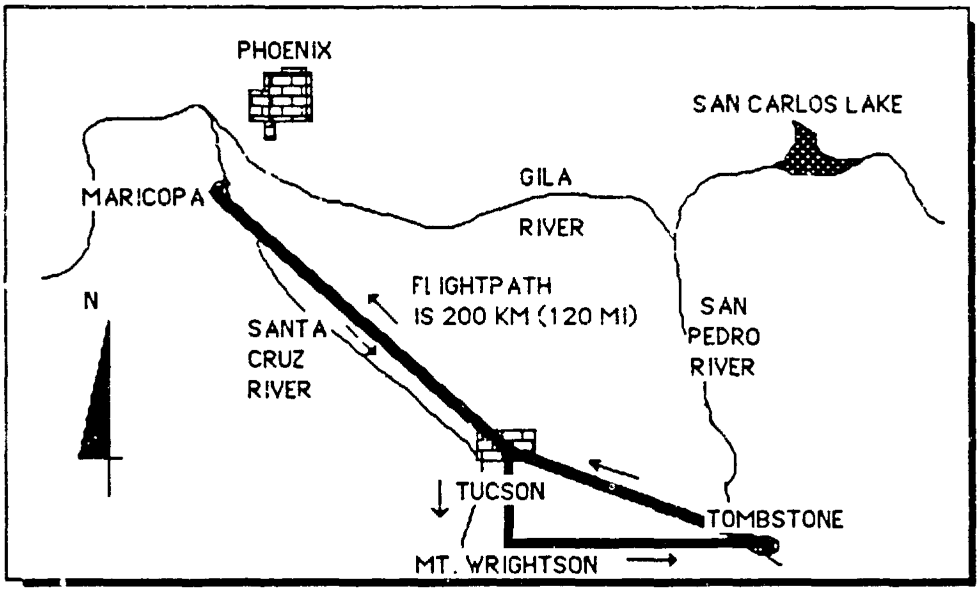


FIGURE 5. USDA MISSION SCHEMATIC.

Data Requirements

Data in seven spectral bands are desired. The bands are listed in Table 3 below.

TABLE 3. SENSOR SPECTRAL BANDS OF INTEREST IN THIS STUDY.

#	BAND	WAVELENGTH (NANOMETERS)	DETECTS
1	BLUE	450 TO 520	AIR & WATER POLLUTION
2	GREEN	520 TO 600	
3	RED	630 TO 680	CHLOROPHYLL ABSORPTION
4	NEAR IR	760 TO 800	VEGETATION DENSITY
5	MID IR	1550 TO 1750	
6	MID IR	2050 TO 2300	
7	FAR IR	10500 TO 12500	VEGETATION STRESS

Operations

The aircraft will be launched from Davis-Monthan AFB with alternate sites being Phoenix and Tucson airports. Palestine, Texas, mentioned in the narrative at the beginning of this report, is an alternate site. Palestine is the launch site for meteorological balloons, and a sizable database of micro-meteorological data exists at that location. Its remoteness to the mission location makes closer sites more attractive, however. Launch will occur about 4:00 AM on a clear, calm night. The large diameter propeller will be fixed in a horizontal position and the aircraft will be towed on a dolly by a ground vehicle. At lift-off speed, straps holding the aircraft to the dolly will be released and the RPV will begin an initial climb to an altitude of approximately 21.3 meters (70 feet). The propeller will then be started and the aircraft will begin its climbout after a brief power system check. Climb to cruise altitude will take about 2 1/2 hours and climb to 5.6 kilometers (18 500 feet) will take about three-quarters of an hour. At this altitude, the lower boundary of positive controlled airspace, the chase planes can be recalled

MISSION TIME LINE

Initial Conditions

In preparation for a mission, the solar HAPP will be monitored on the launch dolly while it is located in a protected enclosure prior to launch. The airplane will be fixed to the dolly with tie downs. In addition, there will be launching connections that will hold the launch dolly to the airplane while it is being towed. Outrigger wheels or supports may be required during ground handling and/or takeoff to support the long, drooping wingtips.

Benign weather conditions are required during launch. Therefore, an adequate weather monitoring and prediction system must be organized and specific go/no-go guidelines established, as is done with spacecraft launches. Favorable launch conditions must be predicted before launch operations are begun. At this point, flight plans,for the HAPP and the chase planes, will be coordinated with local civil and military air traffic control agencies. Prior to launch these pre-filed, or canned, flight plans will be activated.

Payload systems will be checked out in flight as soon as the workload permits; however, they will not be involved in launch preparations. They will be ground tested prior to start of the launch operation and will not require attention until they are activated and tested in flight.

Time Line Format

The essence of this study is the detailed time line which is presented in Table 4. Mission events are shown in tabular form, so the time line can be used as a worksheet. The first column designates time starting at zero and extending throughout the mission. The time line is not complete enough for entries in this column at all mission phases. The second column is entitled "time interval" which is the time interval required to complete the event. Many events are not time critical or the actual time could not be determined until some external factor has been established. For example, moving the vehicle from its protective enclosure to the end of the runway can be determined only after the physical arrangements of the launch station are established. These undetermined time intervals are marked with an asterisk (*).

The third column is a description of the events. The last column identifies the types of personnel involved with the event. They are coded as follows:

LR	Launch and recovery, airplane ground handling and towing crew, and service technicians
FE	Flight engineer in charge of all airplane operations and system monitoring
P	Pilot(s) for takeoff, landing, flight operations and chase plane operations
SD	Sensor/data processing personnel responsible for data subsystem operations

This is a functional categorization and does not necessarily characterize actual persons. For example, the autopilot may accomplish all takeoff and landing operations without anyone being involved in actually flying the airplane. As the worksheet is developed in later studies, those functions will be consolidated and will eventually reflect the actual persons involved in the mission.

Mission Phases

The mission currently envisioned for solar HAPP can be subdivided into distinct phases for analysis.

- Preflight preparations
- Launch

- Climb to cruise altitude
- Transit to station
- Fly mission legs
- Transit back to base for recovery
- Descent to landing
- Recovery

Each phase is detailed in the time line in Table 4 below.

TABLE 4. MISSION TIME LINE.

TIME	TIME INTERVAL	DESCRIPTION	PERSONNEL
		Preflight Preparations	
	*	Preliminary regional weather reports favorable	FE
	*	Coordinate flight planning with FAA	FE
	*	Check current and forecast weather sequence reports at station closest to launch site (and look out the window to verify)	FE
		Load fuel cell reactants (hydrogen and oxygen)	LR,FE
	*	Position vehicle (on launch dolly) at the end of the runway in preparation for takeoff	LR,FE

* Undetermined time interval

TABLE 4. MISSION TIME LINE.

(continued)

TIME	TIME INTERVAL	DESCRIPTION	PERSONNEL
	*	Attach tiedown straps	LR,FE
	*	Position launch tow truck and lay out tow cable	LR,FE
		Attach ground power unit	
		Activate remote control cockpit	FE,P
		Activate vehicle fuel cell-supplied power bus	FE
		Energize air vehicle control system	FE
		Check out control system, remote controls and data link to remote cockpit	FE,P
		Check out payload system and its data link (power up and function only)	FE
		Verify functioning of all formation and navigation lights	LR
		<u>Launch</u>	
		Launch chase plane(s)	P
		Coordinate with FAA for launch time and climb-out instructions	FE,P
		Connect tow line to aircraft	LR
		Start tow vehicle engine	LR
		Start Navigation Subsystem	P
		Disconnect tiedowns	LR
		Confirm power bus energized & Disconnect Ground Power Unit	FG, LR
		Release launch dolly chocks and brakes	LR

* **Undetermined time interval**

TABLE 4. MISSION TIME LINE. (continued)

TIME	TIME INTERVAL	DESCRIPTION	PERSONNEL
DAY 1		Start towing on pilot's command	P,LR
	10 sec		
0 0 10		Lift off	P
	10 sec		
0 0.20		Remote pilot establishes stable towed climb rate	P
0 0:30		Dolly is released when sufficient height is reached to prevent the dolly from bouncing up and hitting the vehicle	P
0 0:30		Start vehicle power train at 21.3 m (70 ft) with prop feathered	P
	15 sec		
0.0 45		Check out vehicle power train	FE,P
	15 sec		
0:01		Unfeather prop and release tow cable when vehicle thrust power stabilizes	FE,P
01:20	20 sec		
		Start powered climbout	P
		Climb to Cruise Altitude	
		Coordinate with chase plane(s) to check out auto pilot	P,FE
DAY 1	5:00		
0:06		Chase and ground pilots coordinate with local FAA: --local departure control after launch	P
0:31	25 min	--switch to center when requested by departure control (before 3.4 km (11 000 ft))	
	17 min	Monitor onboard systems throughout climb	FE,P
0:48	42 min	Chase pilot(s) maintain visual contact through 5.6 km (18 500 ft)	P
1:30		Continue climb under instrument flight rules to 18.4 km (60 000 ft)	
	1.5 hours		
3:00		Switch to military flight control for the rest of climb to cruise altitude of 20km (65 600 feet)	P

* Undetermined time interval

TABLE 4. MISSION TIME LINE. (continued)

TIME	TIME INTERVAL	DESCRIPTION	PERSONNEL
		Check position and navigation system operation	P,FE
		Load station coordinates into navigation system	P,FE
		Check out all sensor systems	FE
3:30		As the sun comes up, check out the solar energy collectors and electrolyzer	FE
3:35	5 min	Switch to fully regenerative internal power	FE
		Fly Mission Legs	
	*	Update navigation system with ground station data (position fix)	P
		Fly to initial coordinates	P
		Power up day and night sensors	FE
		Check sensor data relay to ground station	FE
		As the initial point (IP) for the run approaches internal logic system determines that all equipment, data transmission, and position are satisfactory for a data run	
	4.66 hours	Start first leg of mission	P
			P
		When arriving back at the starting point, commence a 180 standard rate turn and repeat the course.	P
		Power down daylight system as sun sets	FE
		Transit Back to Base for Recovery	
		Check position accuracy (fix) and load in recovery station coordinates	P
		Cruise to recovery site at a favorable altitude for winds aloft	P

TABLE 4. MISSION TIME LINE.

(continued)

TIME	TIME INTERVAL	DESCRIPTION	PERSONNEL
	*	Loiter in vicinity of recovery site until the weather is favorable for descent and landing	P
		Descent	
		Launch chase plane(s)	P
		Start descent at maximum descent rate of 5.1 mps (1000 fpm)	P
		Coordinate with appropriate air traffic control facility for descent	P
	5.5 min	--military to 18.3 km (60 000 ft)	
	49.0 min 18.5 min	--FAA center for segment below 18.3 km (60 000 ft) until hand-off to approach control when approaching the airport traffic area	
		Pick up chase plane(s) at 5.6 km (18 500 ft)	P
		Continue descent to straight-in approach	LR
		Recovery	
	*	Position recovery vehicles near the runway	LR
		Establish visual contact between ground station and aircraft	P,FE
		Establish 1.9 degree glide slope for final approach	P
		Feather propeller in horizontal position at 30.5 m (100 ft)	P
		Use autoland for landing	P
		Place aircraft onto dolly	LR
	*	Move aircraft and dolly to protective enclosure	LR

* Undetermined time interval

CRITICAL INTERFACES

Mechanical and electrical design interfaces between subsystems and functions will be specified in more detail as design of a solar HAPP evolves. Many of these design interfaces are critical to system operation. At this point in the conceptual design process, a much broader view of the interfaces is appropriate. Critical mission/payload/vehicle interfaces are situations where two fundamentally different elements join at a common boundary. Additional information may be required to effect the interface. The following paragraphs describe critical interfaces.

Solar Flux/Solar Cell Interface

The amount of energy collected by the solar array, depends on the position of the sun relative to the airplane, and on the configuration and flight path of the airplane. At times it will be desirable to maximize the collection of energy; at other times, it may be appropriate to operate at less than maximum collection capability. The entire solar radiation environment is described in reference 1. Within limits, system energy collection may be varied by changing the configuration of the airplane (wingtips up or down) and/or the flight path. In operation, the sun/solar cell interface can be managed to provide the energy needs of the entire system. Deciding what to do at the moment will often depend on where one is with respect to various cycles and a prediction of how the cycles (within the time line) will mesh in the future.

System Monitoring/Design and Operational Limits Interface

All system functions will be monitored so that the status of the entire system will be known at all times. Each measurement must be evaluated by comparison with preset values or functions. A virtual mini-"bureau of standards" database must be established for automatic and/or manual system monitoring. Many of the values or functions in the mission database are dependent on mission variables such as time of day, season, and mission cycles. Also, actions to be taken in a given situation will depend on the interrelationships of mission variables.

The aircraft interface with its meteorological environment will affect mission performance at certain times during the mission. As can be seen in Figure 6, winds aloft at this location (Tucson) can be relatively benign during the period of the mission. These data are from a large statistical database and

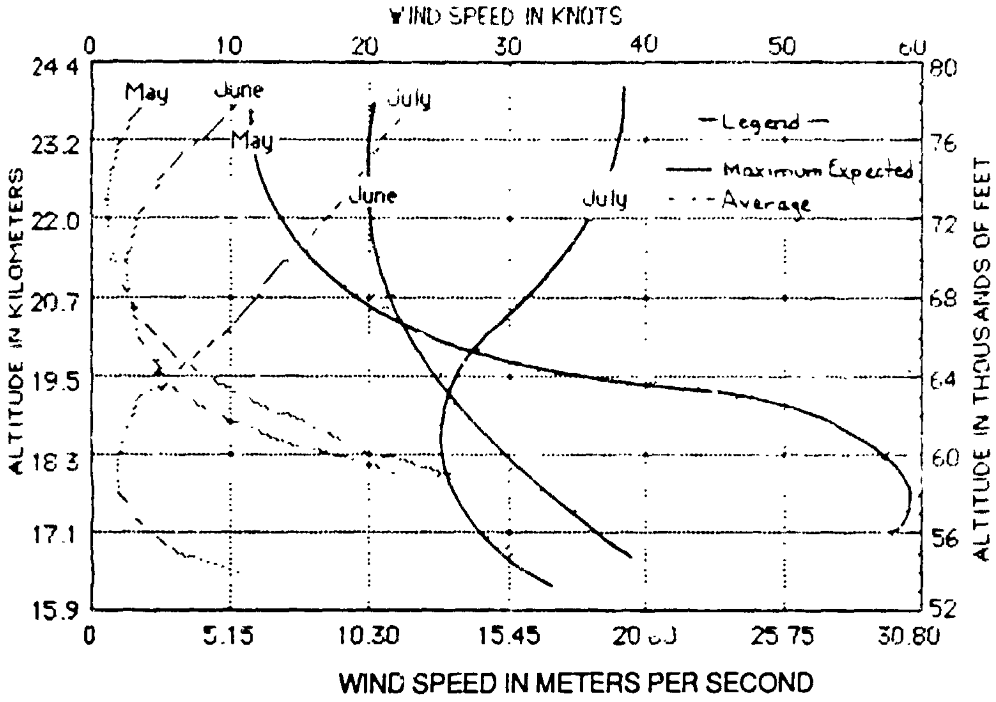


FIGURE 6. AVERAGE AND MAXIMUM EXPECTED WINDS ALOFT AT TUCSON.

are representative of long-term meteorological conditions (Ref's 4 to 8). A minimum (bucket) exists in the winds aloft curves between 17 and 24 km (55 760 and 78 720 ft) during most of a year. This bucket shifts up and down over the duration of the mission, but always exists in the altitude bands of interest for long duration flight. Figure 7 shows the predominant wind direction will shift by 180 ° from May to July. Winds will blow from the west in May, from the south in June and from the east in July.

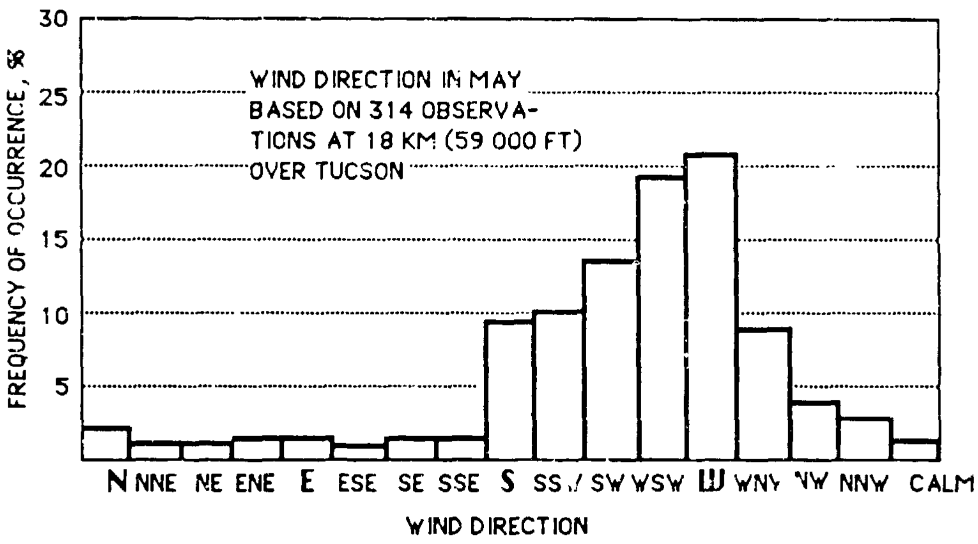


FIGURE 7A. MAY WIND DIRECTION FREQUENCY DISTRIBUTION OVER TUCSON.

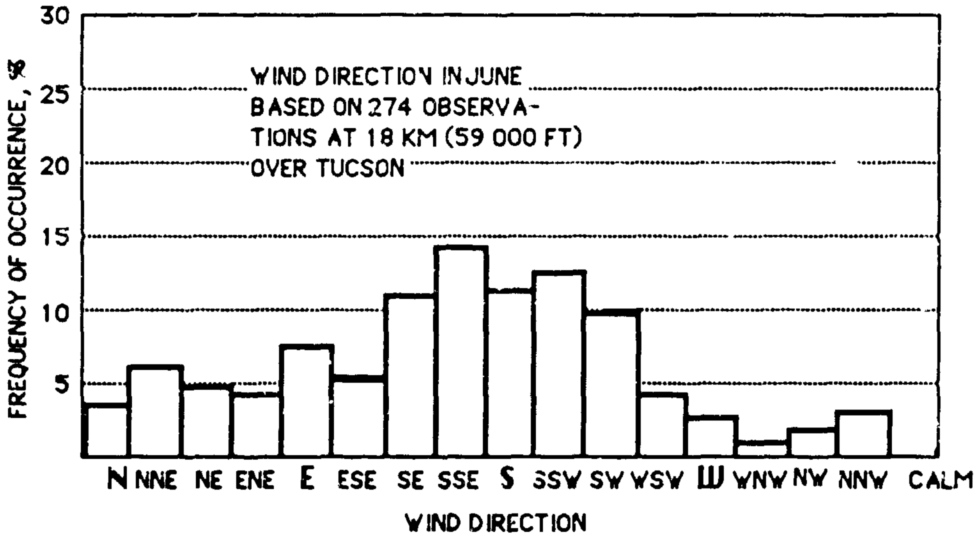


FIGURE 7B. JUNE WIND DIRECTION FREQUENCY DISTRIBUTION OVER TUCSON.

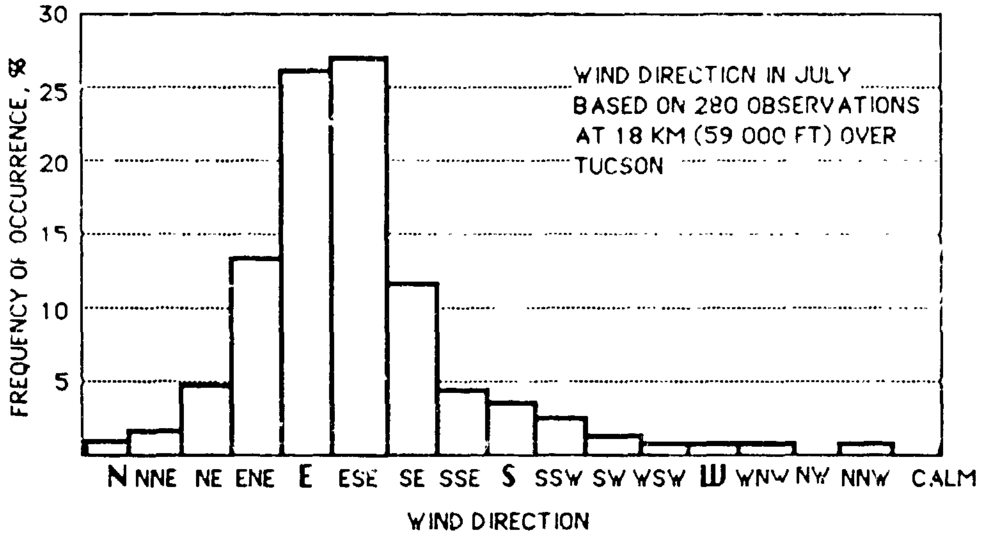


FIGURE 7C. JULY WIND DIRECTION FREQUENCY DISTRIBUTION OVER TUCSON.

Figure 8 presents a strong case that the planned daytime cruise speed of 27 mps (52.5 knots) is adequate over the mission area from May to July. The same may be said of the nighttime cruise speed of 22 mps (42.8 kts). Winds aloft can be expected to exceed these values less than 0.3 % of the time and sufficient energy margin should be planned to increase speed or seek a more favorable altitude during these rare intervals.

Sensor/Data Processing Interface

Sensors will be obtaining data by scanning the ground. Information in Ref. 3 describes anticipated variations in the data because of sun cycle and viewing angle. Some of these effects may be considered in the data processing at the ground station.

Possible Interface Failure Modes

The term failure will be interpreted here as any circumstance which would impair the ability of the solar HAPP to accomplish its mission. In this context, the unique aerodynamic, aeroelastic and

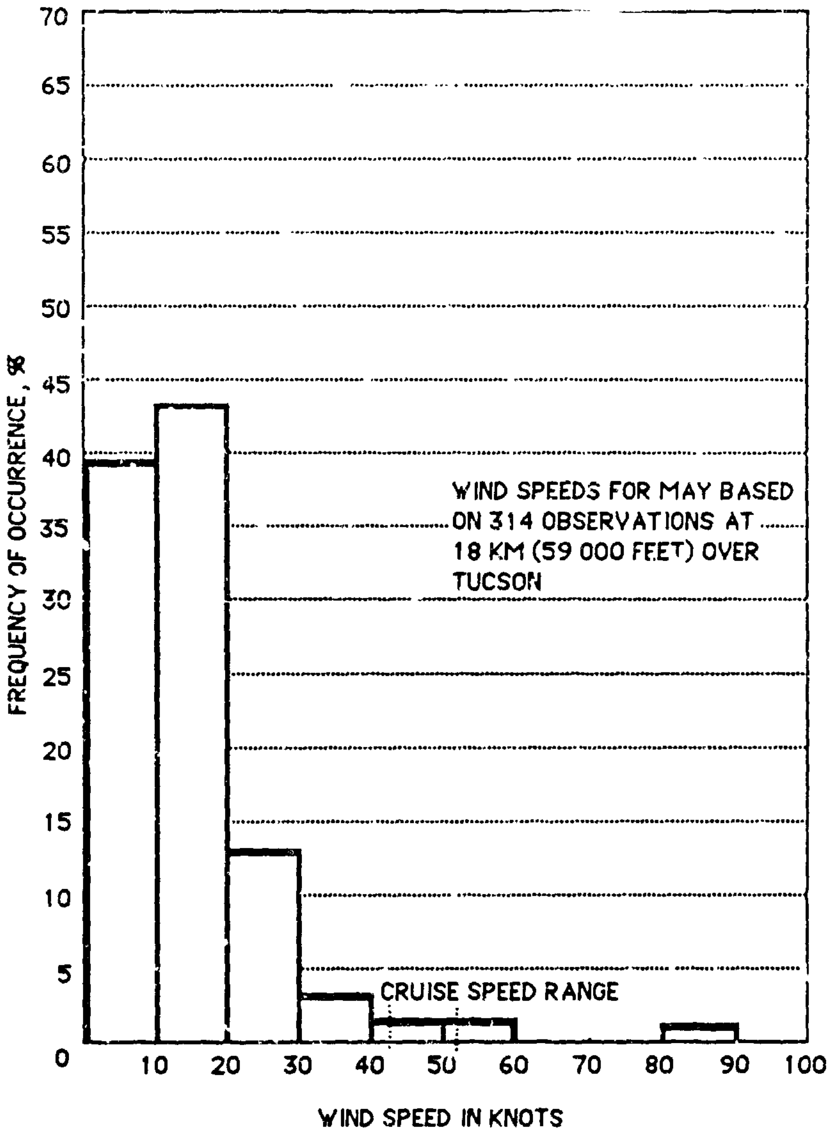


FIGURE 8A. MAY WINDS ALOFT SPEED DISTRIBUTION OVER TUCSON.

structural configuration will present problems not usually seen in conventional aircraft. Although they are discussed here, whether these problems cause failures remains difficult to predict because they are not readily definable. More readily quantifiable problems involve the failure of onboard systems such as the power train, the electrical system, and communication links.

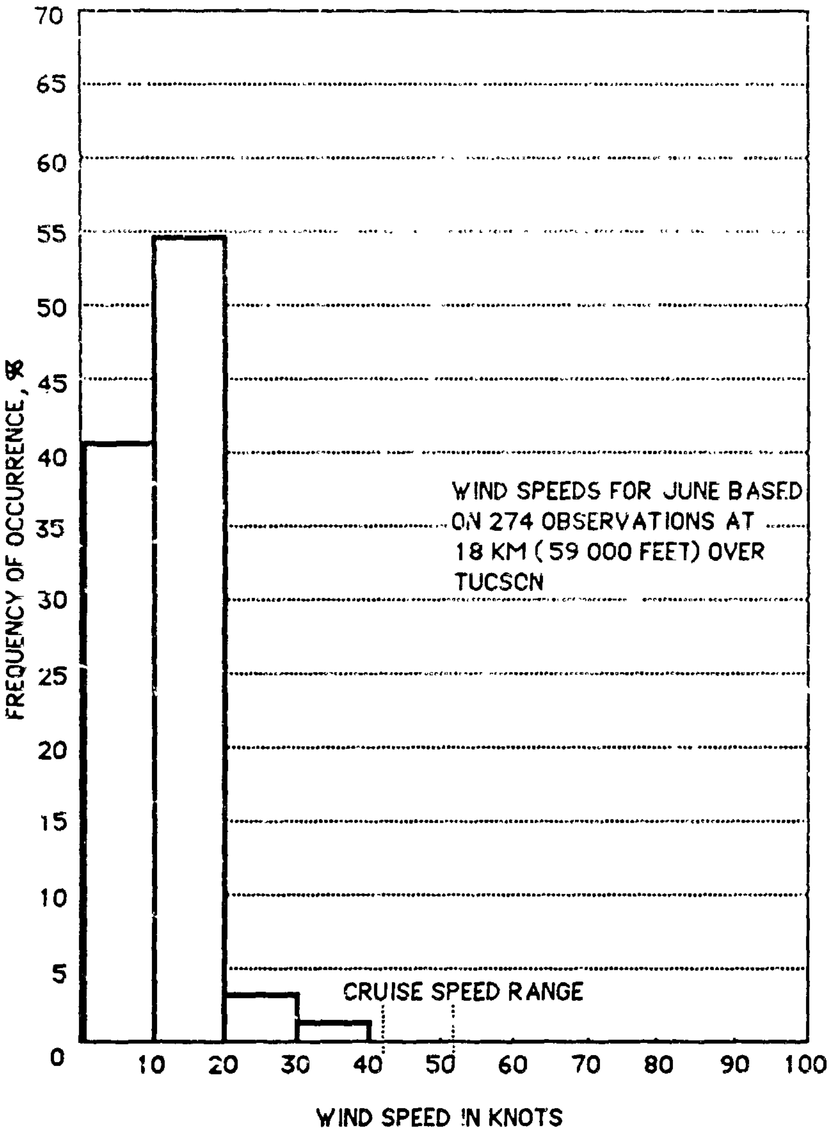


FIGURE 8B. JUNE WINDS ALOFT SPEED DISTRIBUTION OVER TUCSON.

Aside from those circumstances brought about by the vehicle's exceptionally low wing loading and large virtual mass, failure modes and techniques for recovery should not be appreciably different from those of any other RPV. The wing loading effect will be felt particularly as the aircraft responds to both wind velocity and gradients. This characteristic is not seen as a failure, but as a property which merits unusually close attention from the remote pilot. Because of its very large virtual mass, the aircraft will be slow to respond to control inputs at low altitudes and the remote pilot or autopilot system will need to respond quickly to error signals while they are still manageable.

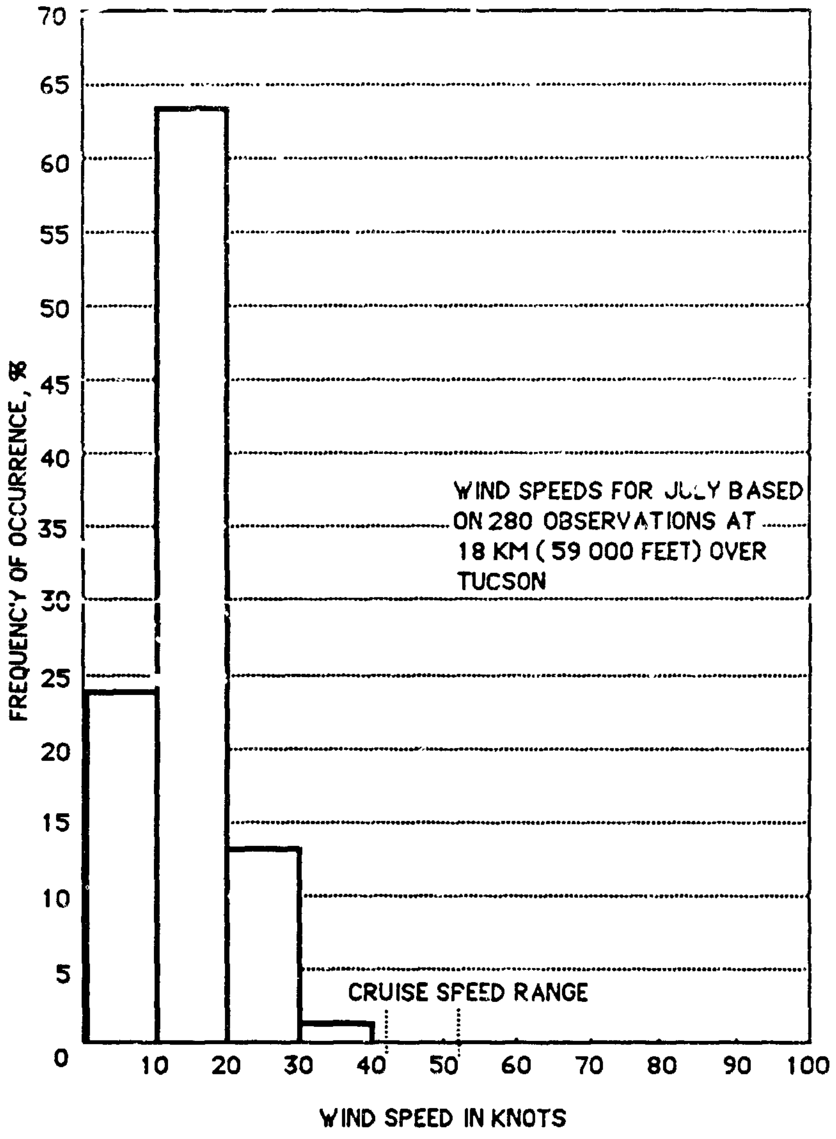


FIGURE 8C. JULY WINDS ALOFT SPEED DISTRIBUTION OVER TUCSON.

The solar HAPP will be designed from the outset to be inherently stable about all three of its principal axes. Any minor upset in flight path, except in the spiral mode, will be correctable by the aircraft's natural stability. In other words, the remote pilot's normal function most of the time will be to keep the aircraft trimmed rather than to fly it. The spiral stability mode can be expected to require special attention, because the solar HAPP may be excessively unstable in this mode. Therefore, turns should be made slowly and kept to shallow bank angles. An autopilot should be incorporated in the aircraft and used whenever possible

The solar HAPP will also have unique aeroelastic properties which are of particular significance because of the long wingspan and low structural stiffness of the high aspect ratio wing. Experience with PROJECT SUNRISE solar powered vehicles of 1975/76 (Ref. 9), should be noted here On two occasions, the vehicles suffered catastrophic structural failure from flutter induced by these same characteristics This is not seen as a failure mode for solar HAPP, but attention should be directed early in the design process to provide a suitable margin between the solar HAPP's cruise speed and its flutter limit. Suitable algorithms will have to be built into any automatic control mechanisms used.

The foregoing describes those hazards to which a solar HAPP is exposed simply because of its size, shape, flexibility and basic operational mode. These are hazards which cannot be eliminated by careful design alone without impacting mission capability. Careful attention to the operating environment and to pilot skill at all times will minimize these hazards.

These failure modes just discussed are unique to solar HAPPs. The next failure modes to be discussed are characteristic of any type of aircraft and remedies can usually be effected by appropriate action on the part of the remote pilot.

At launch. Five possible types of failure have been postulated during this study for the launch phase. These are:

- **Towline breaks or tow equipment loses power before propeller is started.** Pilot action: Release towline at aircraft end. Don't start propeller. Abort flight by shutting off up-link power and permit aircraft to land straight ahead.
- **Towline breaks or tow equipment loses power after propeller is started.** Pilot action: Release towline at the aircraft end. Depress nose of aircraft to gain flying speed. If successful, proceed with climbout. If not, abort flight by shutting off up-link power and permit aircraft to land straight ahead.
- **Loss of propulsive power.** Pilot action: Abort flight. Depress nose to gain flying speed. Try to bring propeller to horizontal position. Shut off up-link power

and permit the aircraft to land straight ahead. Since launch will be at night, aircraft cannot be readily seen No attempt should be made to return to the launch site.

- **Loss of ground control up-link or catastrophic loss of electrical power.** Pilot action: None. The aircraft should be pre-programmed to land automatically straight ahead. If the aircraft is not back on the ground after a suitable time interval after failure has occured, it should self-destruct (non-explosively by cutting bracing wires).

- **Loss of ground control down-link.** Pilot action: Same as for loss of propulsive power above.

During climbout. Three possible failure modes have been postulated. These are:

- **Loss of propulsive power, partial or complete.** Pilot action: If enough power is available to maintain control in level flight, try to bring the aircraft back over the launch site and hold until daylight. Then descend for a normal recovery. If control can be maintained but altitude cannot, try to maneuver the aircraft over an unpopulated area and initiate its self-destruct sequence.
- **Loss of ground control up-link or catastrophic loss of electrical power.** Pilot action: None. The aircraft will self-destruct after a suitable interval has transpired if power is not reinstated.
- **Loss of ground control down-link.** Pilot action: Same as for loss of propulsive power.

During cruise. Several failure modes exist. Three are postulated here:

- **Loss of propulsive power.** Pilot action: If power loss occurs during daylight hours, bring the aircraft back over the launch site and start a normal recovery. If loss occurs at night, lower wingtips to horizontal (if they're not already there) and try to remain airborne until daybreak. Then effect a normal recovery. If this is not possible, maneuver the aircraft over an unpopulated area and initiate its self-destruct sequence.
- **Loss of ground control up-link or catastrophic loss of electrical power.** Pilot action: None. The aircraft will self-destruct after a suitable interval has passed following failure unless power is reinstated.

- **Loss of ground control down-link.** Pilot action: If failure occurs during daylight hours and the aircraft can be tracked by transponder or visually, bring it back over the launch site and make a visual recovery. If failure occurs at night and the aircraft can be tracked, bring it back over the launch site and hold until daylight. Then make a normal visual recovery. If the aircraft cannot be tracked or seen visually, either during daylight hours or darkness, initiate its self-destruct sequence.

The final phase to be considered is recovery. The only failure mode of consequence during this phase would be **premature loss of propulsive power during letdown or final approach.** In this case, pilot action would be to keep the glidepath high and airspeed up and use spoiler and/or throttle control (if partial power remains) to maintain glidepath. If power fails completely during the approach in spite of all other precautions, allow the aircraft to land straight ahead without further pilot input.

DATA AND CONTROL LINKS

Solar HAPP communication needs were reviewed to establish tenative systems requirements for the ground station communication links, data processing, and data storage. The following paragraphs summarize the results:

1. **Ground Station Location:** Preliminary analyses indicate that only one ground station will be required. The microwave horizon for an aircraft at 20 kilometers (65600 feet) is over 480 kilometers (300 statute miles). At lower frequencies, communications over greater distances are possible. Therefore, since the longest mission leg will be less, it will be possible to have only one ground station antenna. Further, if the solar HAPP can be launched from Davis-Monthan AFB, Phoenix, or Tucson, simple relays would be required for low altitude operations during launch and recovery. These relays could take the form of additional payload on one or more strategically positioned chase planes.

2. **Communications Links:** Three communications links will be required. The first will be a GPS receiver to collect navigation signals from satellites. The second will be two-way communications antennas for system monitoring and control from

the ground station(s). The third will be a down link with the ground station(s) for payload data transmission. More than likely, two separate links with the ground station will be required. A trade study will be required to determine the optimum system.

3. **Data Processing:** For simplicity and weight minimization of airborne components, minimal data processing will be done onboard. The airborne part of the data subsystem will be in continuous contact with the ground station and onboard data processing will be only that required for transmission to the ground station. Data processing and storage will be accomplished at the ground station. Figure 9 shows a schematic of the communications links.

PERIPHERAL EQUIPMENT

The equipment identified during the development of the time line is listed in the following four categories:

- Ground and Air Traffic Control
  - remote control cockpit
- Launch and Recovery
  - launch dolly
  - launch tow vehicle
  - tow cable
  - chase planes
  - outrigger gear (wheels or skids) if needed
- Preflight and Other Checkout
  - ground power unit
- Support and Servicing
  - hydrogen and oxygen supply units
  - control system checkout equipment
  - payload checkout equipment
  - navigation system checkout equipment
  - protective enclosure

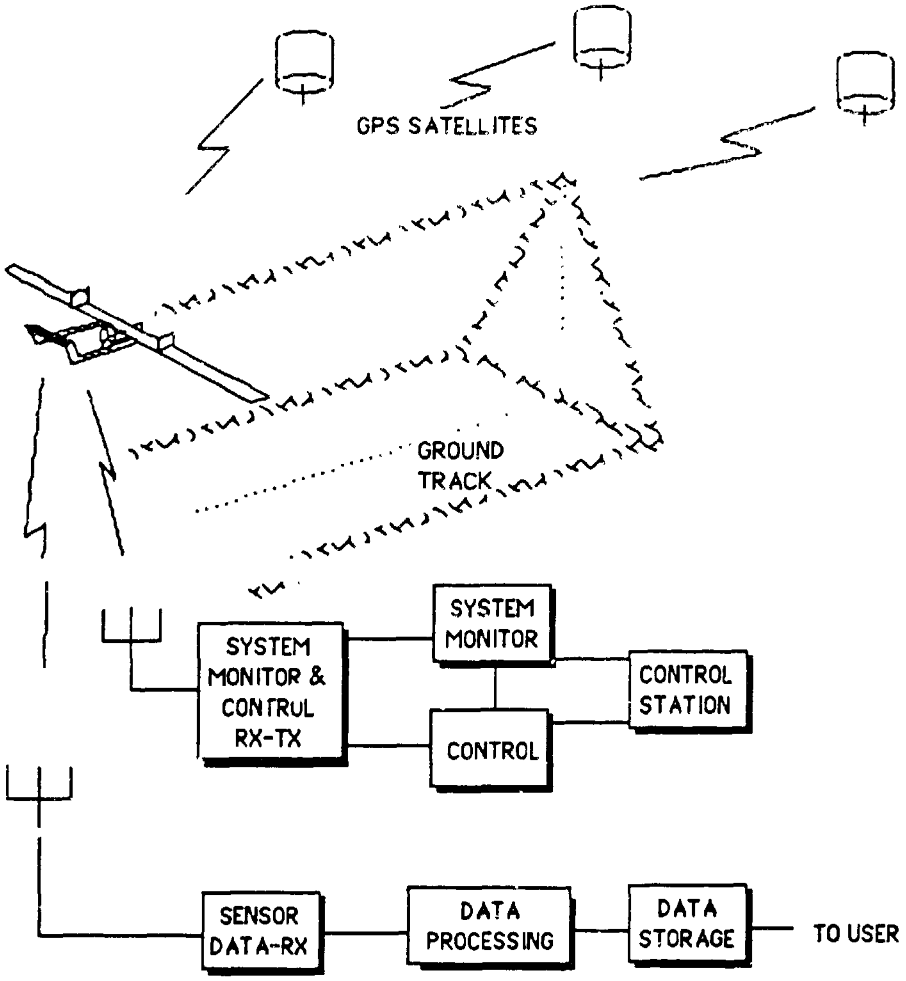


FIGURE 9. SOLAR HIGH ALTITUDE POWERED PLATFORM COMMUNICATION LINKS.

STATE-OF-THE-ART CONSIDERATIONS

Projected operation of solar HAPP in the late 1980's or early 1990's is based on continued advancement of the state-of-the-art in several areas. Reference1 discusses the need for advancement in energy collection and storage, thrust generating components, and airframe design. The need for advancement is not so much in the operational feasibility of the subsystems or components, but in weight reduction and reliability improvement of integrated designs. There are two facets to advancing the state-of-the-art. One is related to matching components; the other is related to refining the design of the components themselves.

Multiple duty cycles and meshing of duty cycles over long missions complicates component matching in energy collection and storage equipment. Design refinements in the components themselves must be keyed to this large low speed application. For example, design improvements in large lightweight propellers can be made. Also, autopilot control algorithms for large, lightweight, slow flying airplanes are required. Improvements in the art of detailed modelling of large lightweight aircraft structures are also required including the ability to analyze the desirability of dynamic soaring.

In addition to advancement in the state-of-the-art of airplane and subsystem design, it is necessary to broaden existing knowledge of world-wide atmospheric conditions to predict high altitude turbulence to assure adequate, but not excessive, structural design margins.

Figure 10 presents an overview of the components affected by these state-of-the-art considerations in a solar HAPP.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Equipment and personnel functions associated with each event in the mission have been identified. Additional information depends on configuration development, design refinement, and other factors such as the physical arrangement of the operations. **The time line worksheet can be used to aid in the development of plans for any future work.**

System monitoring of onboard equipment results in broad operating conditions. Thus, in monitoring the status of the component or system, adequate conditions at one point in the duty cycle could be an indication of impending failure of a component or system at another point in its cycle. Also, the action to be taken for any given situation is heavily dependent on the duty cycle. **The monitoring system will be a key element in the success of the operating system.**

Communications links have been identified. **Yet to be determined are the data requirements for each link, so conceptual designs may follow which will meet mission requirements.**

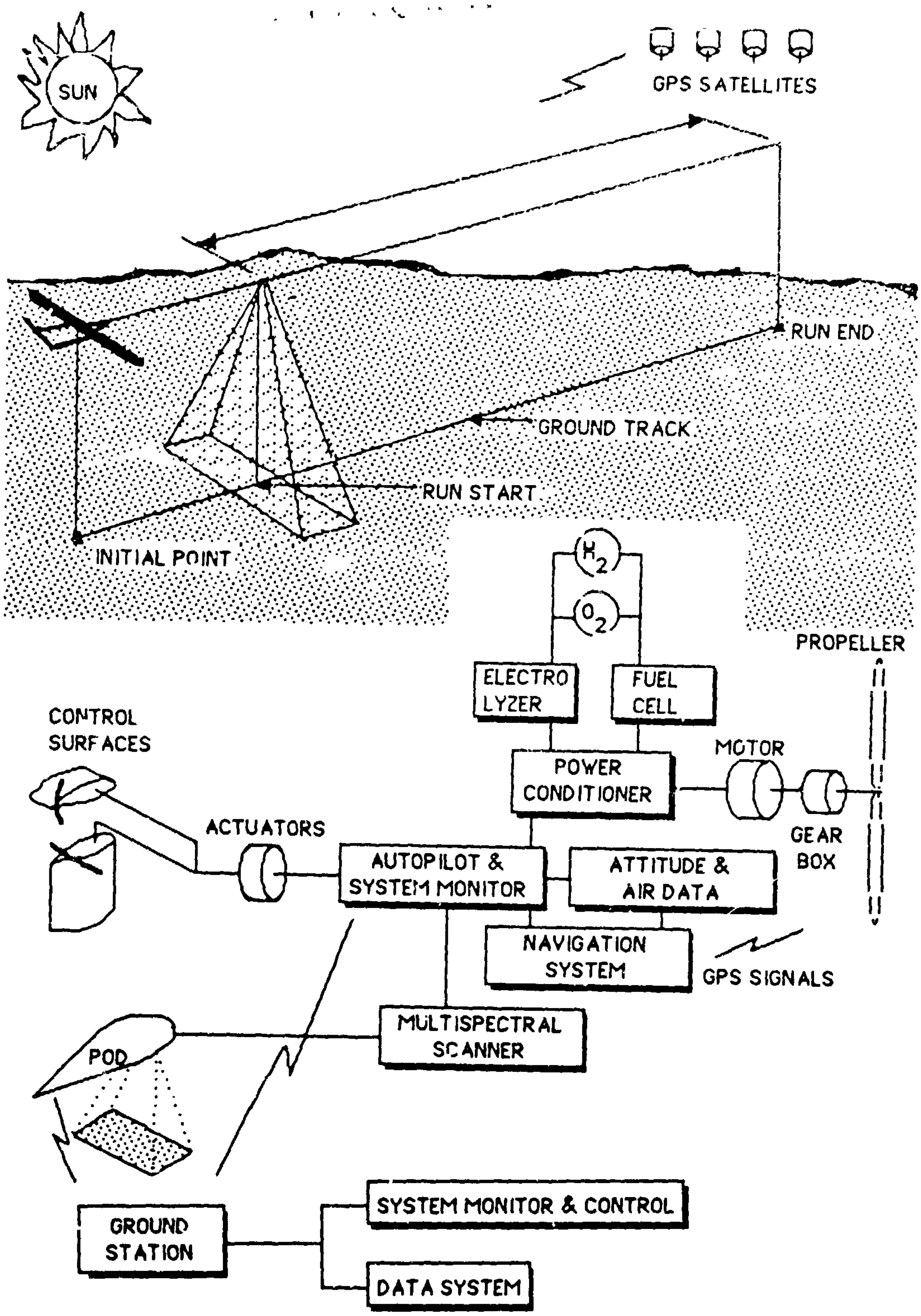


FIGURE 10. SOLAR HIGH ALTITUDE POWERED PLATFORM OVERVIEW.

Component matching is required over a wide range of operating conditions, as discussed in reference 1. Components must be properly matched to provide the best overall design. In actual operation, the components will frequently be operating off their design points. **Future investigations must be broadened to include wider ranges of operations.**

Recommendations

Investigation of the time line indicates a need to simulate operation of a solar HAPP to reveal how various duty cycles mesh together. Further, investigations reveal that a properly designed simulator could also aid component design by evaluating proper component matching. The simulator would be updated and refined as the design progressed and then would be used to evaluate breadboard and brassboard equipment. Finally, the simulator would be used during operations by providing a standard for airborne system monitoring. Thus, a simulator can be used starting with conceptual design and extending through the operational phase **It is recommended that a simulator plan be developed and work be initiated on the simulator.**

Data rates on the two-way communications link for system monitoring and control and the one-way link for mission data should be determined as soon as possible. The amount of data handled by the monitoring and control channel will depend to a great extent on the monitoring scheme used. As noted previously, the monitoring system is a key element in successful operation of a solar HAPP. **It is recommended that a definitive payload and mission be used to perform an airframe/power train/ configuration optimization to determine the degree of inter-dependence of design variables.** This would provide a new baseline for simulator design and subsystem evaluation.

Models of the power train components exist and have operated in various systems, but the exact combination of these components and duty cycles required by a solar HAPP have not been tested. A breadboard model of a solar HAPP is required to investigate interactions between components with off-design point operations. Also, a solar HAPP must be designed for long periods of automonous operations, and experience must be gained in monitoring and automatic control of aircraft. **It is recommended that plans be made to build a breadboard of this subsystem.** The plan would include updating to brassboard as actual components become available. The breadboard and brassboard will be operated in conjunction with the development of the simulator previously discussed. Finally, a solar HAPP would be ground and flight tested with the aid of the simulator.

Acknowlegements

The authors would like to acknowledge assistance received during the performance of this study As this work progressed, quite a few individuals and agencies became involved The industry team included the authors from Lockheed Missiles and Space Company (David Hall, David Watson), Lockheed-Georgia Company (Robert Tuttle) and Stanhall Aero Systems (Stanley Hall) Providing timely inputs were Dennis Dysmachek and Christopher O'Brien (meteorology) and Emanuel Dimiceli (energy conversion and storage) of LMSC's Space Systems Division, Charles Fortenbach (vehicle sizing and stability) and Robert W. Parks (operational considerations of large vehicles) of LMSC's Astronautics Systems Division and Starr Colby (mission analysis) of the Lockheed Missiles, Space and Electronics Group's Research and Development Division.

Government guidance and assistance was from James Young[illegible] (technical monitor), Ray Lovelady and Charles E. K. Morris of NASA Langley Research Center Dr Ray Jackson of The U S Department of Agriculture's Agricultural Research Service in Phoenix provided guidance on operational usage and sensor requirements.

Last, but not least, the authors would like to thank Mr. Mark Wozniak of Computer Plus in Sunnyvale for his assistance in preparation of this final report which was done on an Apple MacIntosh micro-computer and printed on an Apple LaserWriter.

REFERENCES

1. Hall, D W.,Fortenbach, C D.,Dimiceli E V.,and Parks, R W., "A Preliminary Study of Solar Powered Aircraft and Associated Power Trains", NASA Langley Research Center, 1983 (CR3699).

2. Hall, David W. and Hall, Stanley A., "Structural Sizing of a Solar Powered Aircraft",NASA Langley Research Center, 1984 (CR-172313).

3. Jackson, Ray D, "Plant Health; A View From Above", from "Challenging Problems in Plant Health", edited by T. Kommedahl and P Williams, The American Phytopathological Society, 1983.

4. Cochrane, James A., Henry, Robert M., and Weaver, William L., "Revised Upper-Air Wind Data for Wallops Island Based on Serially Completed Data for the Years 1956 to 1964," NASA TN D-4570, 1968.

5. Tolefson, H.B., "An Investigation of Vertical Wind-Shear Intensities from Balloon Soundings for Application to Airplane- and Missile-Response Problems," NASA TN 3732, 1956.

6. Coleman, Thomas L, and Steiner, Roy, "Atmospheric Turbulence Measurements Obtained from Airplane Operations at Altitudes Between 20,000 and 75,000 Feet for Several Areas in the Northern Hemisphere," NASA TN D-548, 1960.

7. Kaufman, John W., Editor, "Terrestrial Environment (Climatic) Criteria Guidelines for Use in Aerospace Vehicle Development, 1977 Revision," NASA TM-78118, 1977.

8. Strganac, Thomas W., "Wind Study for High Altitude Platform Design," NASA RP-1044, 1979.

9. Boucher, R.J., "Project SUNRISE", presented to Joint Propulsion Conference of AIAA/SAE/ASME, June 18-20, 1979 (AIAA 79-1264).

10. Youngblood, James W. and Jackson, Ray D.,"Airborne Reconnaissance in the Civil Sector: Agricultural Monitoring from High-Altitude Powered Platforms", SPIE Paper Number 424-24, 1983.

11. Anonymous, "Bede Scores Three World Records", Sport Aviation, January, 1970, page 4.

APPENDIX A

FEASIBILITY OF ADAPTING EXISTING AIRCRAFT TO A NEAR-TERM AGRICULTURAL MISSION

Background

For the past ten years, industry and government have been studying the feasibility of observing ground targets from remotely piloted, long duration, high altitude aircraft. One mission under consideration during this period has been addressed in reference 10. Another has been addressed in the main body of this report Because of the developmental nature of the solar powered airplane studied in this and other reports (Ref's 1 and 2) and its high cost, the advantages of high altitude, long duration surveillance of crops have not been demonstrated on a practical scale

This appendix addresses the feasibility of modifying several aircraft already in existence to demonstrate crop surveillance in the manner stated in the body of this report. Existing aircraft powered by conventionally fueled engines cannot match the cruise endurance and altitude of a solar powered airplane. Much could be done, however, to prove the concept of high altitude long duration flight by operating a demonstrator below 20 km (65 600 ft) for periods of up to a week. A suitably modified existing aircraft should be equal to the task and it could be flown at a fraction of the cost and time required to develop an operational solar powered airplane.

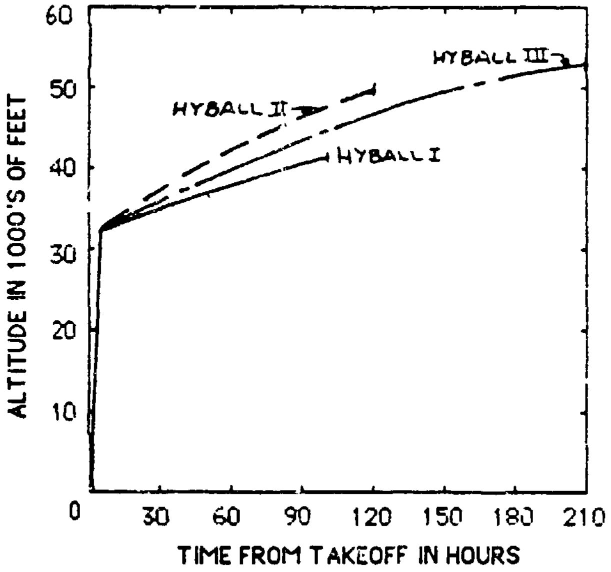
Mission Altitude

The target mission altitude used here is 16.8 km (55 000 ft). One of the primary determinants in the selection of this altitude is the necessity to keep the aircraft clear of most civilian and military traffic. Such traffic seldom operates above 13.7 km (45 000 ft) so the 3.1 km (10 000 ft) margin used here may be excessive when the difficulties and costs of achieving it are considered.

Reaching and maintaining an altitude of 16.8 km (55 000 ft) for long periods of time, especially in an aircraft not designed from the ground up to do so, implies extreme difficulty. Altitudes above 9.2 km (30 000 ft) to 12.2 km (40 000 ft) require particular attention to aerodynamic design.

Since all traffic above 5.5 km (18 000 ft) is under positive FAA control, coordinating HAPP operation with that of other traffic would be a simple matter, particularly if the operation were to be relatively short, say a week. The vehicle will need to carry position reporting equipment so it should be able to operate in traffic just as any other controlled aircraft. The 1968 coast-to-coast flight of the balloon, **Double Eagle**, was carried out with complete safety partly because the aircrew were able to coordinate with local and regional air traffic control facilities along the route at altitudes much lower than being discussed here.

In summary, staying clear of other traffic in HAPPs does not have to be a significant problem, and the operating altitude might be adjusted to as low as 12.2 km (40 000 ft) if prudence or pocketbook dictate. Figures A-1a and b show the benefit of lower altitude operation on endurance for the aircraft about to be discussed.



<u>FIGURE A-1a. ALTITUDE INCREASES POSSIBLE WITH TIME.</u>

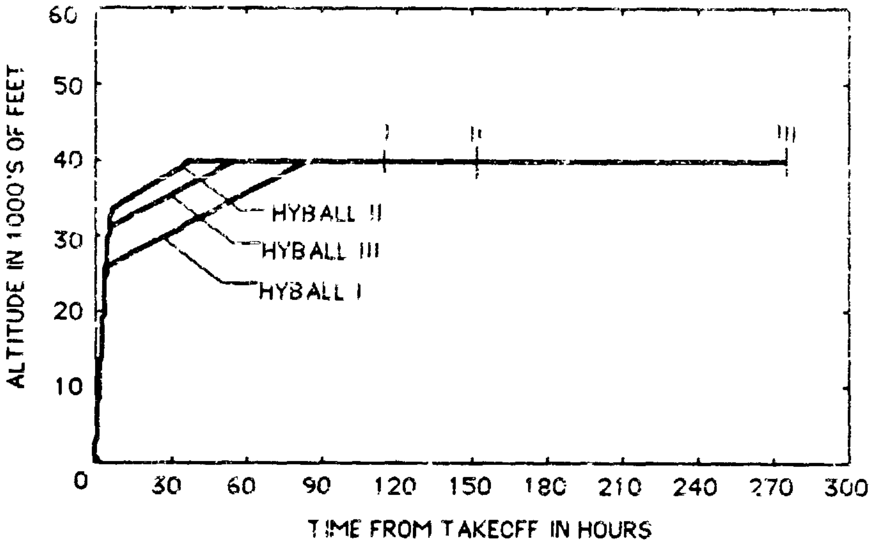
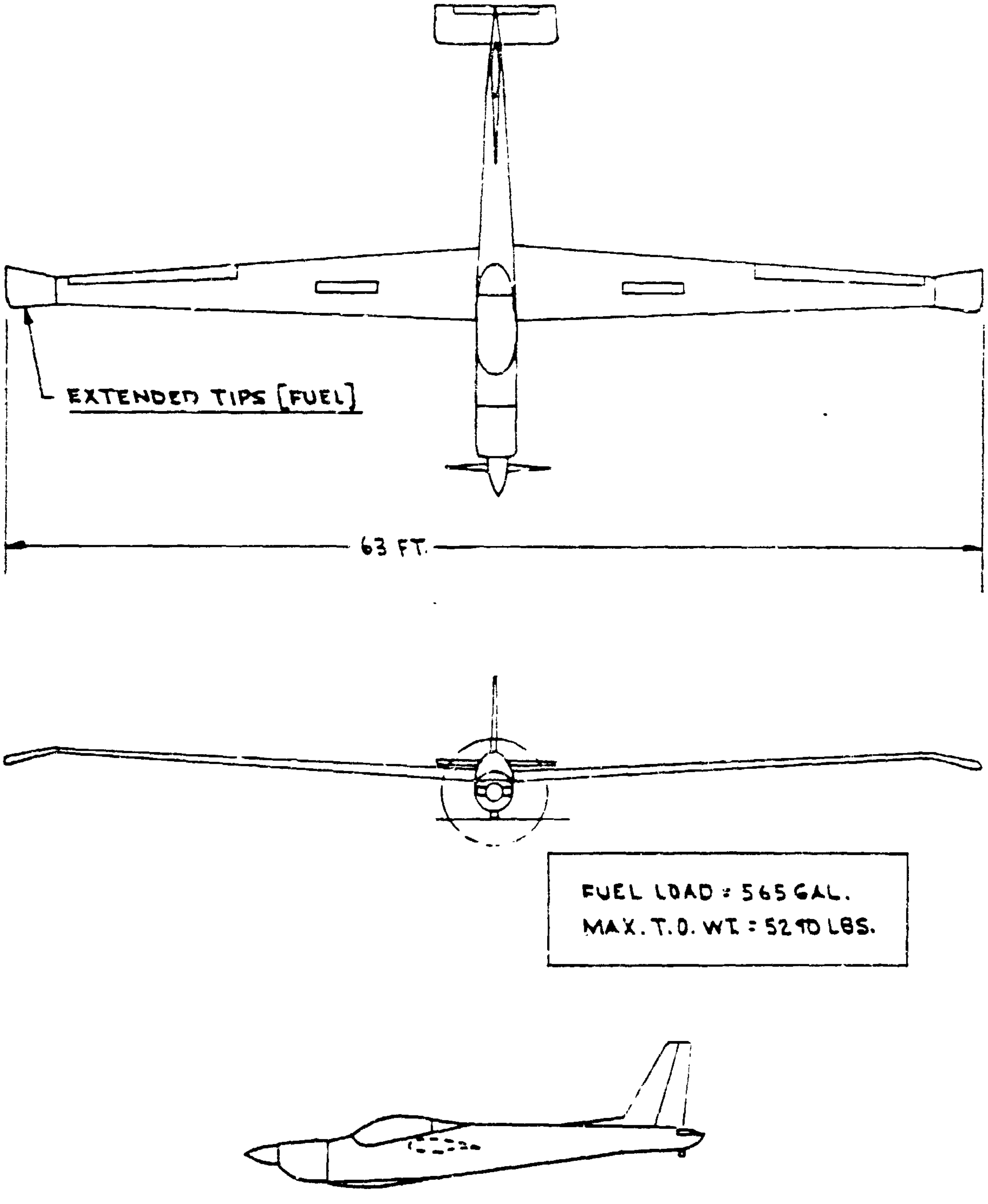


FIGURE A-1b. ENDURANCE POSSIBLE WITH CONSTANT ALTITUDE.

Candidate Airframes

Hyball I (short for high eyeball). The first candidate airframe is a modification of James R. Bede's experimental around-the-world flyer, **Love I** (Ref. 11). Bede designed and built this aircraft in 1969 based on the widely used Schweizer 2-32 sailplane. Figure A-2 shows the general arrangement of the **Love I** with recommended modifications. The present location of this aircraft is unknown; however, it may be in one of the many small aviation museums in this country The Experimental Aircraft Association might be able to locate this and other candidate aircraft.

In **Love I**, the Schweizer 2-32 sailplane was modified for the around-the-world attempt by installing a Teledyne Continental IO-360 rated at 168 kw (225 horsepower) and normally aspirated. Bede extended the wingspan slightly and sealed the interior of the wing to carry fuel. By adding two fuselage tanks for a total of 2140 liters (565 gallons) and installing extensive navigation and life support equipment, Bede hoped to fly around the world non-stop. These modifications increased empty mass from around 318 kg (700 lb_f) in the sailplane version to 884 kg (1950 lb_f). Gross takeoff mass rose comparably to 2399 kg (5290 lb_f).



FUEL LOAD = 565 GAL.
MAX. T.O. WT. = 5290 LBS.

FIGURE A-2. HYBALL I GENERAL ARRANGEMENT.

The calculations made during this study have assumed that both gross mass and aircraft configuration would remain unchanged from the original **Love I**. Pilot, life support systems and navigational equipment would be replaced by payload, additional fuel and communications, command and control (C^3) equipment. With these modifications, this aircraft would reach an initial ceiling of 8 km (26 000 ft) and an end-of-flight ceiling of 13.1 km (43 000 ft). Total endurance could be as high as 110 hours if the mission profile included gradual climb to 12.2 km (40 000 ft) with fuel expenditure. This altitude band will conflict with airliner traffic operating altitudes. Wind and turbulence data are already well established at these altitudes, though. Given the potentially high air traffic controller workload and the poor meteorological data return of this altitude band, this configuration is somewhat less than suitable.

Hyball II. This is a modification of **Hyball I**. The original IO-360 engine would be replaced by a turbocharged engine of higher rating. The engine used for these calculations was the Lycoming TIO-540-R rated at 261 kw (350 horsepower) at 4.6 km (15 000 ft). Other modifications would include addition of 3.1 m (10 ft) to each wingtip which would increase wingspan to 23.5 m (77 ft) and aspect ratio to 28. In the production Schweizer 2-32, these figures are 17.4 m (57 ft) and 18.05, respectively. Two external tanks would be added to increase total fuel load to 3654 l (965 gal). Takeoff gross mass would increase to 3719 kg (8200 lb_f). In this configuration, **Hyball II** would be capable of attaining 10.1 km (33 000 ft) initially and 15.2 km (50 000 ft) at the end-of-run 120 hours later. Leveling off at 12.2 km (40 000 ft) and throttling back would increase endurance to 142 hours with approximately 100 hours at 12.2 km (40 000 ft). Figure A-3 presents a general arrangement of this aircraft.

Since both **Hyball I and II** would carry fuel in a wet wing, the basic wing structure would have to be modified to avoid excess wing deflections. Lockheed Sunnyvale's experience with the Army/Lockheed QT-2, which used unmodified Schweizer 2-32 wings, was that the operating limit load factor had to be set at 2.5 to avoid excessive deflections. The wing on the follow-on Lockheed **Q-Star** was strengthened as was that of the later Army/Lockheed YO-3A. These modifications were all made at the Schweizer factory in the original 2-32 jigs which should still be available.

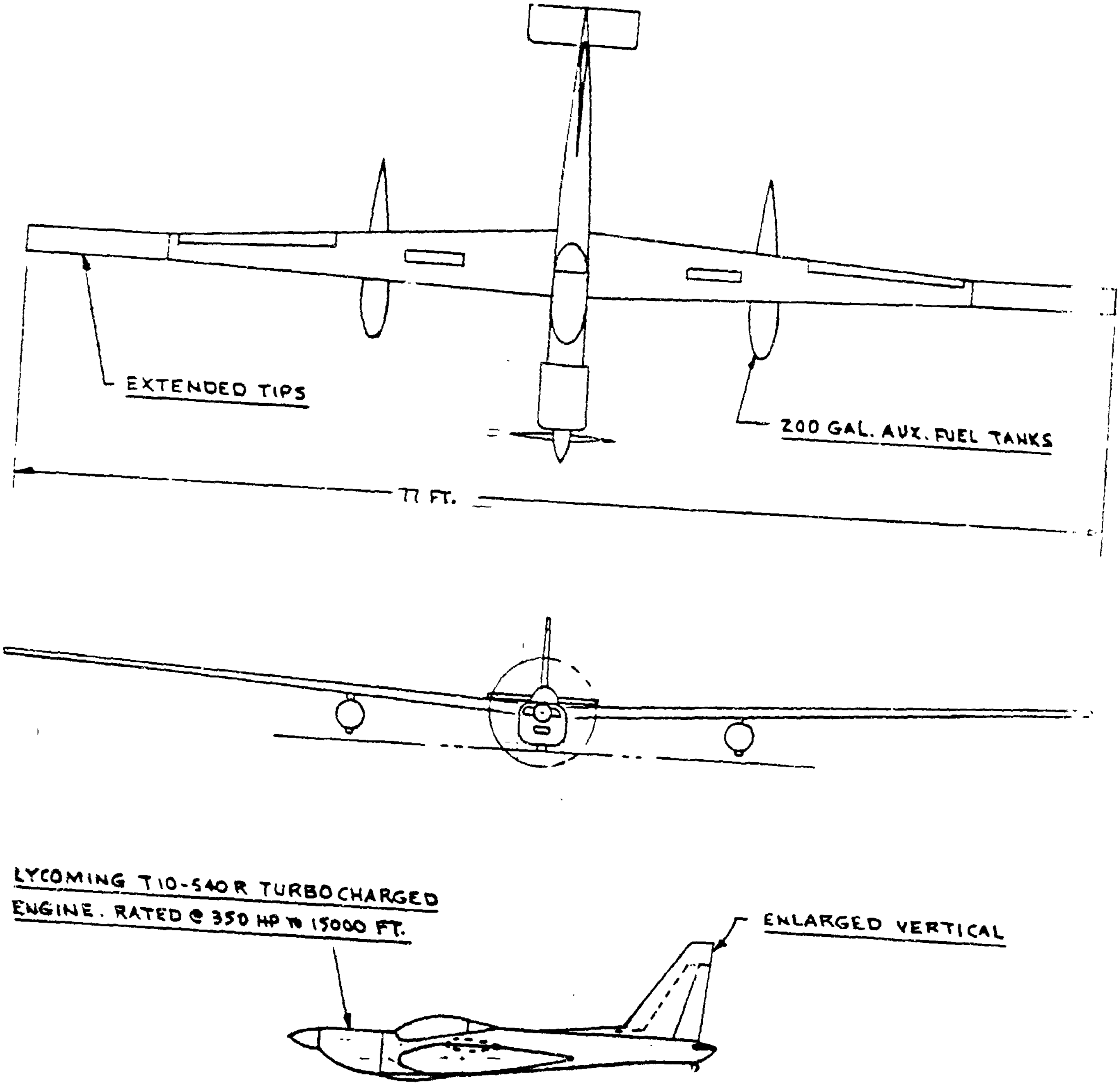


FIGURE A-3. HYBALL II GENERAL ARRANGEMENT.

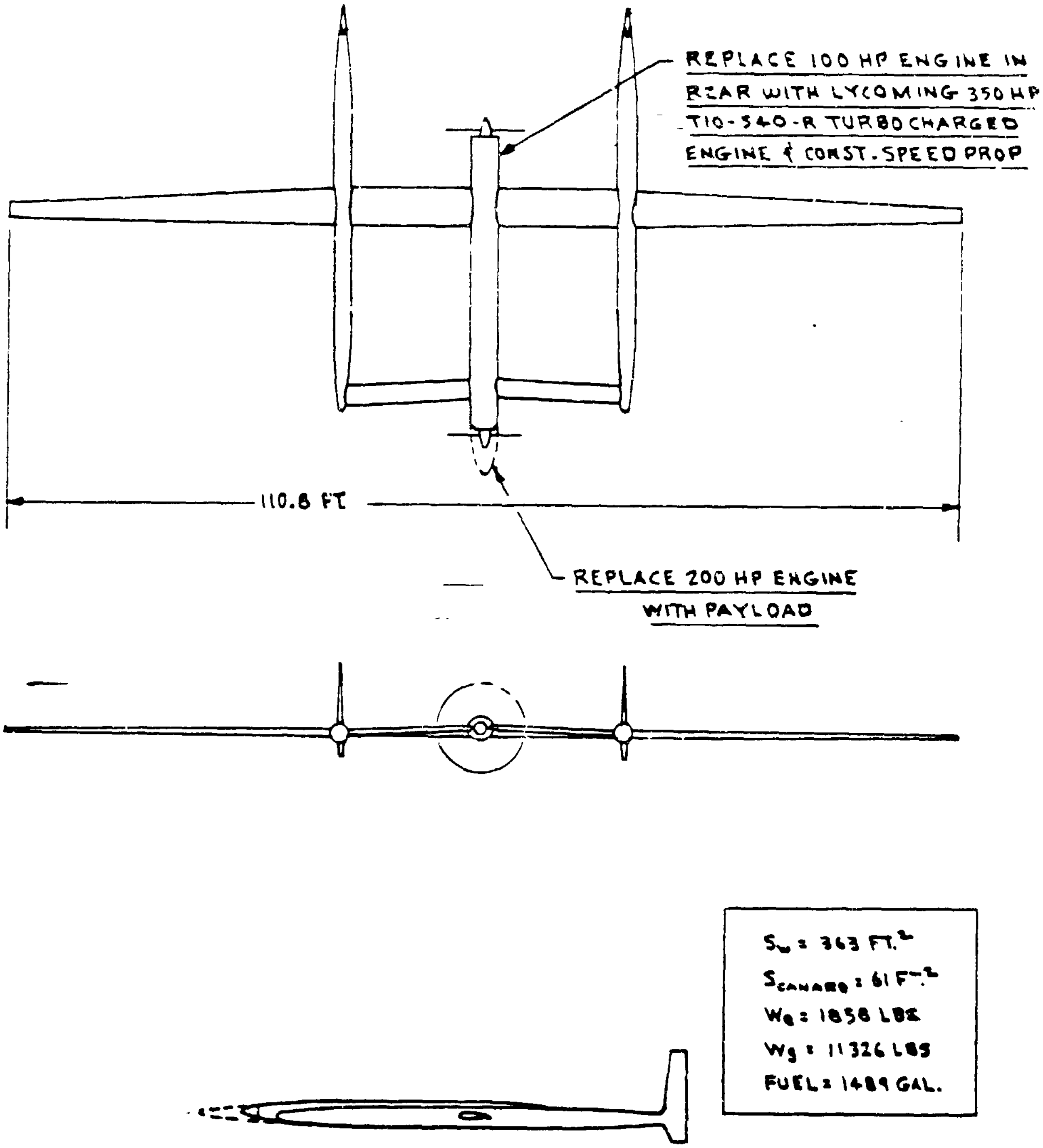
Hyball III. This is a modification of the Rutan Aircraft Factory **Voyager** which has been built to fly around the world non-stop. This tandem engine, twin boom canard configuration of composite construction is capable of very high glide ratios and carries enough fuel to accomplish a worthwhile remotely manned mission at high altitude. The engines to be used on this aircraft are liquid cooled and are capable of being modified for high altitude flight by addition of turbosuperchargers. Teledyne Continental Motors, who are supplying the engines for this aircraft, have suitable background to make the modifications. The general arrangement is shown in Figure A-4

Engines currently installed in **Voyager** are a 75 kw (100 hp) liquid cooled IO-220 aft and a 149 kw (200 hp) IO-330 forward. The forward engine would be replaced by a faired nosecone and the aft engine would have a turbosupercharger and radiators added to it. These additions would roughly triple the weight of the normally aspirated forward engine. Endurance with these modifications would be around 210 hours (8 3/4 days). Initial ceiling would be 9.8 km (32 000 ft) and this would increase to 16.2 km (53 000 ft) as fuel burned off. Levelling off at 12.2 km (40 000 ft) would increase endurance to 275 hours (11 1/2 days) with 215 hours (9 days) at 12.2 km (40 000 ft).

Some caveats must be attached to use of **Voyager** for this mission. The aircraft has a mass of 5137 kg (11 326 lb$_f$) at full load. At an empty mass of 1085 kg (2392 lb$_f$), the structure will probably be flexible and vulnerable to dynamic coupling among various structural components. The bending frequency of the booms, which are also fuel tanks, may cause a problem with the torsional frequency of the very narrow, thin wings to which they are attached. Any significant coupling of these structural components could prove disastrous. Another area of concern is the landing gear which are very fragile. Any attempt to land shortly after takeoff might seriously damage or destroy the aircraft. In the event of a crash landing, the light structure and considerable fuel load might combine to cause a sizable conflagration.

Other exisiting high performance motor sailplanes may be candidates for this mission. Most are constructed of composite materials which may make modification more difficult than with more conventional materials. One candidate is the Lockheed **Q-Star** (no published information exists) which was the company-owned version of the Army/Lockheed QT-2 Quiet Reconnaissance aircraft. Like the QT-2, this aircraft was based on the successful Schweizer 2-32 sailplane. In its definitive version, **Q-Star** was powered by a Curtiss Wright RC-2 rotary engine driving a large, multi-bladed propeller through an over-cockpit driveshaft. The wing was strengthened with additional main spar gussets to resist the higher bending moments expected during operations. **Q-Star** is currently in retirement at the Hill

Country Aviation Museum near Morgan Hill, California. The airframe has only 250 hours of flight time on it so it is essentially new from the standpoint of wear and tear.



REPLACE 100 HP ENGINE IN REAR WITH LYCOMING 350 HP TIO-540-R TURBOCHARGED ENGINE & CONST. SPEED PROP

REPLACE 200 HP ENGINE WITH PAYLOAD

FIGURE A-4. HYBALL III GENERAL ARRANGEMENT.

In order to accommodate the requirements for this mission, **Q-Star** would require new wings of increased span with integral fuel tanks The engine would be replaced with a Teledyne Continental TSIO-330, and the propeller would have to be redesigned for the new flight regime

The Army/Lockheed YO-3A Quiet Reconnaissance Aircraft is another candidate for this mission Modifications to it would be similar to those just discussed for **Q-Star** Several YO-3As are still flying. NASA Ames Flight Research Center has two which are used for airborne sound level measurements around helicopters.

The Caproni A-21J is another candidate for this mission. It is a high performance two-place jet-powered sailplane with an installed engine thrust of 899 N (202 lb_f). In this configuration, the A-21J is reported to have a ceiling of approximately 15 km (49 000) feet and it carries 153 l (42 gal) of fuel Fuel load would have to increased considerably, of course, and the engine would have to be replaced by a Teledyne Continental turbosupercharged engine driving a propeller. Lockheed-Georgia Company presently owns an A-21J which is being used for low speed aerodynamic flight test at the University of Mississippi's Raspit research facility.

The final candidate is the Schweizer 2-37 which is the latest member of a long line of high performance sailplanes. It is powered, but would need wing strengthening modifications as previously discussed to accommodate a wet wing.

In summary, several promising airframes exist which could be modified to perform a rudimentary mission and gather valuable operating data for application to all high altitude long endurance missions.

APPENDIX B

CANDIDATE PAYLOADS

The proposed hypothetical mission will record agricultural data in several spectra in a 20 km (12.4 statute mile) swath along the flight path. The mission requires a remote sensor similar to that used by the **LANDSAT-4** satellite. It will be discussed shortly along with another sensor. The data for these two sensors are presented here to illustrate general requirements and capabilities only and the reader should not conclude that these two sensors are uniquely applicable to the mission discussed in this report. Neither unit will meet all the USDA mission requirements without modification and additional development work. However, the technology currently exists to develop a lightweight multi-spectral scanner in the 1988 to 1990 timeframe. It may be more economically feasible to modify an existing airborne system, though, than to develop a new one.

The **LANDSAT** thematic mapper spectral bands of primary interest are:

•	Blue	450	to	520 nm for air and water pollution
•	Red	630	to	680 nm for chlorophyll absorption
•	Near IR	760	to	900 nm for vegetation density
•	Far IR	10500	to	12500 nm for vegetation stress

These bands should be compared to those in Table 3 in the main body of this report to determine the viability of this thematic mapper to meet many mission needs. Meeting all the requirements of this mission will require a multi-spectral scanner similar to an ADDS 1268 Airborne Thematic Mapper which is manufactured by Daedalus Enterprises, Incorporated, of Ann Arbor, Michigan. The ADDS 1268 is typical of multi-spectral scanners and weighs about 91 kg (200 lb_f). It requires about 1500 watts of power and the sensor focal plane is liquid nitrogen cooled in the far infrared band. This requirement for cooling imposes both weight and sophistication problems which may prohibit its use in the near-term, although both are presently accounted for in satellite applications.

A similar instrument, with reduced weight and power requirements, is the airborne imaging scanner built by Moniteq, Limited, of Canada. This sensor is an 8-channel thematic mapper designed to detect trace gases in the 1000 to 2000 nm band (near infrared). It is significant to note that the gimballed scan

scan head and control system together weigh only 18.1 kg (40 lb$_f$) and use only 150 watts of power. It is able to operate at these lower numbers by eliminating the onboard black body calibrator and liquid nitrogen coolant for the focal plane. The quality and accuracy of the data are less than that of the ADDS class sensor and sensitivity is lower as well.

Perhaps a more novel approach to consider is the use of video cameras instead of a scanner. This would mean limiting the data-gathering portion of the mission to wavelengths through the near infrared region only, but would result in a much simplified design. Large advances have been made in the development of miniature CID and CCD television cameras in recent years and these cameras should prove adequate for gathering information in the spectral band between 400 and 1100 nm. Very low power would be required--about 3 watts, and weight would be around 1 kg (2 lb$_f$). Cameras with a resolution of at least 1045 by 1045 pixels should be available by 1988 if current development trends continue. Cameras that operate well into the infrared spectrum may also be a possibility by the late 1980's.

An alternate approach to the scanner system would use these CCD array video systems as illustrated in Figures B-1 and B-2 below. Figure B-1 is a block diagram of a video system using a single intensified camera.

Multiple filters, rotated between the camera and lens, select the spectral band being viewed. One frame of video data could be transmitted in 17 milliseconds. The filters would be advanced to the next band at the end of two frames, so that all five spectral bands could be viewed approximately six times a second. The camera pod could be gimballed and gravity-stabilized against aircraft roll, pitch and yaw excursions. To achieve the required coverage along the flight path, a slight lens angle adjustment must be applied at 170 millisecond intervals. A system developed along these lines would weigh approximately 29.5 kg (65 lb$_f$) with a power demand of slightly more than 50 watts.

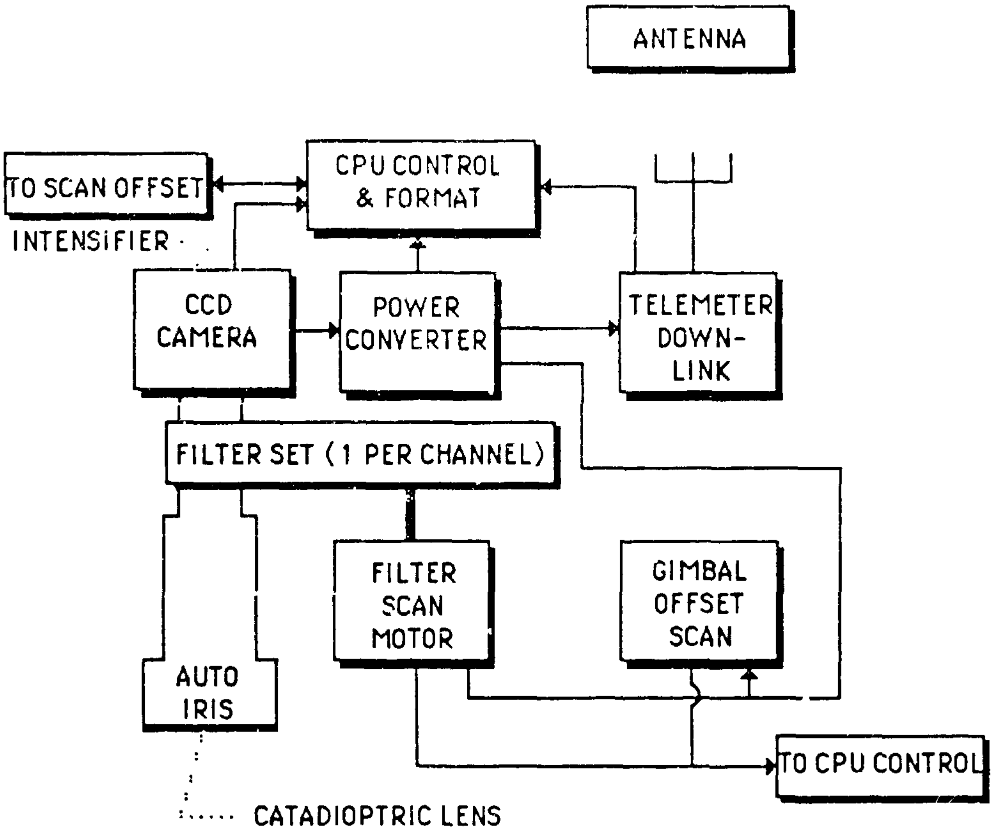


FIGURE B-1. SINGLE CAMERA VIDEO MULTISPECTRAL SENSOR SCHEMATIC.

Figure B-2 illustrates a similar system using five CCD cameras. This system uses a separate camera for each spectral channel. This greatly simplifies development of the system. One channel may use an intensifier camera for nighttime viewing and other channels may use less expensive cameras that are useful only during daylight hours. Multiple cameras, each using selected narrow band lenses, allow transmission of video data continuously and simultaneously over all channels. This system would have a mass of about 25 kg (55 lb_f) and would have a power demand of around 40 watts.

The major benefit derived from the systems outlined in Figures B-1 and B-2 is that standard commercial video equipment and monitors can be utilized at considerable cost savings over space-qualified equipment with cooled focal planes. The major disadvantage of the CCD-CID systems is that a primary band, the far infrared channel from 10500 to 12500 nm, cannot be accommodated. Current

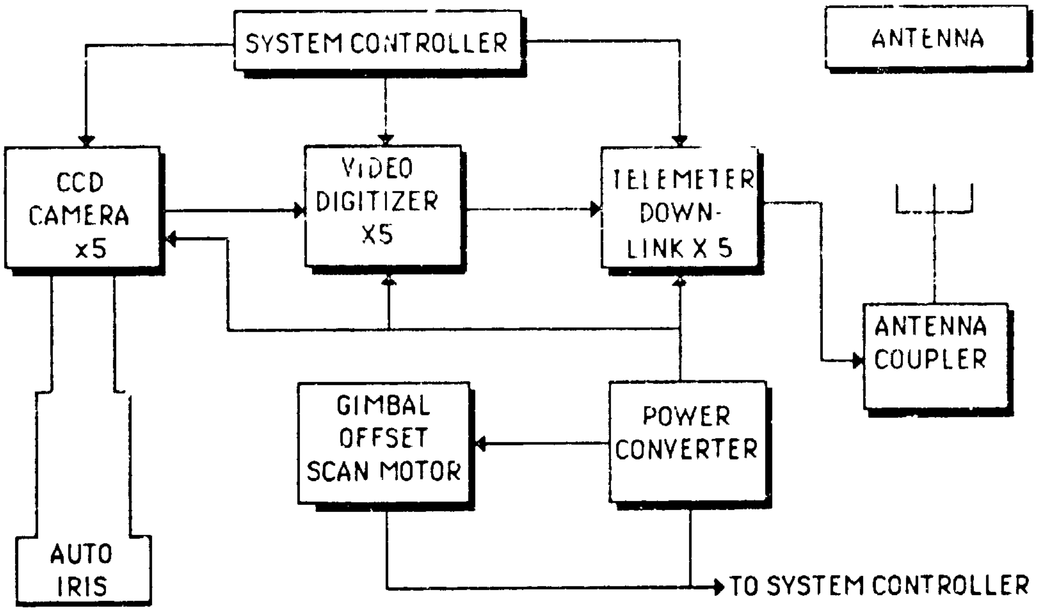


FIGURE B-2. MULTIPLE CAMERA VIDEO SPECTRAL IMAGER (uses one camera for each spectral band).

technology will not allow the two secondary channels in the mid-infrared band from 1550 to 1750 nm and 2050 to 2300 nm. However, this is likely to change prior to the first flight of a solar HAPP in the early 1990's.

It appears feasible to merge a video system into the Moniteq scanner. This would increase the flexibility of the basic instrument with only a small increase in weight and power.

1. Report No. NASA CR-172583	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle MISSION ANALYSIS OF SOLAR POWERED AIRCRAFT	5. Report Date July, 1985
	6. Performing Organization Code
7. Author(s) David W. Hall, David A. Watson, Robert P. Tuttle and Stanley A. Hall	8. Performing Organization Report No.
	10. Work Unit No.
9. Performing Organization Name and Address LOCKHEED MISSILES & SPACE COMPANY, INC. 1111 Lockheed Way Sunnyvale, California 94088-3504	11. Contract or Grant No. NAS1-16975
	13. Type of Report and Period Covered Contractor Report
12. Sponsoring Agency Name and Address NATIONAL AERONAUTICS & SPACE ADMINISTRATION Washington, D.C. 20566	14. Sponsoring Agency Code

15. Supplementary Notes

Langley Technical Monitor: James W. Youngblood
Final Report

16. Abstract

This study was conducted to assess the effect of a real mission scenario on a solar powered airplane configuration which had been developed in previous work. The mission used was surveillance of crop conditions over a route from Phoenix to Tucson to Tombstone, Arizona. Appendices are attached which address the applicability of existing platforms and payloads to do this mission.

This report follows a moreo comprehensive study of solar powered aircraft, NASA CR-3699, and a study to develop structural sizing algorithms, NASA CR-172313.

17. Key Words (Suggested by Author(s)) High Altitude Powered Platform Solar Power RPV Mission Analysis	18. Distribution Statement Unclassified - Unlimited

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 60	22. Price

N-305