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CIVIL USES
OF
REMOTELY PILOTED AIRCRAFT

(FINAL REPORT)

by Jon R. Aderhold, G. Gordon, & George W. Scott

JULY 1976

Prepared under Contract NAS 2-8935 by

LOCKHEED MISSILES & SPACE COMPANY, INC.
Sunnyvale, California

for
AMES RESEARCH CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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16. Abstract

This study is to identify and assess the technology effort required to bring the civil uses of RPVs to fruition and to determine whether or not the potential market is real and economically practical, the technologies are within reach, the operational problems are manageable, and the benefits are worth the cost. To do so, the economic, technical, and environmental implications are examined. The time frame is 1980-85. Representative uses are selected; detailed functional and performance requirements are derived for RPV systems; and conceptual system designs are devised. Total system cost comparisons are made with non-RPV alternatives. The potential market demand for RPV systems is estimated. Environmental and safety requirements are examined, and legal and regulatory concerns are identified. A potential demand for 2,000-11,000 RPV systems is estimated. Typical cost savings of 25-35% compared to non-RPV alternatives are determined. There appear to be no environmental problems, and the safety issue appears manageable.

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PREFACE

In recent years, all three military services have demonstrated many promising uses of remotely piloted aircraft (or Remotely Piloted Vehicles, RPVs, as they are commonly called). The technologies required for reliable real-time remote operation of complex functions have been considerably advanced by these military programs as well as by the space programs and Remotely Piloted Research Vehicle (RPRV) programs of the National Autonautics and Space Administration. If this technology base can be adapted for civil use in RPVs at an acceptable cost and with proper safety and environmental impact, a major new field of aeronautical applications may very well emerge.

Early investigations of this possibility were done in-house by NASA—Ames Research Center, and the indications were sufficiently encouraging to lead to the contracted study by the Lockheed Missiles and Space Company, Inc. (LMSC), that is reported here. Although this modest study does not resolve all the unknowns about RPVs in civil applications, the indications continue to be encouraging.

Mr. Walter P. Nelms of the Advanced Vehicle Concepts Branch, NASA-Ames Research Center, was the technical monitor for the study.

The contents of this Final Report are summarized in NASA CR-137895, the Summary Report.

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REMOTELY PILOTED AIRCRAFT

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SUMMARY

The intent of this study is to identify and assess the technology effort required to bring the civil uses of RPVs to fruition and to determine whether or not the potential market is real and economically practical, the technologies are within reach, the operational problems are manageable, and the benefits are worth the cost. To do so, the economic, technical, and environmental implications are examined. The time frame for application is 1980-85.

In-depth interviews with more than 60 potential users were made, and 35 specific uses are identified and defined, including present methods. Nine of these uses are selected as representative; detailed functional and performance requirements are derived for RPV systems; and conceptual RPV system designs are devised to meet the requirements in eight of the nine selected uses. Total system costs of development, purchase, and operation are estimated for the RPV systems, and cost comparisons are made with competing non-RPV alternatives. The potential market demand for RPV systems is estimated in the uses for which RPVs show a cost advantage.

Environmental and safety requirements and provisions are examined, and legal and regulatory concerns are identified. Areas of technology challenge are also identified, and research and development emphasis is suggested.

A potential demand for 2,000-11,000 RPV systems is estimated. Typical cost savings of 25-35% compared to non-RPV alternatives are determined. There appear to be no environmental problems, and the safety issue appears manageable, although collision avoidance remains the key safety issue. Earliest potential for a demonstration (in a remote area, with a federal government user) is about 1980, with full-fledged use by a federal agency by 1982 and by other government and commercial users by 1985. Government research and incentives will be required, and specific research is recommended, emphasizing safety features and other areas not likely to be covered adequately in military RPV development programs.

INTRODUCTION

The intent of this study is to identify and assess the technology effort required to bring the civil uses of RPVs to fruition and to determine whether or not the potential market is real and economically practical, the technologies are within reach, the operational problems are manageable, and the benefits are worth the cost. To do so, the economic, technical, and environmental implications are examined. Breadth, rather than depth, of coverage is emphasized. The time frame for the application is 1980-85.

The study addresses the following four objectives:

- Identify and describe the potential civil markets for RPVs, and indicate where they may have their earliest civil applications.
- Assess the benefits and cost of using RPVs in civil applications, and compare their effectiveness with conventional or established methods.
- Identify likely candidate vehicle and system concepts and the technology required to satisfy a major portion of these markets.
- Assess the influence of safety requirements and environmental effects on future civil RPV systems.

There are two classes of potential RPV use that are omitted from the study. The first is the high-altitude, broad-area monitoring and mapping job presently being done with LAND SAT satellites and U-2 aircraft. This use is relatively mature and its technologies are already rather well known. The second is the RPRV intended to simulate a specific advanced aircraft configuration and obtain aerodynamic data historically obtained in manned flight tests. Again, the technologies are already being pursued vigorously and have already produced valuable results (Reference 1).

LMSC devotes principle attention in this study to federal (non-military) and state government agencies as potential civil users of RPVs, while also including an appropriate sample of industrial users from the private sector. The original reasons for this emphasis, which were confirmed in the course of the market survey, are as follows:

- The private sector market tends to shy away from new "aerospace" systems' development risks and waits until a government agency has sponsored the development and initial acquisition. This suggests that the entry of RPVs into the private sector is conditioned on prior development by government agencies.
- The broad set of federal and state agencies who might use RPVs is already very conducive to formulation of a large "market" base.
- The private sector and government agencies need equipment rugged enough and safe enough to operate for many years in severe weather, dust, vibration, heat, and rough handling. The private sector will want warranties of performance and serviceability in these tough environments, and these will not evolve easily for RPVs unless federal government agencies have first been involved heavily in the research and development which provides rugged and serviceable equipment.

APPROACH

Overview

The first activity of the study is a market survey—a series of discussions with potential users and others which produced descriptions of the potential uses and alternative (non-RPV) systems presently used, if any. The survey also determined the users' reactions, preferences, detailed requirements, and estimates of the potential demand in the various uses. Thirty-five uses are defined, from which nine are selected for detailed examination. Quantitative functional requirements are then developed for each selected use.

RPV system concepts are devised to satisfy each set of functional requirements, and the cost of doing each job with an RPV system is estimated. The comparable cost of doing each job with present or potential non-RPV means is also estimated, and the two compared. Legal and regulatory concerns raised by the peculiarities of RPV systems are identified and noted, but do not limit the consideration of RPVs for any potential use.

Means are devised for integrating RPVs into each market for which RPVs show a promising cost advantage. The cost-benefit comparisons are used to identify the most promising uses and estimate the market share that RPVs might capture. An accurate estimate of the total RPV market is not attempted. Our goal is to see if there is enough potential demand to justify the continued interest of industry and the NASA in RPVs for civil uses.

Technology areas are identified in which research and development are needed in order to bring the civil use of RPVs to fruition, and development objectives and activities are suggested. Figure 1 shows the relationships of the study tasks and subtasks to each other.

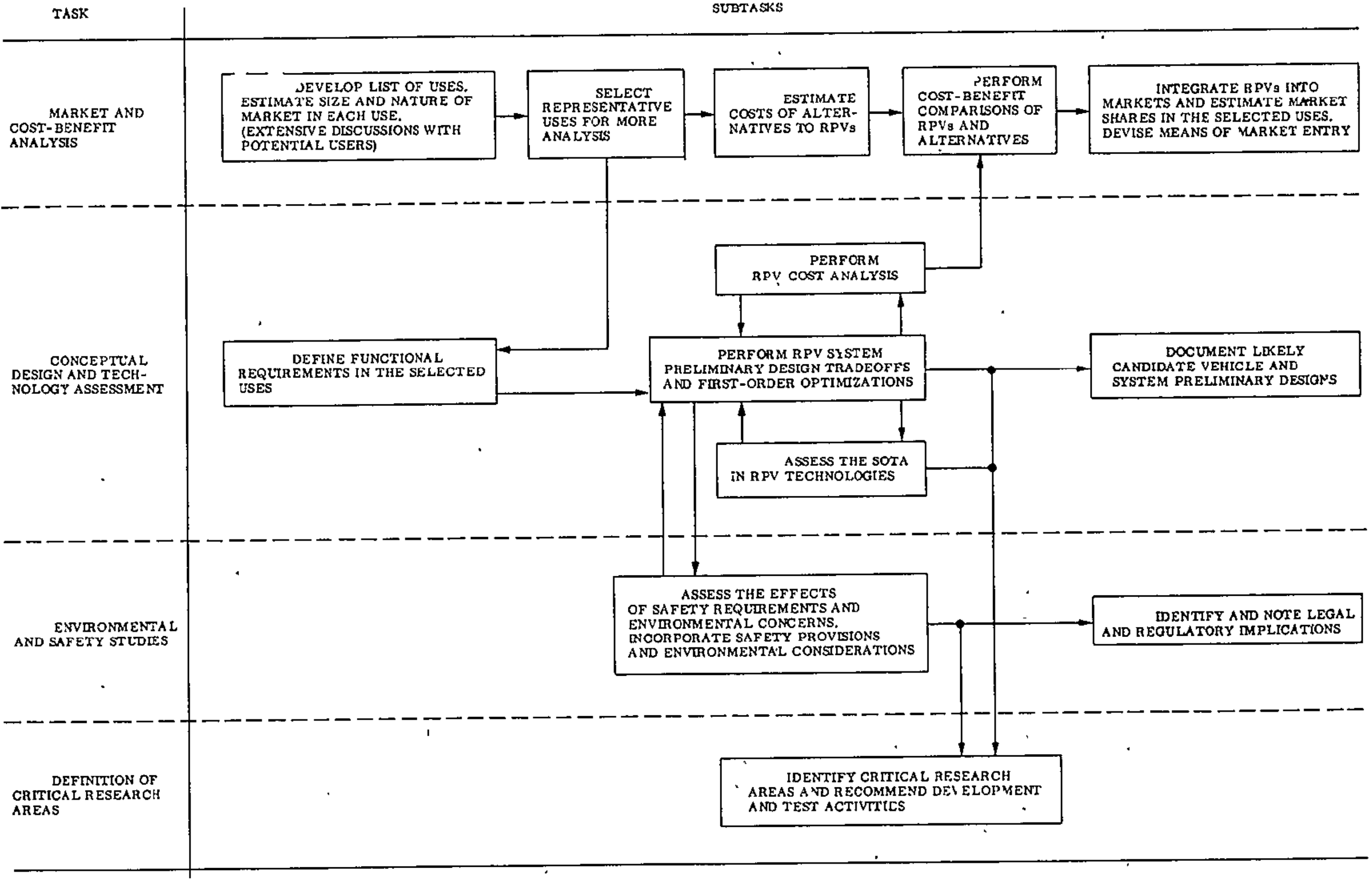


FIGURE 1 Study Flow Diagram

Market and Cost-Benefit Analysis

Survey of potential users. - LMSC personnel held direct personal discussions with representatives of 45 government agencies, non-profit associations, and commercial firms representing a spectrum of potential uses for RPVs. The discussions were structured interviews, using an extensive checklist to be sure that all pertinent subjects were covered with each potential user. Information was acquired about current operations and methods, operating environments, and business and financial practices. Follow-up letters and telephone calls filled in missing information.

From these interviews, thirty-five specific uses are identified and defined by a narrative description of the operation, present methods used and their costs, shortcomings of present methods, desirable features or capabilities, and some estimate of scope, such as square miles patrolled, frequency of coverage, etc.

Selection of representative uses. - From the 35 uses defined, nine are selected for further analysis. The criteria for selection include market potential and likelihood of early application, but the uses are also selected to represent a specturm of RPV system requirements—size, speed, endurance, altitude, number in the air at once, payload weight, precision of control, etc. Six of the nine uses are each representative of several other uses, and the other three are chosen for their peculiar design challenges.

Cost of alternatives to RPVs. - The costs of alternative, non-RPV systems for doing each of the nine selected uses are determined, for later comparison with RPV system costs. Particular care is taken to place RPVs and alternatives on the same cost basis by making consistent assumptions about sunk costs, depreciation, amortization of development costs, operator training, etc. However, due to limitations of time and money, LMSC did not optimize present non-RPV systems or cost potential improvements they might make in response to competition from RPVs.

Cost-benefit comparisons. - The cost-benefit comparisons consist of two parts. The first is a comparison of the total costs to the user to perform the mission in each of the nine uses, using RPVs and non-RPV alternatives. The second is a supplemental assessment of the non-cost-related advantages of RPVs and of the alternatives. No attempt is made to make these advantages commensurable with the dollar costs.

The cost-benefit comparisons identify the kinds of civil uses for which RPV systems show promise. The representative nature of the nine selected uses allows conclusions to be drawn about missions and uses beyond those that were analyzed in detail.

Market integration and shares. Means for integrating RPVs into civil markets are examined, based on information obtained in the market survey—information on customary lease-or-buy practices, financing arrangements, warranty and service expectations, licensing, and insurability, etc. Steps are suggested for getting RPV technology to the "deliverable" stage and for bringing a technology delivery system into being to perform the four functions of R&D, manufacturing, distribution, and financing.

The total scope of activity in the nine selected uses is estimated, and the share that might reasonably be captured by RPVs is assessed for the uses in which RPVs promise cost advantages. The potential demand for RPV systems is extrapolated by analogy over the 35 defined uses. The result is not presented as an accurate total potential, but is an indication that the civil use of RPVs is promising enough to warrant continued attention.

Conceptual Design and Technology Assessment

Defining requirements. - Detailed, quantitative functional and performance requirements are derived for RPV systems in each of the nine selected uses. A mission analysis is done for each of the nine uses, and mission sequences of events developed. The functions required to perform each mission are determined.

The mission requirements that were determined in the user interviews are translated into overall system performance requirements, and combinations of "reasonable" subsystem capabilities that meet those requirements are found. These are taken as provisional subsystem performance requirements against which to develop conceptual designs.

RPV system tradeoffs. - With the functional and performance requirements established, the usual iterative process of conceptual design is followed. Likely combinations of subsystem types were selected and their performance traded off against each other to arrive at RPV systems. As the conceptual designs progressed, tradeoffs frequently were made among subsystem requirements to meet the system requirements at a lower cost or within more conservative technology.

The RPV systems are believed to be well enough suited to the uses that cost comparisons can be made with non-RPV alternatives without doing an injustice to RPVs. To pursue seriously any of the RPV concepts in an actual use would call for a much more thorough tradeoff analysis to achieve a suitable design.

RPV system cost analyses. - RPV system cost analyses are used in two ways. One is to identify system elements that influence system cost most strongly and thus guide the conceptual designs. The other is to provide cost estimates for comparison with non-RPV alternatives. For this latter purpose, the total life-cycle cost to the user of a complete RPV system is estimated, including development costs and all acquisition and operation costs.

Technology assessment. - In addition to a more formal survey of the state-of-the-art in selected key technologies (reported in Appendix F), the conceptual-design process has continuously drawn upon LMSC's regular contacts with the suppliers of RPV components as well as the on-going technology activities and contractual RPV development programs at LMSC. Thus, the most up-to-date projections of weights, volumes, costs, and performance capabilities are reflected throughout the conceptual designs.

Documenting conceptual systems. - Conceptual designs of RPV systems are developed for eight of the nine selected uses. (No suitable RPV concept was found for the remaining one.) Each of these systems is described in drawings, sketches, and tabular information showing general arrangements, operating concepts, and subsystem capabilities and characteristics. The purpose is not to provide a basis for more detailed design, but to give a clear idea of the kinds of RPV systems that could be configured to do the various jobs within the projected state of technology.

Environmental and Safety Studies

Environmental requirements. - The environmental requirements that apply to light aircraft are expected to also apply to RPVs in similar operations. Noise and emission standards are identified, and it is determined that RPVs will have little or no difficulty complying. In special operations at low altitudes over populated areas, muffling and other sound-suppression measures are incorporated into the design.

Safety studies. - The areas of concern about RPV safety are identified, and a number of possible design provisions are suggested. Several are incorporated into the conceptual designs, and the effects of others on design and performance are assessed. The related subject of insurability is discussed in the context of what design, operational, and programmatic features will enhance safety and, thus, insurability.

Legal and regulatory concerns. - New regulations will have to be developed for RPVs. Some of the principles that will be considered by the Federal Aviation Agency in developing these regulations are identified and discussed, along with some logical steps to build public acceptance. The process of certification is described.

Defining Critical Research Areas

The preliminary-design tradeoffs from the conceptual design activity identify the features that promise the greatest gains in RPV system performance or reduction in cost; the environmental and safety studies highlight the needs in these two areas; and the assessment of the state-of-the-art determines how well present technology can realize the promise and satisfy the needs. Where present technology is found to fall short in an important way, an area of needed research exists. These areas are discussed, and development objectives and activities are suggested.

RESULTS

Market Survey

The first phase of the study was a market survey of potential users to identify promising uses, determine mission requirements and desirable features, obtain costs of competitive methods, and assess the size of the potential market. A detailed checklist of needed data was developed and briefing aids for explaining RPVs to potential users prepared. A detailed survey procedure and interview format were rehearsed and field tested, as described in Appendix A.

Forty-five face-to-face interviews were conducted with potential user agencies and organizations and another 15 interviews were held by telephone. The face-to-face interviews averaged 1-1/2 to 2 hours, and often involved several individuals from the user organization. Principal attention was given to federal (non-DoD), state, and local government agencies, but a considerable sample of industrial users were also included. Most interviews of potential users were productive in developing information on operations and mission requirements and on present methods and costs. However, we found that individual users seldom have the data needed to asses market size. For those data, it was necessary to turn to government agencies and industry associations that collect nationwide statistics. The agencies interviewed are also listed in Appendix A.

The list of 35 potential users that were defined in this survey is certainly not exhaustive. However, it does include many of the civil uses of RPVs that come readily to mind, and it appears to be representative enough to see if the potential demand justifies R&D of RPV technology for civil uses.

<u>Potential uses defined</u>.- The more-than-sixty interviews, plus other less intensive contacts, resulted in 35 specific potential civil uses being

defined for RPVs. With one or two exceptions, these were found to fall into natural groupings of missions that place similar performance demands on an RPV system. Table 1 shows the 35 uses, listed in their natural groupings. Many of the uses are self-explanatory, but perhaps a word or two about each will give a better idea of the potential market that was surveyed.

Referring to Table 1, under "small area surveillance": Security of high-value property consists of aerial surveillance to look for theft, fire, or other emergencies in progress in a small area such as a railroad yard, warehouse district, or industrial complex. Surface mining operations are monitored for land-reclamation compliance, pollution of streams, fires in waste materials, ground subsidence near structures, etc. Aerial observation is used during an oil-spill cleanup to direct the placement of boats, skimmers, and containment booms because oil slicks cannot be seen well at a distance from near the surface. Wildfire mapping consists of flying over a wildfire during firefighting operations and furnishing information about hot spots and the dynamics of its perimeter so that suppression crews and equipment can be deployed efficiently. The mission of ice-floe scouting would provide aerial observation to help an icebreaker find the best path through the ice. Spray-block marking involves directing aerial spraying of blocks of timber land. The spray aircraft at treetop level would be directed by reference to a television image from a rotary-wing RPV hovering above the desired spray block and maintaining geographic reference. The purpose of ground-truth verification is to obtain high-resolution aerial photographs of precisely located areas on the ground. The photographs are correlated with data from the LANDSAT satellite to allow interpretation of LANDSAT data on natural resources.

Under "large-area surveillance": The visual "search" portion of a search-and-rescue operation might well be done by an RPV system augmenting manned systems, especially at sea where a lifeboat or floating wreckage offers good contrast against the background. Aerial detection of wildfires consists of flying over large areas of forest, brush, or grasslands with infrared (IR) sensors to detect and locate small, latent-stage fires such as those started by lightning. Federal, state, and local agencies conduct aerial law enforcement operations to provide traffic advisories, to assist ground units in

- Small-area surveillance
  - Security of high-value property
  - Surface-mine patrol
  - Oil-spill clean-up direction
  - Wildfire mapping
  - Ice-floe scouting
  - Spray block marking and tracking
  - Ground truth verification
- Large-area surveillance
  - Search (and rescue)
  - Wildfire detection
  - Fishing Law enforcement
  - Oil-spill detection
  - Ice mapping
  - Fish spotting
  - Law Enforcement
  - Surface resource survey
- Linear patrol
  - Pipeline
  - Highway
  - Border
  - Power line
  - Waterway and shoreline pollution detection
- Aerial spraying
  - Agriculture
  - Wilderness
  - Wildfire fighting
- Communications relay
  - Ad hoc
  - Permanent
- Atmospheric sampling
  - Storm research
  - Meteorology
  - Mapping pollutants
- Monitoring ground sensors
  - Detecting activities
  - Monitoring cathodic protection of pipelines
  - Emergency rescue beacons
- Aircraft research
  - Aerodynamic testing (e.g., transition)
  - Remote measurements
- Air-to-Air surveillance
- Security of nuclear materials in transit

TABLE 1. / POTENTIAL USES DEFINED

identifying and preventing criminal acts, to direct ground units to intercept fleeing suspects, as well as to conduct search and rescue missions. Surveys of surface resources are made by aerial photography and by airborne instruments such as magnetometers. Fishing law enforcement by aerial observation is concerned with detecting illegal fishing by foreign ships in U.S.-regulated waters. Present methods may need to be augmented if the present 12-mile limit is extended to 200 miles. Oil spills at sea along coastal shipping lanes or from unattended offshore pumping stations may require aerial patrol for timely detection and correction. Winter shipping on the Great Lakes is aided by airborne radar imagery of ice area boundaries and ice thickness. The purpose of fish spotting is to find and identify schools of fish in the ocean and direct commercial fishing boats to them.

Under "linear patrol": Gas and oil pipelines are patrolled to detect and report leaks and potential hazards to the pipeline such as agricultural or construction work nearby. Highways are patrolled from the air to locate accidents, motorists in trouble, wanted vehicles, and unsafe road conditions. U.S. borders are patrolled to detect illegal border crossings. Power line patrols look for broken insulators, structural problems such as erosion around towers, and hot spots such as overheated transformers. Streams, rivers, lakes, and coastlines are patrolled to detect industrial waste discharges and thermal pollution from power plants, as well as other sources of pollution.

Under "aerial spraying": Agricultural and wilderness spraying is done for the control of pests and disease. Aerial wildfire fighting is done by dropping fire retardant on the fire.

Aerial communications relay seems self-explanatory.

Under "atmospheric sampling": Extensive research and aerial monitoring of severe storms (thunderstorms, hurricanes, and tornados) are conducted by the U.S. National Weather Service to analyze storm formation and provide forecasts of storm activity. Although storm research is certainly "meteorology", the mission considered here under that name is the more mundane gathering of data such as some of that presently gathered by weather balloons. Pollutant mapping is the sampling and mapping of the spatial distribution of pollutants and the inversion layer over an air basin, so that smog alerts can be issued, trash burning authorized, etc.

Under "monitoring ground sensors": Remote unmanned intrusion detectors are used to detect illegal border crossings, takeoffs and landings from suspected smuggling airstrips, etc. These detectors can be monitored from the air. Cathodic protection systems that prevent electrolytic corrosion of pipelines are set up to show a semaphore signal when they malfunction. These semaphore signals are monitored visually during ordinary pipeline patrols. Emergency resuce beacons from downed aircraft could be monitored by RPVs, and search and rescue operations directed to the area where the signals come from.

Under the last three headings: Aircraft research is already being done with RPVs—both direct subscale testing of aerodynamic concepts and indirect measurements of such things as wingtip vortices and engine emissions. The mission of air-to-air surveillance and tracking involves identifying and following aircraft that illegally cross the border in smuggling operations. The security of nuclear materials in transit from reprocessing plants to nuclear power-generating plants could include continuous aerial surveillance of transport trucks or, perhaps, an RPV that would be launched from the truck when danger is perceived.

Selection of representative uses. - This has been a very brief sketch of the thirty-five uses defined in the market survey. From the list of thirty-five, nine were selected for further, more detailed study. The basis for selection included early judgements about potential demand, likelihood of early application, and the quality of data available for analysis. The uses were also selected to represent a spectrum of RPV system requirements - size, speed, endurance, altitude, complexity, payload weight, etc. The nine uses selected are:

- Small-area surveillance
  1. security of high-value property
  2. wildfire mapping
- Large-area surveillance
  3. wildfire detection
  4. fishing-law enforcement

- Linear patrol
  5. highway patrol
  6. pipeline patrol
- Aerial spraying
  7. agricultural spraying and crop dusting
- Atmospheric sampling
  8. storm research
  9. meteorology

Description of present methods. - Appendix B contains a description of each of the 35 defined uses, including present methods, their shortcomings and flaws, desired features of an ideal method, and indications of the scope of the activity. Some of that information describing the activity and present methods is summarized here for the nine uses selected above.

Security of high-value property: The kind of security operation envisioned would involve two types of activity: a) periodic aerial patrol of the complete area to look for theft, fire, or other emergencies in progress, and b) on-call aerial response to investigate suspected emergencies reported by other means. When an emergency or a suspicious activity is detected, the patrol aircraft would remain over the location of the activity, take a closer look, and maintain surveillance while ground units are sent to the scene. If the suspicious activity involves an apparent crime, the patrol aircraft would follow any suspect escaping on foot or in a vehicle and direct ground units to intercept him.

Some general aerial security patrol is done by police departments using manned aircraft. However, most security patrol of relatively small high-value properties, e.g., railroad yards and refineries, is done on foot or in ground vehicles. In some cases, stationary TV cameras are used for continuous surveillance, both indoors and outdoors. Manned-aircraft security patrol is expensive and noisy. Helicopter patrol has been tried by at least two major railroad yards and abandoned because of those shortcomings. Stationary TV cameras are suitable for some applications, but are inflexible.

Wildfire mapping: The mission of wildfire mapping consists of flying over a wildfire and furnishing the characteristics of the fire to fire-control officers at periodic intervals and in enough detail to allow timely decisions to be made about the use of suppression resources. During control operations, these decisions are based on the dynamic characteristics of the fire perimeter and its relationship to fuels, weather, topography, values threatened, and the availability of suppression forces. During the mop-up, after the fire is controlled, decisions are based on the identification and location of latent hot spots such as smouldering roots and logs.

Wildfire mapping is presently done from manned aircraft, using both infrared (IR) sensors and visual observation. IR sensors are preferable because they detect small "spot" fires more readily than visual observation. Manned aircraft are costly to operate, and the hard-copy imagery of the fire produced by present IR equipment is produced aboard the aircraft. There is a delay in delivering the imagery physically to the main fire camp for photo-interpretation and use.

Wildfire detection: The mission of aerial wildfire detection consists of flying over large areas of forest, brush, or grasslands, detecting small, latent-stage fires, and determining their locations with enough precision to dispatch ground units to control them. The main idea is to locate fires started by lightning storms before the fires can spread. The aerial detection system would be based at a location central to the protected region and would fly missions over areas of the region that have experienced lightning storms. This mission would be flown as soon after the storm as the clouds have cleared, usually a very few hours after the lightning activity.

The aerial detection system is not responsible for locating storms, selecting areas for overflight, or suppressing the fires. These activities are already provided for.

Aerial wildfire detection is presently done from manned aircraft, using both infrared (IR) sensors and visual observation. IR sensors are preferable because they detect small "spot" fires more readily than visual observation, especially when there is little smoke. The major shortcoming of present methods is their relative costliness.

Fishing-law enforcement: Fishing-law enforcement by aerial observation and investigation is concerned with detecting illegal fishing in U.S. regulated coastal waters. It is envisioned that RPV systems would supplement the Coast Guard's surface ships and manned aircraft patrols by performing the routine large-area surveillance for detection, location, and identification of fishing fleets and large fishing vessels. The manned aircraft or surface ships would then spot check at appropriate intervals by close inspection to determine the precise location of fishing vessels.

The location of foreign fishing fleets and vessels are monitored now by manned-aircraft patrols and surface vessels. Present methods are adequate for observation and enforcement with the present 12-mile limit. The possible use of RPV (remotely piloted vehicle) systems for such observation will become of interest if international conventions extend the limits of regulation from the presently recognized (by the U.S.) 12-mile limit to a 200-mile limit, since the resulting, sudden 16-fold increase in area to be regulated will tax the capacity of the U.S. Coast Guard severely.

Highway patrol: The mission is to patrol remote stretches of highways to locate accidents, motorists in trouble, stolen or wanted vehicles, and unsafe road conditions such as landslides, flooded stretches, or washouts. Upon discovery of any of the above items, the information is provided to a dispatcher who directs ground units to take appropriate action.

A number of states patrol heavily travelled highways with manned aircraft, and all states patrol with automobiles. Many stretches of highway are too remote or too lightly travelled to justify the expense of regular patrol by manned aircraft. It is on these very stretches that motorists in trouble, accidents, and unsafe road conditions tend to remain undiscovered for the longest time.

Pipeline patrol: Gas and oil pipelines are patrolled to detect and report leaks and potential hazards to the pipeline. Leaks are indicated by stains, changes in vegetation, dead wild life, gas plumes, etc. Primary hazards are construction and agricultural activities near the buried pipe and excessive soil erosion where the pipe crosses streams and gullies Another item to be observed is the position of the semaphore indicators that signal a malfunction of the cathodic protection system that protects the pipe against corrosion. When any of these observables indicates a potential problem, ground personnel are dispatched to prevent or correct the problem.

Pipelines are patrolled on foot, on horseback, and in ground vehicles, but the most common method is by a single pilot-observer in a single-engine fixed-wing light aircraft. Present methods are satisfactory, but typically cost $0.30-0.38 per line-mile patrolled.

Agricultural spraying and crop dusting: Chemical treatment of orchards and crops, forests, grasslands, and ornamental growth is performed for a number of reasons: pest and weed control, disease prevention, application of fertilizers and feeds, and mosquito control. The basic requirement is to distribute precisely determined quantities of active chemical uniformly over a given area on the ground. Normally this active material is diluted with water, and quantities like 10 to 20 gallons per acre (95-190 l per hectare) are dispensed. However, products labeled as Ultra Low Volume (ULV) chemicals are emerging which can be used nearly undiluted in quantities of fractions of pounds per acre (1-2 l per hectare).

Although some spraying is performed on the ground using equipment mounted on ground vehicles, the majority of the spraying is from the air using mostly fixed-wing aircraft designed especially for that purpose. Some modified helicopters are also used. Present methods are generally satisfactory, but are costly and dangerous to the pilots of the manned aircraft.

Storm research: The U.S. National Weather Service conducts extensive research monitoring and taking measurements of severe storms (thunderstorms, hurricanes, and tornados). The purpose is to analyze storm formation and development in order to provide forecasts of storm activity. Two separate missions are envisioned for RPVs. They are: measurements of meteorological data outside the storm cloud at low altitude, including observation in the vicinity of tornado vortices, and high-altitude monitoring of the growth and decay of thunderstorms.

In addition to storm-watch stations, radar, and instrumented weather balloons, aircraft are currently employed to obtain observation of wind, temperature, pressure and humidity in the immediate vicinity of tornado vortices and thunderstorms. Manned aircraft, such as the F-100, F4C, Queen Air, U-2 and the RV-57F are used. Over ten years ago drones were tried. However, radio control proved to be unreliable, presumably because of atmospheric electrical activity. Gathering storm data by manned aircraft is uncomfortable and hazardous due to the extreme turbulence in the vicinity of severe storms.

Meteorology: The use envisioned here is the routine gathering of daily weather data, as conducted by scores of weather stations across the U.S. and around the world.

Weather balloons are presently used to gather this information. They are tracked visually or by radar. In most applications, they carry radiosonde instruments aloft, although some are simply tracked to determine wind conditions. Weather balloons are not recovered, and a high percentage of the instrumentation packages are lost. These losses amount to a substantial annual cost.

In the next section, the functional and performance requirements for RPV systems in each of these nine uses serve as the starting point for conceptual system designs.

Conceptual System Designs

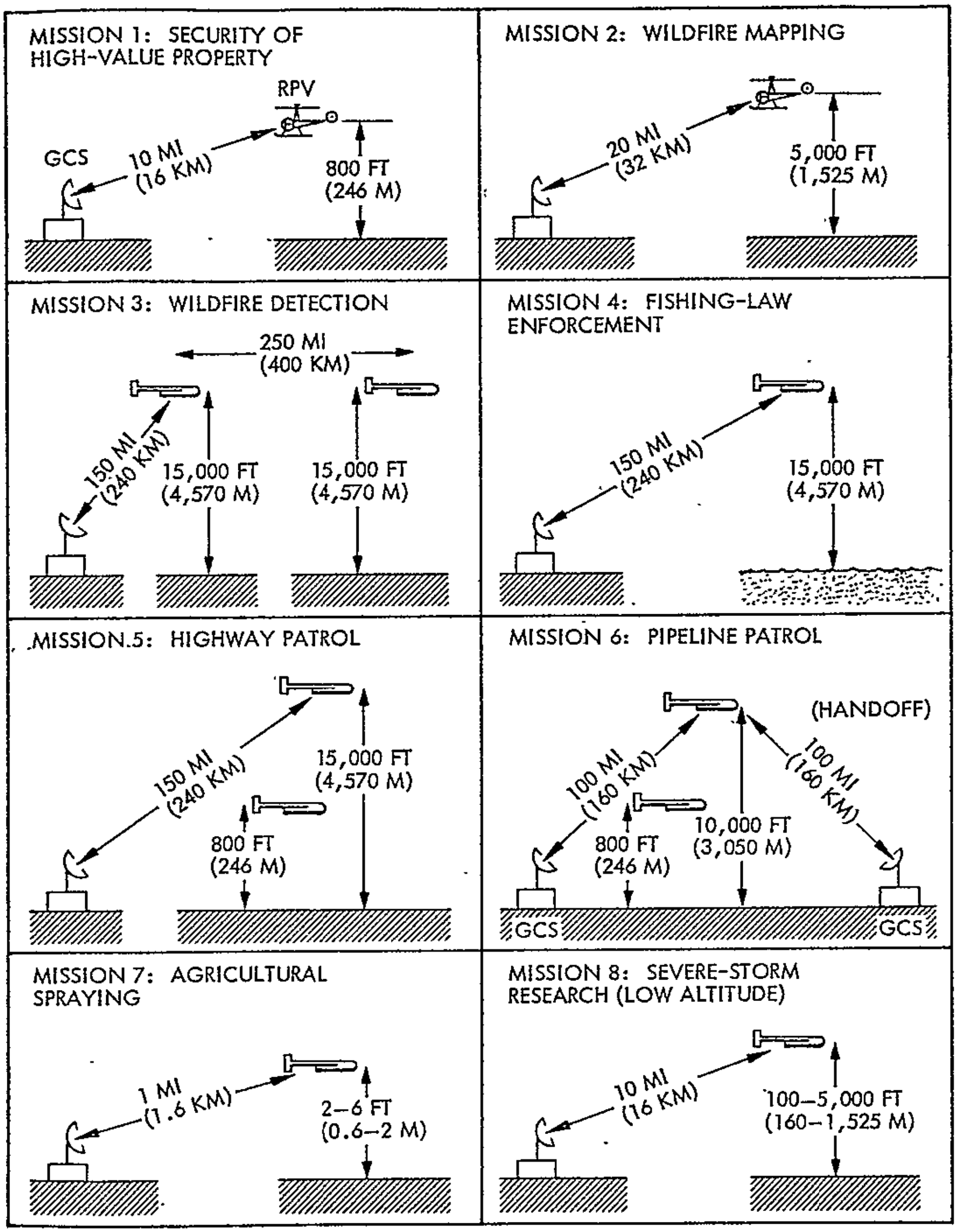
The conceptual designs of RPV systems to satisfy eight of the nine selected uses are presented in this section. They are based on the functional and performance requirements spelled out in detail in Appendix C. No satisfactory RPV concept was discovered for the ninth use.

In the course of the RPV system tradeoffs leading to the conceptual system designs, a continuing process of technology assessment has been conducted, drawing on LMSC's regular dealings with developers and suppliers of RPV equipment and components and on the in-house developments at LMSC. The weights, volumes, and performance capabilities shown in the conceptual designs- and the costs used in the cost-benefit comparisons- reflect that on-going assessment. Appendix F pulls a number of the more interesting parts of that assessment together in one place for convenient reference.

Air vehicle design rationale. - For each mission, an RPV-or two, if a relay is necessary-is designed to satisfy the functional and performance requirements described in Appendix C. The required mission payload equipment was first defined and its weight and volume determined. Then other airborne equipment necessary for data link, navigation, air traffic control, and collision avoidance was determined, along with its weight and volume. These comprised the payload that the air vehicle had to be designed to carry. The range spped, altitude, and other requirements were then used to size the RPVs. Table 2 presents the resulting weights of the RPVs.

The aerodynamic drag estimates used for performance calculations reflect the relatively simple configurations chosen and the rough surface conditions to be expected on vehicles used in day-to-day business operations.

Data and control link design rationale. - The starting point for the design of each data and control link is the range over which it must operate, as determined by the geometry of each mission. These geometries are described in Appendix C and summarized in Figure 2. The second determinant is the data rate (in Hertz) and data quality in (signal-to-noise ratio (SNR)) to be provided, as determined by the information to be transmitted in each direction. This, too, is determined by the mission. Beginning with these requirements and a chosen frequency, a link analysis provides transmitter powers, antenna



MISSION 1: SECURITY OF HIGH-VALUE PROPERTY

MISSION 2: WILDFIRE MAPPING

MISSION 3: WILDFIRE DETECTION

MISSION 4: FISHING-LAW ENFORCEMENT

MISSION 5: HIGHWAY PATROL

MISSION 6: PIPELINE PATROL

MISSION 7: AGRICULTURAL SPRAYING

MISSION 8: SEVERE-STORM RESEARCH (LOW ALTITUDE)

FIGURE 2 Data and Control Link Geometries

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WEIGHT GROUP	1. SECURITY OF HI-VAL. PROP.		2. WILDFIRE MAPPING		3. WILDFIRE DETECTION MISSION RPV		3. WILDFIRE DETECTION RELAY RPV		4. FISHING-LAW ENFORCEMENT	
AIRFRAME	30 LB	13.6 KG	30 LB	13.6 KG	470 LB	213.4 KG	470 LB	213.4 KG	40 LB	18.2 KG
PROPULSION	66	30.0	62	28.2	80	36.4	80	36.4	18	8.2
ELECTRICAL	13	5.9	11	5.0	(INCL.)	(INCL.)	(INCL.)	(INCL.)	11	5.0
FLIGHT CONTROLS	12	5.5	12	5.5	40	18.2	40	18.2	10	4.5
DATA LINK	6	2.7	6	2.7	20	9.1	80	36.4	6	2.7
PAYLOAD										
ATC TRANSPONDER	—	—	2	0.9	2	0.9	2	0.9	2	0.9
NAVIGATION	—	—	—	—	3	1.4	3	1.4	3	1.4
SENSORS	14	6.4	20	9.1	33	15.0	3	1.4	27	12.3
OTHER	8	3.6	—	—	—	—	—	—	—	—
EMPTY WEIGHT	149	67.3	143	65.0	648	297.5	678	308.2	117	53.2
FUEL	16	7.3	25	11.4	332	150.9	302	137.2	29	13.2
TAKEOFF GROSS WEIGHT	165	75.0	168	76.4	980	445.4	980	445.4	146	66.4

TABLE 2 (Page 1 of 2) Weight Summary of All RPVs

WEIGHT GROUP	5. HIGHWAY PATROL				6. PIPELINE PATROL				7. AGRICULTURAL & SPRAYING		8. SEVERE-STORM RESEARCH	
	MISSION RPV		RELAY RPV		MISSION RPV		RELAY RPV					
AIRFRAME	43 LB	19.5 KG	75 LB	34.1 KG	40 LB	18.2 KG	75 LB	34.1 KG	90 LB	40.1 KG	40 LB	18.2 KG
PROPULSION	17	7.7	20	9.1	17	7.7	20	9.1	35	15.9	17	7.7
ELECTRICAL	11	5.0	11	5.0	11	5.0	11	5.0	11	5.0	11	5.0
FLIGHT CONTROLS	10	4.5	11	5.0	10	4.5	11	5.0	14	6.4	10	4.5
DATA LINK	6	2.7	35	15.9	6	2.7	35	15.9	6	2.7	6	2.7
PAYLOAD												
ATC TRANSPONDER	—	—	2	0.9	—	—	2	0.9	—	—	2	0.9
NAVIGATION	3	1.4	3	1.4	3	1.4	3	1.4	10	4.5	—	—
SENSORS	7	3.2	3	1.4	7	3.2	3	1.4	4	1.8	12	5.5
OTHER	10	4.5	—	—	—	—	—	—	55	25.0	5	2.3
EMPTY WEIGHT	107	48.6	160	72.7	94	42.7	160	72.7	225	102.3	103	46.8
FUEL	58	26.4	70	31.8	35	15.9	55	25.0	25	11.4	11	5.0
TAKEOFF GROSS WEIGHT	165	75.0	230	104.5	129	58.6	215	97.7	250	113.6	114	51.8

TABLE 2 (Page 2 of 2) Weight Summary of All RPVs

gains, receiver noise figures, and bandwidths for proper operation. The size, weight, cost, and electrical-power requirements of equipment with these characteristics are then estimated and used in the conceptual system designs and the system costing. Appendix G discusses the link analysis and gives the resulting operating characteristics for the links.

Ground station rationale. - Design tradeoffs and calculations of equipment performance were not performed for the ground station to the same extent as for the RPVs and the data-link equipment, despite the large contribution of the ground station to the system cost. The reason is that the primary technical challenges and unknowns were felt to lie in the RPV and the data link. The functions to be performed and the features to be provided by the ground station in each mission were determined, and the cost of equipment to satisfy the needs was estimated by analogy with equipment used in existing RPV ground stations. The costs of racks, cabling, cabinets, control panels, dials, general displays, and miscellaneous ground support equipment were all included, but the specifics of the designs were not analyzed. Table 3 summarizes some of the main features of the ground stations for the various missions.

The ingredients of an RPV system concept. — An RPV system conceptual design must deal with more than the air vehicle and the data link. The following elements of an RPV system are addressed for each concept.

- Concept of Operations
- Mission Payload
- Air Vehicle
- Ground Station
    - Ground Control
    - Launch and Recovery
    - Checkout
    - Service, Support, and Maintenance
- Data and Control Link
- Navigation Scheme
- Safety Provisions
- Training and Procedures

GROUND STATION FEATURE	1. SECURITY OF HIGH-VALUE PROPERTY	2. WILDFIRE MAPPING	3. WILDFIRE DETECTION	4. FISHING-LAW ENFORCEMENT	5. HIGHWAY PATROL	6. PIPELINE PATROL	7. AGRICULTURAL SPRAYING	8. SEVERE-STORM RESEARCH
RPVs Controlled	1	1	2	1	2	2	1	1
Operator(s)	1	1	2	1	1	1	1	2
Antenna	Autotrack (Rho-Theta)	Autotrack (Rho-Theta)	Autotrack	Autotrack	Autotrack	Autotrack	Autotrack (Rho-Theta)	Autotrack (Rho-Theta)
TV Monitor	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Video Recorder	No	No	No	No	Yes	Yes	No	Yes
Telemetry Recorder	—	—	—	Yes	—	—	—	Yes
IR Processor	—	Yes	Yes	—	—	—	—	—
Radar Data Processor	—	—	—	Yes	—	—	—	—
Navigation Computations	Yes	Yes	No	No	No	No	Yes	Yes
X-Y Plotter(s)	1	1	2	1	1	1	1	1
Communications	Telephone	Field telephone	ATC, through data link	ATC, through data link	ATC, through data link	ATC, through data link	None	ATC, weather radar station
Shelter	Existing building	Shares tent or trailer	Existing building	Existing building	Existing building	Existing building	None	Van
Primary Power	Commercial	Generator	Commercial	Commercial	Commercial	Commercial	Generator	Generator
Emergency Power	Batteries	Batteries	Generator	Generator	Generator	Generator	Batteries	Batteries
Portability	No	Truck or trailer	No	No	No	No	Truck or trailer	Van and RPV trailer

Table 3, Ground Control Station Elements

A considerable amount of thought was given to trying to come up with equipment designs for the various uses with as much commonality as possible. It was found that a few basic designs, with modifications and variations, could serve most of the uses. This is encouraging, since it means that the needed RPV technology developments will have wide application rather than being narrowly specialized.

In the sections that follow, each system concept is described separately, in a format that uses the system elements above as main headings.

Mission: 1. Security of high-value property. - Concept of operation: The RPV system performs regular aerial patrol over a small area to look for pilferage, fire, or other emergencies in progress, operating during the hours of darkness. It carries an electro-optical sensor and transmits a real-time image of the scene below to an operator at a ground control station located in or near the security-guard dispatch office. When an emergency or a suspicious activity is detected, the RPV remains over the location, takes a closer look by optically magnifying the suspicious scene, and maintains surveillance of it while ground units are sent to the scene. If desired, the RPV can illuminate the scene with a spotlight and/or relay communications to people below via a loudspeaker.

A system includes two RPVs and one ground station, with a single, full-time operator. Only one RPV is airborne at any one time. Aerial surveillance is maintained for a total of eight hours between 6 pm and 6 am every day, 365 days per year. The system is automated, so that the operator does not have to fly the RPV directly. Routine patrol paths are preprogrammed, and an autopilot flies the RPV. The operator may override the preprogrammed flight path by commanding different heading, speed, or altitude. The operator may also control the sensor pointing and field of view, may turn the spotlight on or off, and may speak through the airborne loudspeaker. The spotlight is boresighted and gimballed with the sensor.

Routine operating altitude is 800 ft (245 m) AGL (above ground level), with the ability to descend lower for a closer look if desired. The RPV remains at an altitude sufficient to maintain the line-of-sight data link with the ground station antenna.

Mission payload: The mission payload consists of a low-light-level television (LLLTV) camera, a spotlight, and a loudspeaker. The camera has pan and tilt capability and three fields of view, or magnifications. Pan, tilt, and field of view are controlled remotely in flight by the operator. The spotlight is boresignted with the camera and always illuminates the center of the scene viewed.

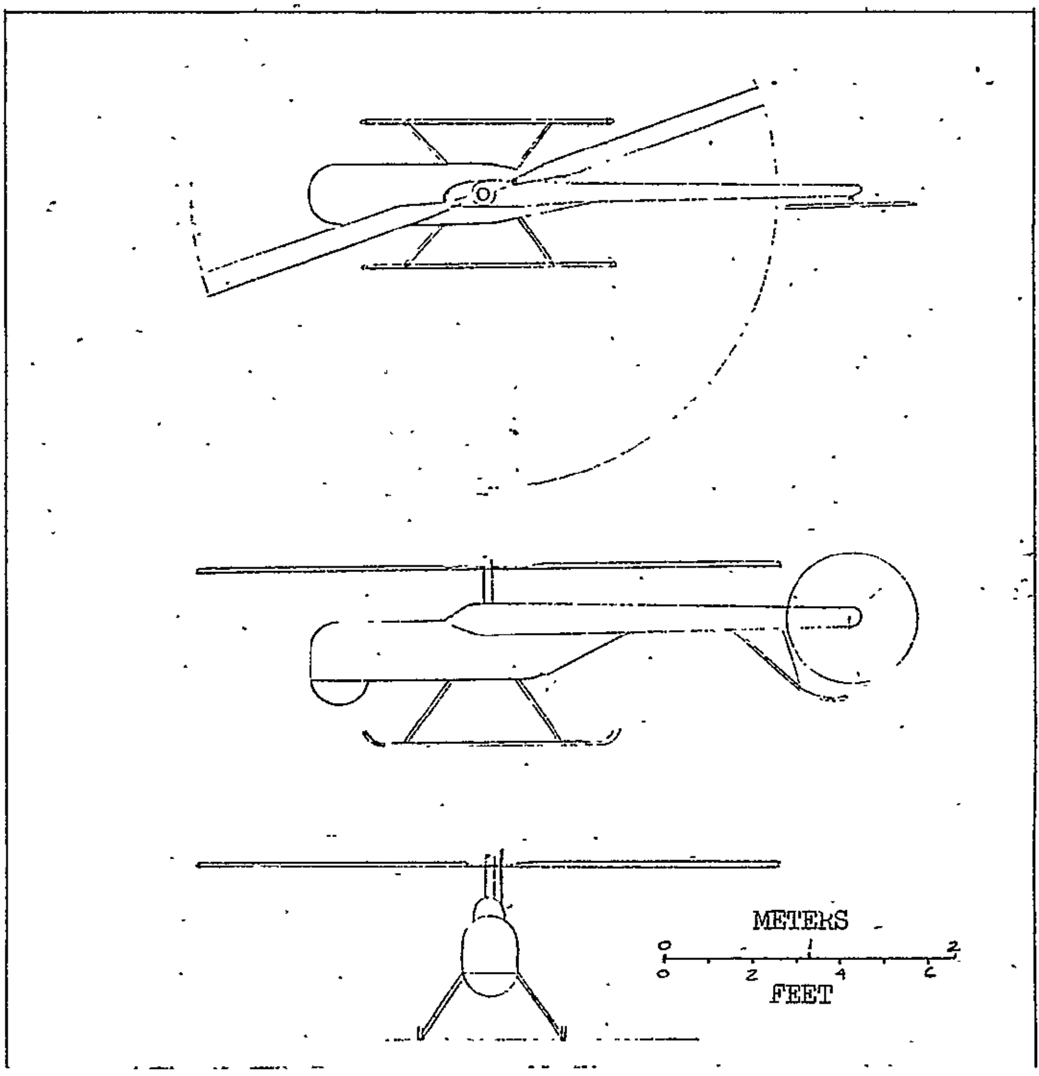
The camera is a two-stage image-intensified vidicon camera. The weight of the camera, lens system, gimbals, controls, spotlight, and loudspeaker total 22 lb (10 kg).

Air vehicle: The air vehicle is a helicopter RPV weighing 165 lb (75 kg) at takeoff and having the physical and performance characteristics shown in Figure 3 . (Note that the payload weights shown on the Figures include navigation, data link, and ATC transponders in addition to the mission payload.)

The rotor is large with a low disc loading of 1.17 lb/ft^2 (5.7 kg/m^2) and a low tip speed of 500 ft/sec (152 m/sec) to reduce rotor noise and to minimize required engine power. A single 2-bladed rigid rotor has been selected for simplicity. The three-bladed tail rotor was selected to minimize noise and avoid resonance with the main rotor vibration modes. A 20% loss of engine power due to extensive muffling was estimated, 15% of available power was estimated to be expended in tail-rotor power and cooling losses and a one-horsepower (746 W) electrical generation load was assumed. The resulting engine size to hover out of ground effect at 6000 ft (1830 m) is 18 horsepower (13.4 kW) at sea level. Current technology suggests that a two-cycle, two-cylinder engine could be provided within an installed propulsion weight of 30 lb (13.6 kg) including the fuel system and muffler.

This vehicle is tailored for low-altitude, low-speed flight with no concern for high altitude operations. Hover at 6000 ft (1830 m) above sea level is possible, thereby allowing operation in all major U.S. cities including Denver, Colorado. Optimum cruise speed is 40 mph (18 m/sec) which permits coverage of relatively large areas in a short period of time.

No major technology risks are envisioned except for the development of a satisfactory miniature stability augmentation system (SAS). The use of a rigid rotor will do much to simplify the SAS.



LENGTH (WITHOUT ROTOR)	4.2m (13.8')	MAXIMUM SPEED	135 Kmh (84 mph)
ROTOR DIAMETER	4.1m (13.4')	CRUISE SPEED	65 Kmh (40 mph)
DISC LOADING	$5.7kg/m^2$ (1.17psf)	CRUISE ENDURANCE	1.3 hr
SOLIDITY (σ)	0.04	CRUISE ALTITUDE	800 AGL
CT. $/\sigma$	0.049	SEA LEVEL RATE OF CLIMB	370m/min. (1200 fpm)
POWER	18 BHP	HOVER CEILING (OGE)	1800m (6000')
TAKEOFF WEIGHT	75 kg (165 lb)	CRUISE CEILING	3000m (10,000')
FUEL WEIGHT	7.3kg (16 lb)	ROTOR TIP SPEED	152m/sec (500 fps)
PAYLOAD WEIGHT	12.7 (28 lb)	ROTOR SPEED	713 rpm

FIGURE 3 RPV For Mission 1, Security of High-Value Property

Ground station: The ground control is by a single full-time operator at a console in an existing building. Only one RPV is in the air to be controlled at any one time. The location of the RPV is displayed continuously (on an X-Y plotter), as is the real-time image from the RPV's LLLTV. RPV speed, altitude, remaining fuel, and other operating data are also displayed. Commercial power is used, with an emergency battery power supply to land the RPV in case of power failure. Launch and recovery are by vertical takeoff and landing on a dedicated helipad near the guard building. Routine checkout and servicing is done by the single operator. Maintenance is obtained from a contractor who provides his own facilities. The RPV is transported to the shop for maintenance on a small utility trailer with tie-down provisions.

Data and control link: The link is line-of-sight, with power and gains designed for operation out to a maximum range of 10 miles (16 km). It uses an omni-directional airborne antenna and a directional autotracking ground antenna.

Navigation scheme: Navigation is by the rho-theta method using the pointing azimuth (theta) of the ground antenna, the range (rho) from antenna to RPV measured by timing a round-trip signal, and the altitude measured by the RPV altimeter. All calculations are done at the ground control station, and commands sent to the RPV for heading, speed, and altitude. Accuracy of location is ± ~100 ft (30 m) at 3 miles (4.8 km) in X and Y, determined by the 6 mil angular resolution of theta and 100 ft range resolution more or less independent of range.

Safety provisions: For positive control in case of loss of link, the RPV climbs in a tight circle to 800 ft AGL and hovers for one minute awaiting reestablishment of link. If link is not reestablished, it reverts to a modified radio control (RC) back-up mode, maintaining hover until RC commands otherwise. The autopilot continues to stabilize the RPV and provide an azimuth reference from an on-board magnetometer. The RC operator can then command a return to the ground station, even without a good visual reference to the RPV, by commanding a heading that brings the RPV back to the general vicinity of the ground station. When the RPV arrives close enough to see clearly, the operator lands it using visual reference.

For collision avoidance, the RPV operates below altitudes allowable to general aviation, and over a known, confined area. Ordinarily, no other precautions are taken, and the RPV is dark so as to be inconspicuous from the ground. However, the RPV has flashing strobe lights that can be turned on by command of the operator in the rare event that the RPV leaves the confines of the patrolled area, or for any other reason the operator chooses.

In case of unplanned descent, the RPV autorotates to the ground at a rate of 22 ft/sec (6.7 m/sec).

Training and procedures: (No special items of note were determined for any of the systems. The training program that was assumed for costing purposes is mentioned in Appendix E. This heading is not included in the remaining system descriptions.)

Mission 2, Wildfire mapping. - Concept of operation: The mission objective is to fly over a wildfire that is being fought and obtain real-time or near-real-time infrared (IR) imagery of the fire, providing the boss of the fire-fighting operation with timely information on the characteristics and spread of the fire. He uses this information to make decisions about the use of suppression forces.

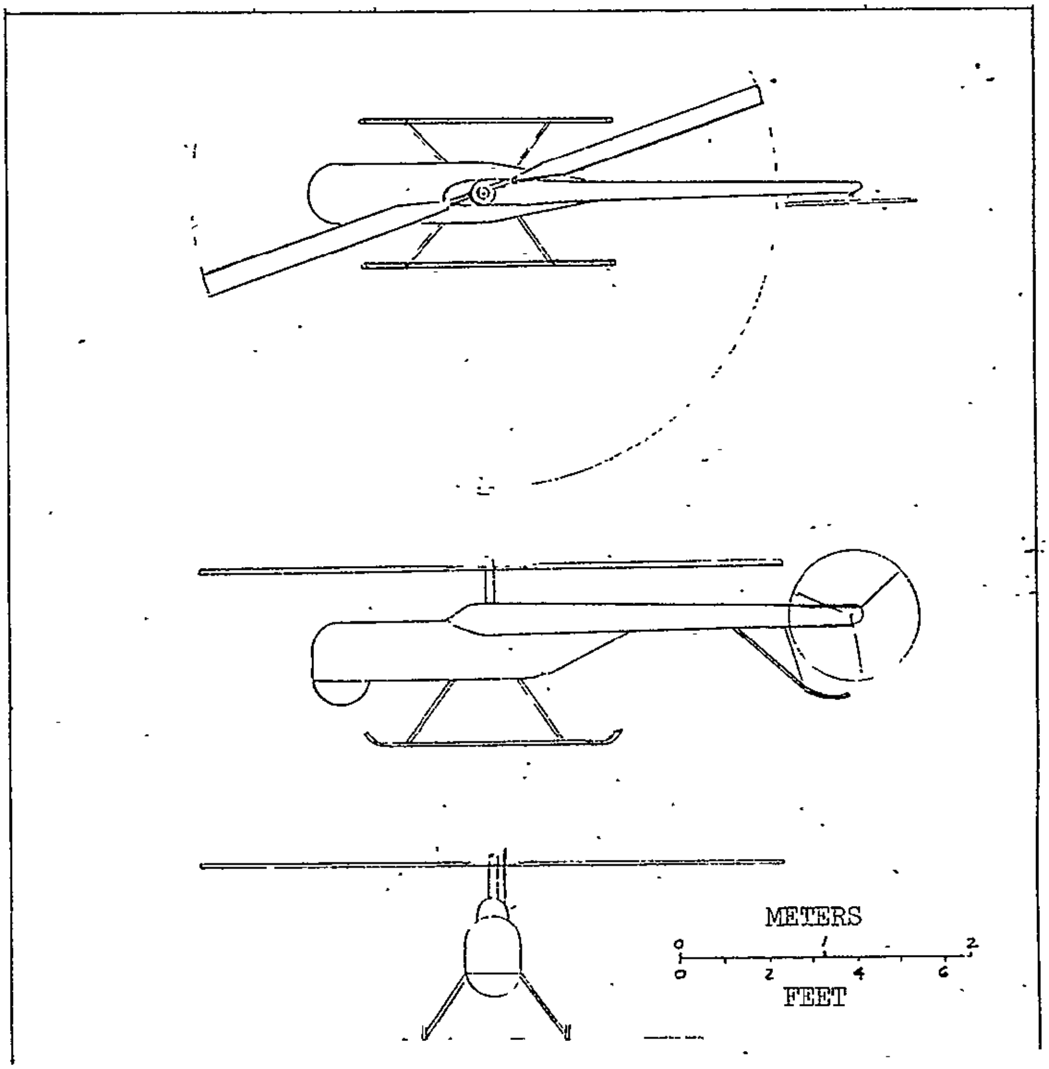
The single RPV and its ground equipment are brought by truck to a site at or near the main fire camp, no more than 10 miles from the fire. After being unloaded, the trucks are freed for other uses. The RPV takes off and lands in a clearing that is otherwise unimproved. It flies up to four missions per day, each about 1½ hours long. It carries an IR imaging sensor over the fire and transmits the image to the GCS via the data link. The image data is processed on the ground into hard copy, which a photointerpreter uses to locate the fire perimeter with respect to fuels, topography, roads, firebreaks, and suppression forces. The hard-copy processor and the photointerpreter are not considered part of the RPV system, since they would be at the fire whether an RPV or a manned aircraft were used for mapping.

The RPV flies at 5000 ft (1500 m) AGL over terrain up to 7000 ft (2100 m) above sea level. It is controlled from the GCS by a single operator, who is in close proximity to (perhaps in the same tent or trailer with) the command center at the main fire camp. The RPV flies a preprogrammed flight path that is laid out to image the fire in overlapping swaths. The operator can override the preprogrammed flight path if necessary, but need not otherwise fly the RPV. This is done by a technique similar to the waypoint guidance used on the LMSC Aquila program, in which coordinates of successive points over which the RPV is to fly are entered into the navigation computer in the ground station.

Mission payload: The mission payload is either an IR line scanner or a forward-looking infrared (FLIR) camera, equipped with a target detection module in the circuitry that provides an indication in the margin and a blip on the image to locate hot spots and enhance the outline of the fire perimeter. Together with a small, fixed FOV, TV camera (gimballed but not stabilized) for piloting during landings, it weighs 20 lb (9 kg), installed, has a scan, or equivalent field of view, of 120°.

Air vehicle: The air vehicle is a helicopter RPV, with the physical and performance characteristics shown in Figure 4. The basic design is the same as the RPV for Mission 1, but with detail differences such as the absence of engine muffling.

The limitation to unimproved takeoff and landing areas suggests a helicopter for the same reasons as stated for mission 1. The payload is the same weight as in mission 1, and there is no requirement for quietness. Therefore, the greater power available without a muffler increases the hover ceiling by 4000 ft (1200 m) and cruise ceiling of 6000 ft (1830 m) to 16,000 ft (4880 m). A maximum speed of 95 mi/hr (153 km/hr) is estimated for the comparatively high-drag configuration. Speed could be increased to 115 mi/hr (185 km/hr) or more by extensive streamlining of all components, particularly the rotor mast and hub, at the expense of ruggedness and accessibility for maintenance.



LENGTH (WITHOUT ROTOR)	4.2m (13.8')	MAXIMUM SPEED	153 Kmh (95 mph)
ROTOR DIAMETER	4.1m (13.4')	CRUISE SPEED	112 Kmh (70 mph)
DISC LOADING	5.8kg/m^2 (1.19psf)	CRUISE ENDURANCE	2 hr
SOLIDITY (σ)	0.04	CRUISE ALTITUDE	3600m (12,000')
CT / σ	0.049	SEA LEVEL RATE OF CLIMB	550m/min (1800 fpm)
POWER	18 BHP	HOVER CEILING (OGE)	3000m (10,000')
TAKEOFF WEIGHT	76kg (168 lb)	CRUISE CEILING	4900m (16,000')
FUEL WEIGHT	11kg (25 lb)	ROTOR TIP SPEED	152m/sec (500 fps)
PAYLOAD WEIGHT	12.7kg (28 lb)	ROTOR SPEED	713 rpm

FIGURE 4 RPV For Mission 2, Wildfire Mapping

Ground station: The RPV is controlled by a single operator at a console located in a temporary shelter (tent, trailer, or van) shared with the rest of the main fire camp's command post. All elements of the ground station are self-contained and readily portable, including a motor-generator set for electrical power, with batteries for emergency backup to land the RPV in case of power failure. The ground station resembles that for Mission 1, but differs in four main regards: a larger, higher-gain autotracking antenna due to the greater distances at which the RPV operates; complete portability; the auxiliary power supply; and more tools and spares for emergency maintenance in the field.

The location of the RPV is displayed continuously on an X-Y plotter, and the image from the TV camera can be displayed when desired. The IR sensor image data is processed to hard copy in near-real-time and provided to the photointerpreter. No special communications with other systems is required.

Launch and recovery is by vertical takeoff and landing from an unimproved clearing, directed by the operator who uses the image from the on-board TV camera for piloting in the vicinity of the landing zone. Maintenance is done by a contractor but routine servicing and minor repairs are done by the operator.

Data link: The data and control link is line-of-sight, with gains and powers designed for operation out to a range of 20 mi (32 km). Except for the longer range and resulting higher-gain ground antenna, the link is designed the same as for Mission 1.

Navigation scheme: Navigation by the rho-theta method described for Mission 1. Accuracy of location is ±250 ft (76 m) in X and Y at a range of 20 miles (32 km). Calculations are made on the ground.

Safety provisions: In case of loss of link, the RPV maintains, or climbs to, an altitude of 5000 ft (1500 m) AGL and flies tight circles. If link has not been reestablished in a predetermined period of time, the RPV flies away from the fire and in the direction of the ground station for a programmed time using an on-board magnetometer for azimuth reference. At the end of the programmed time, it cuts the engine and autorotates to the ground at 22 ft/sec (6.7 m/sec). An emergency locator beacon helps searchers locate and retrieve the RPV later.

For collision avoidance, the RPV has flashing lights for visibility. The area over a forest fire being fought is ordinarily declared a Temporary Restricted Area and general aviation is kept out. Fire-fighting aircraft are notified of the RPV's presence and location and warned to avoid it. They will usually be at a lower altitude when over the fire, in any case.

In case of an unplanned descent, the RPV will autorotate to the ground.

Mission 3, Wildfire detection. - Concept of operation: The mission of wildfire detection consists of flying over large areas of forest, brush, or grasslands, detecting small, latent-stage fires, and determining their location with enough precision to dispatch ground units to control them. The main idea is to locate fires started by lightning storms before the fires can spread. The RPV system would be based at a location central to the protected region and would fly missions over areas of the region that have experienced lightning storms. The mission would be flown as soon after the storm as the clouds have cleared, usually a very few hours after the lightning activity.

The RPV system is not responsible for locating storms, selecting areas for overflight, or suppressing the fires. These activities are already provided for.

The RPV system operates from an existing airport at the center of a forest region 400 mi (640 km) in radius. Using one RPV as a relay for the data-and-control link, an operator flies a mission RPV to a predetermined area anywhere in the region and flies a precise pattern over the area to scan it for fires. Up to 6000 mi^2 (15,300 km^2) are scanned in a mission, at a rate of 2000 mi^2/hr (5100 km^2/hr). The mission RPV cruises at 15,000 ft (4600 m) AGL at 200 mph (90 m/sec), so a maximum mission to the edge of the region takes four hours in transit out and back, plus three hours scanning, plus an allowance for climbing, maneuvers, and headwinds of one hour, for a total of eight hours.

An IR line scanner aboard the mission RPV relays imagery via the relay RPV to the ground station where it is converted to hard copy for a photointerpreter to locate fires that are detected. Control of the mission RPV is relayed through the relay RPV, which takes off first and lands last.

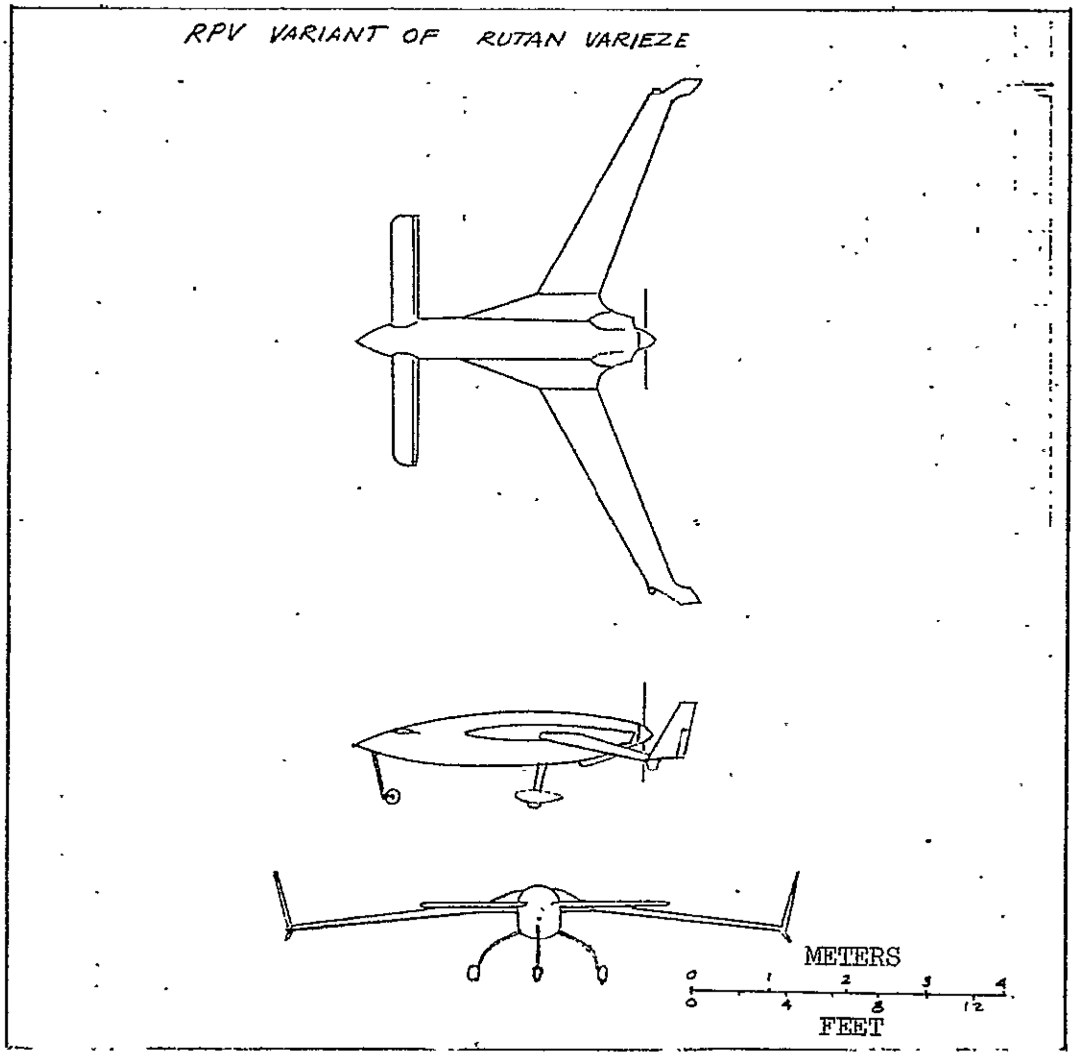
Two operators are on duty, but one can operate the system alone if necessary. All piloting of the aircraft is automatic except takeoff and landing. The operators maintain direct communications with the ATC center(s) that control the areas through which the RPVs will pass on a mission.

Mission payload: The mission payload of the relay RPV is the data-and-control link relay connecting the mission RPV to the ground control station. The mission payload of the mission RPV is an IR line scanner with a target detection module to indicate on the image the location of detected fires. Both RPVs have fixed TV cameras to aid the operator in piloting at takeoff and landing. The IR line scanner and the fixed TV camera weigh 33 lb (15 kg). The relay equipment and the fixed TV camera on the relay RPV weigh 88 lb (40 kg).

Air vehicle: Figure 5 shows the main physical and performance characteristics of the mission-RPV version. The appearance of the relay RPV is the same, and the slower speed at which it is required to cruise decreases fuel consumption more than enough to maintain 8-hour endurance with the added 55 lb (25 kg) of payload weight, so a separate figure is not included for the relay RPV.

A 200 mph (322 km/hr) cruise speed at 20,000 ft (6100 m) altitude for 9 hours is desired for the wildfire detection mission. This long-range mission at a relatively high altitude is ideal for a mildly supercharged 4-cycle engine. Very few engines of aircraft quality and weight exist in the small size range. The most attractive engine with proven long life is the Continental 0-200 used in the Cessna 150 2-place training airplane. A small turbo-supercharger of existing design should be adapted with a minimum of effort. (Many larger engines are available with turbo-superchargers, but are more powerful and expensive than justified for this mission.)

The airframe for the wildfire detection mission could be designed new or might be adapted from an existing small light plane. The high speed requirements eliminate all but the larger light aircraft in U.S. production. The small home-built aircraft field offers several possibilities, however. LMSC does not endorse any particular existing design, but for purposes of illustration has chosen to show an adaptation of the Rutan "VariEze" as typical of designs that might be appropriate.



RPV VARIANT OF RUTAN VARIEZE

LENGTH	4.4m (14.3 ft)	MAXIMUM SPEED	362 Km/hr (225 mph)
WING SPAN	6.8m (22.3 ft)	CRUISE SPEED	322 Km/hr (200 mph)
WING AREA	$4.98m^2$ (53.6 ft^2)	CRUISE ALTITUDE	6100m (20,000 ft)
WING LOADING	$89.3kg/m^2$ (18.3 psf)	CRUISE ENDURANCE	9 hrs
POWER	100 BHP TURBOCHARGED	STALL SPEED	80 Km/hr (50 mph)
TAKEOFF WEIGHT	444 Kg (980 lb)	RANGE (NO RESERVE)	2900 Km (1800 S.M.)
FUEL WEIGHT	151 Kg (332 lb)	CEILING (FULL FUEL)	>7600m (25,000 ft)
PAYLOAD WEIGHT	26.3 Kg (58 lb)		

FIGURE 5 RPV For Mission 3, Wildfire Detection

It is designed for the Continental 0-200 engine. Also, its two-place size could permit manned ferry operation to get the aircraft from one place to another for operation or maintainance even after one seat is replaced with a fuel tank and equipment bays. This aircraft is highly efficient, as is required for long-range, high-speed flight. Its cruise lift-to-drag ratio is over 14. Long range is provided by adding a 38-gallon (144 l) fuel tank in the forward portion of the rear seat area, maintaining the correct center of gravity. This fuel augments the 20 gal (76 liter) tanks built into the wing root gloves.

It is possible to design a smaller and lighter aircraft than the VariEze to perform the wildfire detection mission. The key factor is the availability of a four-cycle engine of about 50-60 hp (37.5-44.5 kW) that could be supercharged. A few engines, including modified Volkswagen engines, are available but none have the reliability of the Continental 0-200. The older Continental C-60 would be a possible engine but it is out of production. Therefore, because of engine availability, the VariEze was taken as a representative air vehicle for this study.

This wildfire detection mission requires operation at range of 400 mi (640 km) from the base of operations. The long range necessitates a relay for communications. An airborne relay is assumed here. The long relay range of up to 250 mi (400 km) requires a high-gain (21 db) directional receiving antenna onboard the relay craft. This 21-dB antenna is a gimballed 21-inch (0.53 m) dish mounted on the forward cockpit area of a VariEze airframe. This location permits a clear view of at least 60° angle to either side of the relay RPV. The system operation assures link closure by having the relay RPV make turns at the same time the mission RPV makes commanded turns. The slower cruise speed of 150 mi/hr (240 km/hr) of the relay due to the shorter distance it must travel requires much less fuel than would be required at 200 mph, which more than makes up for the additional weight of the antenna and data link.

Ground station: The ground station controls two RPVs at once, and is operated by two operators. It's located in an existing facility at an airport and uses commercial power, with an emergency generator for backup in case of power failure. Positions of both RPVs are displayed continuously by X-Y plotters, and the imagery from the fixed TV cameras on the RPVs can be displayed whenever desired, e.g., for takeoff and landings. The IR imagery returned to the ground station in real time is recorded and converted to hard copy for photointerpretation.

Continuous communications are maintained with cognizant ATC centers and with the control tower (if any) at the airport. Navigation calculations are not made on the ground, except for what are necessary to drive the X-Y plotters and to determine proper geometrics for the relay. RPV controls require only that heading, speed, and altitude be transmitted and the autopilots on the RPVs fly the aircraft.

The ground control station is permanent and not portable.

Launch and recovery are by takeoff and landing at the airport, with appropriate traffic control to protect other aircraft.

Checkout, servicing, and maintenance are by a contractor at the airport who provides his own facilities and mechanics.

Data and control link: The link is a long-range (400 mi, or 640 km) line-of-sight link through the airborne relay on the relay RPV. The ground antenna is an autotracking, high-gain antenna, but only for range, not navigation by rho-theta.

Navigation scheme: Navigation is by an on-board Omega navigation system. The accuracy is CEP = 1000 ft (300 m), which is entirely adequate.

Safety provisions: In case of lost link, the mission RPV and/or the relay RPV hold altitude or climb to operational altitude and fly in circles awaiting reestablishment of the link. The cognizant ATC center is notified by the ground station. If the link is not reestablished in a prescribed period of time, the RPVs fly to a predetermined, sparsely populated area, shut off engines, descend in a tight spiral, and finally enter one of the manuevers designed to provide a steep glide path, and thus minimize the time in descent and the area of potential damage on the ground. (See comments about unplanned descents, below.)

For collision avoidance, the RPVs operate in controlled airspace, controlled by ATC. They also have flashing lights for visibility, and collision avoidance system (CAS) beacon transponders for ATC.

In case of unplanned descent, the maneuver is the same as described above when the link is not reestablished. This is not a very satisfactory mode of emergency descent, since it results in a fairly high-speed impact. Further means to slow descent will probably have to be provided, at a weight penalty of perhaps 10%.

Mission 4, Fishing-law enforcement. - Concept of operation: RPV systems would supplement the Coast Guard's surface ships and manned-aircraft patrols by performing the routine large-area surveillance for detection and location of fishing fleets and large fishing vessels. The manned aircraft or surface ships would then perform close inspection for identification of any fishing vessels found operating in U.S.-regulated waters, and for enforcement of any regulations such as licensing, restricted types of catches, limits on size of catch, etc.

The RPV would detect and locate the fishing vessels by surveying an assigned area 200 mi x 200 mi (320 km x 320 km) once daily using a synthetic aperture radar (SAR). The SAR is envisioned as having a minimal airborne portion and telemetering the raw radar data to the surface for signal processing and display.

Operation is from existing U.S. Coast Guard air bases on the coast. To cover the assigned area, the RPV would fly a round trip of about 300 mi (480 km) from the base to within 100 mi (160 km) of the extreme corners of the area, and back, once a day, at 80 mph. This gives a mission time of nearly four hours. Operating altitude is 15,000 ft (4500 m), so no relay is required.

The RPV operates in controlled airspace part of the time, so the operator has continuous communication capability with the cognizant ATC center.

Only a single operator is required, and only one RPV is controlled in the air at once from one ground station.

Mission payload: The mission payload is a synthetic aperture radar. The airborne portion consists of (1) a fixed antenna system using the RPV flight path to provide the scanning function; (2) radar transmitter/receiver; and (3) signal conditioner for RPV telemetry interface. The raw radar data along with RPV attitude data is telemetered to the ground station for siganl processing and display.

Air vehicle: The air vehicle is a fixed-wing RPV weighing 146 lb (66 kg) at takeoff and having the physical and performance characteristics shown in Figure 6.

Three longitudinal rod-like 140 MHz antennas about 3 ft (1 m) long are to be carried with a 25 lb (11.3 kg) radar electronics package. Omega navigation is to be used. The mission is to survey the ocean for 200 mi (320 km) from the coast to detect illegal fishing activities. The radar has a range of more than 100 mi (160 km) from an altitude of 16,000 ft (4900 m). This long range permits a large area to be scanned by a slowly circling RPV about 130 mi (200 km) from shore. The mission can be performed by an RPV with 5½ hour endurance (including reserves) at a speed of 80 mi/hr (36 m/sec).

The desired antenna configuration is a central longitudinal rod followed by two similar rods 13.5 in. (0.34 m) on either side of the centerline. This arrangement is compatible with a twin boom pusher airframe as shown in Figure 6 and suggested for missions 5, 6 and 8. The high-altitude search requirement of this mission requires a slightly larger (10%) engine than suggested for the other missions. Otherwise, the airframe is identical except for payload provisions. Although trailing edge flaps are shown to minimize landing speed, it may be acceptable to land about 30% faster (60 mi/hr, or 27 m/sec) without flaps on the permanent landing strip assumed for this mission.

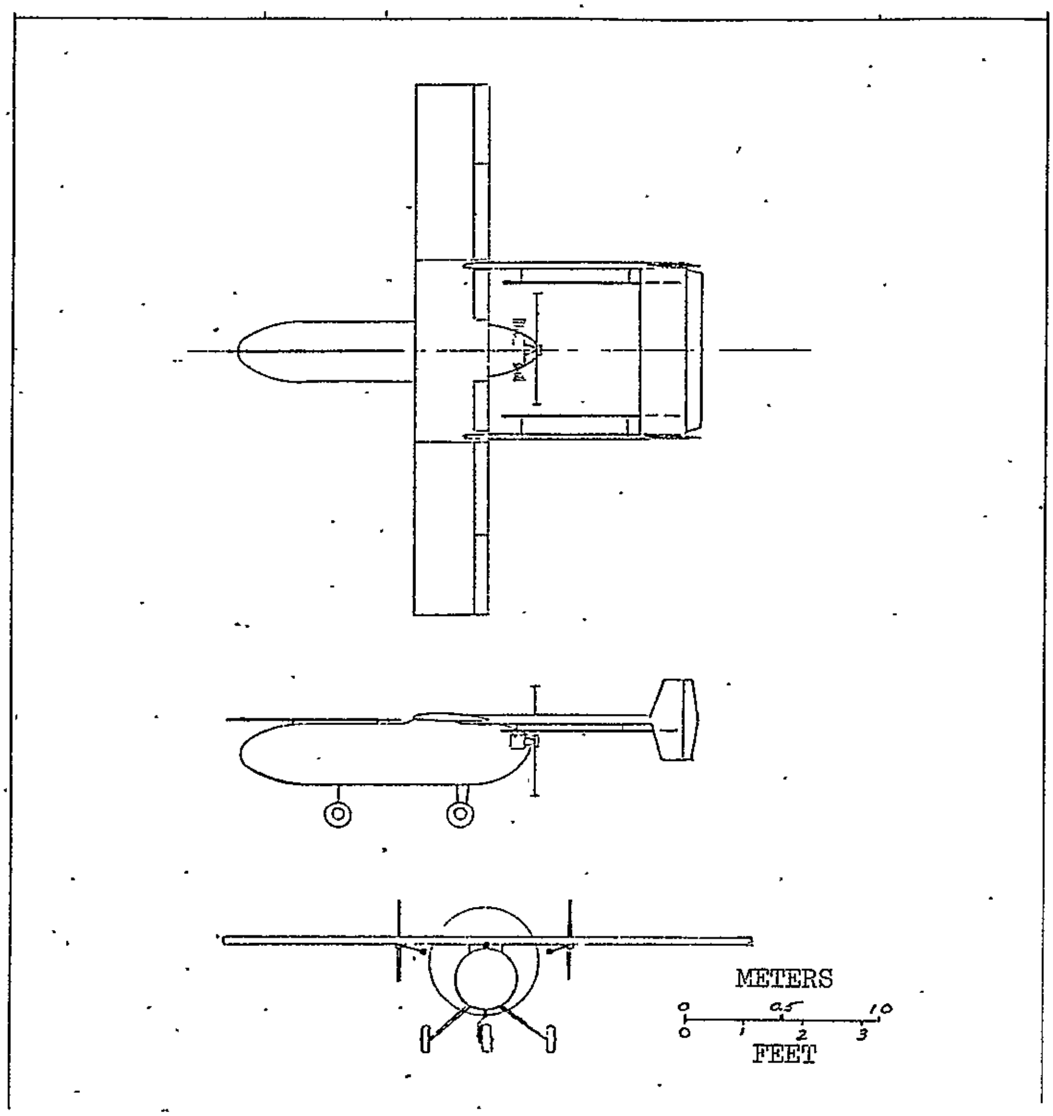
Ground station: One RPV is controlled in the air at any one time, by the single operator at a console in a building or shelter at an existing U.S. Coast Guard Air station. The location of the RPV is displayed continuously (on an X-Y plotter), as are the routine operating data such as speed, altitude, fuel remaining, etc. The image from a fixed camera on the RPV is displayed for aid to the operator during takeoff and landing..

The data returned from the SAR is processed on the ground to determine locations of ships detected. The location information is stored and displayed as required. Navigation calculations are not performed on the ground.

Commercial power is used, with an auxiliary generator as backup in case of power failure.

Communications with ATC are provided.

Launch and recovery are by takeoff and landing from the air strip at the air station.



LENGTH (LESS ANTENNA)	2.35m (7.75')	MAXIMUM SPEED	185 Kmh (115 mph)
WING SPAN	2.75m (9')	CRUISE SPEED	129 Kmh (80 mph)
WING AREA	1.05m (11.25 ft^2)	CRUISE ALTITUDE	4900m (16,000' Av.)
WING LOADING	63kg/m^2(130 psf)	CRUISE ENDURANCE	5.5 hr
POWER	11 BHP	STALL SPEED (FLAPS DOWN)	74 Kmh (46 mph)
TAKEOFF WEIGHT	66.2 Kg(146 lb)	RANGE (NO RESERVE)	704 km (437 S.M.)
FUEL WEIGHT	13.2 Kg (29 lb)	CEILING (FULL FUEL)	5000m (16,500')
PAYLOAD WEIGHT	17 Kg (38 lb)	CEILING (HALF FUEL)	5600m (18,500')

FIGURE 6 RPV For Mission 4, Fishing-Law Enforcement

Checkout, servicing, and maintenance are by a contractor who provides his own equipment and mechanics.

The ground station is permanent and not portable.

Data and control link: The link is line-of-sight with power and gains designed to operate at 150 mi (240 km) range.

Navigation scheme: Navigation is by an on-board Omega navigation system. The accuracy of location is CEP = 1000 ft (300 m).

Safety provisions: Safety provisions are very similar to those for Mission 3 with regard to lost-link manuevers, collision avoidance, and unplanned descent, with the advantage of operating over the ocean where an unplanned descent poses little or no danger to anyone.

Mission 5, Highway patrol. - Concept of operation: This mission for RPVs is to patrol stretches of highway that are too remote or too lightly traveled to justify regular patrol by manned aircraft. The RPVs supplement existing patrols by manned aircraft. Both a mission RPV and a relay RPV are used.

The mission RPV carries a TV camera and transmits a real-time image of the scene below to an operator at a ground control station. The objective is to locate accidents, motorists in trouble, stolen or wanted vehicles, and unsafe road conditions such as landslides, flooded stretches, or washouts. Upon discovery of any of the above items, the necessary information is provided to a dispatcher on the ground, who directs ground units to take appropriate action.

The RPVs fly over an area of 150 mi (240 km) in radius about the airport from which they operate, covering about 700 mi (1120 km) in an eight-hour flight once a day. The mission RPV operates below 800 ft (245 m) AGL and is thus out of line-of-sight of the ground control station much of the time. The relay RPV provides the data and control link by flying at 15,000 ft (4600 m) AGL directly above the mission RPV. One operator controls both RPVs. Only daytime operations are envisioned.

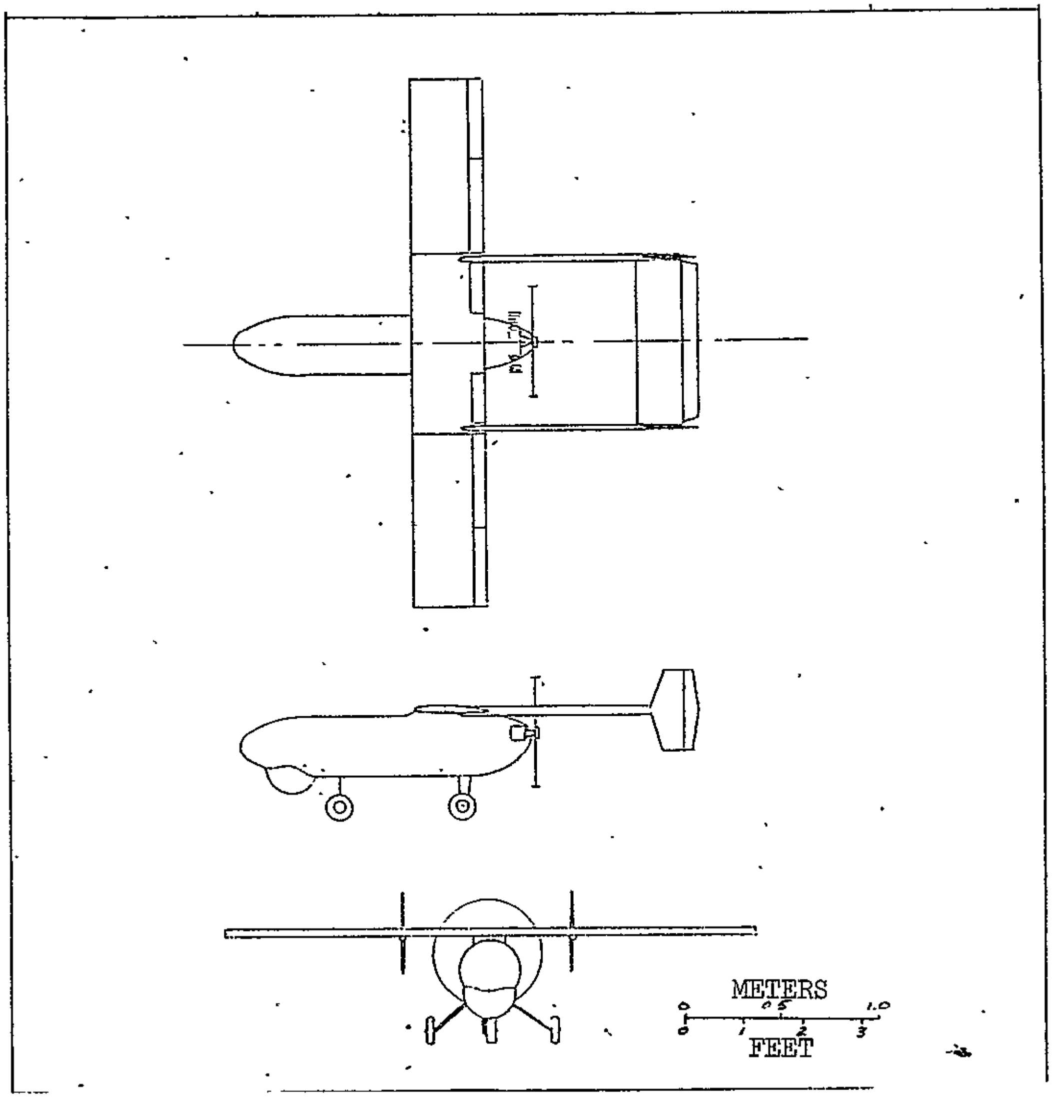
Mission payload: The mission payload is a daylight TV camera with pan, tilt, and zoom (or variable field of view) and a loudspeaker for addressing people on the ground. The total weight is 17 lb (7.7 kg). The mission payload of the relay RPV is the data link equipment for relaying to and from the mission RPV. It weighs 35 lb (16 kg). The relay RPV also has a 3-lb (1.4 kg) fixed TV camera for a visual reference during takeoff and landing.

Air vehicle: Both the mission RPV and the relay RPV are fixed-wing aircraft. Their general features and performance characteristics are shown in Figures 7 and 8, respectively. The unusual flat belly configuration of the relay RPV is to accommodate the antenna for communicating with the mission RPV from approximately overhead.

The highway patrol mission is a low altitude linear surveillance. An altitude of 800 ft (244 m) above the ground is desired at a speed of 90 mi/hr (40 m/sec) for $8\frac{1}{2}$ hours. This combination of relatively high speed and low altitude for a long duration leads to a high-wing-loading RPV. A conventional airstrip is to be available for takeoff and landing, so that no special considerations are required for limited runway length.

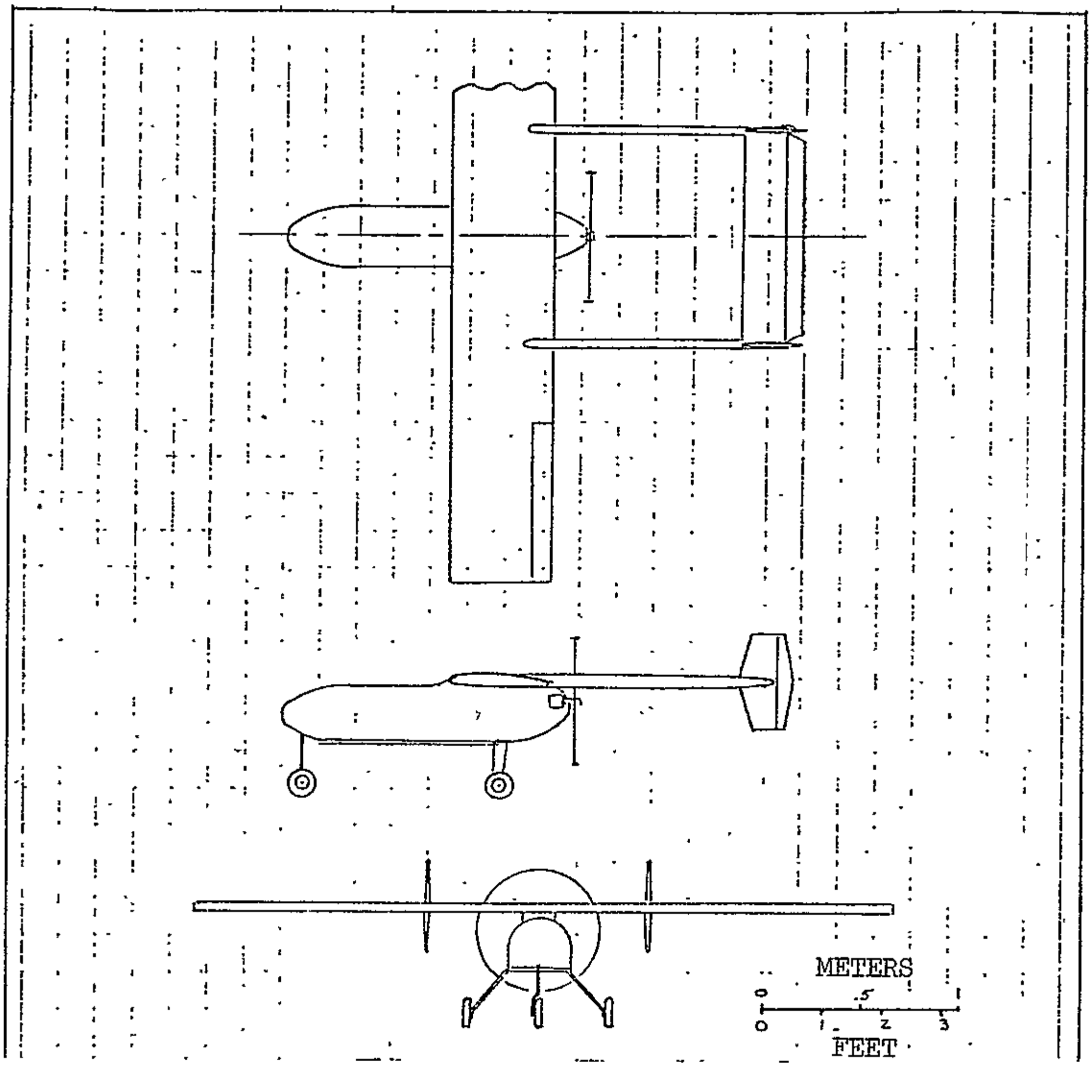
The configuration depicted in Figure 7 is a twin-boom pusher similar to that suggested for Mission 4. The pusher arrangement leaves the lower forward fuselage areas available for mounting the gimballed daylight TV camera and dome. The conventional tail control concept tolerates considerable center-of-gravity variation as would be expected for a vehicle with the large amount of fuel required for this mission. A fixed landing gear is assumed for simplicity and reliability. The high wing loading of 15 lb/ft^2 (75 kg/m^2) leads to unacceptably high landing speeds. Therefore, flaps are suggested to reduce stall speed to a tolerable 50 mph at landing. It is assumed that the ailerons would be deflected downward about 10 degrees to serve as flaps, with enough deflection remaining for adequate roll control. Separate actuators are anticipated for each aileron so their use as flaps does not increase mechanical complication.

The vehicle meets the desired performance with a 10-hp (7.46 kW) engine. Cruise at 90 mi/hr (40 m/sec) requires about 75% power assuming a 1-hp (746 W) electrical power load. In the interest of long engine life and better climb performance, a slightly larger engine would be desirable. The engine size decision can be made when and if an RPV is designed or adapted to perform the highway patrol mission.



LENGTH	2.35 m (7.75')	MAXIMUM SPEED	175 Km/hr	(108 mph)
WING SPAN	2.75 m (9')	CRUSIE SPEED	145 Km/hr	(90 mph)
WING AREA	1.05 m^2 (11.25 ft^2)	CRUISE ALTITUDE	300 m	(1000')
WING LOADING	71 Kg/m^2 (14.7 psf)	CRUISE ENDURANCE	8.5 hr	
POWER	10 BHP	STALL SPEED (FLAPS DOWN)	77 KM/hr	(48 mph)
TAKEOFF WEIGHT	74.8 Kg (165 lb)	RANGE (NO RESERVE)	1230 Km	(765 S.M.)
FUEL WEIGHT	26 Kg (58 lb)	CEILING (FULL FUEL	2700 m	(8900')
PAYLOAD WEIGHT	11.8 Kg (26 lb)	CEILING (HALF FUEL)	4000 m	(13,200')

FIGURE 7 Mission RPV For Mission 5, Highway Patrol



LENGTH	2.64 m	(8.7 ft)	MAXIMUM SPEED	180 Km/hr	(112 mph)
WING SPAN	3.6 m	(11.8 ft)	CRUISE SPEED	145 Km/hr	(90 mph)
WING AREA	1.86 m^2	(20 ft^2)	CRUISE ALTITUDE	4600 m	(15,000 ft)
WING LOADING	56.1 Kg/m^2	(11.5 psf)	CRUISE ENDURANCE	8.5 hr	
POWER	17 BHP		STALL SPEED	77 Km/hr	(48 mph)
TAKEOFF WEIGHT	104 Kg	(230 lb)	RANGE ((NO RESERVE)	1230 Km	(765 S.M.)
FUEL WEIGHT	32 Kg	(70 lb)	CEILING (FULL FUEL)	4900 m	(16,000 ft)
PAYLOAD WEIGHT	17 Kg	(38 lb)	CEILING (HALF FUEL)	5800 m	(19,000 ft)

FIGURE 8 Relay RPV For Mission 5, Highway Patrol

Because of the low-altitude flight of the patrol RPV, a relay RPV is required to fly at 15,000 ft (4570 m) to permit continuous communication with the patrol RPV. The relay craft flies in a station-keeping mode directly over the mission RPV. Signals are received through a 1 x 3 ft (0.3 x 0.9 m) flat antenna with a 10° by 30° beam on the underside of the fuselage and the associated avionics weight combined with the high-altitude flight requirement dictate a larger airframe and engine. A configuration similar to the basic patrol RPV with a 20 ft^2 (1.86 m^2) wing area and 17-hp (12.7 kW) engine meets the relay craft requirements. This 230 lb (104 kg) vehicle is shown in Figure 8 .

Ground station: The two RPVs are controlled by a single operator at a console in an existing building at an airport. The location of the two RPVs is shown continuously on an X-Y plotter, and the real-time image from the mission RPV's TV camera is also displayed continuously. During landing and takeoff of the relay RPV, the picture from its fixed TV camera can be displayed as an aid to piloting. Speed, altitude, heading, remaining fuel, and other operating data for both RPVs are displayed.

A videotape recorder provides a permanent record of the image from the mission TV, at the option of the operator, along with pertinent time, date, and location information.

The operator commands speed, heading, and altitude and the autopilots aboard the RPVs fly the aircraft. The operator can also speak to people on the ground with loudspeakers, and can control the pointing and zoom of the mission TV camera.

Commercial power is used, with an emergency generator in case of power failure.

The operator has continuous communciations with the cognizant ATC center for control of the relay RPV, which operates in controlled airspace. He also has telephone and/or radio communication with the nearest highway patrol substation.

The ground station is permanent, and portability is not required.

Launch and recovery are by takeoff and landing from the airport, using the on-board TV cameras to help the operator in piloting. The relay RPV takes off first and lands last, always relaying control to the mission RPV.

Maintenance, checkout, and servicing are done by a contractor at the airport, who provides his own equipment and mechanics.

Data and control link: The link is a long-range (150 mi, or 240km), line-of-sight link through the relay RPV. The ground antenna is an autotracking, high-gain antenna, but only for range, not for rho-theta navigation.

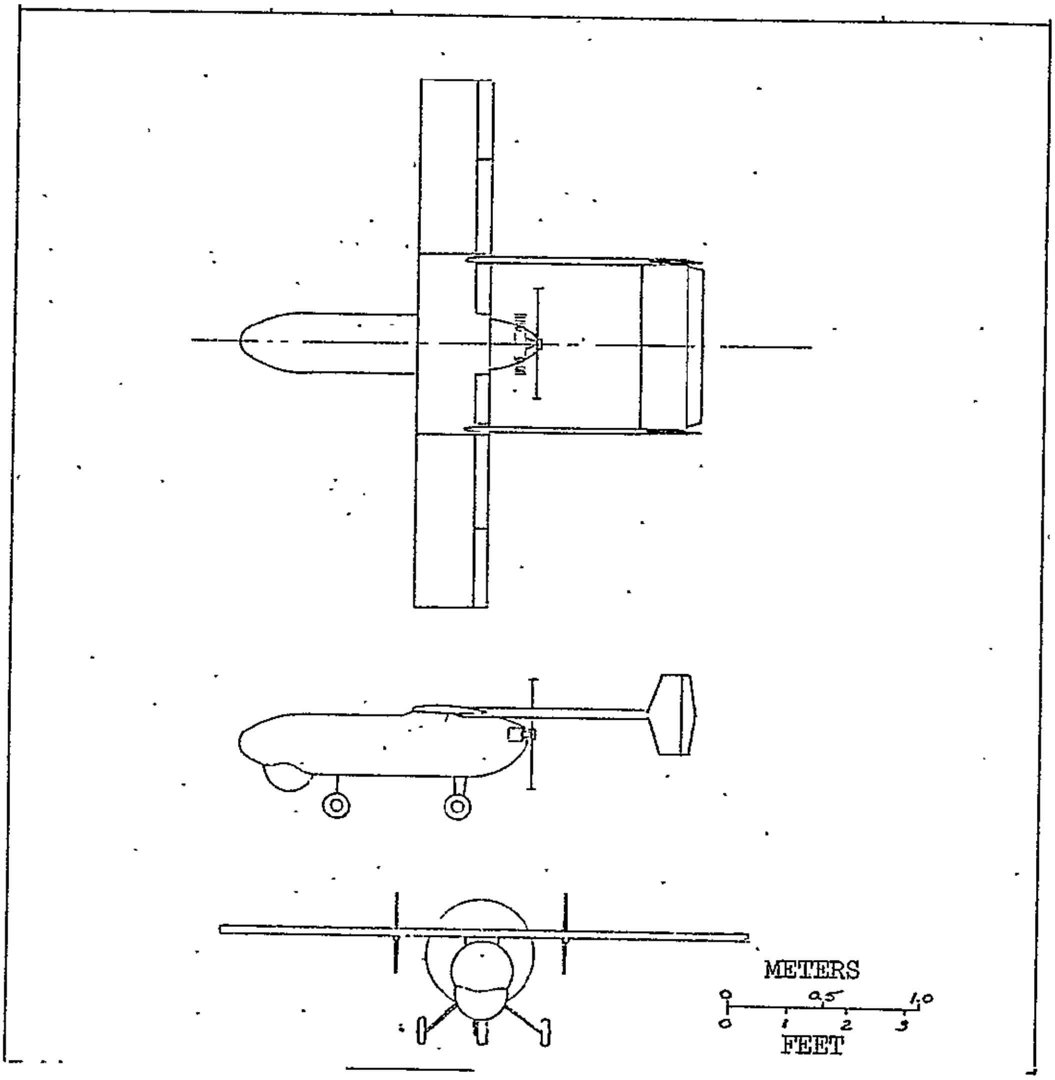
Navigation scheme: Navigation is by an on-board Omega system, with location accuracy of CEP = 1000 ft (300 m). The operator relies on the TV image to adjust the flight path to keep the highway in the field of view.

Safety provisions: The safety provisions are similar to those for Mission 3. Since these RPVs are considerably lighter than the ones for Mission 3, provisions to slow an unexpected descent are more practicable.

Mission 6, Pipeline patrol. - Concept of operation: The RPV system patrols 400 miles of pipeline per day, looking visually for signs of leaks, hazards to the pipeline, and semaphore indications that the cathodic protection has failed. When a problem is detected, ground personnel are dispatched to take care of it. The RPVs (mission and relay) operate from air strips adjacent to existing pumping or control facilities approximately 200 mi (320 km) apart, at which the ground control stations are also located. Control of the RPVs is handed off from station to station along the line, and they do not ordinarily land at the same station from which they took off on any given day.

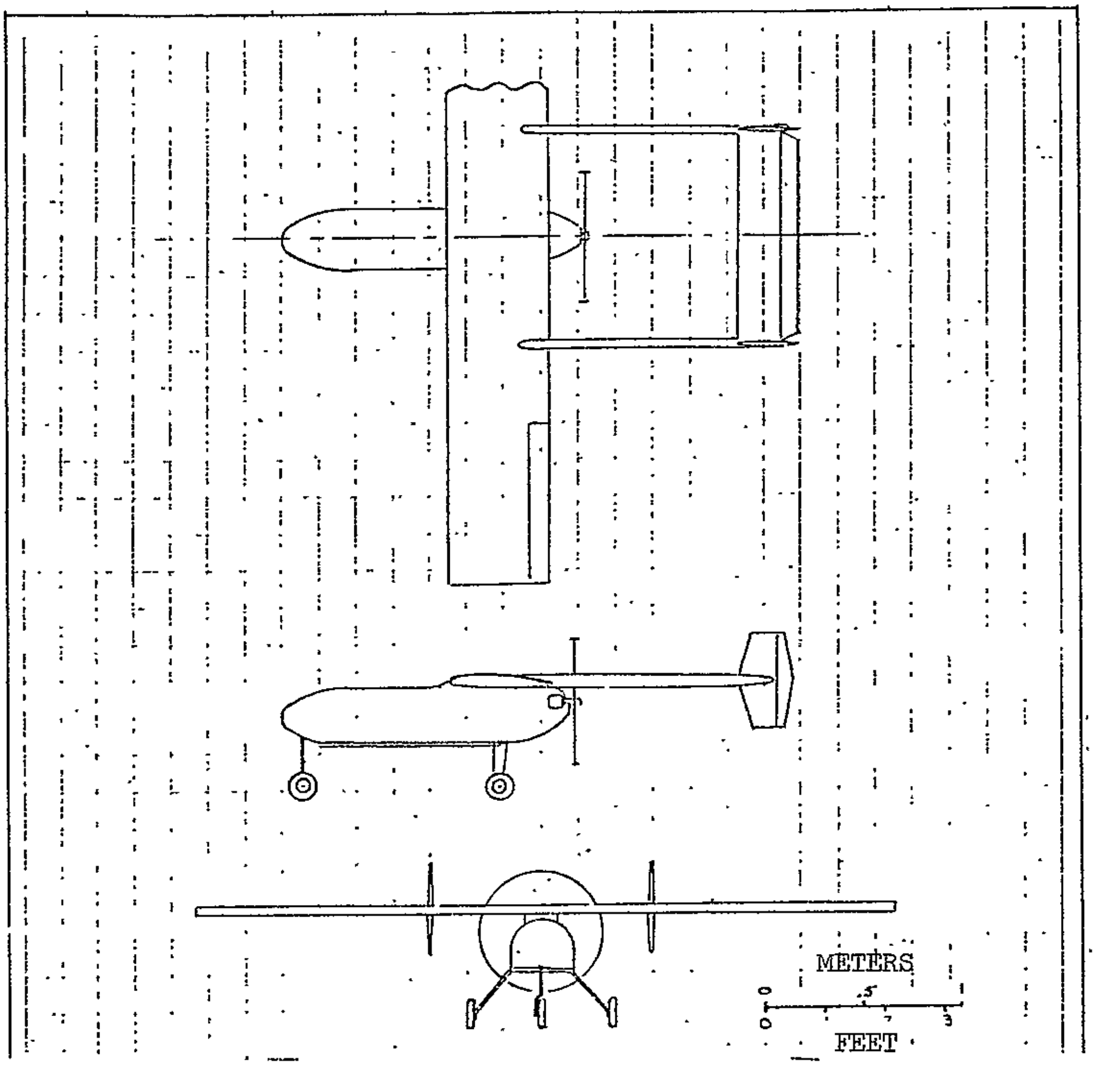
Mission payload: The mission payload of the mission RPV is a daylight TV camera with pan, tilt, and zoom (or variable field of view). It weighs 7 lb (3.2 kg). The mission payload of the relay RPV is the communication relay equipment, which weighs 35 lb (16 kg). The relay RPV also has a fixed forward-looking 3-lb (1.4 kg) TV camera to give the operator a visual reference during takeoff and landing.

Air vehicle: Both the mission RPV and the relay RPV are fixed-wing aircraft. Their general features and performance characteristics are shown in Figures 9 and 10, respectively. The unusual flat belly configuration of the relay RPV is to accomodate the antenna for communicating with the mission RPV from approximately overhead.



LENGTH	2.35 m	(7.75')	MAXIMUM SPEED	180 Kmh	(112 mph)
WING SPAN	2.75 m	(9')	CRUISE SPEED	129 Kmh	(80 mph)
WING AREA	1.05 m^2	(11.25 ft^2)	CRUISE ALTITUDE	300 m	(1000')
WING LOADING	56.0 Kg/m^2	(11.5 psf)	CRUISE ENDURANCE	6.5 hr	
POWER	10 HP		STALL SPEED (FLAPS DOWN)	68 Kmh	(42 mph)
TAKEOFF WEIGHT	58.5 Kg	(129 lb)	RANGE (NO RESERVE)	835 Km	(520 S.M.)
FUEL WEIGHT	16 Kg	(35 lb)	CEILING (FULL FUEL)	4600 m	(15,000')
PAYLOAD WEIGHT	7.3 Kg	(16 lb)	CEILING (HALF FUEL)	5400 m	(17,800')

FIGURE 9 Mission RPV For Mission 6, Pipeline Patrol



LENGTH	2.64 m	(8.7 ft)	MAXIMUM SPEED	182 Km/hr	(113 mph)
WING SPAN	3.6 m	(11.8 ft)	CRUISE SPEED	129 Km/hr	(80 mph)
WING AREA	1.86 m^2	(20 ft^2)	CRUISE ALTITUDE	4600 m	(15,000 ft)
WING LOADING	52.5 Kg/m^2	(10.8 psf)	CRUISE ENDURANCE	6.5 hr	
POWER	17 BHP		STALL SPEED	77 Km/hr	(48 mph)
TAKEOFF WEIGHT	96 Kg	(215 lb)	RANGE (NO RESERVE)	835 Km	(520 S.M.)
FUEL WEIGHT	25 Kg	(55 lb)	CEILING (FULL FUEL)	5200 m	(17,000 ft)
PAYLOAD WEIGHT	17 Kg	(38 lb)	CEILING (HALF FUEL)	6100 m	(20,000 ft)

FIGURE 10 Relay RPV For Mission 6, Pipeline Patrol

This mission is similar to mission 5 in that a low-altitude linear-patrol mission is flown. The payload is lighter, 16 lb (7.3 kg), and flight time is only 6.5 hours at a lower speed of 80 mi/hr (36 m/sec). Considering these reduced requirements, the same configuration air vehicle can be built for a 129 lb (58.5 kg) takeoff weight.

Ground station: The two RPVs are controlled simultaneously by a single operator at a console in an existing building at a pumping or control station on the pipeline. These stations are chosen no more than 200 mi (320 km) apart, the maximum distance being determined by line-of-sight communications to the relay RPV.

The image from the TV camera on the mission RPV is displayed continuously, as is the X-Y location of the RPVs on an X-Y plotter. Also displayed are the operating data on the RPVs, such as speed, altitude, heading, remaining fuel, etc. During landing and takeoff, the image from the relay RPV's TV camera is also displayed.

Speed, altitude, and heading commands are used to guide the RPVs, leaving the autopilot to actually fly the RPVs. The pointing and zoom of the TV camera are also controlled by the operator.

Commercial power is used, with an emergency generator for backup in case of power failure.

The operator has continuous communication with the cognizant ATC center to operate the relay RPV in controlled airspace, and with the stations on either side of his own to coordinate the handovers.

An operator controls the RPV an average of 2-3 hrs once a week and performs other duties unrelated to RPVs the rest of the time.

The ground stations are permanent. The number of them in a system depends on the length of the pipeline, since there must be one about every 200 mi (320 km). For a 1000-mile pipeline, there are 6 stations, counting the ones at each end.

Launch and recovery is by takeoff and landing from a prepared strip near a station. Checkout and servicing is done by the operators, but maintenance is done by a contractor, who supplies his own equipment and mechanics.

Data and control link: The link is a long-range (100 mi, or 160 km), line-of-sight link through the relay RPV, with hand-over capability from station to station. The ground antenna is an autotracking, high-gain antenna, but only for range, not for rho-theta navigation.

Navigation scheme: Navigation is by an on-board Omega system, with location accuracy of CEP = 1000 ft (300 m). The operator relies on the TV image to make adjustments to the flight path to keep the pipeline in the field of view.

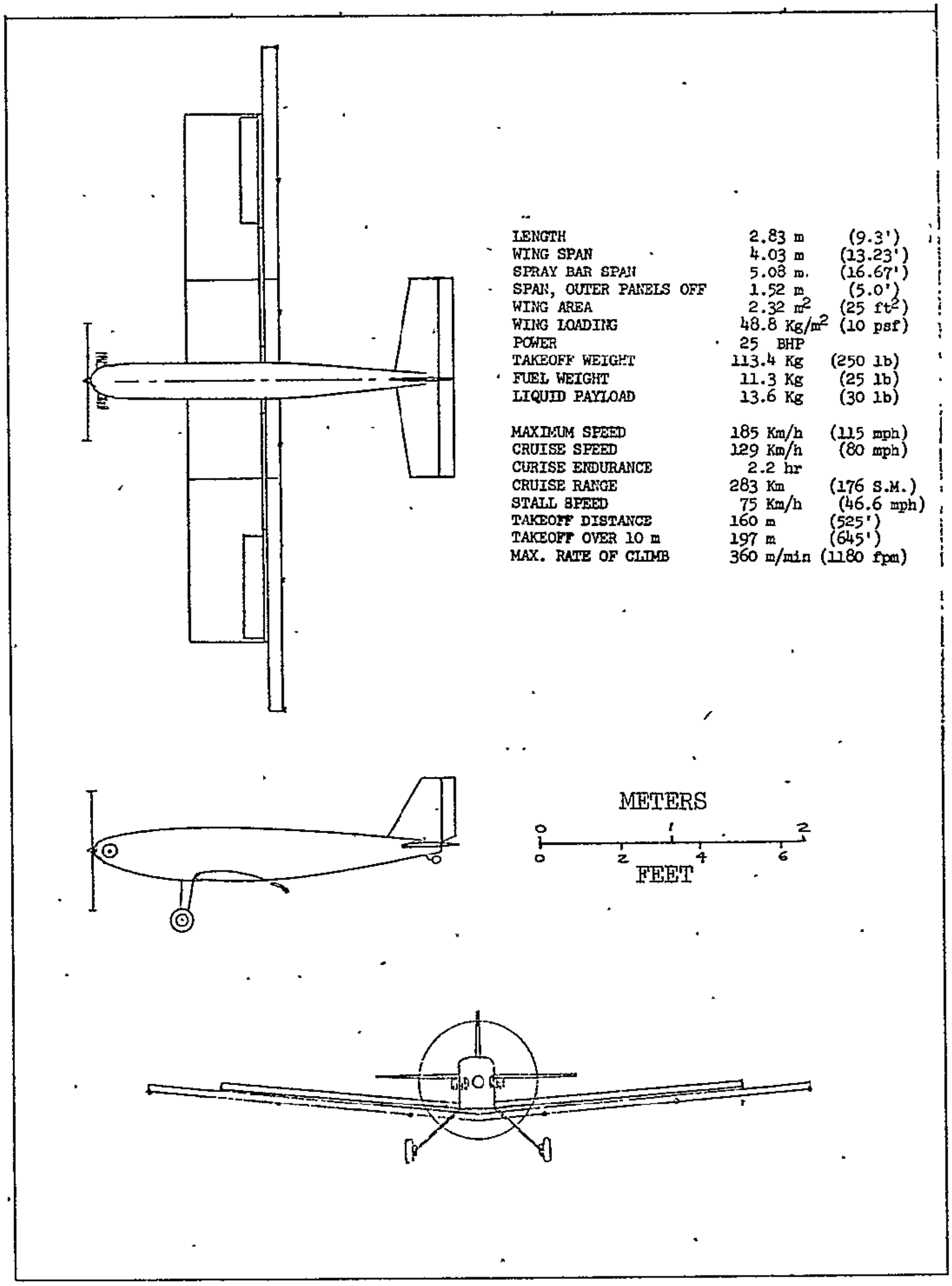
Safety provisions; The safety provisions are similar to those for Mission 5.

Mission 7, Agricultural spraying and crop dusting. - Concept of operation: The RPV is used by a farmer or agricultural aviation operator to spray ultra-low volume (ULV) chemicals on crops for pest control. The RPV is transported to the field by trailer and operates from a farm road or unimproved cleared area, where it is loaded with chemicals between flights. It operates within 1 mile (1.6 km) of the portable ground station, and flies preprogrammed flight paths controlled from a small computer in the ground station. A single operator controls the RPV, possibly assisted by a helper for loading the chemical. Altitude of operation is only a few feet above the crop, and is tightly controlled by an on-board radar altimeter.

It should be noted that this is a very difficult mission, and this conceptual design is a fairly low-confidence design due to the limited time and resources available to investigate solutions to the difficult control problems. However, it is believed to be a plausible design.

Mission payload: The mission payload is 30 lb (13.6 kg) of chemical and a spray system (an air compressor pump and spray bar with associated tankage and plumbing) weighing 25 lb (11.4 kg). For aid in landing and takeoff and in keeping the operator oriented, a fixed forward-looking TV camera weighing 3 lb (1.4 kg) is also carried.

Air vehicle: The RPV is a fixed-wing aircraft. It carries a spray bar permanently mounted behind the trailing edge of the wing. Figure 11 gives its general characteristics and performance capabilities. The outer panels of the wings and spray bar are detachable for transportation by trailer.



LENGTH	2.83 m	(9.3')
WING SPAN	4.03 m	(13.23')
SPRAY BAR SPAN	5.08 m.	(16.67')
SPAN, OUTER PANELS OFF	1.52 m	(5.0')
WING AREA	2.32 m^2	(25 ft^2)
WING LOADING	48.8 Kg/m^2	(10 psf)
POWER	25 BHP	
TAKEOFF WEIGHT	113.4 Kg	(250 lb)
FUEL WEIGHT	11.3 Kg	(25 lb)
LIQUID PAYLOAD	13.6 Kg	(30 lb)
MAXIMUM SPEED	185 Km/h	(115 mph)
CRUISE SPEED	129 Km/h	(80 mph)
CURISE ENDURANCE	2.2 hr	
CRUISE RANGE	283 Km	(176 S.M.)
STALL SPEED	75 Km/h	(46.6 mph)
TAKEOFF DISTANCE	160 m	(525')
TAKEOFF OVER 10 m	197 m	(645')
MAX. RATE OF CLIMB	360 m/min	(1180 fpm)

FIGURE 11 RPV For Mission 7, Agricultural Spraying and Crop Dusting

The RPV is required to spray a swath width of at least 20 ft (6.1 m) at a speed of 80 mi/hr (36 m/sec) at a height of as low as 2 ft (0.6 m) above the crops. The RPV is further constrained to short-takeoff operation from unimproved roads bordering fields being sprayed. An endurance of 2 hours is desired.

The requirement to spray a wide path leads to a long spray bar to spread the nozzles sufficiently. A 40-in (1 m) nozzle spacing with Spraying Systems Company #10900J air-atomizing nozzles provides complete coverage. Six nozzles cover the desired 6.1 meter swath. It is assumed that the six nozzles are spaced evenly along a low-drag airfoil-shaped spray bar that serves as an external airfoil wing flap: This flap lowers takeoff speed and helps to direct the spray downward toward the crops while reducing the drag on the spray system plumbing. The spray bar/flap has been integrated into a conventional low wing airplane configuration as shown in Figure 12.

A large 25 hp (18.7 kW) engine was chosen to provide adequate power for climbs at the end of each spray pass and to reduce takeoff distance to about 650 ft (200 m) over a 30 ft (9 m) obstacle. Further reduction in takeoff distance requires increases in power, takeoff lift coefficient, or wing area. The engine is required to provide about 2 hp (1.5 kW) to drive an alternator, air compressor, and liquid-spray pump. The air compressor is required to provide air for spray atomization.

Ground station: The operator controls one RPV in the air at a time, from the portable control station. The location of the RPV is plotted continuously on an X-Y plotter, and the image from its fixed TV camera is displayed to aid the operator in landing and takeoff and in avoiding obstacles. He does not have to pilot the aircraft or control its attitude or altitude, except during takeoff and landing, since that is done by the autopilot, the ground computer, and the radar altimeter. He does have override capability in case of emergency.

A motor-generator set provides electrical power, with a battery backup to land the RPV in case of power failure.

No communication with other systems is needed or provided.

Launch and recovery are by takeoff and landing from a farm road or cleared dirt strip near the field.

Routine servicing is done by the operator, but maintenance is done by a contractor who supplies his own equipment and mechanics.

Data and control link: The link is short-range and line-of-sight. An omnidirectional airborne antenna and an autotracking high-gain ground antenna for precise tracking in azimuth are used.

Navigation scheme: Navigation is by the rho-theta technique described for Mission 1, with more precision provided by a higher data rate in the control link and a larger ground antenna.

Safety provisions: In case of loss of control link, the RPV begins a climbing turn, shuts off the spray, climbs to an altitude of 300 ft (91 m) and flies tight circles. If link has not been reestablished by the end of a predetermined period, it goes into one of the maneuvers designed to provide a steep glidepath and thus minimize descent time and confine the area of potential damage on the ground.

For collision avoidance, no special provisions are made. Operation is always at a very low altitude well below general aircraft traffic.

In case of unplanned descent, the steep-glide maneuver is also executed, although some modes of failure during spraying will cause a near-instant impact. Fortunately, spraying is done over fields empty of people and equipment.

Mission 8(a), Severe-storm research (low altitude). - Concept of operation: The RPV system is transported to an airport or open field in the vicinity of severe thunderstorms and tornados, assembled and checked out, and flown into the vicinity of the storms to gather meteorological data from just above ground level up to 5000 ft (1550 m). The distance from the mobile ground station to the RPV is generally 10 mi (16 km) or less. The entire system is portable and ready to go at any time on short notice 365 days a year. Actual flying probably takes place on no more than 70-90 days per year, however.

The system is self-contained, but operates in cooperation with weather-radar stations to locate storms and plan flight paths. A two-man crew operate the RPV and the data-recording equipment.

Mission payload: The mission payload consists of a daylight TV camera, an instrument and telemetry package for weather data, and a small chaff dispenser, totalling 17 lb (7.7 kg). The chaff is for radar tracking of winds.

Air vehicle: The RPV is a fixed-wing aircraft with the TV camera mounted in the nose and the instruments mounted internally. Its outer wing panels are easily removable for transportation by trailer. Figure 12 shows its general features and performance capabilities. Research of severe storms at low altitudes below 5000 ft (1500 m) requires a small RPV with a tight turn radius, $1\frac{1}{2}$ hour endurance, and speeds up to 110 mi/hr (49 m/sec). A twin-boom pusher configuration such as those selected for missions 4, 5 and 6 meets these requirements. A transparent nose permits full forward hemisphere observation with a TV camera. A standard weather-data package is also carried to measure pressure, temperature, and humidity. The light weight of 109 lb (49.4 kg) at takeoff permits a relatively tight sustained turn of 265 ft (81 m) radius for cloud observations and avoidance of extremely turbulent areas. Only 11 lb (5 kg) of fuel is required for this mission requirement of $1\frac{1}{2}$ hours. However, endurance could be extended to 3 or 4 hours with only a minor increase in turn radius and no penalty on other performance characteristics.

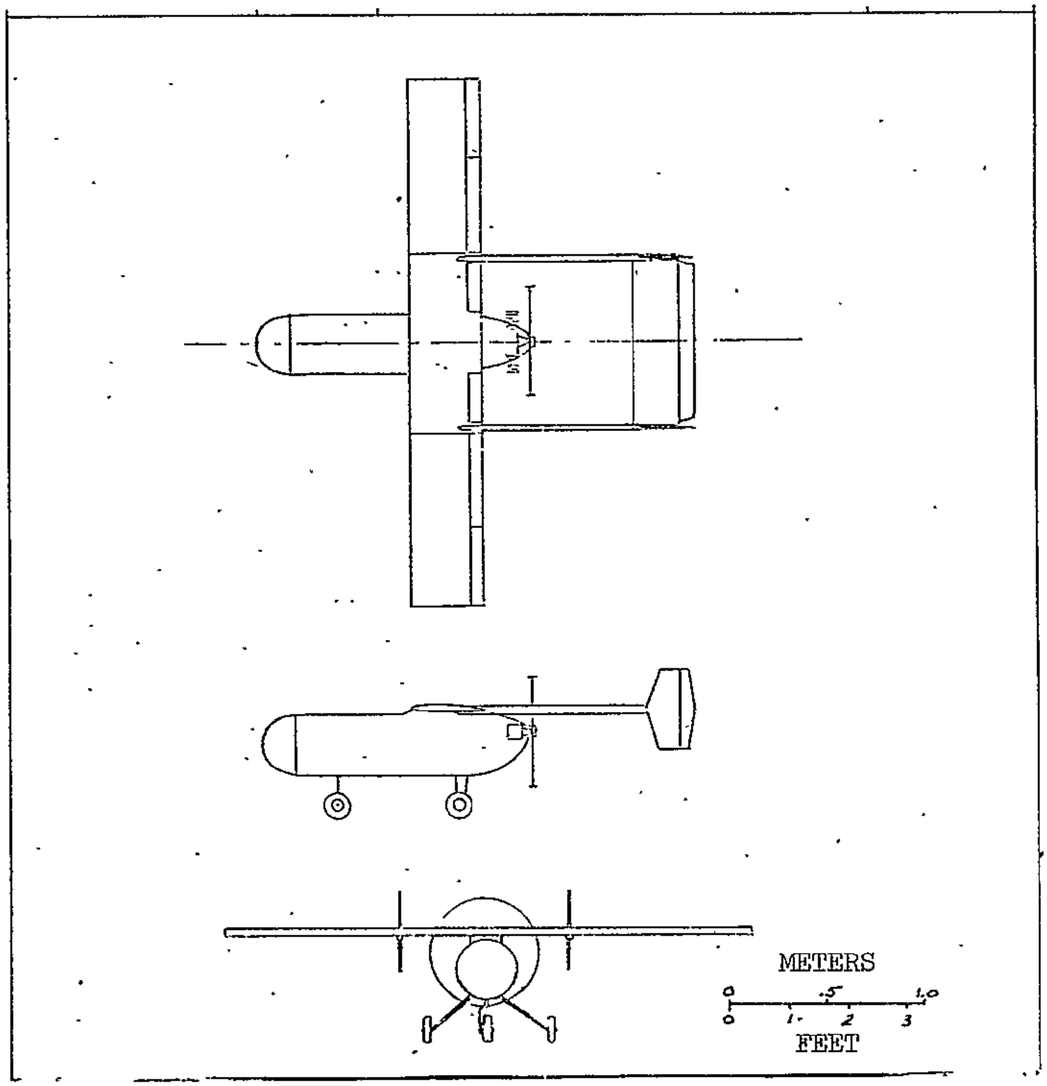
Five bundles of chaff are carried to be dispensed on command. Five lbs (2.3 kg) of weight is allocated for the chaff and dispensing system. Relatively small amounts of chaff tuned to the observing weather-radar frequency will be required.

Ground station: The ground control station is in a van and is completely mobile and self-contained. It controls one RPV in the air at a time, and makes a permanent record of the weather data that is sent by telemetry from the RPV.

Navigation calculations are done in the ground station, and RPV position is displayed continuously on an X-Y plotter. RPV operating data such as speed, altitude, heading, and remaining fuel are also displayed.

The console controls the speed, heading, and altitude of the RPV, the operation of the instrumentation, telemetry, and chaff dispenser, and the pointing and zoom of the TV camera.

The operators have continuous radio communication with the weather radar station with which they are cooperating.



LENGTH	2.3 m	(7.5')
WING SPAN	2.75 m	(9')
WING AREA	1.05 m^2)	(11.25 ft^2)
WING LOADING	49.3 Kg/m^2	(10.1 psf)
POWER	10 BHP	
TAKEOFF WEIGHT	51.7 Kg	(114 lb)
FUEL WEIGHT	5 Kg	(11 lb)
PAYLOAD WEIGHT	17.3 Kg	(25 lb)

MAXIMUM SPEED	182 Kmh	(113 mph)
CRUISE SPEED	145 Kmh	(90 mph)
CRUISE ALTITUDE	SL - 1500 m	(5000')
CRUISE ENDURANCE	2 hr	
STALL SPEED (FLAPS DOWN)	71 Kmh	(44 mph)
RANGE (NO RESERVE)	290 Km	(180 S.M.)
CEILING (FULL FUEL)	5300 m	(17,500')
TURN RADIUS (AT SEA LEVEL) (SUSTAINED)	78 m	(275')

FIGURE 12 RPV For Mission 8, Severe-Storm Research

Power is provided by a motor-generator set, with a battery backup to land the RPV in case of power failure.

Launch and recovery is by takeoff and landing from an airport, if available, or from an open field.

Checkout and routine servicing are by the operating crew, but maintenance is done by a contractor, who furnishes his own equipment and mechanics.

Data and control link: The link is like that of Mission 2. High frequency signal coding prevent interference from the lightning discharges associated with the storms.

Navigation scheme: Navigation is by the rho-theta method, as described for Missions 1, 2, and 7.

Safety provisions: In case of lost link, the RPV circles at altitude for a predetermined period, and if the link is not reestablished it flies to a preprogrammed, sparsely populated area and executes a steep-glide maneuver to minimize descent time and confine the area of potential damage on the ground.

For collision avoidance, the RPV has flashing lights for visibility, and it operates in regions near storms where other aircraft are rare.

In case of an unplanned descent, the RPV descends by the method described above.

Mission 8(b), Severe-storm research (high altitude). - Concept of operation: This mission calls for flying at altitudes up to 60,000 ft (18,300 m) and remaining there for sustained periods of several hours while gathering visual and measurement data of the tops of storms. This extreme altitude requirement requires an RPV that is unlike any of the other systems conceived in this study, and the small potential demand gives scant incentive for a special development program. It is recommended that the existing "Mini-Sniffer" RPV (Reference 1) developed at the NASA Flight Research Center for high-altitude atmospheric sampling be investigated for this use, but no further conceptual design work was done on this mission in this present study.

Mission 9, Meteorology. - No satisfactory RPV system concept was developed that appeared to compete with the cost of weather balloons for this use.

Cost Analysis

Introduction. - Total economic, technical, and environmental impact are examined in this study. Cost analysis addresses the economics of RPV systems viability, market potential, and operations in the 1980-1985 time frame. The objectives of cost analysis are (1) to estimate the costs for each candidate system design concept, (2) to assess the costs of using RPVs in selected civil applications, and (3) to compare RPV costs with conventional or established methods.

Approach. - The following is a review of the approach taken for determining total system costs, including development, investment, and operations for each RPV system concept and alternative method identified in the study. The cost analysis approach is further detailed in Appendix E.

Overview: A subsystem-level hardware element structure (HES) and work breakdown structure (WBS) of hardware, software, services, and other cost items are established for each life-cycle phase of the RPV system. The HES and WBS used in the study are summarized in Tables 5 and 6.

Note that for commercial-systems costing, as compared to military-systems costing, there are several significant cost-element differences, such as the addition of depreciation and insurance to operating costs.

When present or potential methods other than RPVs are identified for the selected uses, total system costs for meeting the functional requirements are estimated. In some cases these costs are obtained from the market survey of present users. LMSC's bank of cost data on RPV systems, aircraft, spacecraft, and ground vehicles provided much of the needed information. For the remaining cases, an independent collection effort filled in the needed cost data.

Particular care is taken to place RPVs and alternatives on the same cost basis by making consistent assumptions about sunk costs, depreciation, amortization of hardware and personnel cost, etc. No attempt is made to optimize

Table 5 . Hardware Element Structure

- Air Vehicle
  - Airframe
  - Engine
  - Guidance and Control
  - Data Link
  - Payload
  - Integration and Assembly
- Ground Control Station
- Launcher/Retrieval System

Table 6 . Work Breakdown Structure

- DDT&E Costs
  - Vehicle
  - Payload
  - Ground Control Station
  - Launcher/Retrieval System
  - GSE
  - Development Spares
  - Flight Test
  - Tooling
  - Management and Integration
- Investment Costs
  - Vehicle
  - Payload
  - Ground Control Station
  - Launcher/Retrieval System
  - GSE
  - Spares
  - Management and Integration
- Operating Costs
  - Annual Fixed Costs
    - Depreciation
    - Insurance
      - Hull
      - Liability
      - Medical
    - Aircraft Storage
    - Crew or Personnel
    - Training
  - Direct Operating Costs
    - Fuel
    - Oil
    - Periodic Incpection
    - Maintenance
      - Airframe
      - Engine
      - Avionics and Ground Control Station

present non-RPV systems or to cost potential improvements that could be made in response to competition from RPVs.

The comparisons of competitive systems costs to perform each of the selected uses assume the same degree of effectiveness (benefit) by an RPV system and by the non-RPV alternative method. The basis for competition is total cost to the user to perform the same mission to the same (or nearly so) degree of effectiveness (benefit).

Cost Analysis: The cost-analysis approach for RPV system concepts makes use of the Lockheed Mini-RPV Cost Model-"C", a parametric total system cost model augmented by direct input (throughout) of certain WBS items. Cost Model-"C" uses RPV system physical characteristics, performance, and program parameters as determinants to estimate development and production costs that reflect commercial-aviation standards.

Average unit production costs, RPV system design, development, test, and engineering (DDT&E) and total investment costs, and annual operating costs are determined, in 1976 dollars, for each of the selected mission RPV system concepts. Test articles and production quantities of air vehicles, ground control stations, and ground support equipment are established from the market survey and analysis.

With the exception of Mission 3, all vehicles considered in this study fall into the mini-RPV class. All vehicles will share some degree of commonality in terms of design and development. Following development of the first system, successive systems are not "start from scratch" development programs. Each is essentially a modification of a previously developed design and will benefit from this inheritance. However, the DDT&E cost estimate for each mission is based on the premise that it is the first mini-RPV system to be funded in an overall plan encompassing mini-RPV systems for many other missions. As a result, the total DDT&E cost for any grouping of the missions studied is not the sum of the DDT&E costs of the individual missions. Further, the DDT&E cost for any particular mission would actually depend on the order in which the various systems are programmed in the overall marketing plan. For these reasons, DDT&E costs are not amortized in the following RPV system cost comparisons with alternative approaches, since the DDT&E costs cannot be prorated for each mission until an overall implementation plan for civil uses of RPVs is developed. In all cases, the rather modest DDT&E costs shown are based on an assumption that the basic RPV system development issues will be resolved by the various military programs and that the adaptations to civil uses are straightforward. Even if the DDT&E were substantially larger, little or no change would be noticeable in the cost comparisons. When prorated over a thousand or more systems and amortized over seven years, the DDT&E adds less than 1% to the annual cost of most RPV systems.

For annual fixed costs, the depreciation and insurance are based on actual or best estimates of procedures and requirements for fixed-wing aircraft and helicopters used by commercial fixed base operators. Crew costs for RPV operators are consistent with reported salaries for private licensed pilots with IFR training working in the civil aviation sector.

An operator and maintenance training program for RPV operators was especially laid out. It includes estimates of class size, instructor-to-student ratio, training equipment and manuals, training duration, and training sequence, drawing on LMSC's experience in training Army personnel on the AQUILA program. The training program is sufficiently flexible to reflect differences due to complexity of the RPV system hardware and operation.

For direct operating costs, the fuel and oil consumption rates are estimated directly from RPV-size-engine specific fuel consumption, RPV concept fuel tank capacity, and typical small-engine fuel/oil ratio. Fuel cost per gallon and oil cost per quart are actuals.

Periodic inspection and maintenance costs again drew on the AQUILA program for estimates of major RPV subsystem maintenance manhours per flight hour. A program was laid out for periodic inspection, airframe and controls maintenance and parts, engine maintenance and parts, and avionics and ground control station maintenance and parts. This program reflects civil aircraft operator requirements, procedures and labor rates for conducting scheduled and unscheduled maintenance, overhauls, and replacement of spare parts.

The cost-analysis approach for alternative fixed-wing aircraft and helicopters was to use actual general aviation aircraft investment and operating costs supplied by fixed base operators, owners, and potential users of RPV systems. The specific alternatives identified for each selected mission during the market survey and analysis are listed in Appendix E.

All development costs for general-aviation aircraft are assumed to be sunk costs. The manufacturer's prices, in 1976 dollars, for alternative aircraft are obtained from the "Aircraft Price Digest" and from discussions with operators and owners, and are adjusted for equipment and options pertinent to the specific missions.

For annual fixed costs, the depreciation varies with usage and type of aircraft. An analysis of the data acquired for forty fixed-wing aircraft and thirteen helicopters shows that the average annual depreciation for fixed-wing aircraft is 5.62%, using a seven-year straight-line depreciation; i.e., they depreciate 40% in seven years. For rotary-wing vehicles, depreciation is 50% of the initial cost over seven years with 50% residual, i.e., 7.14% per year.

There are three types of insurance that must be considered: hull insurance, liability and property damage, and medical insurance. Discussions with operators and owners of general-aviation aircraft suggested the following hull insurance rates:

- Single-engine fixed-wing - cost less than \$40,000: 4% of manufacturer's price (5.6% for agricultural aircraft)
- Single-engine fixed-wing - cost more than \$40,000: 3% of manufacturer's price (5.6% for agricultural aircraft)
- Rotary-wing aircraft: 10% of manufacturer's price (14% for agricultural helicopters)

For liability and property damage, \$1,000,000 combined single limit insurance are:

- One to three place single-engine aircraft: \$300/aircraft/year
- Four place, and over, single-engine aircraft: \$450/aircraft/year
- Twin-engine aircraft: \$4000/aircraft/year
- Agricultural fixed-wing aircraft: \$1730/aircraft/year
- Agricultural rotary-wing aircraft: \$2600/aircraft/year.

Current general-aviation practice is to carry \$5,000 medical insurance for each crew member at the rate of about \$15/person/year. The medical insurance cost for agricultural aircraft pilots is about \$60/person/year.

Aircraft storage costs depend on aircraft physical characteristics and a typical cost of \$0.15 per square foot per month, such as currently charged by fixed-base operators at the San Jose Airport, San Jose, California.

No training costs are included for pilots and observers that operate fixed-wing and rotary-wing aircraft.

Crew costs are a consensus of salary and benefit data acquired for working pilots and observers in the civil aviation sector. Pilots and pilot-observers are assumed to hold valid private pilot's licenses. Fixed wing pilots are assumed to have, at least, some additional instrument training. These costs are discussed in Appendix E.

For direct operating costs, the fuel and oil consumption costs are based on specific fuel consumption rate data from the "Aircraft Price Digest", oil change rates, oil consumption rates, and actual fuel cost per gallon and oil cost per quart.

Periodic inspection and maintenance costs were developed from data offered by San Jose, California, fixed-base operators and information acquired from the market survey. The inspection and maintenance cost analysis included single-engine and twin-engine fixed-wing aircraft, and small, three-to-five seat helicopters. The scheduled and unscheduled maintenance, overhauls, and replacement of spare parts for civil aircraft are discussed further in Appendix E.

Cost Comparisons. - A complete cost comparison is made for RPV system concepts and representative non-RPV systems identified from the market survey for eight of the nine selected uses. (No suitable RPV candidate was found to compete with weather balloons in the nine use, Meteorology.) Appendix E describes the costing assumptions that are used.

Three comparisons are made for each mission in the following discussion:

- o System Comparison
- o Development and Purchase Costs Comparison
- o Total Annual Operating Cost Comparison

Mission 1 - Security of High-Value Property: This mission requires a dedicated aerial surveillance system operating from 6:00 p.m. to 6:00 a.m.

every day. Actual flight time is expected to be about eight hours per day with the aerial systems on standby alert when not airborne.

Two manned-aircraft alternatives are compared against the RPV system. One is a fixed-wing aircraft with a pilot and an observer. The other is a helicopter with a pilot and a pilot-observer. The two-man crew is necessary for this night operation so that one can fly the aircraft while the other monitors the viewing screen from the low-light-level TV. A single operator monitors the viewing screen for that system, since the RPV is flown by the autopilot. Whether RPV or manned-aircraft, the 12-hour period is covered in two shifts by two crews, and the total of eight flight hours per night are flown in several flights, with landings and crew breaks between flights.

In order to get eight hours of flying per day, 365 days a year, and still allow time for maintenance, the helicopter RPV system and the manned helicopter system require two air vehicles.

A system comparison is shown in Table 6. A comparison of development and purchase costs for each system is shown in Table 7. Total annual operating costs of mission candidates are shown in Table 8. The pairs of cost values given in Table 8 for the manned alternatives correspond to the two specific fixed-wing aircraft and the two specific helicopters shown in Table 7.

Table 8 shows that the RPV system can perform the mission at a cost saving of about 27% compared to the fixed-wing aircraft and 45%-65% compared to the helicopter system. It should be noted that no costs or performance penalties have been included for quieting the manned systems, whereas the RPV has been designed for quiet operation. This is a qualitative advantage for the RPV that is not accounted for, but which was rated as very important by some potential users.

As an aside: A third alternative was examined, i.e., fixed LLLTV cameras on poles or towers. The comparison showed that the fixed-camera system is competitive or preferable for very small and compact facilities. However, for larger areas or for facilities that are spread out, the cost of coaxial cables to bring the TV pictures to a central guard facility drives the cost to unacceptable levels.

TABLE 6 SYSTEM COMPARISON

SECURITY OF HIGH VALUE PROPERTY

	FIXED WING	HELICOPTER	RPV SYSTEM
AIRCRAFT PER SYSTEM	1	2	2
GROUND CONTROL	VHF - VOICE	VHF - VOICE	GCS IN GUARDHOUSE
PERSONNEL *			
FLIGHT	PILOT AND OBSERVER	PILOT AND PILOT-OBSERVER	NONE
GROUND	NONE	NONE	OPERATOR
ALERT LOCATION	LOCAL AIRPORT	LOCAL AIRPORT	PAD NEAR GUARDHOUSE
ENDURANCE (20-MIN RESERVE)	9.7 HR.	3.3 Hr.	1.0 HR.
MAINTENANCE	CONTRACTED	CONTRACTED	CONTRACTED

* two crew(s) per day for all candiate systems

TABLE 7 DEVELOPMENT AND PURCHASE COSTS COMPARISON,

SECURITY OF HIGH VALUE PROPERTY

	DEVELOPMENT COSTS	PURCHASE COSTS
<u>FIXED WING</u>		
ONE CESSNA 180J, OR	0	$45,100
ONE CESSNA 182P	0	$43,200
<u>HELICOPTER</u>		
TWO HUGHES 300C, OR	0	$139,600
TWO BELL 206A	0	$320,200
<u>RPV SYSTEM</u>		
TWO RPVs		$42,000
ONE GROUND CONTROL STATION		13,500
ONE SET GROUND SUPPORT EQUIPMENT		2,800
	$5,975,000	$58,300

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TABLE 8 TOTAL ANNUAL OPERATING COST COMPARISON, SECURITY OF HIGH VALUE PROPERTY

	FIXED WING	HELICOPTER	RPV SYSTEM
ANNUAL FIXED COSTS			
DEPRECIATION			
INSURANCE			
HANGAR			
PERSONNEL			
TRAINING			
SUBTOTAL	$118,400-118,700	$154,900-184,500	$74,400
ANNUAL DIRECT OPERATING COSTS			
FUEL AND OIL			
PERIODIC INSPECTION			
MAINTENANCE			
SUBTOTAL	$53,900-55,200	$80,800-171,600	$51,400
TOTAL ANNUAL OPERATING COST	$172,400-173,800	$235,600-356,100	$125,800

Mission 2 - Wildfire Mapping: Mission 2 uses contracted aircraft to conduct wildfire mapping on an as-needed basis. Information from the California Division of Forestry suggests an average fire requires mapping for five days, which includes two peak days of activity. During peak days, airborne systems will operate eight hours per day. The remaining wildfire mapping days require two hours per day of flight time. Two hours per flight is indicated as meeting user needs.

An estimate of about 200 large fires per year (1000 large-fire days per year) suggests a demand of 4400 hours per year. Geographical flexibility of operation requires the distribution of flight hours among aircraft at a number of separated locations, assumed here to be three. For purpose of cost comparisons, a wildfire mapping system is assumed to require 1467 flight hours per year.

The system against which the RPV system is compared is a manned-aircraft which carries the same infrared (IR) mapping equipment as the RPV. Either system is assumed to provide only for carrying the sensor over the fire and transmitting the sensor data to a ground station by a data link. The conversion of the data to hard-copy imagery and the photointerpretation of the result is assumed to be the same for either system, and the costs for personnel and equipment to do those things are excluded from the comparison.

A system comparison is shown in Table 9. A comparison of development and purchase costs for each system is shown in Table 10. Total annual operating costs of mission candidates are shown in Table 11.

One can see from Table 11 that the cost of wildfire mapping with RPVs is approximately the same as with a manned aircraft.

Mission 3 - Wildfire Detection: This mission uses contracted aircraft on an as-needed basis. When required, the aerial detection system operates up to eight hours per day in a single flight. Information from the U.S. Forest Service suggests a service need of 75 days per year per location or 600 annual flight hours for one system.

The system against which the RPV system is compared is a twin-engined manned aircraft which carries the same IR sensor as the RPV, but instead of sending the data to the ground station via a data link as the RPV would, it

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TABLE 9 SYSTEM COMPARISON

WILDFIRE MAPPING

		FIXED WING	RPV SYSTEM
AIRCRAFT PER SYSTEM		1	1
GROUND CONTROL		VHF - VOICE	MOBILE GCS
PERSONNEL *			
FLIGHT		PILOT	NONE
GROUND		NONE	OPERATOR
BASE OF OPERATIONS		LOCAL AIRPORT	FIRE CAMP
ENDURANCE (20-MIN RESERVE)		9.7 HR	1.7 HR
MAINTENANCE		CONTRACTED	CONTRACTED

TABLE 10 DEVELOPMENT AND PURCHASE COSTS COMPARISON

WILDFIRE MAPPING

	DEVELOPMENT COSTS	PURCHASE COSTS
FIXED WING		
ONE CESSNA 180J, OR	0	$53,600
ONE CESSNA 182P	0	$51,800
RPV SYSTEM		
ONE RPV		$31,000
ONE GROUND CONTROL STATION		16,900
ONE SET GROUND SUPPORT EQUIPMENT		2,400
	$6,312,000	$50,300

TABLE 11 TOTAL ANNUAL OPERATING COST COMPARISON

WILDFIRE MAPPING

		FIXED WING	RPV SYSTEM
ANNUAL FIXED COSTS			
DEPRECIATION			
INSURANCE			
HANGAR			
PERSONNEL			
TRAINING			
SUBTOTAL		$39,500	$40,700
ANNUAL DIRECT OPERATING COSTS			
FUEL AND OIL			
PERIODIC INSPECTION			
MAINTENANCE			
SUBTOTAL		$28,400-29,100	$28,400
TOTAL ANNUAL OPERATING COST		$68,000-68,700	$69,100

carries the IR processing equipment aboard and produces hard-copy imagery which is delivered to the photointerpreter when the aircraft lands. In either case, as with Mission 2, the personnel and equipment for producing hard copy and for photointerpretation are excluded from the comparison, on the assumption that they are the same for either system.

A system comparison is shown in Table 12. A comparison of development and purchase costs for each system is shown in Table 13. Total annual operating costs of mission candidates are shown in Table 14.

Table 14 shows that the cost of wildfire detection by RPV is about 32% less than with the manned-aircraft alternative. One qualitative feature of the comparison is that the RPV system provides the hard-copy imagery to the photointerpreter about two hours earlier, since it is transmitted in real time and need not wait for the aircraft to return.

The manned-aircraft system could be competitive if a smaller aircraft such as the Cessna 310 could be used, but the extra fuel required to provide the Cessna 310 an eight-hour endurance makes its payload capacity marginal for the mission. However, if an aircraft with the purchase and operating costs of the 310 could be used, the annual cost would be equal to that of the RPV system.

Mission 4 - Fishing-Law Enforcement: This mission requires a dedicated aerial surveillance system operating every day, on a steady-state basis, the year around. The RPV system operates from U.S. Coast Guard air bases approximately 200 miles (320 km) apart along the coast, and each RPV system covers a 200 mi x 200 mi ocean area each day, with about four hours of flight time. The RPV carries a synthetic aperture radar (SAR) and transmits the radar return signals to the ground station for processing to detect and locate ships. The manned aircraft system against which the RPV system is compared carries both the SAR and the data processor aboard. In a six-hour flight each day at about 200 mi/hr (320 km/hr), the manned aircraft can cover as much ocean area as six RPV systems, delivering the ship locations to the ground at the end of the flight.

A system comparison is shown in Table 15. A comparison of development and purchase costs for each system is shown in Table 16. Total annual operating costs of mission candidates are shown in Table 17.

TABLE 12 SYSTEM COMPARISON

WILDFIRE DETECTION

		FIXED WING	RPV SYSTEM
AIRCRAFT PER SYSTEM		1	1 MISSION RPV 1 RELAY RPV
GROUND CONTROL		VHF - VOICE	GCS IN EXISTING BUILDING
PERSONNEL *			
FLIGHT		TWO PILOTS	NONE
GROUND		NONE	OPERATOR
BASE OF OPERATIONS		LOCAL AIRPORT	LOCAL AIRPORT
ENDURANCE (20-MIN RESERVE)		9.4-10.4 HR	8.7 HR
MAINTENANCE		CONTRACTED	CONTRACTED

* 2 crew(s) per day

TABLE 13 DEVELOPMENT AND PURCHASE COSTS COMPARISON, WILDFIRE DETECTION

	DEVELOPMENT COSTS	PURCHASE COSTS
FIXED WING		
ONE BEECH B80 QUEEN AIR	0	$335,900
RPV SYSTEM		
ONE MISSION RPV AND ONE RELAY RPV		$164,200
ONE GROUND CONTROL STATION		28,300
ONE SET GROUND SUPPORT EQUIPMENT		9,700
	$21,024,000	$202,200

TABLE 14 TOTAL ANNUAL OPERATING COST COMPARISON,

WILDFIRE DETECTION

		FIXED WING	RPV SYSTEM
ANNUAL FIXED COSTS			
DEPRECIATION			
INSURANCE			
HANGAR			
PERSONNEL			
TRAINING			
SUBTOTAL		$52,500	$32,600
ANNUAL DIRECT OPERATING COSTS			
FUEL AND OIL			
PERIODIC INSPECTION			
MAINTENANCE			
SUBTOTAL		$45,700	$32,600
TOTAL ANNUAL OPERATING COST		$98,200	$66,900

TABLE 15 SYSTEM COMPARISON

FISHING LAW-ENFORCEMENT

		FIXED WING	RPV SYSTEM
AIRCRAFT PER SYSTEM		1	1
GROUND CONTROL		VHF - VOICE	GCS IN PREFAB. BUILDING
PERSONNEL *			
FLIGHT		TWO PILOTS AND OBSERVER.	NONE
GROUND		NONE	OPERATOR
BASE OF OPERATIONS		NEAREST COAST GUARD AIR BASE	NEAREST COAST GUARD AIR BASE
ENDURANCE (20-MIN RESERVE)		9.4-10.4 HR	5.2 HR
MAINTENANCE		ORGANIZATIONAL	CONTRACTED

* one crew(s) per day for fixed wing aircraft.
two crew(s) per day for RPV system.

TABLE 16 DEVELOPMENT AND PURCHASE COSTS COMPARISON,

FISHING LAW-ENFORCEMENT

	DEVELOPMENT COSTS	PURCHASE COSTS
<u>FIXED WING</u>		
ONE BEECH B80 QUEEN AIR, OR	0	$421,900
ONE CESSNA 310Q	0	$241,700
<u>RPV SYSTEM</u>		
ONE RPV		$17,200
ONE GROUND CONTORL STATION		132,100
ONE SET GROUND SUPPORT EQUIPMENT		7,500
	$6,570,000	$156,800
		X6
		= $940,800

TABLE 17 TOTAL ANNUAL OPERATING COST COMPARISON, FISHING LAW-ENFORCEMENT

		FIXED WING	RPV SYSTEM
ANNUAL FIXED COSTS			
DEPRECIATION			
INSURANCE			
HANGAR			
PERSONNEL			
TRAINING			
SUBTOTAL		$96,300-113,600	$46,500
ANNUAL DIRECT OPERATING COSTS			
FUEL AND OIL			
PERIODIC INSPECTION			
MAINTENANCE			
SUBTOTAL		$106,000-169,200	$23,400
TOTAL ANNUAL OPERATING COST		$194,700-270,900	$69,900 X6 = $419,700

Table 17 shows that the RPV system, as configured, is not competitive with the manned aircraft, even if the more expensive aircraft (the Beech B80) must be used.

Mission 5 - Highway Patrol: This mission requires a dedicated aerial system operating during daylight hours. Actual flight time totals about eight hours per day, 365 days per year, using two shifts. The aerial systems are on standby alert when not airborne.

The system against which the RPV system is compared is a fixed-wing manned aircraft. No special sensors are carried, since daylight operation is assumed, but a loudspeaker is carried.

The aircraft has a two-man crew, which is common practice for aerial highway patrol, although some departments do fly with only one person.

A system comparison is shown in Table 18. A comparison of development and purchase costs for each system is shown in Table 19. Total annual operating costs of mission candidates are shown in Table 20.

Table 20 indicates that the cost of highway patrol with the RPV system is about 35% less than with the manned system.

Mission 6 - Pipeline Patrol: This mission uses contracted aircraft to patrol oil and gas pipelines. Pipelines are patroled from the air once a week, on the average, according to user information. An average flight time of 25 hours per week, or 1300 hours per year, is estimated for comparison purposes. The system against which the RPV system is compared is a manned aircraft with a single pilot. At 25 hours per week, either system can patrol about 2000 mi (3200 km) of pipeline per week. Thus, an RPV system comparable to the manned aircraft in mission capability would patrol 2000 mi (3200 km) of pipeline with one pair of RPVs and 11 ground stations located 200 mi (320 km) apart.

A system comparison is shown in Table 21. A comparison of development and purchase costs for each system is shown in Table 22. Total annual operating costs of mission candidates are shown in Table 23.

Table 23 shows that the RPV system is not competitive with the manned-aircraft system, despite the optimistic assumptions that existing manned facilities can be found at convenient 200-mile intervals along the pipeline

TABLE 18 SYSTEM COMPARISON

HIGHWAY PATROL

		FIXED WING	RPV SYSTEM
AIRCRAFT PER SYSTEM		1	1 MISSION RPV 1 RELAY RPV
GROUND CONTROL		VHF - VOICE	GCS IN EXISTING BLDG.
PERSONNEL *			
FLIGHT		TWO PILOTS	NONE
GROUND		NONE	OPERATOR
ALERT LOCATION		LOCAL AIRPORT	NEAREST PREPARED RUNWAY
ENDURANCE (20-MIN RESERVE)		9.7 HR	8.2 HR
MAINTENANCE		CONTRACTED	CONTRACTED

* two crew(s) per day for fixed wing aircraft and RPV system

TABLE 19 DEVELOPMENT AND PURCHASE COSTS COMPARISON,

HIGHWAY PATROL

	DEVELOPMENT COSTS	PURCHASE COSTS
<u>FIXED WING</u>		
ONE CESSNA 180J, OR	0	$38,700
ONE CESSNA 182P	0	$36,900
<u>RPV SYSTEM</u>		
ONE MISSION RPV AND ONE RELAY RPV		$42,700
ONE GROUND CONTROL STATION		21,900
ONE SET GROUND SUPPORT EQUIPMENT		3,200
	$10,741,000	$66,800

TABLE 20 TOTAL ANNUAL OPERATING COST COMPARISON,

HIGHWAY PATROL

		FIXED WING	RPV SYSTEM
ANNUAL FIXED COSTS			
DEPRECIATION			
INSURANCE			
HANGAR			
PERSONNEL			
TRAINING			
SUBTOTAL		$133,900	$72,300
ANNUAL DIRECT OPERATING COSTS			
FUEL AND OIL			
PERIODIC INSPECTION			
MAINTENANCE			
SUBTOTAL		$52,500-53,800	$47,600
TOTAL ANNUAL OPERATING COST		$186,400-187,800	$119,900

TABLE 21 SYSTEM COMPARISON

PIPELINE PATROL

		FIXED WING	RPV SYSTEM
AIRCRAFT PER SYSTEM		1	1 MISSION RPV 1 RELAY RPV
GROUND CONTROL		VHF - VOICE	11 GCS IN EXISTING BLDG'S
PERSONNEL *			
FLIGHT		PILOT	NONE
GROUND		NONE	11 OPERATORS (RPV HANDOFF)
BASE OF OPERATION		LOCAL AIRPORTS	NEAREST PREPARED RUNWAYS
ENDURANCE (20-MIN RESERVE)		4.1-9.2 HR	6.2 HR
MAINTENANCE		CONTRACTED	CONTRACTED

* one crew(s) per day for fixed wing aircraft and RPV system

TABLE 22 DEVELOPMENT AND PURCHASE COSTS COMPARISON,

PIPELINE PATROL

	DEVELOPMENT COSTS	PURCHASE COSTS
<u>FIXED WING</u>		
ONE CESSNA 150L, OR	0	$16,200
ONE CESSNA 172M, OR	0	$23,100
ONE PIPER 140 SUPERCUB	0	$20,000
<u>RPV SYSTEM</u>		
ONE MISSION RPV AND ONE RELAY RPV		$43,100
ELEVEN GROUND CONTROL STATIONS		$246,950
GROUND SUPPORT EQUIPMENT		6,700
	$10,805,000	$296,750

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TABLE 23 TOTAL ANNUAL OPERATING COST COMPARISON, PIPELINE PATROL

	FIXED WING	RPV SYSTEM	
ANNUAL FIXED COSTS			
DEPRECIATION			
INSURANCE			
HANGAR			
PERSONNEL			
TRAINING			
SUBTOTAL	$17,500-18,500	$42,700	
ANNUAL DIRECT OPERATING COSTS			
FUEL AND OIL			
PERIODIC INSPECTION			
MAINTENANCE			
SUBTOTAL	$10,800-14,700	$21,400	
TOTAL ANNUAL OPERATING COST	$28,300-33,200	$64,100	

and that the personnel there can be trained to operate the RPV satisfactorily two to three hours per week and perform other duties the rest of the time.

Mission 7 - Agricultural Crop Dusting: This mission uses contracted aircraft on an as-needed (seasonal) basis. Aerial crop dusters perform several short sorties per day, for a total of about four hours flight time per day. User information suggests each system is required to perform approximately 1000 flight hours per year.

The RPV system is compared against both fixed-wing and helicopter agricultural aircraft. A system comparison is shown in Table 24. A comparison of development and purchase costs for each system is shown in Table 25. Total annual operating costs of mission candidates are shown in Table 26. In this mission, annual operating cost is not an appropriate measure of preference. The proper comparison is on the basis of cost per acre sprayed.

To analyze the cost per acre, the main performance variables are aircraft speed and spray-swath width. For the purpose of comparing the cost per acre (hectare) sprayed by candidate aircraft, the following performance and costs are used:

	Fixed Wing	Helicopter	RPV System
Speed, m.p.h. (m/s)	80 (35.8)	65 (29.1)	80 (35.8)
Swath width, ft. (m)	40 (12.2)	40 (12.2)	20 (6.1)
Cost/flight-hour	\$76-\$90	\$108	\$29

The calculations of area sprayed per flight hour assume a square field. At the end of a swath, the aircraft shuts off the spray, turns 180°, and starts another swath in the other direction. Time lost in the turns is accounted for in the calculations. The results of the cost-per-acre (hectare) calculations are displayed for each of the candidate systems in Figure 17 as a function of total area sprayed.

One can see from Figure 13 that the RPV system is preferred over both the helicopter and the fixed-wing manned aircraft for all field sizes analyzed. It should be remembered that this comparison applies only to the application of ultra-low volume (ULV) pesticides for which the greater payload (about seven times greater) of the manned aircraft does not give an advantage. ULV

TABLE 24 SYSTEM COMPARISON

AGRICULTURAL CROP DUSTING

	FIXED WING	HELICOPTER	RPV SYSTEM
AIRCRAFT PER SYSTEM	1	1	1
GROUND CONTROL	VHF - VOICE	VHF - VOICE	MOBILE GCS
PERSONNEL, *			
FLIGHT	PILOT	PILOT	NONE
GROUND	NONE	NONE	**OPERATOR**
BASE OF OPERATIONS	PREPARED/ SEMI-PREPARED "RUNWAYS"	PREPARED/ SEMI-PREPARED "PADS"	**SEMI-PREPARED RUNWAY**
ENDURANCE (20-MIN RESERVE)	1.8-3.1 HR	2.7 HR	1.9 HR
MAINTENANCE	CONTRACTED	CONTRACTED	CONTRACTED

* one crew(s) per day for all candidate systems

TABLE 25 DEVELOPMENT AND PURCHASE COSTS COMPARISON,

AGRICULTURAL CROP DUSTING

	DEVELOPMENT COSTS	PURCHASE COSTS
<u>FIXED WING</u>		
ONE GRUMMAN G164A AGCAT, OR	0	$49,400
ONE PIPER PA-25 PAWNEE, OR	0	$32,200
ONE CESSNA 188 AG WAGON	0	$40,300
<u>HELICOPTER</u>		
ONE BELL 47G4A	0	$78,800
<u>RPV SYSTEM</u>		
ONE RPV		$20,700
ONE GROUND CONTROL STATION		20,200
ONE SET GROUND SUPPORT EQUIPMENT		8,500
	$7,507,000	$49,400

TABLE 26 TOTAL ANNUAL OPERATING COST COMPARISON, AGRICULTURAL CROP DUSTING

	FIXED WING	HELICOPTER	RPV SYSTEM
ANNUAL FIXED COSTS			
DEPRECIATION			
INSURANCE			
HANGAR			
PERSONNEL			
TRAINING			
SUBTOTAL	$57,000-58,900	$69,900	$19,300
ANNUAL DIRECT OPERATING COSTS			
FUEL AND OIL			
PERIODIC INSPECTION			
MAINTENANCE			
SUBTOTAL	$19,300-31,800	$38,500	$10,200
TOTAL ANNUAL OPERATING COST *	$76,300-90,600	$108,500	$29,500

* The proper measure of preference is cost per acre sprayed, as shown in Figure 17.

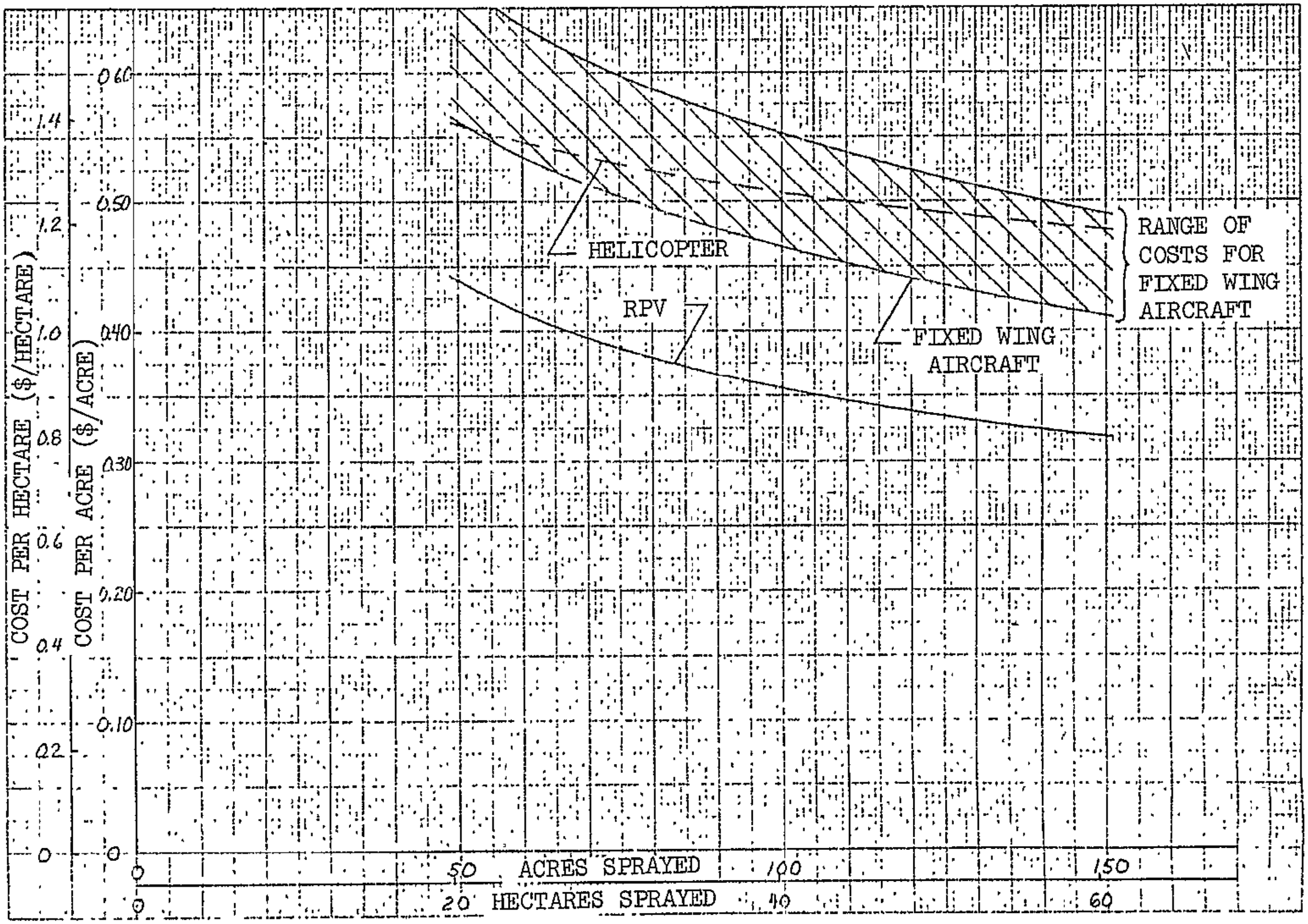


FIGURE 13 Cost Per Acre and Cost Per Hectare Sprayed

pesticides comprise about ten percent of the agricultural spraying. For the other ninety percent, the more frequent landing and reloading of the RPV would raise the per-acre cost by an amount that has not been analyzed in this study.

Mission 8a - Severe Storm Research - Low Altitude: Mission 8a uses both "surplus" military aircraft and contracted aircraft on an as-needed basis. The availability and age of military aircraft and the use of crews for other missions when not on this one preclude the assignment of annual fixed costs to these alternative aircraft. Direct operating costs, only, are charged against the military systems. Civil aircraft and RPV systems costs include all the conventional fixed and operating costs.

The low-altitude severe-storm-research mission analysis suggests that for each storm there should be three hours of flight time or three sorties of one hour flight time each. An average of about 70 storm days per year is estimated for each aerial system, resulting in a need for 200 flight hours per year.

A system comparison is shown in Table 27. A comparison of development and purchase costs for each system is shown in Table 28. Total annual operating costs of mission candidates are shown in Table 28. In looking at these comparisons, it should be evident that an RPV with a 25-lb (11.4 kg) payload cannot really be compared on an equivalent basis with the large aircraft that are presently used. Although instruments to make the measurements specified in Appendix C can probably be made within the payload weight, common sense insists that the vastly greater payload of the aircraft gives them better utility. Without a more thorough analysis of the mission, the worth of that payload is hard to estimate. However, it is worth noting that even if all the RPV costs in Table 29 except personnel were increased by a factor of five, corresponding to an RPV system of substantially greater capability, the RPV would still be 40 percent cheaper than the fixed-wing civil aircraft.

Common Airframe Development Tradeoff. - Missions 3, 5, and 6 require both a mission vehicle and a relay vehicle to comprise a complete aerial system. For missions 5 and 6, the relay vehicle airframe is larger and heavier than the aircraft of the mission vehicle. These missions pose the

TABLE 27 SYSTEM COMPARISON

SEVERE STORM RESEARCH-LOW ALTITUDE

	MILITARY F.W. AIRCRAFT	CIVIL F.W. AIRCRAFT	RPV SYSTEM
AIRCRAFT PER SYSTEM	1	1	1
GROUND CONTROL	VHF - VOICE	VHF - VOICE	MOBILE GCS
PERSONNEL *			
FLIGHT	TWO PILOTS	TWO PILOTS	NONE
GROUND	NONE	NONE	TWO OPERATORS (RPV + TELEMETRY)
BASE OF OPERATIONS	STORM RESEARCH CENTER/AIR BASE	STORM RESEARCH CENTER/AIR BASE	VAN
ENDURANCE (20-MIN RESERVE)	5.4-16.5 HR	9.4 HR	1.7 HR
MAINTENANCE	ORGANIZATIONAL	ORGANIZATIONAL	CONTRACTED

* one crew(s) per day for all candidate systems

TABLE 28 DEVELOPMENT AND PURCHASE COSTS COMPARISON,

SEVERE STORM RESEARCH-LOW ALTITUDE

	DEVELOPMENT COSTS	PURCHASE COSTS
MILITARY FIXED WING		
ONE LOCKHEED 749 CONSTELLATION, OR	0	AVAILABLE AT NO COST
ONE McD-DOUGLAS F-4C, OR	0	AVAILABLE AT NO COST
ONE NORTH AMERICAN (RI) F-100F	0	AVAILABLE AT NO COST
CIVIL FIXED WING		
ONE BEECH B80 QUEEN AIR	0	$318,400
RPV SYSTEM		
ONE RPV		$14,200
ONE GROUND CONTROL STATION		17,700
ONE SET GROUND SUPPORT EQUIPMENT		8,000
	$5,710,000	$39,900

TABLE 29 TOTAL ANNUAL OPERATING COST COMPARISON,

SEVERE STORM RESEARCH-LOW ALTITUDE

	MILITARY F.W. AIRCRAFT	CIVIL F.W. AIRCRAFT	RPV SYSTEM
ANNUAL FIXED COSTS			
DEPRECIATION			
INSURANCE			
HANGAR			
PERSONNEL			
TRAINING			
SUBTOTAL	-0-	$42,000	$7,900
ANNUAL DIRECT OPERATING COSTS			
FUEL AND OIL			
PERIODIC INSPECTION			
MAINTENANCE			
SUBTOTAL	$105,900-200,000	$14,400	$2,000
TOTAL ANNUAL OPERATING COST	$105,900-200,000	$56,500	$9,900

question: is it more economical in terms of life cycle cost to develop two separate airframes or one common airframe? That is, do the cost savings from a common development program and the learning effects from the larger production run of a common airframe offset the cost of making 1000 of the airframes larger than necessary for the mission? A preliminary cost tradeoff analysis was performed for mission 5 to assess the effects of both approaches in meeting the requirements for a quantity buy of 1000 systems (with two RPVs per system). As the next two paragraphs indicate, no clear cost preference can be determined between the two approaches at the present state of design definition.

The first approach assumes a dual development program, i.e., the mission and relay vehicle airframes are developed individually. Investment costs are based on producing 1000 of the relatively smaller mission vehicle airframes and 1000 of the larger relay vehicle airframes. The second approach assumes a common airframe development program for development of the larger airframe only. Investment costs for this approach are based on producing 2000 of the larger airframes to satisfy the quantity requirements for both mission and relay vehicles.

The results of the common airframe development tradeoff showed that differences between the dual and common programs in terms of investment costs and operating costs are insignificant. The cost penalty for producing more of the larger vehicles (common program) instead of one mission vehicle and one relay vehicle (dual program) is practically cancelled out by the effects of learning that accrue by producing a greater quantity of a single airframe. The cost difference in the DDT&E program came out to be about 10 percent, which is overshadowed by the uncertainties in the cost estimates.

Environmental and Safety Studies

Environmental requirements and criteria. - For all practical purposes, there are only two areas of environmental concern that apply to RPVs in civil uses. Those are engine emissions that pollute the air and aircraft noise. Although there are no known environmental regulations that refer to RPVs specifically, it seems likely that RPVs will have to meet the same environmental criteria that other aircraft do. An argument could be made that some special remote-area uses never bring RPVs into proximity with the public, and therefore the criteria could be relaxed if an overriding public interest demanded it. However, control of emissions and noise present no special problems peculiar to RPV design, and there appears to be no compelling reason to seek exemption.

With this in mind, the paragraphs that follow describe the requirements and criteria that apply to all aircraft in general, with comments on how they pertain to RPVs.

Engine emmissions: Reference 2 gives a good overview of the U.S. Environmental Protection Agency's (EPA) program for regulating emissions from aircraft. The abstract of Reference 2 summarizes it very well:

> "In 1970, the United States law relating to air pollution control, The Clean Air Act, was amended to require the Environmental Protection Agency to analyze the role of aircraft operations in determining community air pollution levels and to develop emission standards applicable to aircraft, if necessary to achieve and maintain the national goals for ambient air quality. The analysis was made, and it was concluded that aircraft operations do have a significant influence on air quality levels in and around major U.S. air terminals and that these contributions are likely to increase throughout the next two decades unless control is undertaken. The report presenting these findings was followed by promulgation by the Environmental Protection Agency of emission standards which apply to commercial and private aircraft on

July 17, 1973. The first of these standards went into effect in January 1974, while additional requirements become effective in 1975, 76, 78, 79, and 81. The Federal Aviation Administration was directed by Congress to enforce the standards promulgated by the EPA and they are issuing enforcement regulations periodically as the time of implementation for each of the EPA emission standards draws near."

Much of this discussion is taken from Reference 2 .

The discussion is made easier by first looking at the five elements of aircraft emission standards.

- The engine classification system
- The landing—takeoff (LTO) cycle that defines the engine operating conditions to be used for measurements
- The units for expressing emissions
- The exhaust sampling system
- The pollutant-analysis instrumentation.

The last two are not discussed here, but the first three need to be understood.

Table 30 shows the complete engine classification system developed for the EPA standards. One thing that immediately comes to mind is that most of the classes are of little interest for RPVs in civil uses. Only Class P1 applies to the conceptual designs in this report, although designs using engines of class T1 or P2 could fit into some of the uses.

Table 30 . Engine Classification System for EPA Standards

Symbol	
T1	Turbojet/Turbofan less than 8 000 lbs thrust
T2	Turbojet-Turbofan greater than 8 000 lbs thrust (except JT8D and JT3D)
T3	P&W JT3D
T4	P&W JT8D
T5	Turbojet/Turofan engines for supersonic aircraft
P1	Opposed piston engines
P2	Turboprop engines

The distinction between Class T1 (small engines) and Class T2 (large engines) is necessary because of differences in the surface-to-volume ratios of the combustors and other engine design considerations as well as the markets for these engines. The standards take into consideration the lesser impact of the smaller engines on community air pollution problems, since, in the United States, these are used mostly for irregular business and corporate travel as opposed to scheduled airline service. Their use in RPVs would be consistent with this lesser impact.

A special class (T3) was set aside for the Pratt and Whitney JT3D engine, basic powerplant for the B 707/DC 8 class aircraft, so as to facilities establishing a special smoke standard and retrofit schedule. The same statement applies to Class T4, the Pratt and Whitney JT8D engine, basic powerplant for the B 727/737 and DC 9 aircraft.

Class T5, applicable only to engines designed for supersonic commercial aircraft, was found to be necessary because the engine thermodynamic cycles which are practicable for this service are not as low in fuel consumption over the LTO cycle as other large engines (T2), which means that for the same combustor design technology they cannot be expected to achieve as low emissions over the LTO cycle.

Class P1, consisting of opposed piston engines only, is necessary because of the distinctly different types of emission problems and technology problems applicable to these types of engines and the smaller impact which they have on community air pollution.

Class P2, consisting of turboprop engines only, was found to be necessary because of different problems with the technology, the age of some of these engines, and the service in which they are used. It is recognized that, in many cases, the basic engine and combustor may find itself in both classes T1 and P2 applications. Ultimately, it is hoped by the EPA that future regulations can draw these requirements somewhat more closely together.

The engine operating conditions used in measuring pollutant emissions are chosen to represent a landing-takeoff cycle including all operations below 3000 feet altitude, representing the times in modes typical of high activity periods at major United States metropolitan airports. With this approach, the time and basic engine operating modes came out as listed in Table 31.

Table 31 LTO Cycles for Emission Measurements

Power Mode	Engine Class			
	T1, P2	T2, 3, 4	T5	P1
Taxi out	19 min.	19 min.	19 min.	12 min.
Takeoff	0.5	0.7	1.2	0.3
Climbout	2.5	2.2	2.0	5.0
Approach	4.5	4.0	1.2	6.0
Taxi in	7.0	7.0	7.0	4.0

With the goal of producing numbers as meaningful as possible for relating to the emission burden at airports, along with minimizing the number of engine classes, "mass pollutant per thrust-hour over the LTO cycle" was adopted as the unit for expression of emission data in the EPA standards. As the note on Table 32 indicates, this unit is interpreted to fit the mode of power extraction for turbojet, turboprop, and piston engines.

Gaseous emission standards are scheduled to become effective for 1979 on all newly produced engines, and more stringent 1981 standars will apply to advanced-design, newly certified engines after that date. However, only the large turbine engines will be affected by the 1981 change. Table 32 lists the specific requirements applicable to all engine classes for engines newly manufactured after January 1, 1979. The standars, as applied, refer both to the newly produced engines and to these same engines during their service life. It is expected that testing will be carried out at normal overhaul periods to demonstrate compliance. In Table 32, HC is "hydrocarbons", CO is "carbon monoxide", and NO_x is "oxides of nitrogen".

As mentioned earlier, the requirements applicable to small turbojet engines are more lenient than those applicable to larger engines, because of less available technology, small markets and lesser pollutant impact. For Class T5, engines for supersonic propulsion application, the standards are presently in the proposed rather than fully promulgated stage. Consequently, a range of numbers is shown.

Table 32 Gaseous Emissions Standards

Engine Class		Allowable Upper Limit*		
		HC	CO	NOx
T1	Turbojet/Turbofan less than 8000 lbs thrust	1.6	9.4	3.7
T2	Turbojet/Turbofan greater than 8000 lbs thrust (except JT8D and JT3D)	0.8	4.3	3.0
T3	P&W JT3D	0.8	4.3	3.0
T4	P&W JT8D	0.8	4.3	3.0
T5	Turbojet/Turbofan Engines for supersonic aircraft (proposed)	3.0-4.7	20.0-24.7	6.9-9.0
P1	Opposed Piston Engines	0.0019	0.042	0.0015
P2	Turboprop Engines	4.6	26.8	12.9

*NOTE: "T" Standards as: Lbs/1000 lbs thrust-hour/ LTO cycle
"P2" Standards as: Lbs/1000 horsepower-hours/ LTO cycle
"P1" Standars as: Lbs/rated power/ LTO cycle

(In addition to these standards, a standard for allowable emission of visible smoke is specified, but presents few challenges for RPV-class turbine engines and none for RPV-class piston engines.)

In all cases, the turbine engine standards are expected to be met by combustor modifications, fuel atomization improvements, and possibly by water injection. The piston-engine standards can be met by relatively minor changes in air-fuel mixing and better cooling. The much more extensive types of changes being made to automobile engines marketed in the U.S. will not be necessary because of the relatively small effect of piston-powered aircraft on air quality.

Aircraft noise: As with the regulations on engine emissions, most noise-limit rules for aircraft are aimed at ameliorating the annoyance or health problems of people at or near airports. (The rules that are intended to protect passengers and crew are, obviously, not relevant to RPVs.) The most relevant rule for RPVs is the FAA rule, taking effect on February 7, 1976, for small propeller aircraft. The standards set forth by that rule, as summarized in Aviation Week & Space Technology, February 3, 1976, are:

- Noise level for aircraft for which a type certificate was requested after October 9, 1973—which would include all RPVs—cannot exceed 68 A-level decibels (dBA) up to a gross weight of 600 kg (1320 lb). The limit then increases at a rate of 1 dBA/75kg (165 lb) up to 82 dBA/1650 kg (3630 lb). The 82-dBA limit then applies up to 5680 kg (12,500 lb).
- That limit drops to 80 dBA for aircraft weighing over 1500 kg (3300 lb) and for which a type certificate was sought after January 1, 1975.

These sound levels are measured at 1000 ft (305 m) using a meter set to the American Standards Association curve "A" frequency response. Figure 14 shows a typical RPV engine, the 11-hp McCullough MC-101, measured against these standards. Other U.S. aircraft are also plotted, for comparison.

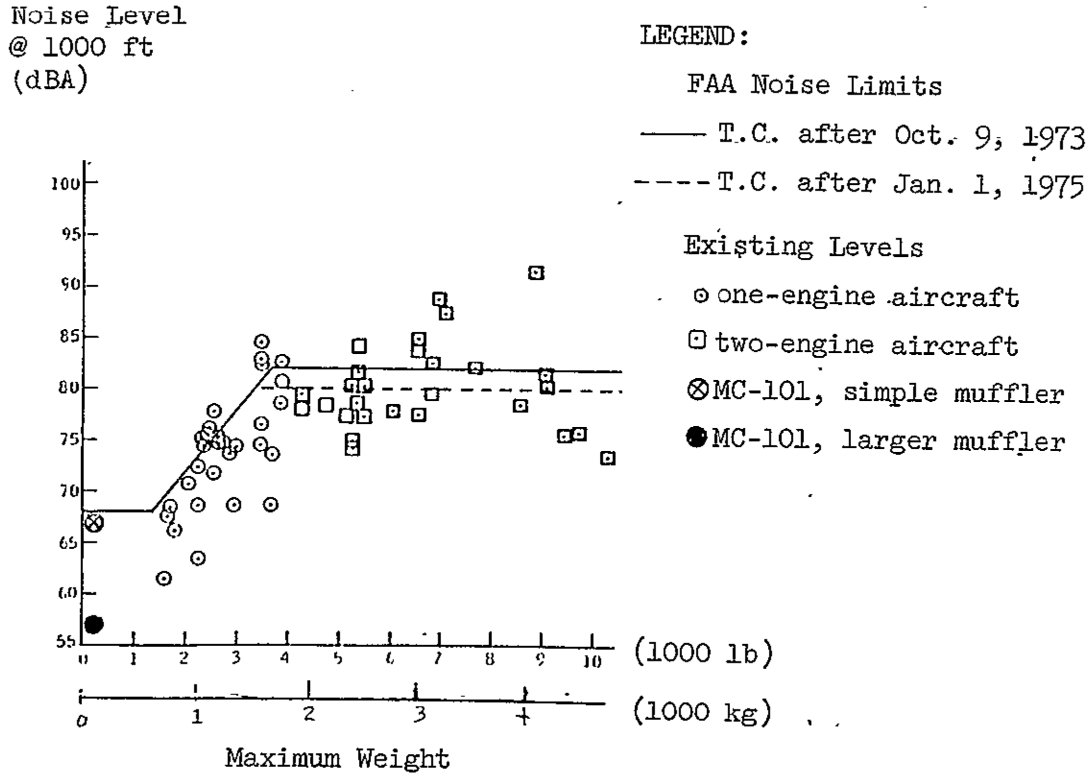


FIGURE 14 FAA NOISE LIMITS, WITH EXISTING AIRCRAFT COMPARED

EPA-FAA Interplay: Both the EPA and the FAA are involved in regulating aircraft environmental impacts. Section 231 of the Clean Air Act, as amended by public law 91-604, directs the EPA Administrator to establish standards for aircraft or aircraft engines. Section 232 directs the Secretary of Transportation to issue regulations insuring that the standards are met. Public Law 92-574, The Noise Act of 1972, directs the EPA to submit proposed regulations for the control of aircraft noise and sonic booms to the FAA.

After receiving the first set of proposed regulations and reviewing them to insure that basic aircraft safety was not compromised, the FAA, after customary hearings, issued Federal Aviation Regulation (FAR) Part 36 covering noise standards. In addition, FAA Directive 1050.1A was issued stating FAA policy and procedures for meeting the requirements of the National Environmental Policy Act 1969 (NEPA). The directive also states the policy and procedures governing impact statements and negative declarations.

The role of the OSHA: OSHA emission and noise control regulation 29 CFR 1910.93 and .95 are concerned primarily with worker safety in the overhaul/repair and flight-preparation mode. Emission control, therefore, is aimed at the mandatory dissipation of carbon monoxide and other noxious fumes while operating the engine indoors. The general sound limitations under 29 CFR 1910.95 appear to be appropriate:

- Up to 90 dB -- workers may be exposed up to 8 hours without ear muffs
- 90-115 dB - workers may be exposed up to 15 minutes without muffs
- over 115 dB - muffs must be worn at all times.

The role of the states: The individual states, usually under authority of their respective Public Utilities Commissions (PUC) enact state laws based on Federal regulations, that further control noise as it effects the community environment. The State of California, for example, under Department of Aeronautics Title 4, Subchapter 6, "Noise Standards" goes into great detail in describing tolerable Community Noise Equivalent Level (CNEL) and Single Event Noise Exposure Level (SENEL) near airports. The state's primary concern is for the effect of excessive noise within the Noise Impact Boundary (NIB) and the land use within the NIB. Generally, CNEL is set at 65 dB for new airports and military airports converted to civilian use and, with certain exclusions, existing airfields will be permitted to operate at 70 dB until 1985. SENEL is generally higher.

Regarding smoke and emission control, the states have no control themselves and defer to federal regulating agencies for aircraft emission. In early 1971 the Los Angeles County Air Pollution Control District (APCD) attempted to enforce smoke emission control regulations on aircraft operating out of Los Angeles International Airport. They specified that no emission could exceed a Ringleman 2 Scale (visual) reading. A federal court decreed that the APCD regulation was uninforcible under the original act (42 USC 1857 as amended by PL 91-604) and all complaints were quashed. This decision, under 42 USC 1857 (F-11) makes it clear that neither states nor subdivisions thereof can control aircraft emissions unless their control is identical to federal standards.

Environmental comparison of RPVs and present methods. - The present or potential non-RPV methods in the 35 defined civil uses involve conventionally manned aircraft in an overwhelming majority of cases. In those cases, there appears to be no environmental disadvantage to RPVs. In fact, the generally smaller size of RPVs implies a lesser environmental impact, albeit negligible.

There are two of the defined uses in which RPVs are at some environmental disadvantage, although again the disadvantage appears negligible. The first is in the security of high-value property, in which the non-aircraft alternatives to RPVs are fixed television surveillance and increased ground patrols. These alternatives are not economic except in special cases, but they are quieter than RPVs. RPVs designed for this use will require quieting for operational stealth, and this quieting will more than satisfy environmental concerns.

The second is meteorology, in which use weather balloons are certainly quieter than RPVs. However, weather stations tend to be located either at remote areas or at airports. Thus, the concern with RPV noise if minimal.

In summary, no idication has been discovered that RPVs will cause an adverse environmental impact compared to alternatives.

Safety requirements and criteria. - There are presently no regulations that apply specifically to RPVs. The closest analogy to RPVs now in widespread use are the popular radio-controlled model aircraft that are flown as a hobby. They are not regulated, but the national model associations have a voluntary code of safety rules which their members generally observe. Such an informal situation can not be expected to apply to RPVs in civil uses in the civil airspace.

The areas of concern about RPV safety are collision avoidance, unplanned descent, and maintaining positive control. These areas and others were discussed with headquarters personnel of the FAA Western Region, with the objective of understanding the basic principles and key concerns that apply to developing safety requirements and criteria. The next few paragraphs give the highlights of those discussions. None of the comments or suggestions here should be taken as official FAA policy. Rather, they should be viewed as thoughtful comments by knowledgeable people who are experienced in promotion and regulation of civil aviation.

Collision avoidance: Lights and paints should be used to enhance visibility, but do not completely solve the problem. In special emergency situations such as oil spills, forest fires, and natural disasters, Temporary Restricted Areas (TRA) can be established. Air traffic is directed not to enter the TRA, but pilots occasionally wander in. Also, special military operations such as firing on aerial gunnery ranges use radar and observers to look for traffic entering the range. They halt the operation until the traffic is clear of the range. Neither of these special situations is a good model for most civil RPV operations.

If the RPV operates in air space where all traffic is controlled (e.g., above 18,000 ft) the RPV must use a beacon transponder and communication with the ATC. In these circumstances the RPV would be controlled exactly as any other aircraft, and the operator would have to be as knowledgeable and well qualified in ATC procedures as a pilot aboard any conventional aircraft.

Unplanned descent: The probability of casualties from an unplanned descent must be very low. One analogy if the reliability requirement for automatic landing systems. The FAA requires that their probability of failure during the few seconds between irrevocable commitment and touchdown be no more than 10^{-9}. Note that RPVs may not have to meet such stringent hardware requirements, since the likelihood of casualties from an RPV failure is much lower than from failure of an automatic landing system. However, to be certified, RPVs will have to have at least the reliability and redundancy that manned aircraft have, e.g., dual ignition systems. Reliability will be one of the key capabilities to be demonstrated during system development.

If the consequences of an unplanned descent can be made tolerable, the allowable probability of such an event will be correspondingly higher.

Positive control: The reliability comments above apply also to the command link. Redundancy and automatic features for reestablishing the link will be required. It was also pointed out that the command and data links will need licensing by the Federal Communications Commission as well as the FAA.

Safety comparisons of RPVs and present methods. - As was noted above in the environmental comparison of RPVs and present methods, the great majority of present methods involve the use of conventionally manned aircraft, so the main safety comparison is with them.

The fundamental principle of aircraft collision avoidance is "see and be seen". This principle, which applies even under instrument flight rules (IFR), causes the greatest safety concern for RPVs. The on-board pilot is the safety advantage that a conventional aircraft has over an RPV, and his absence is a safety challenge to RPV systems. Although RPVs can readily be made as visible as conventional aircraft of the same size class, the problem of making them "see" other aircraft at an acceptable cost has not been solved. Other approaches to collision avoidance must be used, and are discussed in later sections.

With respect to unplanned descent, the generally smaller size of RPVs makes it easier to devise systems to slow the descent and tends to minimize the damage due to impact. There is no inherent reason why RPVs should have more such emergencies than conventional aircraft, except for the possibility of losing the control link. This possibility of losing the link through electronic failure is the second safety challenge for the RPV developer. Fortunately, it is tractable through straightforward engineering.

One significant point that is often overlooked in comparing RPVs and conventional aircraft for safety is that the danger from unplanned descents is overwhelmingly borne by the occupants of the aircraft.

Table 33 shows the total number of small fixed-wing aircraft and rotorcraft accidents, and the resulting fatalities and injuries, for 1969-72. The figures are taken from the National Transportation Safety Board's annual statistical reviews. In the four years covered, over 100 million hours of flight time were accumulated in small aircraft, and 18,018 accidents were reported. There were 7833 fatalities or serious injuries to persons aboard the aircraft and 145 to persons on the ground. Only about one accident in 125 killed or injured someone on the ground, whereas about four out of every ten accidents killed or injured someone aboard. Over 90% of all general aviation aircraft accidents occur to small fixed wing airplanes, the majority of these during some phase of pleasure or other non-commercial flying activity. The most frequently cited cause of fatal accidents is some form of pilot error, such as flying into adverse weather conditions, failure to obtain or maintain flying speed, inadequate preflight planning, poor judgement, etc.

The largest number of commercial small aircraft accidents occurred during agricultural aviation flight operations. Table 34 lists the number of

TABLE 33 AVIATION ACCIDENT SUMMARY

	1969	1970	1971	1972
SMALL FIXED-WING				
ACCIDENTS (ALL TYPES)	4,406	4,347	4,307	3,931
FATALITIES ABOARD	1,238	1,192	1,263	1,279
FATALITIES ON THE GROUND	11	8	11	35
SERIOUS INJURIES ABOARD	627	610	668	610
SERIOUS INJURIES ON THE GROUND	8	18	14	17
ROTORCRAFT				
ACCIDENTS (ALL TYPES)	273	264	245	245
FATALITIES ABOARD	50	29	30	64
FATALITIES ON THE GROUND	1	3	5	2
SERIOUS INJURIES ABOARD	36	26	34	40
SERIOUS INJURIES ON THE GROUND	4	6	2	0

TABLE 34 AGRICULTURAL AVIATION ACCIDENTS

	1972	1973	1974	SEP 1975
• ACCIDENTS	346	378	438	388
• FATALITIES	–	39	29	28
• INJURIES.	–	35	54	32
• AIRCRAFT DESTROYED	–	78	112	110
• SUBSTANTIAL DAMAGE	–	268	301	269

agricultural aircraft accidents and the resulting deaths, injuries, and damages from 1973 through October 1975. These include both fixed-wing and rotary-wing aircraft. There is no indication that any of these accidents resulted in casualties to persons on the ground. Property losses, especially destroyed or damaged aircraft, however, are very high. Interestingly enough, the rate of death or injury is only 0.18, or less than two out of every ten accidents. This is less than half the rate for general aviation as a whole and may reflect the fact that there is ordinarily only one person aboard.

During the four year period 1971-1974, there were 114 midair collisions between U.S. civil aviation aircraft; 63 of these accidents resulted in 213 fatalities, only one of which was a person on the ground.

If any inference may be drawn from these data, it must be that hazards to life and property on the ground because of small-aircraft accidents is indeed minimal.

Safety analysis and system features. - The system features to respond to safety concerns about RPV systems are discussed under the three subjects of positive control, collision avoidance, and unplanned descent.

Positive control: Features to ensure positive control include back-up systems or redundancy, means of reestablishing a lost control link, and protection from electromagnetic interference (EMI). They generally require no more than good engineering practice rather than technology development, so they are discussed only briefly.

Back-up systems and redundancy are self-explanatory and include such things as an ordinary manual radio-control system to take over in case of autopilot failure near the takeoff and landing site and an auxilliary power supply in case of electrical power failure. They also include switchable or parallel redundant components in the ground station and airborne portions of the data an control link.

Reestablishing a lost control link is required in situations such as a temporary failure of electrical power to the ground station. When power is restored, the task is to put the main lobe of the ground antenna pattern on the RPV and synchronize any signal coding that may be used for EMI resistance. Synchronization, if used, is readily incorporated into the link circuits, and the job of putting the main lobe on the RPV is made manageable by programming a "lost link" maneuver such as a tight climbing turn into the RPV so that the volume of sky that needs to be scanned about the last known RPV location is kept small. The lost-link maneuver must also include a provision for safe descent if the link is not reestablished. (See the discussion of unplanned descent below.)

EMI protection is achieved by operating on assigned channels to minimize extraneous signals and by coding the command signal uniquely for each RPV so that the RPV ignores commands intended for other RPVs. This kind of provision can be routinely built into encoder/decoder circuitry. The more complex anti-jam techniques of military-RPV command links are not required for civil RPVs.

Collision avoidance: Features for collision avoidance are discussed under the four subjects of visibility, precise knowledge of location, air traffic control (ATC), and operation in assigned airspace. A fifth subject, active detection of non-cooperating aircraft, is touched briefly.

Visibility for RPVs will be provided the same way as for other aircraft, i.e., with paint, highly reflective surfaces, and lights. Available lights include the usual red, green, and white running lights, high-intensity strobe lights, and other flashing lights. There are other possibilities, such as trailing a colored smoke plume, which may make sense in temporary, short-duration situations but which are not acceptable environmentally or practically for sustained use.

Precise knowledge of location in three dimensions is an important adjunct to other, procedural means of collision avoidance such as operating at assigned altitudes or in restricted air space and in avoiding airspace that is likely to be congested. Fortunately for the cause of safety, precise knowledge of position will be provided, in most cases, for routine control of the RPV and for proper performance of the mission. In those few uses that do not require precise navigation, collision avoidance may require that it be provided anyway. (Navigation is discussed above in the system conceptual designs and in Appendix F.)

The picture with respect to ATC is fairly encouraging for RPVs. The FAA is pursuing a comprehensive plan for a National Airspace System. It is expected to evolve through an orderly series of development and implementation steps to a point in the early- to mid-1980s, by which time a network of ground computers and airborne transponders and displays will provide separation-assurance service to general-aviation aircraft in uncontrolled airspace. The network will include, and grow from, the present ATC system that serves aircraft in controlled airspace now. The March 15, 1976 issue of Aviation Week and Space Technology carries a by-line article by Philip J. Klass that gives a good overview of the planned evolution.

The cost of the airborne portion of the system is estimated to be about $2000, compared to the $600-700 cost of the present collision-avoidance system transponders now on approximately 60,000 U.S. aircraft. For this reasonable cost, and with the necessary modifications to put the cockpit display on the ground-control console and provide communications between the RPV operator and the cognizant ATC center, RPVs can enter the airspace on the same operational basis as conventional aircraft, with the single exception of the lack of an airborne pilot to provide visual backup to the automatic systems.

One way to minimize the danger of collision between RPVs and other aircraft is to assign restricted airspace to RPVs and try to keep other aircraft out. Except in limited and specialized situations, this is not a desirable approach. Most of the missions for which RPVs appear promising do not lend themselves to this approach.

The last item for discussion under collision avoidance is the possibility of providing the RPV with means for detecting and locating non-cooperating aircraft, i.e., aircraft without transponders. Two basic possibilities are active radar and imaging sensors such as TV. No present or planned system has been discussed or devised in the course of this study that promises acceptable cost, but follow-on studies of RPV safety should pursue the possibilities. Of the two possibilities, radar appears to be the more promising. An effective system at an acceptable cost would be a breakthrough in allowing RPVs to operate in a see-and-be-seen environment.

Unplanned descent: Features for minimizing damage to people and property on the ground in case of an unplanned descent fall into two categories—systems to control the landing point and systems to slow the descent. In both of these areas, the problems are tractable.

With regard to controlling the landing point, the problem is to get the RPV to as sparsely populated an area as possible for its landing and to bring it in as nearly vertical as possible, to confine any damage to the smallest area. Two situations are of concern. The first is when the control link is lost but the RPV can still fly normally. In that case, the preprogrammed lost-link maneuver would include a timer that would give up the effort to reestablish link after a predetermined period and would activate a second maneuver. This second maneuver would be to take up a planned heading and fly by dead reckoning toward a sparsely populated area. For example, if an operation is being conducted in a coastal region, the maneuver might be simply to fly out to sea. In other regions, the maneuver would be to fly to the least-populated area within range. During normal operations, while the control link is intact, the lost-link maneuver would be updated as frequently as necessary to reflect changes in the RPV location and the relative location of the emergency landing area.

The second situation of concern is a failure in some subsystem (e.g., an engine failure) that precludes extended flight. In this situation, the only landing-point control might be to cause as steep a glide path as possible so as to confine damage. If emergency recovery systems to slow descent are used, they will accomplish this steep path, but even in their absence some things can be done so long as back-up power is available to move the control surfaces. One possibility is a deep-stall recovery, in which the elevator is locked in a hard "up" position, perhaps 80-90°. If the wings are kept level to prevent a spin, the RPV will descend steeply in a series of stalls. Another possibility is to lock the ailerons in a hard-over (90°) position, causing high drag and a near-vertical spiral to impact. For a helicopter RPV, near-vertical autorotation can be used, although that is discussed below, under "slowing the descent".

Even in the lost-link situation discussed above, the final descent into the chosen, sparsely populated area should be made by the steepest (and slowest) means possible.

A number of concepts are available for slowing the descent of an RPV. Five are discussed here: Magnus Effect wings, a stowed-rotor system on fixed-wing RPVs, autorotation of helicopter RPVs, autorotation with pitched wings (called the Spin Recovery System), and parachute recovery. The objective is to slow the impact speed to about 20 ft/sec (6.1 m/sec), which is equivalent to a free fall from about six feet (two meters).

Magnus Effect wings: The Magnus Effect is the name given to the principle that lift is generated by a rotating body in an air stream due to the difference in relative speed, on opposite sides of the axis of rotation, between the air and the object. It makes a baseball curve and also gives lift to a wing rotating about its span. This effect can be used to slow the descent of an RPV. In normal flight, the wings would be locked in position. In an emergency, the entire wings or the outer panels would be unlocked. They would be given an initial spin in the desired direction about the axis of rotation and/or the ailerons and some auxilliary opposite surfaces would be deployed.

Since the lift force is perpendicular to the relative wind, vertical descent is not possible. The steepness depends on the amount of drag, the weight of the RPV, how much of the wing is allowed to rotate, and the coefficient of lift. The coefficient of lift of unpowered Magnus Effect wings is variously reported in the literature as being in the range of 1.0-2.0.

The design tradeoffs, mechanization, and stability and control characteristics of Magnus Effect wings for RPVs have not been investigated in this study. However, the subject appears to be a fertile one for exploration, especially if the rotation is powered so as to obtain the lift coefficients approaching 10.0 that are estimated in the literature, in which case the approach holds promise as a STOL launch-and-recovery technique.

Stowed-rotor: The technique of deploying a stowed rotor for near-vertical landing of a fixed-wing RPV has been demonstrated by LMSC using a radio-controlled model. The model, shown in Figures 15 and 16, is the commercially available "Ugly Stick" model, which has a wing span of 58 in. (1.47 m) and weighs 10 lb (4.5 kg). Various disc loadings, rotor-blade airfoil sections, and rotor blade pitch were investigated in more than 60 flights. Successful deployment, spin-up, maneuvers as an autogyro, and landing with no ground roll were demonstrated and recorded on moving picture film.

The design work necessary to get an accurate estimate of the weight of stowed-rotor systems for larger RPVs has only begun. However, the relationships

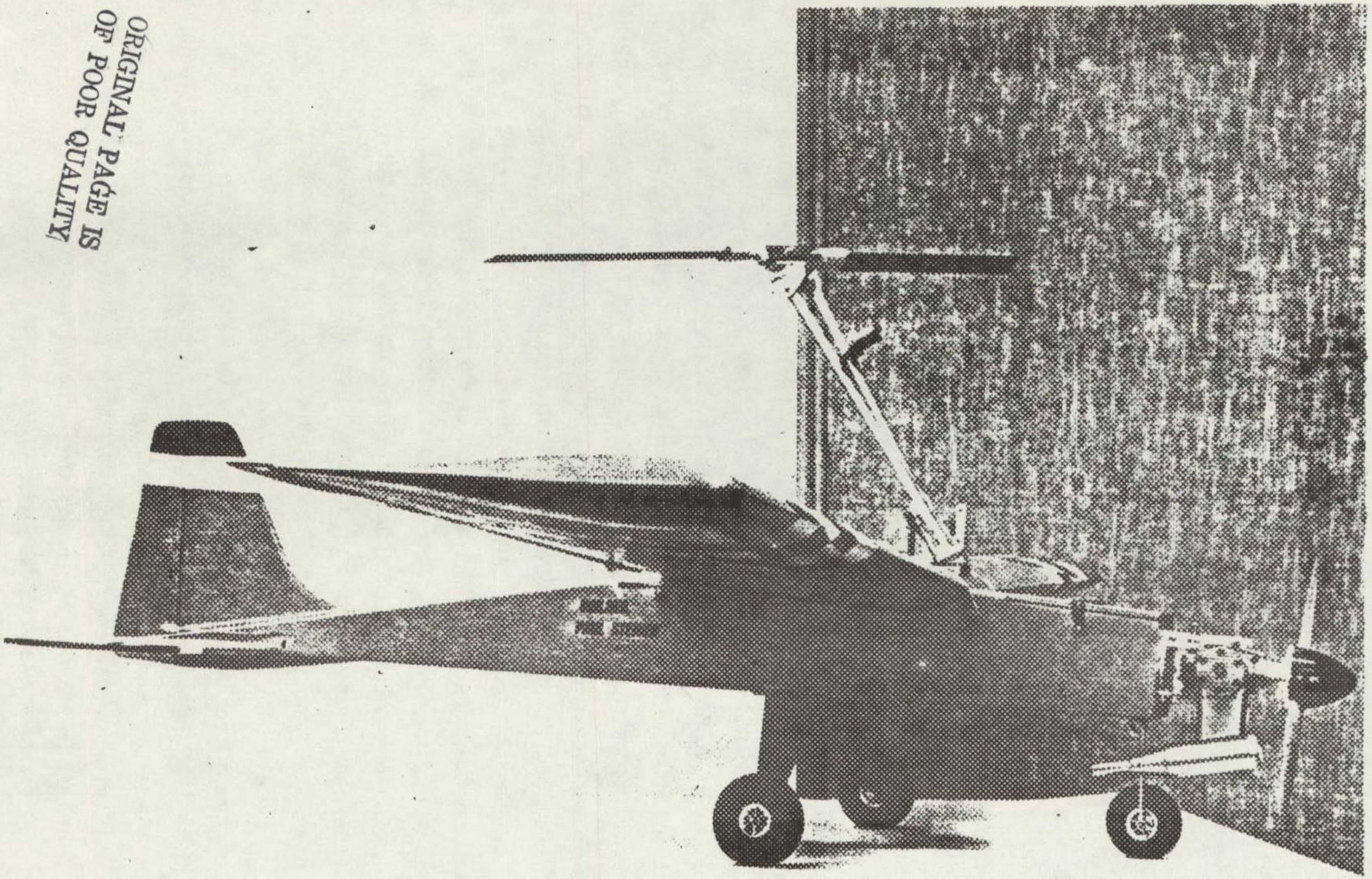


FIGURE 15 STOWED ROTOR DEPLOYED (DEVELOPMENT MODEL)

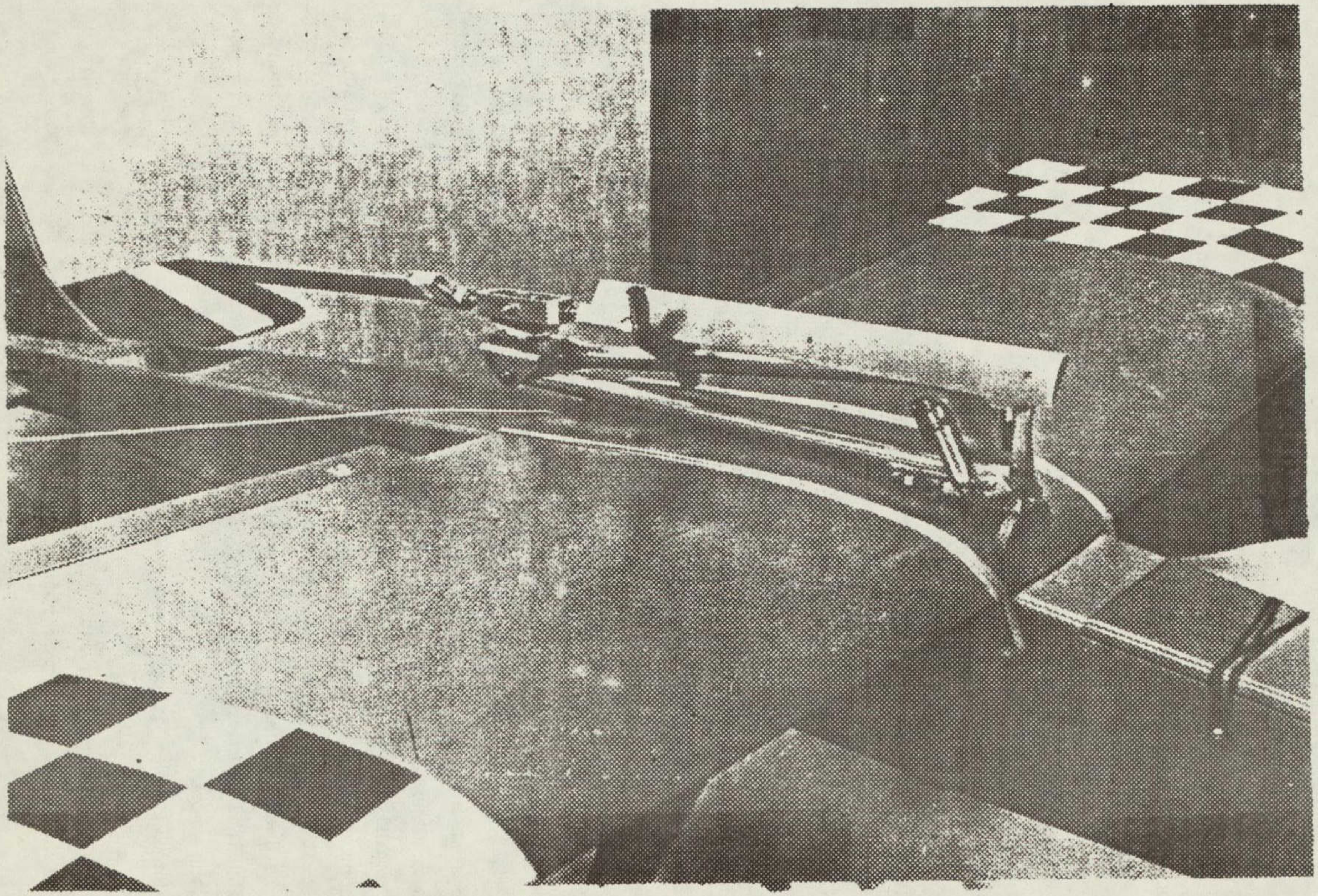


FIGURE 16 STOWED ROTOR IN STOWED POSITION (DEVELOPMENT MODEL)

among RPV gross weight, rotor size, and descent rate are known, and estimates of the weights of the necessary deployment mechanisms can be estimated with reasonable accuracy. Figure 17 shows, for example, that a stowed rotor to slow a 150-lb (68 kg) RPV to a descent rate of 20 ft/sec (6.1 m/sec) would weigh about 18 lb (8.2 kg).

With regard to recovery by autorotation of a helicopter RPV, the relationships in Figure 17 hold true, but the weight curve does not apply; the rotor is already a part of the RPV instead of an emergency system that is carried along. Figure 17 can be used to estimate the autorotational descent rate of helicopter RPVs designed for missions 1 and 2. Although their solidity ratio is less than that assumed in Figure 17 , the effect is only to increase tip speed. The autorotational tip speeds are still below the regime of excessive drag. Interpolating on Figure 17 shows that the mission-1 RPV, with a rotor radius of 6.7 ft (2 m) and a weight of 165 lb (75 kg) would have an autorotational descent rate of about 22 ft/sec (6.7 m/sec).

The Spin Recovery System has been analyzed for recovery of the XMQM-105 Aquila RPV built by LMSC for the U.S. Army, and has been demonstrated with an unpowered model. The calculations reported here apply to an RPV weighing about 130 lb (59 kg). The intent of the original investigation was to recover RPVs routinely this way, with a crushable-structure nose to absorb impact.

The Spin Recovery System utilizes the pitched wings of the RPV as a rotor system. Recovery is achieved by transmitting a signal to the aircraft which releases forward wing attachment pins by means of an electric solenoid and commands a hard roll. The pitching moments generated by the deflected ailerons cause the wings to pivot 88 degrees in opposite direction about the wing-feathering axis. With the wings pitched, lift normal to the longitudinal axis is destroyed immediately, the aircraft noses down, and spinning about the longitudinal axis, descends vertically at 28.7 ft/sec (8.7 m/sec) until impact with the ground.

Should lower descent rates than 28.7 ft/sec be desired, rotor flaps as shown in Figure 18 can be extended during the recovery cycle. One rotor flap would be hinged on each wing and would be spring loaded. As the wings are pitched to a -2 degree rotor pitch the flaps would be released and would

BASIS:
- o Two blades
- o Solidity ratio=0.07
- o 5° blade pitch

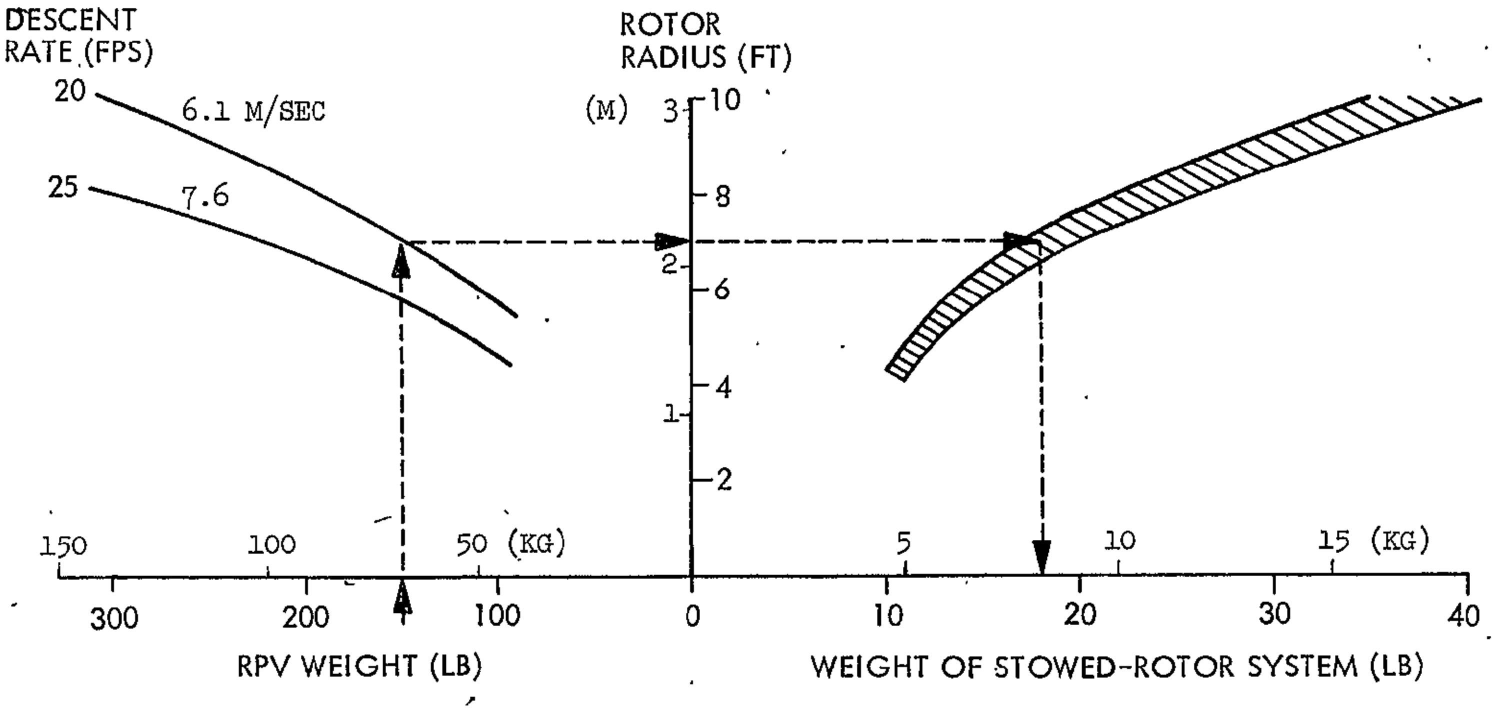
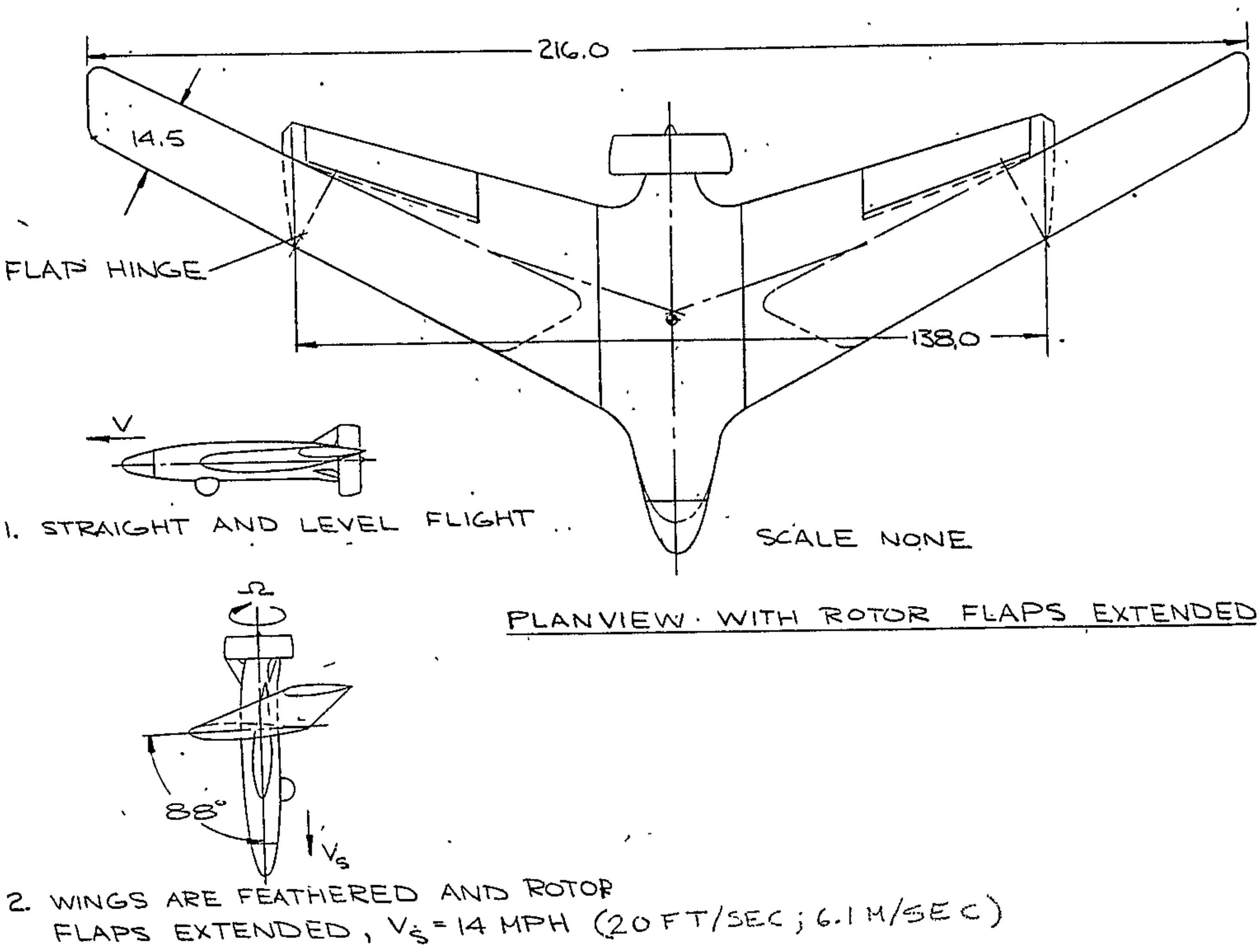


FIGURE 17 SIZE AND WEIGHT OF A STOWED-ROTOR DESCENT SYSTEM



1. STRAIGHT AND LEVEL FLIGHT

PLANVIEW · WITH ROTOR FLAPS EXTENDED

2. WINGS ARE FEATHERED AND ROTOR FLAPS EXTENDED, V_S = 14 MPH (20 FT/SEC; 6.1 M/SEC)

FIGURE 18 SPIN RECOVERY SYSTEM

fold to the position shown in the figure. During flight the flaps would be faired into the wing such that the top surface of the flap would form the top surface of the wing. A rotor radius of 9 feet and a descent velocity of 20 ft/sec (6.1 m/sec) will be realized with the flaps extended.

The total weight, including the rotor flaps, is:

Reinforcement structure	8.7 lbs
Two electric solenoids	1.5
Two rotor flaps	9.3
	19.5 lb (8.9 kg)

It should be recognized that some of the structure required for the spin recovery system must be incorporated regardless of what type of a recovery system is used. For example, in any use that requires the RPV to be transportable, the wings must be readily detachable from the fuselage. A two-fitting lug attachment which will allow easy detachment will most likely weigh as much as the feathering hinge, which will also allow quick wing detachment.

Finally, the most conventional means of slowing descent is a parachute system. Figure 19 shows the weight penalty incurred by carrying such a system.

In summary, emergency systems to slow descent to 20 ft/sec (6.1 m/sec) can be incorporated for a weight penalty (depending on RPV weight) of 6-10% for a parachute, 11-14% for a stowed rotor or Spin Recovery system, an unknown amount for Magnus Effect wings, and no penalty at all for autorotation of a helicopter RPV. Some of these methods merit investigation as candidates for prime V/STOL methods of launch and recovery.

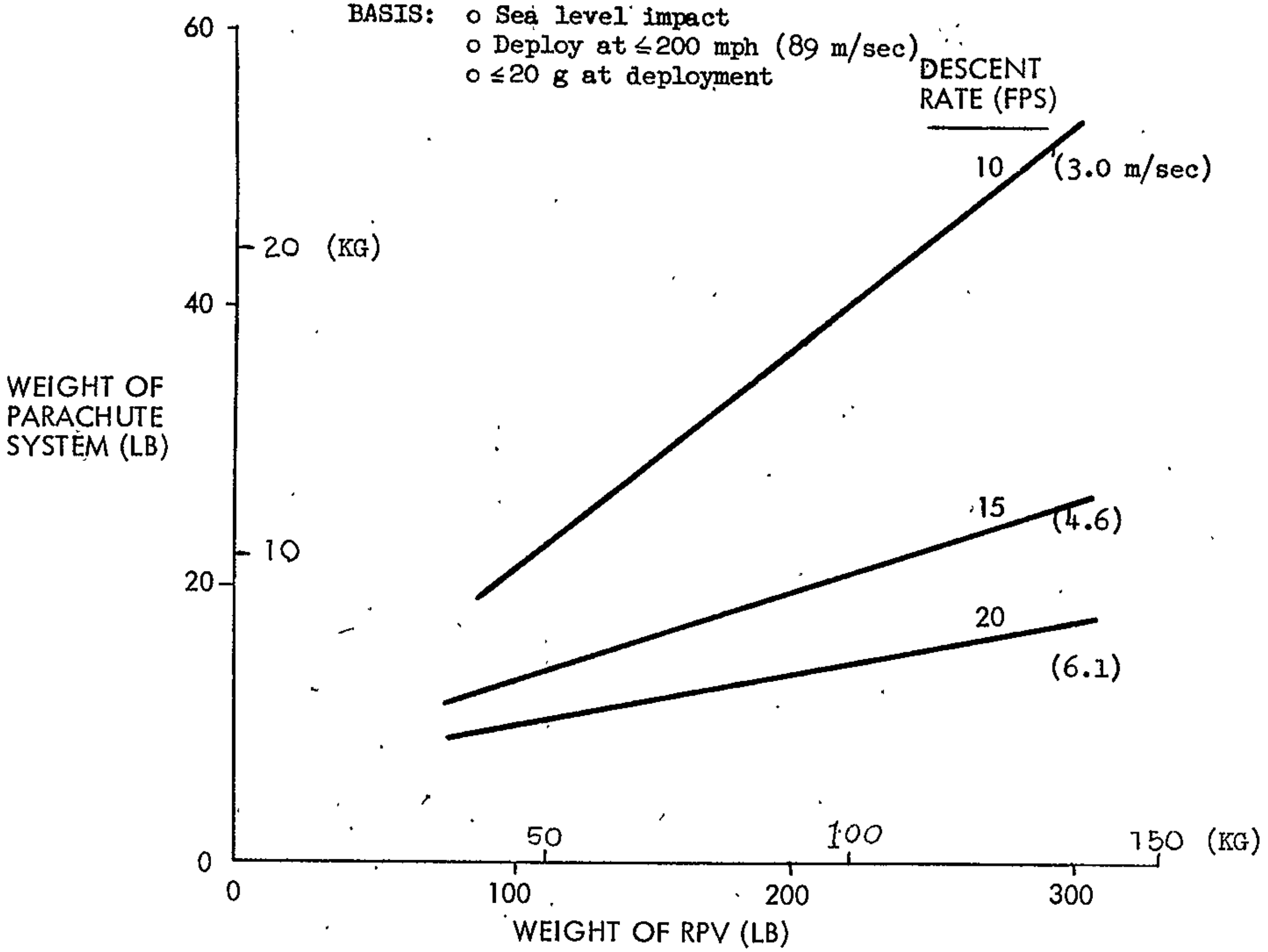


FIGURE 19 WEIGHT OF PARACHUTE DESCENT SYSTEM

Legal and regulatory implications. - The major concerns that give rise to laws and regulations for aircraft are for the safety of people and property, both in the air and on the ground. Environmental effects, particularly noise and emissions, are the next-greatest concerns. Closely related to these concerns are the questions of public acceptance, liability of RPV sellers and users, and the insurability of RPV systems. All of these issues were investigated in the course of the study and are discussed here.

In the discussions with FAA personnel, mentioned above under "Safety requirements and criteria", it was found that there are no Federal Aviation Regulations (FARs) that specifically deal with RPVs. Generally speaking, all existing FARs would probably apply to RPVs insofar as they are appropriate. For example, noise and emission standards applicable to manned aircraft would also apply to RPVs.

In introducing RPV systems into regular use of civil air space, public apprehension will have to be allayed. A logical approach to doing this would be to use RPVs first in remote areas until a history of reliable, safe operations can be demonstrated. Another suggestion, only half facetious, was to sell the systems abroad first and build up experience in countries where the governments do not ask their people's approval. If RPVs are (eventually) used over populated areas for police patrol, public concerns for invasion of privacy will have to be overcome in addition to the safety concerns. One "plus" for RPVs would be quieter operation to replace manned police helicopters in this kind of work.

The question was raised with the FAA whether regulations would be less stringent if a person wanted to operate an RPV only over his own property, e.g., for security surveillance. The answer is no, since "the man owns the ground, but everyone (the government) owns the air above it".

There are three main areas of regulation by the FAA that must be considered for RPVs. They are qualifications of operators, operating and flight rules, and certification of equipment.

With regard to qualifications required of an RPV operator, the approach to take is to start with the qualifications required of a pilot to operate a manned aircraft in the use for which RPVs are envisioned, then subtract whatever qualifications he doesn't need because he is not in the aircraft. The operating and flight rules are the area in which there is the least guidance to be had from experience with conventional aircraft. The sum of present thinking on the subject, which is not very extensive as yet, is given above in the section on "Safety requirements and criteria".

Certification: Certification is official acknowledgement that a manufacturer has complied with a set of safety rules. For a conventional aircraft, the rules are found in the Federal Aviation Regulations. They deal with airworthiness, design, quality assurance procedures, operations, and flight. For RPV systems, new rules will have to be developed.

The first step is for the manufacturer to develop and propose the set of rules that should apply to his new system. To do this, go element by element through the planned system to see what could endanger people or property. Change the system or devise a rule to eliminate each danger. This gets you a draft proposal to give to the FAA. The FAA works with this proposal in preparing the "certification basis" to be presented at a formal meeting with the manufacturer. (It is important to note that it is up to the manufacturer to work his way through the FARs and see what applies. The FAA will add whatever it thinks he has missed.)

The next step is the formal meeting between the FAA and the manufacturer at which the FAA lays out the certification basis (i.e., rules to be satisfied by the system) and the manufacturer gives his development plan and schedule. The development plan provides for FAA participation throughout the process.

The next series of steps consists of many discussions and data exchanges with the FAA during the design and development. The manufacturer and the FAA work closely together to see that the airworthiness and design rules are satisfied.

The next step is the preflight meeting before the first flight. At this meeting, the FAA issues the Type Inspection Authorization (TIA), which instructs its inspectors and monitors as to how the flights and inspections in the flight test program are to be conducted. When the flight test program satisfactorily demonstrates full compliance with the certification basis, a "ceremonial" meeting called a Final Type Board is held, and a type certificate is issued to the manufacturer. This completes the certification process.

With a knowledgeable team, certification of a small aircraft takes no more than two years from the first formal meeting to the Final Type Board. Add to this whatever time is required to develop a proposed set of rules for the certification basis. NASA can aid the certification process by supporting system studies and developing and demonstrating technology, especially in areas related to safety and reliability. Beyond that, neither NASA nor any other agency (e.g., a potential user) should insert itself into the working relationship between the FAA and the manufacturer. That tends to lengthen the process instead of expediting it.

If there were an overriding public interest, a public aircraft (RPV), i.e., one operated by a government agency for non-commercial purposes, could be certified immediately without the formal procedure, but it would not be certified for general use.

Other regulatory items: An environmental impact statement will be required for any system proposed. It doesn't look like a problem for most RPV uses. Also, the Federal Communications Commission (FCC) will have to license the data and control link for RPV systems and allocate frequencies for their operation. Since the cost of data link equipment is related directly to frequency, it is important to apply for an allocation as soon as possible in order to get the lowest available frequencies, which now are probably in the upper end of the UHF band.

Insurability issues: In order to understand the liability and insurability principles related to RPV systems operated routinely in civil air space, especially by non-government users, discussions were held with representatives of four aviation insurance underwriters. A summary of the principles follows.

The two keys to insurance are the probability of occurrence of accidents and the monetary damages that arise out of accidents that do occur. These two things are determined by statistics when there is enough operating history built up, but must be estimated for a new system or operation. The tendency is to charge a conservatively large premium at first, then adjust it as experience is gained and statistics become available.

Underwriters base their rates and the user's continued insurability on a number of other things that influence the probability of accidents. First of all, they want to see a rigorous certification process and a demonstration of the reliability of the equipment as designed. Then, they want to see competent manufacturing processes with high repeatability and good quality control, augmented with thorough after-sale service and maintenance. They also want to see high standards for operator selection, thorough operator training and licensing, and a set of duties and procedures that minimize the complexity, stress, and fatigue of the operator's duties. In addition, they like to see regulatory standards and certification procedures that give them confidence in the uniformity and predictability of both the operation and the equipment performance.

With regard to monetary damages, exposure is strongly influenced by the legal climate in which the system operates. The legal climate consists of legal limits to liability, restrictions on bringing suit, etc., as well as controls on other aircraft, restrictions on air space, and rules governing rights of way and air traffic control. This legal climate will be a strong factor in determining cost and availability of insurance.

Another factor, also related to exposure to damages, is the operating area. Operating over congested urban areas having a lot of air traffic (e.g., in a city near an airport) is the worst case, and operating over rural areas with very little traffic is the best case. The underwriters suggested that we concentrate on early uses in the latter category until experience is gained and reliability is demonstrated.

They said it is too early to try to establish a cost of insurance, but ventured a rough guess that $50,000,000 liability coverage might cost $10,000-$15,000 per RPV per year, at first. This is obviously a low-confidence estimate at this time. They also said that we should assume that RPV insurance would be available to large corporations as a part of an overall insurance package, but that an individual (e.g., crop-duster) would have a hard time getting insured until a lot of experience had been built up in RPV operations. They would also like to see a lot of systems in use, so the "law of large numbers" can begin to apply, before good rates could be set. (The system cost comparisons in the cost-benefit analyses, in earlier sections, assumes mature systems and RPV loss experiences similar to conventional aircraft.)

Market Analysis

This section discusses the potential demand for RPVs in the civil sector and the issues involved in integrating RPVs into that sector. By their very natures, both topics contain a large measure of speculation. No pretense is made here of a definitive treatment of either, but it is believed that a promising potential demand is indicated and that certain necessary steps by government and industry are identified.

Market size and market share. - Two approaches are taken to this subject, and the results are compared. The first approach is an independent survey by the LMSC Marketing staff, based on many telephone calls and interviews and a literature search. This was in addition to the survey reported above under "Market Survey", which formed the basis for the second approach. The independent survey by the Marketing staff is described first. The very voluminous data and impressions gathered are only briefly described.

Table 35 lists the 9 applications that were selected from the total 35 defined in the study and shows the estimated count that could be sold in the 1980-85 time frame if safety, reliability, and regulatory considerations are satisfied. The analysis was made by personal contacts, phone interviews, and literature search by a member of the LMSC R&D Division Marketing staff. The same analytical criteria used in evaluating other new starts was applied to the evaluation of data obtained in this portion of the study. The next few paragraphs describe the derivation of the numbers in Table 35.

With regard to mission 1, the gross count for law enforcement organizations provided by the Law Enforcement Assistance Agency (LEAA), (20 000 departments nationally), plus the rounded figure of private firms (5000 firms in 19 potential RPV user categories) was used for our gross population figure. The probability-of-buy number was set at 30% because of the high level of interest shown by those interviewed. Our net figure (7500) is reasonable, considering that 638 aircraft are now used by police departments alone and many more are used privately by firms for surveillance of their facilities.

TABLE 35 PARTIAL CIVIL RPV DOMESTIC MARKET POTENTIAL

POTENTIAL USE	INTEREST LEVEL			POTENTIAL NUMBER OF SYSTEMS		
	LOW	MED.	HIGH	GROSS COUNT	BUY PROBABILITY %	1980-85 POTENTIAL
o SMALL-AREA SURVEILLANCE						
1. SECURITY OF HIGH-VALUE PROPERTY			X	25 000	30	7 500
2. WILDFIRE MAPPING			X	103	30	31
o LARGE-AREA SURVEILLANCE						
3. WILDFIRE DETECTION			X			
- FEDERAL				150	50	75
- STATE				205	50	103
- PRIVATE				2 500	20	500
4. FISHING LAW ENFORCEMENT			X	100	50	50
o LINEAR PATROL						
5. HIGHWAY PATROL			X	6 370	25	1 592
6. PIPELINE PATROL			X	663	30	199
o AERIAL SPRAYING						
7. AGRICULTURAL CROP DUSTING		X		8 000	10	800
o ATMOSPHERIC SAMPLING						
8. STORM RESEARCH			X	78	50	39
9. METEOROLOGY			X	258	50	129
TOTALS				43 427		11 018

With regard to mission 2, an arbitrary figure of 2 mapping RPVs per state plus 3 for the federal Boise Interagency Fire Center (BIFC) was considered to be conservative notwithstanding the interest shown by wood-processing-company fire personnel interviewed. The 30% factor reflects those states that have the least forested area and never, or rarely, use BIFC's services.

With regard to mission 3, the total gross figures were derived as follows:
a) Federal - Since the U.S. Bureau of Land Management (BLM) and the U.S. Forest Service together own and lease about 150 aircraft, with a large commitment to Alaska, and have prime responsibility for wildfire detection in the federal land area, the gross count for the 1980's was set at 150. The high probability factor (50%), is used because of the high interest in RPVs expressed by federal interviewees. This figure is considered to be conservative comparing the number of RPVs to the land area owned by the federal government (729 million acres, not counting the armed forces' land).
b) State - The 11 western states, who do not have as good a road network in their forests as the eastern states do, could buy as many as 10 RPVs each. At least half of the remaining 39 states could be expected to buy 5 RPVs each. The resultant gross count (205 units) is factored by a high 50% because of the enthusiastic response of interviewees to the RPV concept in this role.
c) Private Sector - The figure for the 2500 member companies of the National Forest Products Institute was used in lieu of the 13 238 total Sic Code 2411 (loggers) count or the 696 total of logging firms with more than 20 employees because of the Institute's rationale. The low factor (20%) compensates for a limited poll sample size. The Eastern U.S. sector, where most of the logging activity occurs, appears to have more of a built-in reluctance to change from manned aircraft and fire watchtowers than the West.

With regard to mission 4, 25 U.S. Coast Guard Air Stations are situated in reasonable frequency along the coast line. They would be ideal for logistic support of an RPV network. This number, times 4 RPVs for each air station, was used. The 3 Great Lakes Air Stations were left in the count to compensate for possible coverage deficiencies such as noted in Alaska and Hawaii.

With regard to mission 5, the total gross count (6370 RPVs) was derived from the total of all aircraft used for law enforcement (870) added to 5 percent of the 261,000 police cars that could be replaced by air patrol (13 000 cars net). Since the sum of these two figures includes 7500 RPVs already accounted for under mission 1, "Security of high-value property", this amount was subtracted. Since only a small sample of user reaction to the RPV concept was obtained and most of the data came from a literature search, the probability factor was set at 25% for conservatism.

With regard to mission 6, the total gross count (663) was derived from the number of liquid pipeline companies (99) plus the number of gas pipeliners (122) and an estimate of 3 RPVs per company. The factored figure of 199 is reasonable when compared to the existing 300 aircraft estimated to be used for pipeline patrol nationally.

With regard to mission 7, the 8000 gross-count figure came from the FAA's figure for existing crop dusting aircraft. Since only a fraction of the spraying is ultra-low volume material suitable for our RPVs a low probability-of-buy figure (10%) was used.

With regard to mission 8, the total present number of NOAA and NASA research aircraft (8 and 6 respectively) were used as a basis in deriving the gross count of 78 RPVs. Based on our interview with key individuals at both agencies, an increase of 6 times the present manned-aircraft count was made to NOAA's figure and 5 times NASA's present inventory were applied to compensate for projected new hazardous missions, such as flying into tornado funnels, that would be instituted for RPVs when they become available. The 50% buy factor is high because of the on-going interest in RPVs at both agencies for special hazardous missions.

With regard to mission 9, the 258 gross figure was summation of U.S. Weather Service Balloon Launching Stations (78), NASA's (3), and Department of the Interior's (5), multiplied by 3 RPVs at each site. The high probability of buy factor (50%) is based on the rationale that the weather sampling community has an existing interest in RPVs, the annual cost of continuing the present method ($5M) makes a change attractive, and the improved capability of an RPV (steerable) makes it very saleable in this application. (Note that no satisfactory RPV system concept was devised for this use, despite the attractive possibilities for a suitable system that might later be devised.)

The Marketing Department survey just described gives one set of estimates of the potential demand, as shown in Table 35. Selecting only those uses that the cost-benefit comparisons show to be most attractive, and including estimates for promising uses for the rest of the 35, gives an estimate of demand as follows:

1. Security of high-value property	7500	
2. Wildfire mapping	30	
Other small-area surveillance	270	
3. Wildfire detection	680	
5. Highway patrol	1600	
Other linear patrol	30	
7. Agricultural Crop Dusting	300	
8. Severe-storm research	40	
Total	10,950	systems

The second approach, independent and deliberately more conservative, developed the following numbers for the same attractive potential uses.

1. Security of high-value property			
- 260 refineries x 40% =	100		
- 300+ railroad yards x 50% =	150		
- 2200 offshore facil. x 25% =	550		
- ? industrial complexes	250		
Subtotal		1050	
2. Wildfire mapping		30	
Other small-area surveillance		70	
Fish spotting		200	
3. Wildfire detection		50	
5. Highway patrol (20 large states x 10 each)		200	
Other linear patrol (Border patrol)		10	
7. Agricultural (4000 operators x 10%)		400	
8. Severe-storm research (4 centers x 5 each)		20	
Total		2030	systems

Considering the uncertainties in estimating, one should not take any of these numbers too literally. However, either total estimate indicates that the potential demand is adequate to justify a harder look at the technologies and the applications of RPVs in the civil sector.

Integration and Entry Into the Market. Even when many federal, state and local government agencies as well as consortia are already performing a multitude of monitoring, surveillance and sampling operations with manned aircraft, there will be required a considerable and concerted effort to develop and achieve acceptance of RPV systems for these same missions. There is enough inertia and conservatism in most user organizations to deter for a long while the employment of a set of new ideas such as RPVs. The issues of safety, operational flexibility, reliability and economies of operation compared with alternate techniques all represent considerable hurdles which must be overcome before RPVs are readily accepted for non-military uses.

Furthermore, the process of "developing" the market requires the involvement of many institutions which must be netted together in an integrated and cooperative manner before assured acceptance of RPVs in the civil sector can take place. As compared to the DoD military uses of RPVs, where the requirements, funding, R&D, production, training, operation and maintenance are all sponsored by the "end user", evolution of RPVs for the civil market will require the involvement of a more complex set of participants. This section will discuss the participants, actions required and approximate time phasing of the process of entering RPVs into the civil market.

The process is akin to the concept of a "Technology Delivery System" (Reference 3), in which the network of institutions which must become involved in bringing a new technology to actual use in a market is identified for an integrated "development" and "utilization" for that market. The institutions involved will vary depending on the end user of the system (Federal agencies, States or local government agencies, private firms or consortia), but generally will involve

- R&D organizations
- manufacturing firms
- distributor/service organizations
- lending institutions and insurance underwriters
- regulatory agencies

During the conduct of surveys with potential users of RPVs, qualitative assessments were made of the likely willingness as well as reservations which such users would have in utilizing RPVs for their airborne missions. The general consensus appears to be that most potential users will have to be shown (by analyses and demonstrations and government acceptance) that RPVs will truly benefit their missions and operations before they commit to purchase RPV systems. Certain incentives may have to be employed along the way to entice progressive trials and introduction of RPVs into the civil market. Some examples are provided in the following sections.

Participants and actions required: For the purposes of this market entry discussion, the assessments will be made according to the issues peculiar to the three main classes of end users. For the nine generic RPV applications chosen for detailed analysis in this study, the end user mix would probably evolve as shown in the following table:

Mission	End User		
	Federal Govt. Agency	State or Local Govt. Agency	Private Firm or Consortia
Wildfire Detection	x	x	x
Wildfire Mapping	x	x	x
Fishing Law Enforcement	x	x	
Severe Storm Research	x		
Meteorological Sampling	x	x	
Highway Patrol		x	
Security-High Value Property	x	x	x
Pipeline Patrol			x
Agricultural Spraying			x

For each application and user, the various institutions noted previously will become involved, and there also may exist separate organizations to operate the RPVs for the sponsoring user. Table 36 lists the most likely candidates for each of the participating institutions, and a few observations about each category follows.

Operators of RPV equipment: While some end users may have their own functional department to operate the RPVs (police departments, Coast Guard,

SPONSOR & END USER	OPERATORS OF RPV EQUIPMENT	DISTRIBUTORS	MANUFACTURERS	RESEARCH & DEVELOPERS	FINANCIAL SOURCES	REGULATORY AGENCIES
FEDERAL GOVT. AGENCY STATE OR LOCAL GOVT. AGENCY PRIVATE FIRM OR CONSORTIA	OWN DEPARTMENT OR CONTRACTED OPERATOR OR LEASED SERVICE	PRIME MANUFACTURER OR AVIONICS DISTRIBUTOR OR GEN. AVIATION DISTRIBUTOR OR MFGR'S LICENSEE	AEROSPACE FIRMS & AVIONICS SUPPLIERS	GOVT. LABS UNIVERSITIES NON-FOR-PROFIT FIRMS AEROSPACE FIRMS SUBSYSTEM SUPPLIERS	CONGRESS STATE LEGISLATURES LENDING BANKS INSURANCE UNDERWRITERS IRAD	FCC FAA EPA STATE OR LOCAL CODE & REGULATORY AGENCIES

TABLE 36 PARTICIPANTS IN TYPICAL RPV MARKET EVOLUTION

FBI, etc.) many others may obtain the mission function by contracting to special private firms who historically provide on-call services and who possess the hardware to perform the service (e.g., aerial mapping firms, crop dusting firms, fire fighting aircraft firms). In other instances the end users may purchase and sustain the RPV equipment, operating it from their premises, but purchase the services of trained operators and maintanance engineers. Conversely, the end user may retain onboard staffs to operate and maintain the RPVs, while leasing the actual hardware from a distributor.

For each of these cases, the role of the operator will have to be assessed later with regard to his involvement in warranties, promotion, servicing, and operational specifications.

Distributors of RPV equipment: The prime manufacturer of the RPV systems may often perform his own distribution, marketing and service of the production hardware. This would typically involve promotion of improved mission payloads, upgrading of equipment over its life span, and responsibility for warranties and spares. Conversely, the manufacturer may license his RPV system product to a specialized distributor firm, such as the network of general aviation or avionics distributors that exist. He may also find that the immediate customer is one of the separate operating firms who provide aerial services and equipment to the end user.

The roles of these different classes of distributors will vary considerably in the evolution and entry of RPVs into the civil market. Special attention will have to be given to their involvement in financing, promotion and warranties.

Manufacturers: Because of the need for a highly integrated implementation of many technologies to arrive at effective RPV systems, it is expected that the successful manufacturers will come from the mainstream of "aerospace" system firms, especially those with major expertise in electronics, data management, interactive displays and software. While many subsystems of the total RPV system would be procured from specialty firms as suppliers, the integrated and operable total system is the entity which must pass the test of certification, warranties and system effectiveness. To meet these requirements, it is expected that interdisciplinary aerospace firms will become the prime manufacturers, and most probably from those firms who are most active in the DoD military classes of RPVs.

Research and developers: Many organizations have been or will become involved in the research and development of RPVs for civil use. As needs and benefits for RPV use evolve, and the institutional network of funding sources and incentives emerge, then all of the classic sources of R&D participants may expect to become involved.

Extensions of the ongoing DoD funded R&D for RPVs will entice the existing DoD laboratories, aerospace firms and subsystem firms to investially partially in R&D to enhance their chances for a long-term role in civil RPV applications. Government laboratories in NASA, EPA, ERDA, Interior and Justice Departments can be expected to conduct inhouse R&D as well as contracted R&D for special mission issues or equipment improvements within their expertise and charter.

Universities and not-for-profit firms, especially those who already have well established grants or contractural arrangements with federal or state government agencies, can be expected to be involved in portions of the R&D process.

The actual mix of R&D participants will depend heavily on the sources of funds and the promotion role played by the participants. On the expectation that a large and sustained promotion for RPV acceptance in civil uses is required, then the principal R&D participants will find that it is their chore to provide much of the operations analysis, generation of specifications, certification criteria, prototype demonstrations, sales promotion campaigns and interfaces with regulatory agencies, as well as the constant interaction with eventual end users. For such a multi-year endeavor it may be expected that the larger aerospace firms are among the few R&D participants who can shoulder this complex set of responsibilities. Exceptions may develop when a particular end user establishes on his own a strong need for an RPV system, and commences to fund the development, production and distribution of the system principally on his own initiative. Such cases are likely to be rare for the next decade.

Financial sources: The evolution and employment of civil RPV systems will involve numerous participants. Even with governmental agency charters established to perform various of the nine generic missions, those agencies are likely to have to go to their legislators for special funding authority during the early period when the perceived risks of utilizing RPVs is high.

Funding of the major tasks of system R&D will likely remain a federal government agency challenge until several versions of RPV systems are deployed, acceptance is assured, and private capital can be attracted to the market. Even for state and local government users of RPVs, who seldom fund advanced multi-discipline R&D of the class required, there will be a need for Federal agency sponsorship and funding for many years to come.

Lending institutions will have to be motivated to share the risk of civil RPV development, production, distribution and warranties. Funding institutions may also become involved in warranty provisions, user payment schedules, and licensing provisions.

Insurance underwriters will become involved in liability protection, and may have a voice in certification criteria.

Industry independent research and development (IRAD) funds and/or private capital will undoubtedly be required for priming the pump toward progressive development of civil RPVs. However, such funding will most likely come forth only in consort with strong evidence of pending or parallel financing by the government or other civilian sponsors. Incentives for such funding are discussed in the next section.

Regulatory agencies: As discussed in an earlier section, the environmental and safety aspects of RPV operations in civil air space will certainly involve participation by at least the FAA, FCC, EPA and state or local agencies involved in codes and regulations. Such institutions will become involved in determining operational and technical parameters which feed into specifications. The FAA will be particularly involved in approving certification criteria and the actual certification of equipments for most cases of RPV use. Since many of the RPV uses will involve governmental agencies as sponsors and users, these regulatory institutions will also become involved in intra- and intergovernmental agency negotiations of operational constraints and liability responsibilities. For example, should RPVs of certain types require real-time interaction with air traffic control, or utilize navigation nets and collision avoidance provisions also used by general and/or commercial aviation, then the FAA, CAB and FCC will all have a substantive participation in the operation and safety compliance of civil RPVs. Details of how those interactions should be planned for and implemented are beyond the scope of the present study. They warrant detailed consideration before RPVs are developed for civil applications.

Actions required of participants: The complexity of integrating the many participants into a cohesive team to bring RPVs to the civil marketplace is characterized in Figure 20 . In this matrix chart, the simultaneous involvement of several of the participating institutions is shown for several of the key actions or steps toward implementation. The connections are noted at this time principally to suggest that the development of this market will often become more difficult than usual DoD or NASA development and acquisition of new systems. There will be more institutions involved in any one action or decision process. There will be complex interweaving of the push-and-pull amongst participants. Resolution must be achieved as to which institutions generate the several actions, which fund each action and which must approve each action. The double XX entrees in the chart suggest those participants which must originate, carry out and approve each action. The single X entrees suggest additional participants who must become involved in at least a supportive role.

From this qualitative assessment it is reasoned that the prime manufacturer of the RPV system will find himself shouldering the main responsibility for creating and implementing the civil RPV market. This responsibility cannot be assumed unless there are clear indicators that such a market has profit potential. Which reasoning leads to the likely requirement for incentives to such manufacturers to commence this market development.

Incentives for progress: Because first-generation civil RPV systems will face considerable risks in terms of

- safety provisions required
- certification steps and costs
- regulatory constraints yet to be defined
- marketing and distributions
- warranty and insurance provisions and costs,

ACTION ↓ PARTICIPANT →	SPONSOR / END USER			OPERATORS	DISTRIBUTORS	MFGR'S	R&D	LENDING & INSURANCE	REGULATORY
	FED. GOVT.	STATE LOCAL	PRIVATE						
OPERATIONAL REQMTS ANAL.	XX	XX	X			XX	XX		
SPECIFICATIONS	XX	X	X			XX	XX		X
CERTIFICATION & RULES	X					XX	X		XX
WARRANTIES	X	X	X	X		XX		XX	
INSURANCE PROVISIONS	X	X	X	XX		X		XX	
MARKET ANALYSIS	X					XX	X	X	
PROMOTION					XX	XX	X		
SERVICE & SPARES					XX	X			
TRAINING				X	XX	X			
INCENTIVES FOR PROGRESS									
- FED. R&D FUNDING	$	$					XX	$	
- FED. LOAN GUARANTEES	XX					XX	X	$	
- FED. PROTOTYPE DEMOS.	XX	XX	X			XX			
- COST SHARING	$	$				$	$		
- LEASE FOR TRIAL USE	XX					XX			
LICENSING/PATENTS	X	X	X		X	XX			
PUBLIC ACCEPTANCE CAMPAIGN	X	XX	XX		X	XX			

FIGURE 20 PARTICIPATION IN ACTIONS TO DEVELOP CIVIL RPV MARKET

considerable attention will have to be given by the early Federal agency sponsors and the aerospace industry to incentives for distributing these risks amongst participants. Examples of incentives are shown in Figure 20, and they are discussed briefly here.

Federal R&D funding: Until military RPVs become fully operational in several classes, it is unlikely that private firms or state and local government agencies will entertain RPV uses unless they are essentially identical to the military equipment. Even then, there is a strong likelihood that operational requirements will differ for the civilian use, and regulations, safety criteria and measures of cost/effectiveness will be different enough to cause additional R&D to take place. It is therefore judged that the logical first applications of civil RPVs will arise for other Federal agency users, whose charters and missions meet national needs which warrant the expense of further R&D to meet those needs. By focusing on such Federal agency applications, there is more likelihood of justifying and acquiring the funding necessary to support both government and private developers.

Federal loan guarantees: As the Federal agency uses of RPVs emerge, the state and local government applications may flounder for lack of "risk capital" at the disposal of those government agencies. Consideration may be given to have Federal government provide loan guarantees to private lending institutions to encourage the development and acquisition of RPVs for these local governments. Precedents for such loan guarantees exist in other government activities such as the Small Business Administration and FHA, where the public interest is being served locally via Federal assistance and encouragement.

Federal prototype demonstrations: It may be of importance to entice the earlier Federal agency sponsors of civil RPVs (or even the military services) to utilize one or more sets of their proven RPV systems' hardware in prototype demonstrations of mission utility for state/local government potential users or even certain private sector consortia. A derivative of this incentive technique could be the nominal-cost leasing of the RPV system equipment procured by a Federal agency to some other federal, local, or private potential user for an extended trial use.

Cost sharing: Cost sharing between the developer or manufacturer and the sponsoring end user may be necessary to facilitate the early and progressive exploitation of RPVs. This incentive would possibly draw out a somewhat higher-risk participation by the combined R&D/manufacturing firms, who would risk the early involvement at an interim loss if they had good prospects of profitability in later manufacturing and services to overcome the R&D phase cost sharing.

While it is too early to suggest the specific incentive modes that will enhance civil RPV developments, it can be projected that some form(s) of incentive(s) will be crucial to catalyze a workable team of participants in the next several years.

Roadmap and time phasing of RPV market entry: Figure 21 presents an approximate timephasing of the flow of activities required to reach field operation of RPVs in all three end user classes:

- Federal agencies
- State or local government agencies
- Private firms or consortia

It is provided as a rough estimate of the overlapping sequence of events which will be appropriate and necessary in order to bring RPVs to the civil marketplace in the coming decade. The time spans shown are intended only as guidelines for planning such a complex sequence of actions, and to suggest the relative time phasing amongst the development, production and use of RPVs for the three classes of end users. Some highlights concerning this suggested interwoven acquisition process follow.

Federal Government Applications First: For reasons stated earlier, it is judged that RPV uses in the state or local government arena or in the private sector will be hamstrung for many years unless some non-DoD Federal Agencies sponsor RPV applications first. It is therefore suggested that from one to three federal agencies need to be stimulated to fund civil RPV R&D over the next few years in order to head for one or more system developments by 1978-79. An aid to triggering those decisions might be the use of DoD RPV hardware for utility demonstration to these other Federal agencies during the period 1977-80.

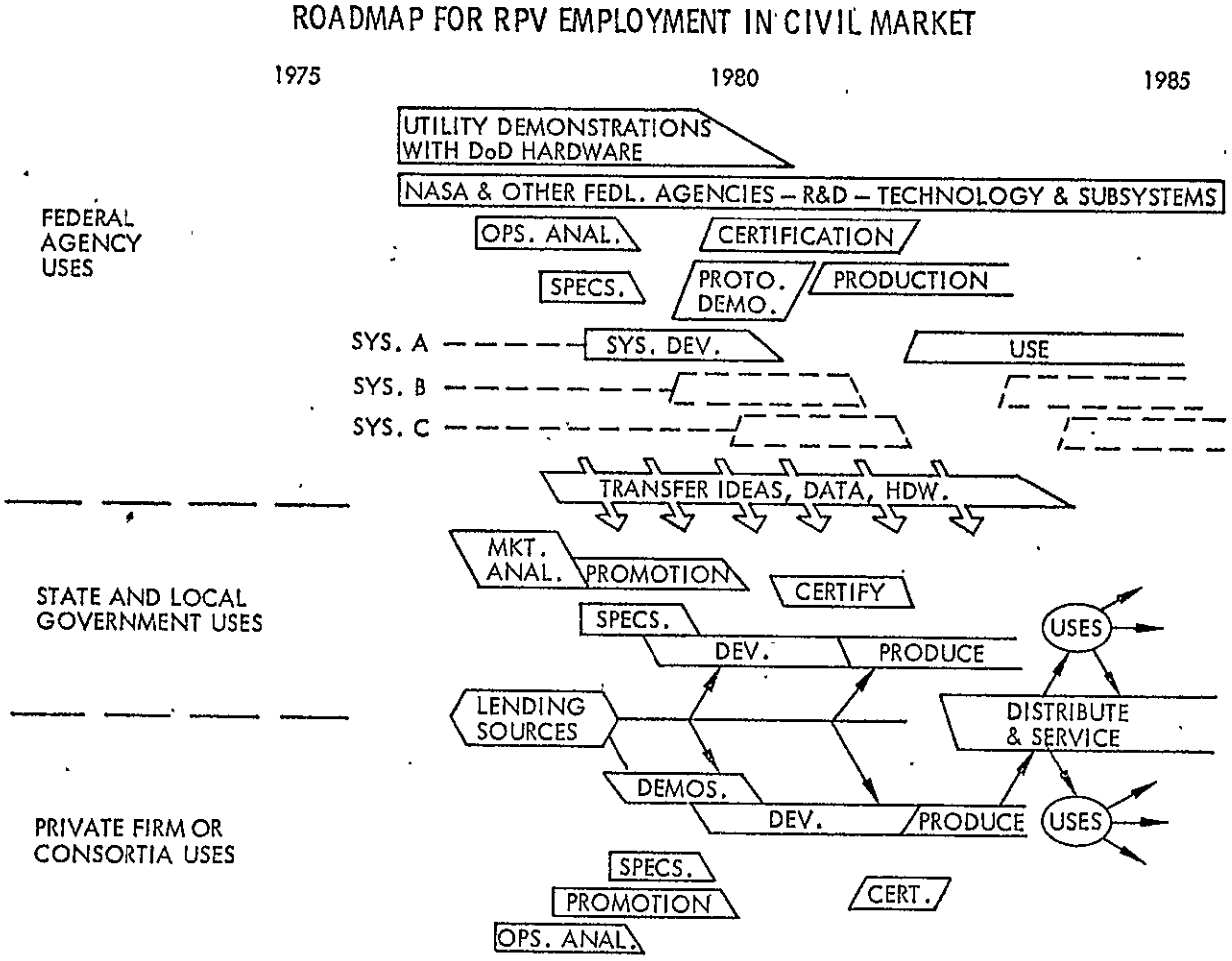


FIGURE 21 Roadmap For RPV Employment In The Civil Market

Parallel subsystem R&D sponsored by NASA and the sponsoring Federal Agency is considered vital and would be an ongoing effort throughout the coming decade.

As operations analysis, specifications, prototype demonstrations, system development and certification are achieved by the early 1980s for one or more of these federally sponsored civil RPVs, then a major transfer of this know how, confidence and investment in technology can be expected to be welcomed by the state and local government agencies. To prepare them for the arrival of this data and experience, it is suggested that market analysis, promotion of uses, and specification should or can proceed in parallel to the federal agency projects. In this way, the earliest synergism could be achieved to entice the state or local government agencies to adapt their requirements as closely as possible to the federal agency requirements, thus increasing the chances that a broader set of RPV uses could be accepted around the minimal set of separate hardware subsystem elements. This would result in substantially less total costs for bringing RPVs into the overall civilian market. For example, it might result in the need for only one certification process and one ground control system to serve multiple users.

Also during this parallel phasing of the state or local government development of RPVs, the network of lending institution participants could be created. The acceptability of loans for government sponsored projects may be greater than loans to more speculative private sector uses. As the funding-sources network emerges for these government uses, then the awareness and confidence of RPVs as a capital risk item would become more accepted by the lending institutions and they would hopefully be more receptive to providing funds for private ventures into RPV uses.

Lagging perhaps not more than a year behind the acquisition phases for state and local government uses, it is suggested that promotion and development of RPVs for private firms or consortia could occur. In these cases, the private sector users may expect a majority of the technical risks and associated R&D to have already been absorbed by the prior sequences of action at federal and local government levels. Such prior actions, including resolution of the regulatory implications and insurance/warranty provisions, may be key prerequisites to acceptance by the private sector users to invest their capital into development modifications, production and use of RPVs.

The process of developing, integrating and entering the civil RPV marketplace will present major challenges to both industry and government agencies. The number and types of participants in the process are much more varied than occur in DoD or NASA acquisition programs. The steps required for securing development funding, certification, operational regulations, distributing and operation RPVs suggests a process at least as complex as the introduction of an all weather and substantially new aeronautical flight system which requires interfaces with air traffic control, assured and safe emergency recovery technique, and positive control from remote ground station.

After identifying clearly important requirements and cost/performance-benefits that can be achieved by RPVs in civil applications, there will be required a concerted effort to promote, motivate and then catalyze the decisions and actions of the many participants. This is a task that has been done on many new system ventures in the past, but it is not easy to achieve. Progressive actions are expected earliest by Federal Agency applications of RPVs, where the national needs, funding sources, and precedents for R&D investment are best understood.

AREAS OF NEEDED RESEARCH

This section discusses research areas that require federal-agency sponsorship in order to verify the utility and safety of RPVs for the civil sector. The NASA's aeronautics charter for R&D can be the foundation for this research.

Propulsion

Durable, reliable, lightweight propulsion is a major need for small RPVs, especially in civil uses. Most present RPV engines in the 5 to 60 hp (3.7 to 45 kw) power spectrum are adaptations of go-cart, chain-saw, snowmobile, and other small engines designed for different duty cycles. For available engines in this range above about 18 hp (13 kw), the power-to-weight ratio is generally about 1/2 hp/lb (1/6 kw/kg) instead of the one hp/lb that can be found in some engines below 18 hp. Especially among the smaller engines, useful lives are short, and they require a high proportion of maintenance time to flying time. The major manufacturers of such appliance and hobby engines are not interested in spending engineering and development money on the RPV market because of the small (for them) quantities involved.

The Army Aviation Systems Command (AVSCOM), the military organization most active in development of mini-RPVs, has announced plans to request proposals for engine designs in the 20-hp (15 kw) class to be fabricated from modified commercial components. This should lead in the direction of solutions to a large share of the propulsion problems.

What is needed is more durable engines in the lower part of the power spectrum and lighter engines in the middle and upper part. A goal for mean time between overhauls (MTBO) should be substantially higher than the twenty hours that is typical today, but need not equal the 1000-1500-hour MTBO characteristic of light manned aircraft. An MTBO of 500 hours at a reasonable price might be a reasonable goal, although the tradeoff between initial cost and maintenance cost must be examined.

Research is also needed in dual (or at least very reliable) ignition systems, reliable carburetion, propeller and duct combinations, in-flight restart capability, and efficient, small electric power generation driven off the main engine.

Aerodynamics

The design of small, low-speed RPVs puts the aerodynamicist into a Reynolds Number regime that is lower than the published wind-tunnel data on most airfoils and shapes. The mini-RPVs in this study operate in the regime of Reynolds Number 200,000 to 1,000,000. Lift and drag, as well as other aerodynamic characteristics, of RPVs operating in this regime have been found to depart significantly from predictions based on extrapolations downward from published data. Similarly, there is little published data on the performance and installed efficiency of small propellers, up to 30 in. (80 cm) in diameter, and of small shrouded propellers. There is a need for a compilation of basic wind-tunnel data on suitable airfoils, shapes, propellers, shrouds, etc., in the low Reynolds Number regimes corresponding to mini-RPV design practice.

There is also a need for high-lift designs, with suitable stability and control, to facilitate recovery at the lowest practical speeds without going to the exotic STOL features that might be affordable on larger aircraft.

Takeoff and Landing

Although some of the RPV systems examined in this study are assumed to operate from existing airfields, it is likely that safety and operational considerations will require most civil RPVs to operate from separate facilities. V/STOL capability or reliable, inexpensive takeoff and landing techniques are needed that will allow routine operations from modest facilities or from unimproved open areas. The military RPV programs recognize this important need, and the Directorate of Defense Research and Engineering (DDR&E) plans to spend 30% (about $14M) of its requested FY 1977 technology-base RPV funds on improving launch and recovery techniques, according to Mr. Thomas Nyman of DDR&E speaking at the National Association for RPVs symposium in Dayton, Ohio, in May 1976.

The main problems are in the landing. Takeoff by catapult offers few technical challenges, but needs to be compared on a cost basis with alternatives such as rotary wing designs and launchers that tether or mount the RPV to a rotating member and use the RPV's own power to generate flying speed before releasing.

For landing, reliable and inexpensive V/STOL stability and control and novel methods such as a stowed rotor, a balloon-supported vertical line to be snagged, powered Magnus Effect wings, and others need to be examined. There are numerous possibilities, many of which will be explored by the military technology programs. However, it should be noted that the military may reject some means that would be adequate for civil uses because their criteria are different, e.g., air mobility, rapid relocation, concealment.

Automatic landing systems to guide and control the approach path are also desirable.

Safety Features

Collision avoidance. - Collision avoidance is the key safety issue in the civil use of RPVs. The operational interactions with air traffic control centers, the on-board equipment to operate in controlled airspace, the feasibility of on-board sensors to detect and locate non-cooperating other aircraft (i.e., without depending on their transponders), all should be the subjects of detailed study and research. An example would be R&D for an RPV radar which could detect non-cooperating aircraft within 5 km and send the bearing and range raw data to the ground station for diagnosis.

Unplanned descent. - Safety research is also needed to develop suitable software and hardware for guiding the RPV to a preselected landing zone of minimum population density in case of a lost link or an engine failure, and for slowing the descent to minimize the chance of damage to objects on the ground. The required procedures and guidance equipment should be examined, and so should the various emergency systems such as parachutes, stowed rotors, pitched wings, Magnus Effect wings, and controlled autorotation of helicopter RPVs.

Touchdown load attenuators such as airbags need further research for minimizing shock loads on both the RPV and any structure which the RPV might impact.

The tradeoffs associated with multiple engines for reliability should also be examined.

Navigation and Positive Control

There are several fruitful areas for research and development in the navigation and data-link areas. One is the adaptation of RPV systems to an interaction with existing navigation aids. Low-cost Omega navigation for RPVs is being developed, but its accuracy is variable with time of day and other conditions. What is needed is equipment and software small enough and light enough for RPVs but which will allow an automated determination of location and flight path, in the manner of R-NAV systems for manned aircraft. Another possibility, perhaps farther in the future, is the integration of RPV navigation into the Global Positioning System of satellites at a reasonable size, weight, and cost. Developments in this direction should be actively monitored while other, nearer prospects are pursued.

In the command-link area, low-cost airborne tracking antennas and techniques for low-cost control of multiple RPVs are needed. Military programs are pursuing control of multiple RPVs, but their data links also include extensive anti-jam features that are costly and unnecessary in civil uses.

All Subsystems

A conscious and concerted research and development effort is needed across the board in RPV subsystems to develop flight-quality equipment at the low end of the performance spectrum, i.e., in low-horsepower engines, small actuators and mechanisms, lightweight structures, air data sensors, attitude and rate sensors, etc. In order for the RPV community to move out of the model-airplane era and into the operational world, equipment comparable to commercial aviation quality is required in many subsystems that have been below the performance threshold of aviation, up until now.

"Flight quality" in a civil RPV means, among other things, that FAA standards for certification will have to be met. Although those standards have not been set for RPVs, the early indications are that such features as dual ignition systems on RPV engines will be required for safety. Military RPV programs do not now envision such developments, so they must be sponsored elsewhere.

One concern that falls into the bothersome category is the absence of a coherent body of design principles and criteria for RPV systems comparable to those that have been built up over the years of design of man-rated aircraft. Trial and error is the only course presently open to the designer who wants to take full advantage of the absence of an airborne pilot but who must also provide reliable and safe remote operation. Routine questions, such as the efficient sensing and adjustment of trim, call for the RPV designer to re-think the standard solutions.

The NASA could provide a major service to the community, albeit not a glamorous one, by collecting, organizing, and publishing the lessons learned in the various RPV design programs going on in the country.

CONCLUSIONS AND RECOMMENDATIONS

This section concentrates largely on general conclusions drawn from the results of the study. Recommendations are confined to suggesting the research and development objectives that are most important for providing RPV Systems for civil uses and to recommending the focus of continuing studies.

Many more pages of detailed observations could be brought together here, but for the sake of brevity they are left to the reader or to the appropriate section of the report from which they emerge.

Market

Potential demand. - The potential is estimated to be 2,000 to 11,000 RPV systems in uses for which RPV systems show a cost advantage over alternatives. This appears to justify continued exploration of the technology and operational issues of RPVs in civil uses.

Most-promising uses. - The uses for which the potential demand is greatest are also among the most promising uses from a cost viewpoint, i.e., security of high-value property, highway patrol, and agricultural spraying and crop dusting. They are characterized by operating areas small enough to allow control from a single ground station per system and by competing against alternatives that have high personnel costs.

Severe-storm research is also a promising use, but represents a small potential demand.

Least-promising uses. - The least-promising of the uses examined are fishing-law enforcement and pipeline patrol, unless RPV-system concepts can be devised that are greatly different and much less expensive than the ones studied. Both uses require operations over distances great enough to call for multiple ground stations and/or multiple complete systems to do the same job that a single, self-contained manned aircraft could do.

Technology transfer and market entry. - Most potential users will have to be shown by analyses, demonstrations, and government acceptance that RPVs will benefit their operations, before they will buy them. Funding of RPV research and development will depend on the federal government until one or more RPV systems is demonstrated and accepted in civil uses.

The participants in the process of developing, manufacturing, distributing, servicing, regulating, insuring, and operating RPV systems in civil uses are much more numerous and varied than in DoD or NASA procurements. Their interactions are examined in this study, but further conclusions and recommendations should await a detailed investigation.

Likely timing. - The next logical step toward introducing RPVs into the civil sector is a detailed operations analysis of a selected use, leading to specific planning for a demonstration program by a federal non-DoD agency by 1980. Such a demonstration would use hardware developed for military RPV programs. Certification, production, and use by federal agencies could come by 1982, assuming a successful demonstration and a parallel R&D program on the technologies and subsystems peculiar to civil uses. Systems, marketing, distribution, financing, servicing, etc., could be developed on a schedule that would lead to initial use by non-federal government agencies and by private firms by 1984-85.

Costs

Attainable costs. - The life-cycle costs of RPV systems can be significantly less than those of non-RPV alternatives in a number of uses. In those uses with the greatest potential demand, the saving is typically 25-35%, i.e., for the uses typified by security of high-value property and highway patrol, and for agricultural crop dusting.

Major source of savings. - The major saving from RPV systems compared to non-RPV alternatives is in reduced personnel costs. The only exception to this statement among the uses for which RPVs are preferred is in the severe-storm research mission, which comprises a small part of the potential demand.

Development costs. - Development costs are a minor part of the life-cycle cost of RPV systems. When prorated over, perhaps, 1000 systems and amortized over seven years, development costs amount to less than one percent of the annual cost of owning and operating an RPV system.

Legal and Regulatory Considerations

Safety of people and property, both in the air and on the ground, are the primary regulatory concerns. Noise and emission effects are the next greatest concerns. Liability and insurability of RPV developers and users must also be considered.

Certification. - The Federal Aviation Agency (FAA) will require RPVs to be certified for operations in civil airspace. Certification is official acknowledgement that an aircraft complies with a set of safety rules regarding airworthiness, design, quality assurance procedures, operations, and flight procedures. New rules will have to be developed, since the present Federal Aviation Regulations are built around manned aircraft. The developer will have to bring the FAA into the development process at the beginning and work with the FAA throughout development, typically for the period of about two years before first flight.

Operator licensing. - Operators of civil RPVs will be licensed, just as pilots are. The qualifications they must have will be determined by starting with those required of the pilot of a manned aircraft in the same use and then deleting those not needed because the operator is not in the aircraft.

Operations. - There are presently no regulations that apply specifically to RPV operations. New ones will have to be developed, addressing the three primary safety concerns of collision avoidance, unplanned descent, and maintaining positive control.

Environmental impact statement. - An environmental impact statement will probably have to be filed for each new kind of use of RPVs in civil airspace. Since RPVs have a minimal effect on the environment, no problems are apparent.

Radio frequency assignments. - A frequency assignment will have to be made by the Federal Communications Commission (FCC) for the data and control links, and operators will have to be licensed. The earliest reasonable application should be made, so as to secure the lowest available frequencies (in the UHF band). The lower the frequencies, the lower the cost of electronic equipment.

Liability and insurability. - The legal climate in which RPV systems operate will strongly influence the availability and cost of insurance. The legal climate consists of any legal limits to liability, restrictions on bringing suit, etc., as well as controls on other aircraft, restrictions on airspace, and rules governing rights of way and air traffic control.

RPV insurance will probably be available early to large corporations as part of an overall insurance package, but an individual (e.g., a crop-duster) will have a hard time getting insurance until a lot of experience has been built up in RPV operations.

Environment and Safety

Environmental acceptability. - There are only two areas of practical concern that apply to RPVs in civil uses: engine emissions and aircraft noise. Neither presents any special problems peculiar to RPVs, and no indication has been discovered that RPVs will cause an adverse environmental impact compared to alternatives.

Safety. - The areas of concern about RPV safety are collision avoidance, unplanned descent, and maintaining positive control. Collision avoidance in uncontrolled airspace is the most troublesome, since the problem of making an RPV "see" another aircraft has not yet been solved at an acceptable cost. In controlled airspace, an RPV, with the appropriate transponder and communications with the responsible air traffic control center, is as safe as a manned aircraft. The problems of minimizing danger to people and property on the ground from unplanned descent and of maintaining positive control are tractable through straightforward engineering. Much of that engineering remains to be done.

A point often overlooked is that the danger from unplanned descents is overwhelmingly borne by the occupants of the aircraft. Only about one general-aviation accident in 125 kills or injures someone on the ground.

Needed Research

There are numerous areas of needed research in the young technology of RPVs, and they are discussed at length in the section above, under the heading of AREAS OF NEEDED RESEARCH. Several of these areas are not likely to be emphasized in the military RPV programs, and suggest areas of focus for NASA sponsorship.

Recommended Next Steps

It is recommended that the following steps be undertaken by the NASA as a logical sequence for advancing the technology of RPVs for the civil sector.

- Pursue those areas of R&D identified above as not well covered by military RPV development programs, using a combination of in-house research and technology contracts to industry.
- Begin detailed R&D of safety alternatives for both collision avoidance and unplanned descent. Start with a thorough analysis to evaluate the available alternatives and lead to a selection of the most promising approach in each area (collision avoidance and unplanned descent) for a technology demonstration.
- At the same time as the technology R&D is proceeding, begin the exploratory planning for an operational demonstration. This will require stimulating the interest of a potential user (a federal agency operating in a remote area), working closely with him to perform a detailed analysis of his operation and how an RPV system would fit in, and developing a detailed plan and proposal for the demonstration.

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APPENDIX A

MARKET SURVEY TECHNIQUES AND POTENTIAL USERS INTERVIEWED

A market survey was conducted as the first step in the study for the purpose of obtaining the following kinds of information:

- Identification of potential users of remotely piloted vehicle (RPV) systems.
- Description of the mission and operational requirements of each user.
- Description of techniques and equipment currently employed in the conduct of these missions, and descriptions of the desirable features of an RPV system to perform those missions.
- The required characteristics of a system to perform any mission not practicable by present methods.
- Cost data for current methods and equipment.
- Data enabling an assessment of the potential RPV market for selected uses.

The procedures used in conducting the market survey and the potential users interviewed are described in this appendix.

Most of the information supporting the market survey was obtained through direct contact and interviews with personnel in potential user organizations. This information was further augmented from documents furnished by potential users, a number of telephone conversations, and a limited library literature search. The 45 direct face-to-face interviews and the 15 telephone interviews were conducted in accordance with a four-phase procedure that was developed, rehearsed, and field tested before the survey began. The four phases were:

1. The preliminary contact, by telephone
2. The intorduction to the interview
3. The interview proper
4. The follow-up.

The objectives of each phase were worked out in detail, and a "reminder" list of key-word memory aids was used by the interviewer to be sure all objectives were covered. Figure A-1 shows the memory aids.

The preliminary contact. - Each potential user was first contacted by telephone in order to identify the type of operation conducted, assess the feasibility for an RPV application, identify the right individuals to talk to, and determine the willingness of the agency or organization to discuss RPV uses. Appointments for the interviews were then scheduled, if appropriate. Every effort was made to identify those individuals directly involved in the field with a given activity, as well as knowledgeable planners, research scientists, and decision makers, and to avoid setting up appointments with people who were merely curious about RPVs.

The introduction to the interview. - At the beginning of each meeting, the interviewer made it clear that he was not selling RPVs or anything else, that he was working on a study contract for the NASA. That set the right tone and usually prevented any attitude of sales resistance on the part of the interviewee(s). Since most potential users had little or no knowledge of RPVs, the interviewer gave a short (5-10 minute) briefing on what an RPV is, the history of RPVs, past and present RPV programs, the state of technology, and some possible civil uses. The briefing was illustrated with photographs and charts. The objectives of the NASA study and the topics to be covered in the rest of the interview were then explained, and the interviewer made clear what he hoped to get from the interview.

The interview proper. - The interview itself was structured to get answers to the question in the interview checklist shown in Figure A-2, but the format was not rigid. The checklist is not a questionnaire. The interviewee was not asked to fill it out, or even read it, although it was shown to him and he was given a copy if he wanted it. (Few did.)

No two interviews ever followed the same exact sequence. The most effective method of interviewing was to ask for a description of the interviewee's operation, then ask clarifying and directing questions as the topics on the

1. **Contact**

   - o My name & job
   - o "J. B. suggested . . ."
   - o NASA study on civil uses of . . .
   - o Your operation, as a potential use. (You're an industry leader)
   - o Are you active in . . . Have you been? If not, who?
   - o Will you talk to us? (We want answers, not questions.)
   - o Make appointment ~1½ hrs
   - o We'd like to cover _____. Bring your _____ people.

2. **Introduction**

   - o My name
   - o NASA study
   - o Here's a copy of the contract
   - o LMSC, but not selling
   - o Your operation seems promising
   - o An RVP is . . .
   - o Here's my plan for the next hour.
   - o Background, history of RPV's
   - o RPV's are operational now
   - o Transfer technology to civil sector
   - o NASA's objectives are:
     - Promising uses
     - Required features
     - Acceptable costs
   - o I understand that you do. . .
   - o (Organization "chart")
   - o Tell me about your operation
     - mission
     - how?
     - costs
   - o Specific items
   - o Do you mind if I take notes?
   - o Do you have any questions?

3. **Interview Guide**

   - o Review at end of each section
     - --bring out questions not clearly answered
     - --ask to be referred to people who have info not answered

Wrap-up

- o Cover all missed questions
- o Where can we get the info not given?
- o Review areas where respondent has offered to help
- o Cover points we said we'd come back to
- o Are there points I haven't asked that we should cover?

4. **Follow-up**

   - o Send a note:
     - --thanks
     - --reminder to points to be followed up
     - --any points that are missed or unclear
   - o Telephone (couple of days later)
     - --follow up all points

FIGURE A-1 Memory Aids for the Four Phases of the Survey

Interview Checklist,
Market Survey

GENERAL

G1, Generally describe your operation.

G2 What are the most favorable features of your present methods?

G3 What are the main problems?

G4 What other activities (organizations) does yours interact with?

G5 Are there things you would like to do that are not practical with present methods? What?

OPERATIONAL REQUIREMENTS

O1 Do you:
- o Patrol an area or path, ending at the starting point? (distance/area)
- o Loiter (time and area)
- o Operate between points; don't return to the starting point on same trip (distance)
- o Other

O2 At what altitude do you operate now? Why?

O3 How often do you survey a given area, path, etc? (per hour, per day, per week)

O4 What environments do you operate in?
- o Weather, turbulence, sand, temperature ranges, day/night
- o Radio interference
- o Terrain, sea state
- o Launch altitude and temperature
- o Other

O5 Do you move your operation from place to place for different jobs?

O6 What is your operational profile?
- o Seasonal; stand-by
- o Hours per day/week/month
- o Trips per day
- o Continuous
- o Other

O7 Do you have to respond to emergencies?
Describe a typical situation. What frequency?

O8 Is your effectiveness related to quickness of response? How?

O9 What limits your operating time?
- o Daylight
- o Crew endurance
- o Weather
- o Other

O10 What airspeed is required (max, min)? Why?

MISSION REQUIREMENTS

M1 What do you want to look at on the ground?
What information do you want to get by looking at it?

M2 How accurately do you need to know locations of things on the ground?

M3 In your current operation, is it necessary to know the location of your aircraft precisely? How precisely?

M4 Is airborne endurance important? Why?

M5 What restrictions do you operate under?
- o Legal/regulatory
- o Policy
- o Assigned areas, radio frequencies, etc.
- o Safety
- o Other

M6 Do you operate in populated areas or areas in which there is other aircraft activity? Describe.

FIGURE A-2 (page 1 of 2) Interview Checklist

COST - BENEFIT INPUTS

C1 Review of present methods:
- o Types and quantity of equipment
- o Size and composition of crews
- o Procedures (sequence of events)

C2 Dedicated personnel and equipment?

C3 How many crews and sets of equipment are in use at one time?

C4 What other methods are you familiar with? How do you rate them?

C5 What do your present methods cost? (cost composition)

C6 What affects your costs most strongly?

C7 What is the rleiability of your equipment? How do you measure it?

C8 What are your personnel turnover rates?

SIZE OF THE MARKET

S1 How many companies/agencies conduct operations like yours?

S2 Is your operation typical in size?

S3 What is the annual budget for your operation? What does that cover
What is the breakdown?

S4 Are your activities stable, expanding, declining?
How do you see the future? Why?

S5 How rapidly is it growing (declining)?

S6 How often do you replace equipment? Why?

S7 Who collects industry-wide data? (agency or association)

METHODS OF MARKET ENTRY

(Assuming you could be shown that RPV systems were effective and economical in your operation:)

E1 How do you acquire systems?
- o Off the shelf, and modify
- o Develop requirements, turn-key
- o Contract for services
- o Develop in-house; contract or build
- o Other

E2 Would you rather operate an RPV system with your own people, or what?

E3 Do you prefer to lease, purchase, lease/purchase, or _____?

E4 Would you do your own maintenance?

E5 Would RPV's
- o Replace immediately
- o Phase in as equipment wears out
- o Add to present equipment
- o Other?

E6 What warranties or service guarantees are customary?

E7 What kind of financing is customary?

E8 How do you evaluate investments in major equipment?

E9 What is your customary approach to new equipment?
- o Test it under lease
- o Buy one and test it before buying others
- o Immediately buy as many as you need
- o Wait and see other companies' experience
- o Other

WRAP - UP

W1 What features would an ideal system have?

W2 What RPV capabilities look promising to you?

W3 What RPV features look like potential shortcomings in your operation?

W4 Can you think of any things I haven't asked about that we should have covered?

FIGURE A-2 (page 2 of 2) Interview Checklist

checklist arose. Periodically in the course of the interview, the interviewer would refer to the checklist to be sure nothing was overlooked and would ask questions that had not been covered. Notes were taken on a separate sheet of paper in whatever order they arose. As soon after the interview as possible the interviewer filled out a copy of the checklist himself, working from his notes and memory.

At the end of the interview, the interviewer went over all previously unanswered questions, asked where to get answers that were not known by the interviewee, reviewed any promises for follow-up help to be sure he understood and that the interviewee remembered, and thanked the interviewee. A typical interview, including the introduction, took $1\frac{1}{2}$-2 hours.

The follow-up. Every interview was followed up with a thank-you letter, which included a reminder of any follow-up items that might have been agreed to. A telephone follow-up was sometimes made, if necessary and appropriate.

The interpersonal climate. - Almost all interviewees were friendly and cooperative. Considerable thought was given to how the interviewer should conduct himself to encourage and build on that attitude. Figure A-3 shows some notes and thoughts that were compiled to guide the interviewers.

Potential users interviewed. - Personal, direct interviews were conducted with forty-five different agencies and organizations. However, the input to the study data base is actually larger, since more than one office or division was contacted in several of the agencies. In addition, fifteen interviews with potential users were conducted by telephone and well over thirty more contacts proved to be valuable sources of needed information. In varying degrees of detail all interviews were productive in developing information on operations and mission requirements and on present methods and costs. However, it was found that individual users seldom have the data needed to assess market size. For those data, it was necessary to turn to government agencies and industry associations that collect nationwide statistics. Frequently internal reports or other document references were provided

NOTES ON INTERPERSONAL CLIMATE

1. Avoid the areas where respondent can't contribute. Be aware of when we get into an area where the respondent doesn't know.
2. Where respondent <u>does</u> help, leave it open for follow-up.
3. Start from topics of concrete knowledge, before moving to topics of speculation and projection.
4. Get respondent involved early in the interview. Put him at ease. Explain frankly why you're there. Stress similar background. Be personal. "Would you describe......." "Would you tell me about....."
5. Reflective listening. Feedback his comments in the form of clarifying questions.
6. Elicit "best estimates" by not threatening him. Make it easy to answer. "Off the top of your head."
7. Ask for help. "This is important." "You're not alone in this." He's a contributor, not a "thing" to be drained of information.
8. Involve him in joint speculation.
9. Ask, early, "Is it all right if I take notes?" Say, "I'll send you a copy."
10. Send a "thank you" note afterward, along with the copy.
11. "Write it down, feed it back."
12. If you're hung up on a point (there's a conflict, an uncertainty, a reluctance), write it down and come back to it. Be sure to come back to it.
13. ~~Warn him~~ Let him know in advance that we're going to cover some specific questions, but we are the ones to be flexible. Ask him to discuss things at his own pace and sequence.
14. If the respondent doesn't know costs, ask questions like "How many people? What education level? Are there GS ratings for those jobs?"
15. Don't ask who else to talk to until the end, when you're reviewing and summing up.
16. Tell him the ground we hope to cover. Tell him at the beginning that "we may ask you questions that don't make sense. If we do, tell us."
17. Make him comfortable. Use first names, etc., if possible and appropriate.
18. Keep checking on your understanding of his answers. Feedback. Ask if you've noted the right things.

FIGURE A-3 (page 1 of 2) Notes on Interpersonal Climate

19. A good idea is to dictate into a tape recorder <u>after</u> the interview. Include your feelings.

20. Document each interview immediately.

21. On questions he didn't answer, wait until the end and clarify whether he <u>wouldn't</u> or <u>couldn't</u>. Ask his help about how we can get the information.

22. As a subliminal clue to keep us identified with NASA, not LMSC, have an "artifact" on display, e.g., a copy of the contract, a notebook with NASA on the cover, etc.

23. We may run into people who are talking to competitors about buying RPVs. Clarify our role. We're not selling; we work for NASA; we don't want him to give us confidential information from our competitors.

24. Respect any confidentiality of relationships between government agencies. Back off, and get NASA to open doors if necessary. Use our disclaimer : "We're a NASA contractor"

25. Ask NASA: Can we tell respondent we will arrange to send them a copy of the final report? What is in the public domain?

26. Get information about specific present operations from individual operators. Get industry-wide data from trade associations.

27. Silence is OK. "If there's silence, you're in charge." "If at any time you have a question, please ask it."

28. "If there are questions I haven't asked, and you feel the information is important, please help me by bringint it out."

29. Interview climate is the key. Content and method are tied together.

30. Be sensitive to <u>respondent's</u> point of view. Focus on that.

31. Sum up at the end. Cover all issues that were left hanging.

32. Leave the door open for additional information. "If you have any additional ideas, call me at _________".
You are always pleased to listen.

FIGURE A-3 (page 2 of 2) Notes on Interpersonal Climate which covered details not possible during the personal interviews. Figure A-4 shows the organizations interviewed, listed under the headings into which the 35 uses were grouped. Some agencies or companies appear under more than one heading because they have more than one potential use for RPVs. Those organizations that were data sources rather then potential users are indicated as such.

POTENTIAL CIVIL RPV USERS INTERVIEWED

(Listed by general use category,
showing specific application or as a data source)

SMALL AREA SURVEILLANCE

Agency	Application
Los Angeles Police Dept.	Law Enforcement
Los Angeles County Sheriff Dept.	Law Enforcement
San Mateo County Sheriff Dept.	Law Enforcement
Richmond Police Dept.	Law Enforcement
Oakland Police Dept.	Law Enforcement
Houston Police Dept.	Law Enforcement
San Francisco Police Dept.	Law Enforcement
East Bay Regional Park District	Law Enforcement
San Jose Police Department	Law Enforcement
Standard Oil Refinery	Property Security
Southern Pacific Railroad	Property Security
Nuclear Regulatory Commission (Sandia Laboratory)	Property Security
Clean Bay, Incorporated	Oil Spill Surveillance
U. S. Coast Guard	Oil Spill Surveillance
San Jose Fire Department	Urban Fire Detection
U. S. Forest Service	Forest Fire Mapping
California Dept. of Forestry	Forest Fire Mapping
Bureau of Land Management	Forest Fire Mapping
Bureau of Indian Affairs	Forest Fire Mapping
U. S. Forest Service	Spray Block Marking
U. S. Coast Guard (NASA Lewis Research Center)	Ice Breaker Navigation
Cartwright Aerial Survey	Photogrammetry
Mardela Corp.	Commercial Fish Spotting
Environmental Protection Agency U. S. Coast Guard	Small Waters Pollution Monitoring
American Society for Industrial Security	Data
Association of American Railroads	Data
Aerial Law Enforcement Association	Data
Mardix Security	Data
Lockheed Security	Data
Burns Detective Agency	Data

LARGE AREA SURVEILLANCE

Agency	Application
Los Angeles County Sheriff Dept.	Law Enforcement
East Bay Regional Park District	Law Enforcement
U. S. Customs Service	Law Enforcement
Drug Enforcement Agency	Law Enforcement
U. S. Forest Service	Fire Detection
East Bay Regional Park District	Fire Detection
U. S. Bureau of Land Management	Fire Detection
California Dept. of Forestry	Fire Detection
Bureau of Indian Affairs	Fire Detection
U. S. Bureau of Mines	Monitor Strip Mine Reclamation and Surface & Underground Mine Fires

FIGURE A-4 (page 1 of 3) Potential Users Interviewed

Agency	Application
U. S. Coast Guard	Fishing Law Enforcement
National Marine Fisheries Service	Fishing Law Enforcement
California Dept. of Fish & Game	Fishing Law Enforcement
U. S. Geological Survey	Mineral, Lands, & Vegetation monitoring
U. S. Forest Service	
Bureau of Land Management	
Environmental Protection Agency	
U. C. Berkeley, Remote Sensing Lab.	
U. S. Coast Guard	Oil Spill Detection
NASA Lewis Research Center	Ice Mapping & Research
U. S. Coast Guard	
U. S. Geological Survey	
Los Angeles County Sheriff Dept.	Search - Personnel, Aircraft, Boats, Ground Vehicles
East Bay Regional Park District	
U. S. Coast Guard	
Civil Air Patrol	
Bureau of Indian Affairs	
U. S. Customs Service	
Drug Enforcement Agency	
Federal Bureau of Investigation	
LINEAR PATROL	
California Highway Patrol	Motorist Aid & Law Enforcement
Kansas State Highway Patrol	
also including	
Federal Bureau of Investigation	Track Suspect Automobiles
All Police & Sheriff Depts.	
U. S. Customs Service	
U. S. Border Patrol	
U. S. Border Patrol	Search for Illegal Border Crossing; Personnel & Vehicles
U. S. Customs	
Standard Oil Pipeline	Pipeline Patrol
Williams Pipeline Co.	Pipeline Patrol
El Paso Natural Gas Co.	Pipeline Patrol
Southwest Gas Co.	Pipeline Patrol
Pacific Gas & Electric Co.	Pipeline & Powerline Patrol
American Petroleum Institute	Data
Association of Oil Pipelines	Data
Environmental Protection Agency	Pollution Monitoring along Rivers and Shorelines
U. S. Coast Guard	
AERIAL SPRAYING	
Ohio Dept. of Natural Resources	Crop Spraying Operations
Precissi Flying Service	
U. S. Forest Service	
Chevron Chemical Co.	Data
NAMCO Agricultural Chemicals Co.	Data
California Agricultural Chemical & Feed Div.	Data
University of North Dakota	Data
National Agricultural Aviation Assoc.	Data
International Flying Farmers Assoc.	Data
California Div. of Forestry	Spray Fire Retardants
U. S. Forest Service	

FIGURE A-4 (Page 2 of 3) Potential Users Inverviewed

Agency	Application
AIR TO AIR SURVEILLANCE	
U. S. Customs Service	Track Illegal Aircraft Border Crossings
MONITOR GROUND SENSORS	
U. S. Border Patrol U. S. Customs Service	Monitor Intrusion Detection Systems
Pipeline Co.'s	Monitor Cathodic Protection Systems
Civil Air Patrol	Locate Emergency Landing Transmitters
Nuclear Regulatory Commission (Sandia Laboratory)	Track Transport of Nuclear Materials
AIRCRAFT RESEARCH	
Lockheed California Co.	Testing Stopped & Stowed Rotor Concepts
COMMUNICATIONS RELAY	
U. S. Forest Service Bureau of Indian Affairs Nuclear Regulatory Commission (Sandia Laboratory) California Dept. of Forestry	Communication Relay Between Ground Units
ATMOSPHERIC SAMPLING	
Environmental Protection Agency	Air Pollution Monitoring
Bay Area Pollution Control District	Air Pollution Monitoring
U. S. Weather Service U. S. Forest Service	Weather Data and Forecasts
NOAA – Severe Storms Laboratory	Severe Storms Research

FIGURE A-4 (page 3 of 3) Potential Users Interviewed

APPENDIX B

POTENTIAL USES AND PRESENT METHODS

This appendix presents summary descriptions of the 35 potential uses for RPVs that were defined in the study. For each one, there is a description of the use, present methods used, shortcomings of present methods, desired features of a system for the use, and some indications of the scope and size of the activity. The summary descriptions are given in the sequence shown in Table B-1.

POTENTIAL USE: Security of High-value Property

DESCRIPTION: The kind of security operation envisioned would involve two types of activity: (a) periodic aerial patrol of the complete area to look for theft, fire, or other emergencies in progress, and (b) on-call aerial response to investigate suspected emergencies reported by other means. When an emergency or a suspicious activity is detected, the patrol aircraft would remain over the location of the activity, take a closer look, and maintain surveillance while ground units are sent to the scene. If the suspicious activity involves an apparent crime, the patrol aircraft would follow any suspect escaping on foot or in a vehicle and direct ground units to intercept him.

PRESENT METHODS: Some general aerial security patrol is done by police departments using manned aircraft. However, most security patrol of relatively small high-value properties, e.g., railroad yards and refineries, is done on foot or in ground vehicles. In some cases, stationary TV cameras are used for continuous surveillance, both indoors and outdoors.

SHORTCOMINGS OF PRESENT METHODS: Manned-aircraft security patrol is expensive and noisy. Helicopter patrol has been tried by at least two major railroad yards and abandoned because of those shortcomings. Stationary TV cameras are suitable for some applications, but are inflexible.

DESIRED FEATURES: An ideal system would be much less noisy and much less costly to own and operate than manned-aircraft systems.

INDICATIONS OF SCOPE: There are at least 20 major railroad companies operating an average of 40 railroad yards, more then 600 petroleum and petrochemical refineries, and an unknown number of large industrial facilities, warehouse districts, etc., in the United States. In addition, the security of the 2200 offshore oil installations is becoming increasingly a matter of concern.

POTENTIAL USE: Surface Mine Patrol

DESCRIPTION: Extensive surface mine monitoring operations are conducted by the U.S. Bureau of Mines, on federal lands, and the individual states on privately owned mines, for the purpose of locating the following:

- Evidence of non-compliance with land reclamation regulations
- Fires in filled coal strip mines and mine waste materials, as well as fires in abandoned underground mines
- Ground subsidence in or near populated areas
- Rivers and streams showing effects of acid mine drainage.

PRESENT METHODS: LANDSAT satellite imagery is used to the extent possible with follow-up verification through aerial photographic and infrared missions. Visual inspections at ground level are also made providing the area is relatively small and accessible and personnel resources are available.

SHORTCOMINGS OF PRESENT METHODS: Satellite data do not provide required resolution, and the high cost of manned aircraft severely limits the amount and frequency of the coverage obtained.

DESIRED FEATURES: The preferred system would be low-cost, probably portable, capable of obtaining high-resolution black and white, as well as color, photographs of areas up to 10 miles (16 km) long. Thermal imagery is desirable for fire detection. Economy and simplicity of operation would permit expanding the number and frequency of the surveys. Neither nighttime flights nor real-time information are required; however, image location accuracy must be at least equal to that achievable from manned aircraft.

INDICATIONS OF SCOPE: In 1971 over 206,000 acres (800 km^2) of land was mined and 163,000 acres (660 km^2) reclaimed (most recent data available). The

- Small-area surveillance
  - Security of high-value property
  - Surface-mine patrol
  - Oil-spill clean-up direction
  - Wildfire mapping
  - Ice-floe scouting
  - Spray block marking and tracking
  - Ground truth verification
- Large-area surveillance
  - Search (and rescue)
  - Wildfire detection
  - Fishing Law enforcement
  - Oil-spill detection
  - Ice mapping
  - Fish spotting
  - Law Enforcement
  - Surface resource survey
- Linear patrol
  - Pipeline
  - Highway
  - Border
  - Power line
  - Waterway and shoreline pollution detection
- Aerial spraying
  - Agriculture
  - Wilderness
  - Wildfire fighting
- Monitoring ground sensors
  - Detecting activities
  - Monitoring cathodic protection of pipelines
  - Emergency rescue beacons
- Aircraft research
  - Aerodynamic testing (e.g., transition)
  - Remote measurements
- Air-to-Air surveillance
- Security of nuclear materials in transit
- Communications relay
  - Ad hoc
  - Permanent
- Atmospheric sampling
  - Storm research
  - Meteorology
  - Mapping pollutants

TABLE B-1 POTENTIAL USES DEFINED

Bureau of Mines and Bureau of Land Management have jurisdiction over 460 million acres (1.9 million km^2) of federal lands (mined area unknown); 32 states have enacted surface-mine and mined-land reclamation laws.

POTENTIAL USE: Oil-spill Clean-up Direction

DESCRIPTION: Cleaning up oil spills on water requires that the oil be contained with booms, then recovered with skimmers, debris boats, sorbents, and suction trucks. Oil slicks on large bodies of water are hard to locate because they cannot be seen well at a distance from near the surface. Aerial observation is used to direct boats and skimmers to the oil and to direct the placement of the booms.

PRESENT METHODS: Manned helicopters are used in present operations.

SHORTCOMINGS OF PRESENT METHODS: Helicopters are costly to lease, operate only in daylight, and are frequently diverted for transportation of personnel and equipment.

DESIRED FEATURES: An ideal system would be less costly than a manned helicopter, would operate day or night, and would be dedicated to the aerial-observation role. It would be available for quick response on short notice and would provide a real-time picture of the oil and the clean-up operation. The individual pieces of surface equipment (e.g., boats, skimmers) would be readily identifiable in the aerial imagery.

INDICATIONS OF SCOPE: Of the 100 incorporated oil-spill clean-up copperatives in the United States, 80 are currently functioning. These are non-profit organizations whose member companies are in some aspect of the oil business. Each cooperative stands ready to clean up oil spills in a defined geographic area, and each has detailed contingency plans and has equipment either dedicated or committed to it for immediate use in a spill.

POTENTIAL USE: Wildfire Mapping

DESCRIPTION: The mission of wildfire mapping consists of flying over a wildfire and furnishing the characteristics of the fire to fire-control officers at periodic intervals and in enough detail to allow timely decisions to be made about the use of suppression resources. During control operations, these decisions are based on the dynamic characteristics of the fire perimeter and its relationship to fuels, weather, topography, values threatened, and the availability of suppression forces. During the mop-up, decisions are based on the identification and location of latent hot spots such as smouldering roots and logs.

PRESENT METHODS: Wildfire mapping is presently done from manned aircraft, using both infrared (IR) sensors and visual observation. IR sensors are preferable because they detect small "spot" fires more readily than visual observation.

SHORTCOMINGS OF PRESENT METHODS: Manned aircraft are costly to operate, and the hard-copy imagery of the fire produced by present IR equipment is produced aboard the aircraft. There is a delay in delivering the imagery physically to the main camp for photointerpretation and use.

DESIRED FEATURES: An ideal system should be less costly to own and operate than a manned-aircraft system and should provide near-real-time hard-copy imagery to both the main fire camp and the zone camps around the fire perimeter.

INDICATIONS OF SCOPE: More than 4000 wildfires were fought by the U.S. Forest Service in 1974 (the most recent year for which figures are available). More than 13,000 flight hours were flown by manned aircraft for wildfire mapping of those fires.

POTENTIAL USE: Ice Flow Scouting to Assist Ice Breaking Operations

DESCRIPTION: The U.S. Coast Guard conducts ice breaking operations in the navigable waters of the Great Lakes, Alaska, and the North Atlantic.

PRESENT METHODS: Ice breaker vessels are stationed at key locations to maintain open traffice lanes primarily for commercial ships during the winter/ice season. When available, aircraft surveillance is used to guide the Coast Guard ships to the most likely areas for ice breaking services.

SHORTCOMINGS OF PRESENT METHODS: Limited aircraft availability and frequent poor weather conditions restrict aerial surveillance operations. Ice breakers are then limited to near-sea-level observation (horizon line of sight), and frequently rely on chance to locate feasible paths for breaker operations. Also, at times ships are restrained in part because of lack of any information useful in conducting operations.

DESIRED FEATURES: An RPV capable of being launched and recovered from the ice breaker would be desirable. This RPV would be tracked by the ship's radar, be controlled from the ship, and be equipped with an imaging sensor with direct readout aboard ship. Daylight vidicon might be sufficient to provide the ice breaker with adequate navigation information; however, operation during fog and nighttime would be desirable. The range of the RPV need be no longer than 25-30 miles (40-50 km) with a one-hour total flight time.

INDICATIONS OF SCOPE: Coast Guard application would be limited to the number of operational ice breaker vessels. However, should a reliable, effective, and low cost RPV system be developed, it is envisioned that other applications, such as search and rescue operations from all ships and navigation aid to commercial vessels, could provide an expanded market.

POTENTIAL USE: Spray Block Marking and Tracking

DESCRIPTION: The U.S. Forest Service is investigating the use of an airborne TV monitoring system to guide the flight path of aerial spraying operations over forests and other wilderness areas.

PRESENT METHODS (CONCEPT): The concept envisions a helicopter hovering over the spray area with closed-circuit TV viewing of ground area and the spray aircraft. A crew of three is required. The TV monitor traces the flight path of the spray aircraft on a transparent overlay placed over the screen of the tracking TV monitor. By comparing the path of the spray aircraft with lines on the overlay, information necessary to correct the spray-aircraft flight path and maintain desired swath width is determined and relayed to the spray-aircraft pilot by radio.

SHORTCOMINGS OF PRESENT METHOD (CONCEPT): The system has not been demonstrated; therefore, there are no operational data to evaluate. However, it would appear that the high cost of helicopter operations and a 3-man crew would inhibit potential user acceptance.

DESIRED FEATURES: A potentially attractive system would be a low cost, probably rotary wing type, RPV to replace the helicopter. The payload would be a stabilized video camera transmitting to a ground-stationed receiver where flight path traces would be made and corrective information forwarded to the spray aircraft pilot.

INDICATIONS OF SCOPE: The extent of spraying operations by the Department of Agriculture is unknown.

POTENTIAL USE: Ground Truth Verification

DESCRIPTION: The purpose of this activity is to obtain high-resolution aerial photographs of precisely located areas on the ground. The photographs are correlated with data from the LANDSAT satellite to allow interpretation of LANDSAT data on natural resources. Typical areas of operation are croplands, forests, and deserts.

PRESENT METHODS: The photography is typically obtained from a light, twin-engine fixed-wing aircraft by a two-man crew. The pilot locates the target from landmarks and flies a precise path over it. The cameraman takes pictures at 5-second intervals, alternating between two manually operated 35mm cameras mounted in the aircraft. The aircraft is typically rented.

SHORTCOMINGS OF PRESENT METHODS: Present methods are satisfactory. The operation is a low-budget one, and savings would be welcomed.

DESIRED FEATURES: An ideal system would be less costly than a manned aircraft, would have very precise navigation for location of target areas, and would produce high-resolution photographs. A stabilized camera mount would be desirable.

INDICATIONS OF SCOPE: Federal agencies currently employing aircraft for photogrametric survey include NOAA, U.S. Geological Survey, and the Department of Agriculture. In addition there are over 100 private aerial survey companies in the U.S., and approximately 45 geophysical survey companies, some of which are in Canada.

POTENTIAL USE: Search (and Rescue)

DESCRIPTION: In addition to the potential application of an RPV to track downed aircraft by monitoring Emergency Locator Transmitters (ELT), visual search operations also appear promising. Numerous search activities are conducted each year to locate vessels at sea, lost hikers, or campers in difficulty, and downed aircraft with inoperable ELTs.

PRESENT METHODS: Current methods include aerial reconnaissance by the U.S. military, U.S. Coast Guard, the Civil Air Patrol, ground search parties, and ships at sea. Most operations are successful.

SHORTCOMINGS OF PRESENT METHODS: Poor weather and darkness limit air and sea search effectiveness, as well as ground search progress. Quick response under all weather conditions is essential to improving the likelihood of individual survival. Also, in cases of great uncertainty of the general location of those lost or missing, extensive air operations and ground search parties are required over very large areas. These operations can become very expensive.

DESIRED FEATURES: Preferred RPV system performance characteristics would include long endurance (8 to 10 hours), all-weather capability, sensors and data link providing high resolution imagery through fog, haze, and rain. Targets would include people, aircraft and boats at sea, plus vehicles and small fires on land. Low cost, simplicity of operation and high navigation accuracy are also essential features.

INDICATIONS OF SCOPE: Many federal, state, and local government agencies conduct search and rescue operations. Quantities were not determined.

POTENTIAL USE: Wildfire Detection

DESCRIPTION: The mission of aerial wildfire detection consists of flying over large areas of forest, brush, grasslands, detecting small, latent-stage fires, and determining their locations with enough precision to dispatch ground units to control them. The main idea is to locate fires started by lightning storms before the fires can spread. The aerial detection system would be based at a location central to the protected region and would fly missions over areas of the region that have experienced lightning storms. The missions would be flown as soon after the storm as the clouds have cleared, usually a very few hours after the lightning activity.

The aerial detection system is not responsible for locating storms, selecting areas for overflight, or suppressing the fires. These activities are already provided for.

PRESENT METHODS: Aerial wildfire detection is presently done from manned aircraft, using both infrared (IR) sensors and visual observation, especially when there is little smoke.

SHORTCOMINGS OF PRESENT METHODS: The major shortcoming of present methods is their relative costliness.

DESIRED FEATURES: An ideal system should be less costly to own and operate than a manned-aircraft system.

INDICATIONS OF SCOPE: More than 4000 wildfires occurred in 1974 (the most recent year for which figures are available). Nearly 39,000 flight hours were flown by manned aircraft for wildfire detection in 1974.

POTENTIAL USE: Law Enforcement

DESCRIPTION: Federal, state and local law enforcement agencies conduct aerial operations for a variety of crime-deterrent and air-surveillance activities. The primary function of airborne police is to assist ground units in identifying suspicious or obvious criminal acts, directing these ground units to exact locations of crime activity, tracking suspect personnel or vehicles, providing traffic advisories, and conducting search and rescue missions.

PRESENT METHODS: Both fixed-wing and rotary-wing aircraft are employed, although helicopters appear to be preferred because they are not limited to minimum altitudes in urban areas, and they can fly slowly and hover when required. Most flights are conducted with both a pilot and an observer, and tend to concentrate over areas with high crime incidence. Effective radio communications with ground units is maintained.

SHORTCOMINGS OF PRESENT METHODS: Law enforcement agencies utilizing aerial surveillance are unanimously enthusiastic about the effectiveness of the system. The principal shortcomings are the high operational maintenance costs (helicopter costs being substantially higher than fixed wing aircraft). Recently, San Francisco, California terminated its police air operations because of high costs.

DESIRED FEATURES: It is unlikely that an RPV system would replace manned aircraft in law enforcement operations. However, it appears that RPVs could effectively augment police aerial operations. The preferred RPV system would

have a flight endurance of 4 to 6 hours, carry a video or other sensor payload capable of transmitting high-resolution imagery to a ground control station and mobile units, and capable of positive and high-accuracy flight control.
INDICATIONS OF SCOPE: There are well over 200 law-enforcement agencies in the U.S. conducting air operations.

POTENTIAL USE: Surface Resource Survey
DESCRIPTION: LANDSAT satellite multi-spectral scanner imagery with low altitude verification is widely used to locate and assess a broad range of natural earth resources. Independently, a number of agencies both public and private conduct aerial surveys from aircraft using a variety of sensors to investigate the characterisitcs of the following earth resources:

- Agriculture, forestry and other vegetation
- Geology and mineral resources
- Hydrology and water resources
- Geography, cartography and cultural resources
- Oceanography and marine resources

LANDSAT data are used wherever possible.
PRESENT METHODS: Aircraft such as the C-130, Electra NP3A, RP57F, and a number of general-aviation aircraft are used. Several types of still and motion picture cameras, infrared systems (line scanners, scanning spectrometers, radiometers), and radiation thermometers are employed aboard the aircraft. Passive microwave radiometers, scatterometers and side-looking airborne radar (SLAR) are also used depending upon the type of remote sensing required.
SHORTCOMINGS OF PRESENT METHODS: The high cost of aircraft operations and image processing tends to limit the extent of the surveys required. As an example, the Bureau of Land Management desires aerial photo maps of all of the 460 million acres (1.9 million km^2) of Federal lands under the jurisdiction of the Bureau; however, the cost is prohibitive.
DESIRED FEATURES: An attractive RPV system requires good navigation accuracy, long endurance, and the ability to acquire high-resolution imagery from a number of different sensor types. Overall costs much less than manned aircraft are essential.

INDICATIONS OF SCOPE: The Bureau of Land Management, Bureau of Indian Affairs, U.S. Forest Service, as well as over 150 geophysical survey companies and aerial photogrammetric contractors are potential customers.

POTENTIAL USE: Fishing-Law Enforcement

DESCRIPTION: Fishing-law enforcement by aerial observation and investigation is concerned with detecting illegal fishing in U.S. regulated coastal waters. It is envisioned that RPV systems would supplement the Coast Guard's surface ships and manned aircraft patrols by performing the routine large-area surveillance for detection, location, and identification of fishing fleets and large fishing vessels. The manned aircraft or surface ships would then spot check at approprate intervals by close inspection to determine the precise location of fishing vessels.

PRESENT METHODS: The locations of foreign fishing fleets and vessels are monitored now by manned-aircraft patrols and surface vessels.

SHORTCOMINGS OF PRESENT METHODS: Present methods are adequate for observation and enforcement with the present 12 mile (20 km) limit. The possible use of RPV (remotely piloted vehicle) systems for such observation will become of interest if international conventions extend the limits of regulation to a 200 mile (320 km) limit, since the resulting, sudden 16-fold increase in area to be regulated will tax the capacity of the U.S. Coast Guard severely.

DESIRED FEATURES: An ideal system would be able to patrol large areas of ocean, covering each area frequently. It would be able to detect, discriminate, locate, and identify fishing vessels accurately and provide the information to surface units or to a shore base. It should do all this at a much lower cost than manned-aircraft patrols.

INDICATIONS OF SCOPE: An increase from a 12 mile (20 km) limit to a 200 mile (320 km) limit would increase the area to be regulated by a factor of sixteen, from 150,000 miles^2 (185,000 km^2) to 2.2 million miles^2 (5.6 million km^2).

POTENTIAL USE: Oil Spill Detection

DESCRIPTION: Oil spills in harbors and near refineries usually are quickly detected and there is minimum delay in initiating clean-up operations.

However, accidental spills or intentional purging of tankers at sea, or spills from unattended offshore pumping stations, do present problems in early detection, corrective action, and determination of responsibility. Concern is for spills near shore and along coastal shipping lanes.

PRESENT METHODS: Surface ship and aerial visual patrols are conducted, and a number of sensors have been tried to improve detection effectiveness. The U.S. Coast Guard is now testing and evaluating a multi-spectral sensor especially developed for oil detection.

SHORTCOMINGS OF PRESENT METHODS: Visual observations, both from the surface and airborne, are generally unreliable and ineffective. Various sensors have shown promise in oil detection depending upon oil type, reflectivity, and oil/water mix. In any event, the high cost of aerial operations limits the extent of the coverage, and some spills are detected late; thus there is difficulty in identifying the violators.

DESIRED FEATURES: The RPV should be capable of long-distance patrol equipped with oil detection sensors and real-time readout at ground stations. Capability of accurate location is required and identification (such as ship registry, name, etc.) of the oil spill source is desirable.

INDICATIONS OF SCOPE: There are over 2000 offshore installations in the Gulf of Mexico and several thousand miles of U.S. coast line to be patrolled.

POTENTIAL USE: Ice Mapping

DESCRIPTION: The NASA Lewis Research Center, in cooperation with the U.S. Coast Guard and the National Weather Service, conducts a program to provide radar imagery and interpretive ice charts to assist vessel navigation in the Great Lakes to avoid ice areas which impede vessel transit. Ice-area boundaries are located and ice thickness measured. Information is furnished the vessels in near-real-time.

PRESENT METHODS: A multi-engine, U.S. Coast Guard C-130 aircraft equipped with an all-weather microwave side-looking airborne radar (SLAR) surveys selected regions of the Great Lakes. Radar imagery is transmitted to the U.S. Coast Guard Ice Navigation Center in Cleveland, Ohio, over two possible communication networks: (1) a near-real-time transmission from the aircraft by an S-Band microwave downlink and on to the Ice Navigation Center or (2) by a continuous real-time transmission from the aircraft to the SMS/GOES Satellite in geosynchronous orbit by a VHF uplink from the aircraft and a subsequent microwave downlink from the satellite to the Wallops Island, Virginia, ground station, and on to the Ice Center by special dedicated telephone lines.

At the Ice Center, the SLAR data is used to generate a high-quality SLAR image and ice thickness measurements. As soon as a Product is prepared and at other prearranged times throughout the day, these Products will be rebroadcast over the Lorain MARAD and Central Radio Marine VHF networks to vessels operating on the Great Lakes equipped with the appropriate facsimile receiver.

SHORTCOMINGS OF PRESENT METHODS: The current system is very effective, having been developed expressly for this operation. The C-130 requirement is dictated by the size and weight of the airborne equipment. However, C-130 operational costs are high, and a less expensive system would allow increasing the frequency of the operations.

DESIRED FEATURES: An RPV which could be accurately navigated over a preprogrammed flight path approximately 1700 miles (2700 km) long, and perform the same functions now conducted aboard the C-130 less expensively, would be desirable.

INDICATIONS OF SCOPE: The Great Lakes program conducts an average of 2 flights per week throughout the winter season. Expansion is being considered to include shipping lanes to Canada, Hudson Bay, and the North Atlantic Coast.

POTENTIAL USE: Fish Spotting

DESCRIPTION: The purpose of this activity is to find and identify schools of fish in the ocean and direct commercial fishing boats to them. The faster a boat can fill its hold with fish and return to port, the greater the rate at which it earns money. Aerial fish spotting cuts down the time spent in searching for fish.

PRESENT METHODS: Many present commercial fishing boats carry a helicopter or float-equipped fixed-wing aircraft. These are operated by a contract fish spotter who flies and maintains his own aircraft.

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SHORTCOMINGS OF PRESENT METHODS: Visual observation works only in daylight and fair weather and cannot spot schools below the surface.

DESIRED FEATURES: An ideal system would find schools of fish and identify their type whether they were on or below the surface and in day, night, or fog.

INDICATIONS OF SCOPE: Virtually all of the U.S. tuna boats now carry an aerial fish spotter. Other commercial fishing boats could benefit from them and could be expected to use them if they were made economically feasible.

POTENTIAL USE: Pipeline Patrol

DESCRIPTION: Gas and oil pipelines are patrolled to detect and report leaks and potential hazards to the pipeline. Leaks are indicated by stains, changes in vegetation, dead wild life, gas plumes, etc. Primary hazards are construction and agricultural activities near the buried pipe and excessive soil erosion where the pipe crosses streams and gullies. Another item to be observed is the position of the semaphore indicators that signal a malfunction of the cathodic protection system that protects the pipe against corrosion. When any of these observables indicates a potential problem, ground personnel are dispatched to prevent or correct the problem.

PRESENT METHODS: Pipelines are patrolled on foot, on horseback, and in ground vehicles, but the most common method is by a single pilot-observer in a single-engine fixed-wing light aircraft.

SHORTCOMINGS OF PRESENT METHODS: Present methods are satisfactory, but typically cost $0.30 to $0.38 per line mile ($0.19-0.24 per line kilometer) patrolled.

DESIRED FEATURES: An ideal system would have capabilities equivalent to those of a manned aircraft, but would be less costly to own and operate.

INDICATIONS OF SCOPE: According to the American Petroleum Institute there are 250,000 miles (400,000 km) of interstate gas transmission pipelines, and 225,000 miles (360,000 km) of oil pipelines. There are over 100 companies engaged in oil transmission alone in the United States. These are patrolled, on the average, once per week, and the most common method is from a manned aircraft.

POTENTIAL USE: Highway Patrol

DESCRIPTION: The mission is to patrol remote stretches of highways to locate accidents, motorists in trouble, stolen or wanted vehicles, and unsafe road conditions such as landslides, flooded stretches, or washouts. Upon discovery of any of the above items, the information is provided to a dispatcher who directs ground units to take appropriate action.

PRESENT METHODS: A number of states patrol heavily travelled highways with manned aircraft, and all states patrol with automobiles.

SHORTCOMINGS OF PRESENT METHODS: Many stretches of highway are too remote or too lightly travelled to justify the expense of regular patrol by manned aircraft. It is on these very stretches that motorists in trouble, accidents, and unsafe road conditions tend to remain undiscovered for the longest time.

DESIRED FEATURES: An ideal system for this use would have the capabilities of a manned-aircraft patrol at a much lower cost. All-weather and day/night operations would also be desirable.

INDICATIONS OF SCOPE: At least 26 states patrol highways with manned aircraft. In one operation (i.e., California), each of the 3 fixed-wing aircraft is operated 2900 hours per year, and each of 3 rotary-wing aircraft is operated 1800 hours per year. These operations are conducted along routes with histories of high incidence of accidents. Several thousands of miles of state and country receive little or no coverage because of lack of resources and the high cost of manned aircraft patrol.

POTENTIAL USE: Border Patrol

DESCRIPTION: The U.S. Border Patrol, Bureau of Customs, and the Drug Enforcement Agency each conduct aerial operations in the enforcement of federal immigration and drug traffic regulations. The activities are designed to detect and apprehend illegal alien border crossers, on foot or in vehicles, and suspect aircraft and boat traffic. The Border Patrol conduct routine, daily aerial surveillance of international borders searching for evidence of illegal aliens.

PRESENT METHODS: As an example, the Border Patrol employs Piper Super Cubs and Cessna 182 aircraft along the Mexican border the Pacific Coast to

Brownsville, Texas. Flight altitude varies between 500 and 700 feet (150-210 m) when practicable, seeking evidence of border violations on foot or by ground vehicle. In addition, seismic and magnetic sensors are located along known crossing paths, and I.R. sensors are installed in tunnels and culverts. These are monitored at communications stations. Any indication of illegal entry into the U.S. is forwarded to ground mobile units that investigate at the location of suspect activities.

SHORTCOMINGS OF PRESENT METHODS: Current use of manned aircraft is a proven success. Limitations in maximum effectiveness is because of restriction to daylight operations and need for more aircraft. Night observation systems (LLTV and searchlights) are being tested; however, the characteristic noise of approaching conventional aircraft tends to negate any advantage of surprise. Most border crossings occur at night.

DESIRED FEATURES: A low-cost RPV capable of being accurately navigated along the border and providing high-resolution, real time imagery detecting personnel or vehicle movement would effectively augment present manned aircraft operations. Quiet night operation is especially desirable.

INDICATIONS OF SCOPE: There are approximately 22 aircraft and 50 pilots presently assigned to the southern U.S. border. Again, these are limited to daytime operations. Expansion of surveillance in underway along the Canadian border in anticipation of increased illegal border crossings during the Olympic Games.

POTENTIAL USE: Power-Line Patrol

DESCRIPTION: Electric power transmission lines are patrolled routinely to detect and report broken insulators, structural problems with towers (e.g., erosion around the base), and "hot spots" such as overheated transformers. When a problem is detected, ground units are dispatched to correct the problem. When a break occurs, an emergency inspection is made to locate it. Storms are the most common cause of breaks, however, and usually prevent an immediate aerial inspection.

PRESENT METHODS: Power lines are patrolled on foot, on horseback, in ground vehicles, and in fixed-wing light aircraft and helicopters.

SHORTCOMINGS OF PRESENT METHODS: Present methods are satisfactory, but a less costly method would be desirable. Aerial patrol typically costs $0.30-0.38 per line mile ($0.19-0.24 per line kilometer) patrolled by fixed-wing aircraft. Helicopter patrol is more costly, but is done incidentally with aircraft that are owned primarily for other uses.

DESIRED FEATURES: An ideal system would allow low, slow visual observation of power lines and structures, with the lines at eye level.

INDICATIONS OF SCOPE: The demand for RPVs in this use is unknown, but routine patrol of power lines is considerably less frequent than patrol of pipelines. The Pacific Gas and Electric Company, for example, covers their complete network of lines once a year, whereas pipelines are routinely patrolled once a week.

POTENTIAL USE: Waterway and Shoreline Pollution Detection

DESCRIPTION: Several federal, state and local government agencies routinely patrol and monitor streams, rivers, lakes and U.S. coastal waters to detect violations of the Federal Water Pollution Control Act and local water quality regulations. Sources of potential pollution include irrigation runoff, acid mine drainage, industrial waste discharge, oil drilling and thermal discharges from power plants.

PRESENT METHODS: Aerial remote sensing is used extensively by the Environmental Protection Agency and other organizations in conducting water pollution monitoring operations. A variety of sensors and aircraft are employed to detect, identify, or measure pollutants or other indicators of water quality. Sensor types most frequently employed are day or night infrared scanners useful for detecting oil, waste outfalls and heated water discharge; cameras for mapping in black and white, color or infrared color; reconnaissance cameras for low altitude, ultra-high resolution photographs; and closed circuit TV regarding pictorial information on tape.

SHORTCOMINGS OF PRESENT METHODS: Current techniques have proven to be very effective and several successful prosecutions of violators have been attributed to evidence obtained by these techniques. Operational costs are high because large aircraft are required since mission distances are long and airborne sensor equipment is bulky and heavy.

DESIRED FEATURES: Predicated upon the development of lightweight, small airborne sensors, RPVs could effectively augment, and in some cases replace, manned aircraft. The system would require high navigational accuracy and ability to store, and under certain conditions transmit to ground stations, the required imagery. Low cost and simplicity of operations are essential for the system to be adopted by state and local government.

INDICATIONS OF SCOPE: Unknown.

POTENTIAL USES: Agricultural Spraying and Cropdusting

DESCRIPTION: Chemical treatment of orchards and crops, forests, grasslands, and ornamental growth is performed for a number of reasons: pest and weed control, disease prevention, application of fertilizers and feeds, and mosquito control. The basic requirement is to distribute precisely determined quantities of active chemical uniformly over a given area on the ground. Normally this active material is diluted with water, and quantities like 10-20 gallons per acre (95-190 l per hectare) are dispensed. However, products labeled as Ultra Low Volume (ULV) chemicals are emerging which can be used nearly undiluted in quantities of a few ounces per acre (1-2 l per hectare).

PRESENT METHODS: Although some spraying is performed on the ground using equipment mounted on ground vehicles, the majority of the spraying is from the air using mostly fixed wing aircraft designed especially for that purpose. Some modified helicopters are also used.

SHORTCOMINGS OF PRESENT METHODS: Present methods are generally satisfactory, but are costly and dangerous to the pilots of the manned aircraft.

DESIRABLE FEATURES: An ideal system would be less costly to own and operate than manned aircraft, and safer.

INDICATIONS OF SCOPE: There are presently more than 8000 agricultural-spraying aircraft in the United States being used by more than 4000 companies and farm operators. During the years 1973 through September 1975, there were 1204 accidents involving aircraft dispensing chemicals, resulting in 96 persons killed and 121 severely injured.

POTENTIAL USE: Wilderness Spraying

DESCRIPTION: In the Pacific Northwest and the northeastern United States of America and Canada there are millions of acres of conifers, such as Douglas fir and spruce forests, that are continually endangered by the crop pest called the spruce budworm. Attempts to control the pest are conducted by both countries.

PRESENT METHODS: To date aerial tankers, such as converted Constellations, PV-2s, TBMs, and C-4s, have proven to be the most efficient and effective dispensers of pesticides because of the need to cover very large, remote areas. Small spotter or chase planes are used to guide the spray planes. As in conventional agricultural spraying operations, uniform distribution of the chemical is required. The common name for one widely used pesticide is malathion which is available in an Ultra Low Volume (ULV) form. Other chemicals are being tested.

SHORTCOMINGS OF PRESENT METHODS: Current techniques are very effective; however, it is understood that only 15% to 20% of the forests can be treated annually because of high costs and limited resources to cover the very large forest areas.

DESIRED FEATURES: Large quantities of chemicals must be dispensed during each RPV sortie in order to be competitive with the operational cost of manned aircraft. Thirteen fluid ounces (380 cc) of ULV are required per acre (4000 m^2) of forest. Therefore, roughly one pound per acre (0.45 kg per 4000 m^2) is needed. The RPV payload required for the application was not determined; however, it is likely that a large payload, e.g., 500 pounds (225 kg), would be necessary to be economically feasible. Spray altitude is 150 feet (45 m) above the forest canopy.

INDICATIONS OF SCOPE: In 1975 a 2.2 million acre (8000 km^2) spray project was conducted in Maine using 45 airplanes and employing 46 pilots. Spraying was confined to only the most seriously affected forest area.

POTENTIAL USE: Wildfire Fighting

DESCRIPTION: Aerial wildfire fighting is done by dropping water and/or fire retardant on wildfires.

PRESENT METHODS: Both fixed-wing aircraft and helicopters are used to drop fire retardants, with fixed-wing aircraft accounting for about 85% of the flight hours flown for retardant dropping.

SHORTCOMINGS OF PRESENT METHODS: Present methods are generally satisfactory. However, the turbulence and poor visibility due to smoke in the vicinity of large wildfires make accurate delivery difficult. Up to one-third to one-half of the retardant dropped can be wasted in severe situations.

DESIRED FEATURES: An ideal system would deliver the retardant accurately to the desired target, even in the face of turbulence, and would be able to see through the smoke so as to locate the target accurately.

INDICATIONS OF SCOPE: In 1974, more than 4000 wildfires were fought by the U.S. Forest Service. More than 7800 flight hours were flown in delivering 14.7 million gallons (55 million l) of fire retardant on those fires. At least 75% of those flight hours were flown by commercially owned fixed-wing aircraft. Comparable figures for fires not fought by the USFS were not obtained.

POTENTIAL USE: Detecting Activities (Monitoring of Intrusion Detection Devices)

DESCRIPTION: Seismic, Accoustic, Magentic, and other types of intrusion detection systems are employed by federal law enforcement agencies to detect illegal personnel and vehicle border crossings, suspect aircraft take-off and landings, and trespassers on government property. In addition, uses by the private sector are increasing.

PRESENT METHODS: Detectors are implanted at critical areas and monitored at ground stations. The sensors are coded or otherwise identified to the exact ground location. Repeaters are required over long distances in remote areas.

SHORTCOMINGS OF PRESENT METHODS: Electrical storm activity occasionally interrupts relay transmissions; otherwise, the systems operated satisfactorily. Installations in extremely remote areas (such as aircraft landing strips) is desirable; however, relay distances are often too great to be practicable.

DESIRED FEATURES: An RPV that could serve as a ground sensor monitor and repeater station would require long transit range, approximately 100 miles

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(160 km), and long on-station capability (8-10 hours).

INDICATIONS OF SCOPE: The U.S. Border Patrol now employs sensors along the Mexican border, and expansion along Canada is underway. U.S. Customs desires similar capability within the U.S. to assist in the detection and interdiction of aircraft engaged in smuggling and drug traffic when they land at remote airstrips.

POTENTIAL USE: Emergency Rescue Beacons (Tracking Emergency Locator Transmitter (ELT))

DESCRIPTION: On July 1975 all general aviation aircraft owners were required to install an ELT system to assist in locating downed aircraft. ELTs operate at 120 MHz (240 MHz military), compatible with standard general-aviation VHF radios. Severe weather conditions, which may have caused the accident, frequently inhibit air search operations by manned aircraft.

PRESENT METHODS: The Civil Air Patrol (CAP), a civilian auxiliary of the U.S. Air Force, is a volunteer corps of civilians enlisted and organized to conduct aerial search in manned light aircraft for missing aircraft. The armed forces also assist as required.

SHORTCOMINGS OF PRESENT METHODS: Severe weather restricts manned aircraft search operations. It is not unusual for search operations to be delayed from 3 to 5 days in mountainous areas, during which time the survival probability of pilot and passengers is reduced drastically.

DESIRED FEATURES: An ideal RPV for this use would be equipped with a VHF receiver and would be capable of being accurately navigated through severe weather conditions and also capable of being tracked (or by other techniques located) at that point of maximum ELT signal strength.

INDICATIONS OF SCOPE: The FAA reports that over 900 general aviation aircraft accidents each year are attributable to weather. However, no estimates were made of how many downed aircraft are objects of aerial searches each year.

POTENTIAL USE: Monitoring Cathodic Protection of Pipeline

(Note: This is not done separately, but is included in the Pipeline Patrol use described elsewhere.)

POTENTIAL USE: Aerodynamic Research

DESCRIPTION: The military services, NASA, and private industry are continually conducting research programs, design studies, testing and evaluating new concepts, materials and techniques to improve aircraft performance, efficiency, and reliability. This work results from either the establishment of entirely new requirements, or research is conducted to extend or expand the current state-of-the-art.

PRESENT METHODS: Initial research findings are based upon applications of known aerodynamic principles, laboratory and wind tunnel testing, and, on occasion, subscale, non-piloted model flight tests. Lengthy, full scale flight tests are ultimately required to satisfy military standards or to qualify for FAA type certification.

SHORTCOMINGS OF PRESENT METHODS: Unique aircraft concepts and designs for which there is little or no background data, experience, or engineering precedence present risks during full-scale flight tests. This is particularly true if not all aerodynamic phenomena can be thoroughly analyzed and understood from studies,and laboratory and wind tunnel tests.

DESIRED FEATURES: Modular fixed remotely piloted research vehicles (RPRV) should be useful in evaluating free-flight characteristics of alternative wing and empennage designs, control surfaces, etc. The key feature would be rapid and simple substitution of alternative designs enabling low-cost flight analysis and trade-offs which would be very expensive using full scale aircraft. Numerous RPRV's applications have already been demonstrated or planned, including rigid rotor helicopter designs, the 3/8 scale F-15, and NASA Ames skewed wing concept. RPRVs should also be useful in investigating stowed and stopped-rotor helicopter transition phenomena.

POTENTIAL USE: Air to Air Surveillance and Tracking

DESCRIPTION: The U.S. Customs Service conducts air operations throughout most of the U.S. to identify and track aircraft suspected of international illegal transportation of narcotics or other goods.

PRESENT METHODS: Missions are flown over both sides of the border utilizing a variety of aircraft, including the OV-1, S-2D, Cessna 210 and 337, and the

Maule M-5. Normally flights to locate and follow suspect aircraft are conducted at night and based upon some type of prior intelligence and/or informer's reports. Infrared sensors and radar are used aboard some aircraft. Attempts are made to locate staging areas (airstrips) on either side of the border.
SHORTCOMINGS OF PRESENT METHODS: Current methods and aircraft have proven to be very effective, though costly. Improved sensor performance at lighter weight is desired.
DESIRED FEATURES: A potentially useful RPV system should be a high performance vehicle, with 800-1000 mile long range (1300 to 1600 km) and high speed 350-450 knots (650-800 km/hr). Also, it would be essential that the RPV be accurately navigated and tracked, as well be able to lock on a suspect aircraft and continuously follow its movements.
INDICATIONS OF SCOPE: There are 6 U.S. Customs airborne units along the southern U.S. border, each operating from 8 to 10 aircraft.

POTENTIAL USE: Communications Relay
DESCRIPTION: Clearly there are many civil activities where reliable communication between both air and ground operations is a key requirement. These activities include law enforcement and fire fighting, search and rescue, and long-range patrols (pollution monitoring, border patrol, pipeline patrol, and many others). During this study, however, two requirements emerged as potentially practicable applications for an RPV as a communications relay. One is in the Bureau of Indian Affairs (BIA) that administers over 50 million acres (30,000 km^2) of Indian lands and reports that communications between ground units is usually limited to 30 miles (50 km) or less. The second is during the conduct of fighting large timber and brush fires in remote areas.
PRESENT METHODS: Manned aircraft are most frequently used during wildfires as relays among mobile units and the base fire camps. Permanent watch towers have limited use; however, they are expensive to construct and maintain and cannot cover the thousands of square miles of forest area. Permanent towers for use by the BIA are economically impractical for the same reasons.

SHORTCOMINGS OF PRESENT METHODS: Manned aircraft employed for communications relay functions are expensive and sometimes limited in use because of weather conditions.

DESIRED FEATURES: An effective system would be a low-cost, portable RPV capable of remaining on station from 6 to 8 hours. Also, it must be easily launched, recovered, and serviced in remote areas.

INDICATED SCOPE: There are over 260 Indian reservations in the continental U.S. and Alaska, approximately 40 of which have an area of 2500 square miles (6500 KM^2) or greater. More than 4000 wildfires occurred in 1974, but no estimate is available of how many required communication relays.

POTENTIAL USE: Security of Nuclear Materials in Transit

DESCRIPTION: The Nuclear Regulatory Commission is conducting studies of future requirements and techniques for the future safeguard of special nuclear materials, including the security of these materials during transit from processing and reprocessing plants to reactor stations.

PRESENT METHODS (CONCEPTS): The most common and flexible mode of transportation envisioned would be truck/trailer type ground vehicles. The advantage of trucks over rail and air transportation is the ease in modifying routes (at will, if necessary) and varying the time of the movement. Security is provided by strong-box containers, alarms, and security guards. Aerial surveillance would be a desirable augmentation to security, by providing potential early warning of hijack attempts, and by providing communications to reaction forces.

SHORTCOMINGS OF PRESENT METHODS (CONCEPTS): The difference in aircraft normal cruise and road traffic speeds and long distances travelled (and corresponding total transportation time) are drawbacks to the use of aircraft.

DESIRED FEATURES: A concept under consideration would provide for an RPV stowed in a special compartment built into either the truck van or trailer. In case of any suspected or overt attempt to interfere with the vehicle, the RPV would be launched, climb to an appropriate altitude, and maintain surveillance over the transport vehicle. It would require the capability of sensing and tracking any movement of seized nuclear material and the ability to communicate accurate position location to reaction forces and law enforcement agencies.

INDICATIONS OF SCOPE: Not predictable, but it is expected that the number of U.S. nuclear power plants will increase to several hundred over the next 20 years.

POTENTIAL USE: Severe-storm Research

DESCRIPTION: The U.S. National Weather Service conducts extensive research monitoring and taking measurements of severe storms (thunderstorms, hurricanes, cyclones, and tornados). The purpose is to analyze storm formation and development in order to provide forecasts of storm activity. Two separate missions are envisioned for RPVs. They are:

1. Measurements of meteorological data outside the storm cloud at low altitude, including observations in the vicinity of tornado vortices.
2. High-altitude monitoring of the growth and decay of thunderstorms.

PRESENT METHODS: In addition to storm-watch stations, radar, and instrumented weather balloons, aircraft are currently employed to obtain meteorological observations of wind, temperature, pressure and humidity in the immediate vicinity of tornado vertices and thunderstorms. Manned aircraft, such as the F-100, F4C, C-120, Queen Air, U-2 and the RV-57F are used. Over ten years ago drones were tried. However, radio control proved to be unreliable, presumably because of atmospheric electrical activity.

SHORTCOMINGS OF PRESENT METHODS: Gathering storm data by manned aircraft is uncomfortable and hazardous due to the extreme turbulence in the vicinity of severe storms.

DESIRED FEATURES: An ideal system would have capabilities similar to a manned aircraft system but without the hazard and discomfort to the operators.

INDICATIONS OF SCOPE: The National Severe Storms Laboratory, Norman, Oklahoma; Hurricane Research Laboratory, Miami, Florida; and the Environmental Research Laboratory, Boulder, Colorado, are three major R&D organizations studying storms growth, structure, and dynamics. Severe storm frequency varies from 40 to 90 per year along the Atlantic Coast and the Gulf of Mexico and from 50 to 70 in the midwest U.S.

POTENTIAL USE: Meteorological Data Collection

DESCRIPTION: The use envisioned here is the routine gathering of daily weather data, as conducted by scores of weather stations across the U.S. and around the world.

PRESENT METHODS: Weather balloons are presently used to gather this information. They are tracked visually or by radar. In most applications, they carry radiosonde instruments aloft, although some are simply tracked to determine wind conditions.

SHORTCOMINGS OF PRESENT METHODS: Weather balloons are not recovered, and a high percentage of the instrumentation packages are lost. These losses amount to a substantial annual cost.

DESIRED FEATURES: An ideal system would be simple to operate, reliable, and less costly to own and operate than the present system of balloons. It should also be substantially compatible with the ground portions of the present system.

INDICATIONS OF SCOPE: The Weather Service expends weather balloons in the following annual quantities:

80,000 balloons to 90,000 feet (27,500 m)
35,000 balloons to 20,000 feet (6,000 m)
Approximately 6,500 balloons to 10,000 feet (3,000 m)

Of those, the ones to 90,000 feet (27,500 m) and 10,000 feet (3,000 m) carry instrument packages. Only 25% of the instrument packages are recovered. The balloons are launched from over 150 stations throughout the U.S.

POTENTIAL USE: Mapping Pollutants

DESCRIPTION: Air-pollution control districts model and map the horizontal and vertical distribution of meteorological and pollution attributes over an air basin. They do it regularly and routinely to determine when trash may be burned, when to issue smog alerts, etc. They map temperature and wind structure, turbulence, solar radiation, and the distribution of CO, NO_x, SO_x, hydrocarbons and other organics, and particulates. RPVs could be used to fly instruments and sampling devices to various altitudes and take the necessary measurements.

PRESENT METHODS: In addition to balloon-gathered information from U.S. Weather

Service, various methods are now used to gather the data. Civic-minded local volunteers sometimes fly their own manned aircraft, charging only for fuel costs. Fixed instruments mounted on existing radio or TV transmitter towers are used. Groundbased acoustic sounders measure the altitude of the temperature inversion. In some places, radio-controlled model aircraft have been used.
SHORTCOMINGS OF PRESENT METHODS: Manned aircraft are too expensive unless donated by volunteers. Also, they are not allowed to sample below 1000 feet (300 m) altitude over populated areas. U.S. Weather Service balloon soundings are taken only at weather stations and are too costly to be taken by the pollution control district frequently and at many locations. Fixed instruments on transmitter towers are good but are limited to locations where towers exist. Acoustic sounders map the temperature inversion altitude but cannot measure winds or pollutants. Radio-controlled models depend on visual control and do not give precise navigation accuracy.
DESIRABLE FEATURES: An ideal system would provide low-cost, frequent samples routinely. It would provide real-time readout of data and would take measurements from 50 feet (15 m) altitude on up to 5000 feet (1500 m). It would measure wind speed and direction aloft to within ±1m/sec and ±10°, respectively, and would take such measurements at about 10-sec intervals. It would be able to sample many points (perhaps 20) throughout an area of 4000-500 square miles (10,000-13,000 km^2).
INDICATIONS OF SCOPE: Each U.S. state and many city governments conduct air pollution sampling and control programs. The Environmental Protection Agency operates nationwide. In addition, the National Weather Service provides advisories on weather conditions affecting atmospheric pollutants from Air Stagnation Adivsory Areas throughout the U.S.

APPENDIX C

CAPABILITIES NEEDED IN POTENTIAL USES

The functional and performance requirements for RPV systems are organized here into the same format for all of the nine selected missions. First, a general mission description is given, general system requirements are given, and then the requirements for the major subsystems are given. The headings are:

A. System Capabilities
B. Sensor/Payload
C. Air Vehicle
D. Ground Control Station
E. Data and Control Link
F. Launch and Recovery
G. Support and Maintenance.

Requirements Common to All Uses

Many of the required or desired capabilities that were established are common to all nine of the selected uses and, by extension, to the remaining 26. The common ones are listed here and are not repeated in the sections for the separate uses.

A. System capabilities. -

- Be operable by a minimum number of operators (preferably one) with a minimum of specialized training.
- Operate with a minimum of operator attention consistent with the mission.
- Be less costly to own and operate than a manned-aircraft system.

B. Sensor/payload. - For the systems that use sensor payloads for producing visual imagery of the ground or ocean surface, the following capabilities are common.

- Be controllable in azimuth and elevation to cover at least the lower hemisphere, e.g.,

  azimuth ± 180°
  elevation + 10°, - 90°.
- Have a field of view (FOV) and magnification variable in flight, either by continuous zoom or in two or more discrete steps.
- Be stabilized in both pitch and roll.
- Be self-limiting or self-adjusting for changes in light intensity, so that areas of both bright light and shadow can be observed.
- Be able to track a surface point and keep it within the FOV, either automatically or by remote control from the ground station.

C. Air vehicle. -

- Be stabilized in pitch, roll, and yaw and controlled in speed, altitude, and heading by an autopilot so that the operator is not required to pilot the aircraft.
- Have fail-safe provisions for reestablishing a lost control link and for a programmed safe descent if the link is not reestablished.

D. Ground control station. -

- Display continuously the speed, altitude, heading, and location of the air vehicle.
- Display air-vehicle operating data (e.g., fuel remaining) required for safe operation.
- Provide for commanding speed, altitude, and heading (or their respective rates) to the air vehicle.
- Be operable by a minimum number of operators (preferably one) with a minimum of specialized training.
- Operate on ordinary commercial power if it is available, with provisions to return and land the air vehicle safely in case of failure of commercial power.

- o Perform the continuous calculations and control necessary for navigation and flight control and to drive the displays.

E. Data and control link. -

- o Be resistant to electromagnetic interference.
- o Operate continuously for positive control of the air vehicle.
- o Be able to reestablish a lost link readily.

F. Launch and recovery. - Prevent or minimize danger to other aircraft that may be in the vicinity.

G. Support and maintenance. - Provide for routine servicing of the entire system with a minimum of personnel with a minimum of specialized training.

Requirements in the Nine Specific Uses

The reader should bear in mind that the numerical values presented here are approximate only. If a system were to be actually designed for one of these uses, the requirements should be thoroughly examined in detail. These values, however, are believed to be internally consistent and representative of actual requirements.

Mission 1, Security of High-Value Property. - The kind of security operation envisioned would involve two types of activity: (a) periodic aerial patrol of the complete area to look for theft, fire, or other emergencies in progress, and (b) on-call aerial response to investigate suspected emergencies reported by other means. The RPV would carry an electro-optical sensor (e.g., a TV camera) and transmit a real-time image of the scene below to an operator at a ground control station.

When an emergency or a suspicious activity is detected, the RPV would remain over the location of the activity, take a closer look by optically zooming in on the suspicious scene, and maintain surveillance of it while ground units are sent to the scene. If the suspicious activity involves an apparent crime, the RPV would follow any suspect escaping on foot or in a vehicle and direct ground units to intercept him. A permanent record, by videotape or hard-copy, could be made of the imagery transmitted to the ground control station, for use as evidence if necessary. The following are tentative top-level performance requirements for an RPV system to perform security patrol of high-value, small-area property such as railroad yards, warehouse districts, and industrial facilities. They are derived partially from discussions with potential users.

A. System capabilities. -

1. Operating from one corner of an area two miles by one mile (3.2 km x 1.6 km), be able to cover every point in the area once every hour on routine patrol.

2. Be able to respond to any point in the area in no more than five minutes from a stand-by, engine-off condition on the ground.

3. Be able to maintain any point in the area under continuous real-time surveillance indefinitely (within the limits of aircraft endurance).

4. Operate at or below 800 feet (245 m) above ground level (AGL), to avoid interference with general aviation.

5. Detect people on the ground, day or night, from operating altitude. Be able to observe their activity and assess its legitimacy. Transmit a continuous, real-time image to the ground operator.

6. Distinguish motor vehicles by type, style, and manufacturer from operating altitude.

7. Be able to follow a particular motor vehicle (or person) and keep it (or him) under surveillance as long as it (or he) remains in the open.

8. Determine the location of objects (people, vehicles, etc.) on the ground with sufficient accuracy to direct ground units to intercept them.

9. Be quiet enough to go unnoticed from directly below when at 800 feet (245 m) altitude.

10. Take off and land the air vehicle(s) from an area 50 feet by 50 feet (15 m x 15 m) without restricting normal traffic and human activities in the surrounding areas.

11. Ability to communicate with people on the ground (e.g., with a loudspeaker) and to illuminate ground objects is desirable, but not essential.

12. Be able to provide a permanent record of selected imagery and information transmitted to the ground control station, when desired by the operator.

Derivation of performance requirements: The FOV is selected to obtain the required coverage rate of the area patrolled within the constraints of the maximum operating altitude, the available sensor resolution, and two other factors affecting the likelihood of detecting objects or activities on the ground, i.e., image motion and the length of time an object is in the field of view. The relationships among these variables are as follows.

$$C = VW \tag{C1}$$

where C = coverage rate (area per unit time)
V = speed of the aircraft
W = width of the strip of ground within the FOV.

Assuming the sensor points straight down during patrol,

$$W = 2a \tan(\theta_c/2) \tag{C2}$$

where a = altitude of the aircraft
θ_c = FOV measured across the flight direction.

The expression for resolution recognizes that objects at the edge of the FOV are farthest from the sensor and thus subtend greater angles than objects nearer the center, i.e.,

$$R = l\,\theta_c/N \tag{C3}$$

where R = resolution of the sensor, in radians per resolution cell
l = slant range to an object at the edge of the FOV
N = number of resolution cells oriented across the flight path.

By simple geometry, $l = a/\cos(\theta_c/2)$. (C4)

These four equations can be combined into an overall expression relating coverage rate, speed, altitude, sensor resolution, number of resolution cells, and FOV:

$$C = 2\,VRN\cos(\theta_c/2)\tan(\theta_c/2)/\theta_c \tag{C5}$$

The time, T, a point on the flight path is in the FOV is given by

$$T = L/V = 2\,a\tan(\theta_L/2)/V \tag{C6}$$

where L = length of the strip of ground within the FOV
θ_L = FOV measured along the flight direction.

Image motion is given in Reference 4 as

$$\dot{\alpha} = (V/a)\sin\beta\,(1 - \cos^2\psi\,\cos^2\beta)^{\frac{1}{2}} \qquad \text{(C7)}$$

where $\dot{\alpha}$ = angular image motion (rad/sec)

β = line of sight depression angle

ψ = line of sight azimuth angle.

Image motion should be less than about 0.05 rad/sec, in order not to degrade resolution too much. (The actual value depends on sensor characteristics.)

From the requirement to cover the patrol area once every hour, and adding ten percent for overlap and lost time, let $C = 2.2\ \text{mi}^2/\text{hr}$ ($3.1\ \text{km}^2/\text{hr}$). The following values were found to give that value and also to be consistent with sensor technology, the altitude limit, and adequate resolution.

R = 8 in. (20 cm)

N = 600 resolution cells

a = 800 ft (245 m)

V = 30 mi/hr (13 m/sec)

$\theta_c = 30^\circ$

$\theta_L = 30^\circ$

These values give an image motion of 0.055 rad/sec and a value of T = 9.7 sec. They are the basis for the performance requirements that follow.

B. Sensor/payload. -

1. Have a FOV of 30° by 30° for general patrol.

2. Have resolution sufficient to detect people on the ground anywhere in the FOV from an operating altitude of 800 feet (245 m) AGL, while at the 30° by 30° FOV setting, and identify their general activity.

3. Have resolution and magnification sufficient to distinguish motor vehicles anywhere in the FOV by type, style, and manufacturer from an operating altitude of 800 feet (245 m) AGL, at the highest magnification setting.

4. Operate day or night with no artificial lighting other than ambient light ordinarily present.

C. Air vehicle. -

1. Cruise at 30 mph (13 m/sec) at an altitude of 800 feet (245 m) AGL.

2. Have an endurance of at least one hour with reserve fuel for 15 minutes, at a speed of 60 mph (26 m/sec) true air speed (TAS) at MSL (to operate in 30 mph winds).

3. Take off and land in winds up to 30 mph.

4. Have a top speed of at least 60 mph TAS at MSL. A top speed of 90 mph (i.e., 60 mph into a 30 mph wind) is desirable.

5. Be capable of starting, warming up, and taking off in two and one-half minutes or less.

6. Be capable of refueling and turn-around (land, refuel, takeoff) in five minutes.

7. Be able to either hover over a point on the ground or turn tightly about the point to keep it continuously in sight.

D. Ground control station. -

1. Display a continuous real-time image of what the sensor payload on the air vehicle sees.

2. Control the pointing of the sensor and the zoom or FOV adjustment.

3. A positively controlled, preprogrammed patrol flight path is desirable, with manual override capability and provisions for changing the preprogrammed path readily.

4. Control the air vehicle to fly the desired flight path and mission profile with corrections for winds and gusts up to 30 mph from any direction.

E. Data and control link. - (Covered above, under "Common requirements")

F. Launch and recovery. -

1. Mobility or portability are not required.

2. Take off and land the air vehicle from a dedicated area 50 feet by 50 feet without restricting normal traffic and human activities in the surrounding areas.

3. Be able to operate over twenty-foot obstacles (e.g., buildings) adjacent to the 50 feet by feet operating area.

G. Support and maintenance: Provide support and maintenance to keep each air vehicle in the air four hours out of every 24 hours in a steady-state operation.

Mission 2, Wildfire Mapping. - The mission of wildfire mapping consists of flying over a wildfire and furnishing the characteristics of the fire to fire-control officers at periodic intervals and in enough detail to allow timely decisions to be made about the use of suppression resources. During control operations, these decisions are based on the dynamic characteristics of the fire perimeter and its relationship to fuels, weather, topography, values threatened, and the availability of suppression forces. During the mop-up, decisions are based on the identification and location of latent hot spots such as smouldering roots and logs.

The following are tentative top-level performance requirements for an RPV system to perform the wildfire mapping mission. They are derived from discussions with the U.S. Forest Service and the California Division of Forestry, but should not be considered official thinking of either agency. However, References 5 and 6 were used extensively as source documents.

A. System capabilities. -

1. Image large fires in such a way that the fire perimeter, including smouldering edges and flaming fronts, can be located accurately with respect to geographical features, i.e., to the nearest fifty feet (15 m).

2. Locate small spot fires adjacent to a large fire. (See Section H, Definitions, below, for definitions of small and large fires.)

3. Locate small, hot fires within a large burned area during mop-up operations.

4. Provide near-real-time high-quality imagery of the area mapped, with good background detail, e.g., roads, firelines, and fuel breaks to the nearest fifty feet (15 m) outside the fire perimeter.

5. Provide intelligence about fire perimeter locations, rate of spread, spot fires, fire intensity, and location of interior unburned areas.

6. Provide the imagery to both the main fire camp and zone camps around the fire perimeter.

7. During the uncontrolled state of a fire, provide imagery at least four times per day. Once a fire has been contained, provide imagery twice per day, during mop-up.

8. Be able to operate with a minimum of operator attention.

9. Provide a permanent record of imagery and information.

10. Map fires at a rate of at least 150 mi^2/hr (385 km^2/hr).

The speed, altitude, and FOV calculations for this mission were made using equations C1 and C2.

B. Sensor/payload. -

1. While covering a large fire at a rate as low as 150 square miles per hour (385 km^2/hr), operational equipment must image large fires without distortion on the imagery adjacent to hot areas so that the fire perimeter, including smoldering edges and flaming fronts, can be located to the nearest fifty feet (15 m).

2. Cover an equivalent total field of view (TFOV) of 100° (nadir $\pm 50^\circ$) with $\pm 10^\circ$ correction for aircraft roll, giving a total equivalent scan of 120°.

3. Meet environmental requirements normally applicable to aircraft equipment.

4. Operate day or night.

5. Observe background temperature differences of 1 C° for adequate terrain-feature mapping.

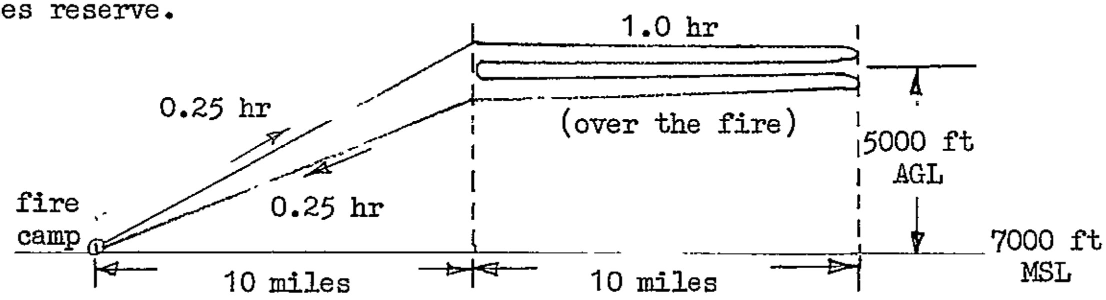
6. Have an angular resolution of 1 mrad or better.

(NOTE: Many sensor-related requirements that can be met potentially by signal processing and display on the ground are discussed in Section D, below.)

C. Air vehicle. -

1. Be able to cruise at 70 mph TAS at an altitude of 12,000 feet (3650 m) above mean sea level (MSL), i.e., 5000 feet (1500 m) above ground level (AGL) over terrain of 7000 feet (2100 m) elevation.

2. Have endurance for the following mission profile (1½ hours) plus 30 minutes reserve.



3. Take off and land in winds up to 30 mph (13 m/sec).

4. Have a top speed of 100 mph (45 m/sec) true air speed (TAS), i.e., be able to return to base at 70 mph (30 m/sec) against 30 mph winds.

5. Be maintainable enough to spend eight hours in the air out of every 24 hours for a period of ten days (i.e., four flights per day).

6. Navigate with sufficient accuracy to follow the mission flight track within ± $\frac{1}{2}$ mile.

7. Be easily transportable by standard truck or trailer over rough roads. After delivering the air vehicle and its ancillary equipment, the truck should be freed for other uses.

D. Ground control station. - There are two main functions of the ground station. One is to control the air vehicle, and the other is to process the data and portray the imagery from the air vehicle. The equipment for the two functions should be separable, with the data processing and imagery located at one or more fire camps and the control of the air vehicle at or near the main fire camp.

1. Control a single air vehicle in the air at any one time.

2. Display a continuous real-time image of what the sensor payload on the air vehicle sees.

3. Provide a positively controlled, preprogrammed patrol flight path for the air vehicle with manual override capability and provisions for changing the preprogrammed path readily.

4. Control the air vehicle to fly the desired flight path and mission profile with corrections for winds and gusts up to 45 mph (20 m/sec) from any direction.

5. Provide near-real-time, hard-copy, high-quality imagery of the area patrolled. The imagery must display terrain features with enough resolution for a photointerpreter to locate spot fires to the nearest 0.25 mi (0.4 km) and terrain features to within 50 feet (15 m).

6. Provide automatic target discrimination (i.e., spot-fire detection), and mark the hard-copy imagery to indicate the location of a discriminated target.

7. Be easily portable by helicopter or pickup truck.

8. Operate on locally-generated power or on ordinary commercial power, with provision to land the air vehicle safely in case of failure of commercial power.

9. The system must discriminate and mark small fire targets with a radiometric power of 1/10 the maximum background variation on the imagery, and at the same time reduce false alarms to near zero. Techniques such as spectral discrimination and scan-to-scan and time correlation may be used to eliminate spurious aircraft noise, navigation pulses, and external radar signals.

10. Slant-range correction (rectilinearization) must correct for changes in aspect ratio from nadir to the edge of the scan. Ground distances measured on the image from nadir to $\pm 40^{\circ}$ must be linear to within two per cent. The average density caused by slant range correction must not vary more than one gray scale across the image perpendicular to the line of flight.

E. Data and control link. - (Covered above, under "Common requirements")

F. Launch and recovery. - Take off and land from a cleared, unimproved area at a temporary fire camp.

G. Support and maintenance. - Provide support and maintenance adequate to keep the air vehicle in the air eight hours out of every 24 hours for two weeks at a time.

H. Definitions. - (From Reference 6)

Small forest fire	For this specification, at least one square foot ($0.1\ m^2$) of hot burning material (600° C.) that does not meet the requirements of a large forest fire.
Large forest fire	Any fire that has escaped initial suppression forces and requires additional manpower to contain.
Spot fire	Similar to the small forest fire, but near a large forest fire.
Background	All objects within a surveillance area that have radiometric temperatures of 50° C. or less. Other signals normally considered as background (e.g., solar reflections from buildings or water, geysers,

	and hot highways) are excluded and must be taken into account when targets are interpreted.
Gray scale	Defined as $1/\sqrt{2}$ times density from the maximum density to fog level of the image medium.

Mission 3. Wildfire Detection. - The mission of wildfire detection consists of flying over large areas of forest, brush, or grasslands, detecting small, latent-stage fires, and determining their locations with enough precision to dispatch ground units to control them. The main idea is to locate fires started by lightning storms before the fires can spread. The RPV system would be based at a location central to the protected region and would fly missions over areas of the region that have experienced lightning storms. The missions would be flown as soon after the storm as the clouds have cleared, usually a very few hours after the lightning activity.

The RPV system is not responsible for locating storms, selecting areas for overflight, or suppressing the fires. These activities are already provided for.

The following are tentative top-level performance requirements for an RPV system to perform the wildfire-detection mission. They are derived partly from discussions with the U.S. Forest Service and the California Division of Forestry, but should not be considered official thinking of either agency, although References 5, 6, and 7 were used extensively as source documents.

A. System capabilities. -

1. Operating from a base centrally located in a forest region 400 miles (640 km) in radius, be able to fly to any area in the region and fly a predetermined, precise pattern over the area to scan it for wildfires.

2. Patrol 6000 square miles (15,300 km^2) per mission, covering at least 2000 square miles (5100 km^2) per hour.

3. Detect small, latent-stage wildfires with nearly 100 percent probability, in the presence of background temperature extremes.

4. Present information in such a way that a photointerpreter (PI) can locate the fire to the nearest 0.25 mile (0.4 km).

5. Provide high-quality, near-real-time imagery of the area patrolled.

6. Takeoff and landing may be from an ordinary air strip, provided proper air traffic control is provided around the air strip to prevent danger to other aircraft.

7. Provide a permanent record of imagery and information.

The speed, altitude, and FOV calculations for this mission were made using equations C1 and C2.

B. Sensor/payload. -

1. While covering a search area at a rate of at least 2000 square miles per hour (5100 km^2/hr) from 15,000 feet (4600 m) above terrain with backgrounds ranging from 0° to 50° C., operational equipment must detect (with nearly 100 percent probability) every unobscured, one-square foot (0.1 m^2) 600°C. fire. Of equal importance, image quality must be sufficient to permit PI interpretation of fire location to the nearest 0.25 mile (0.4 km).

2. Cover an equivalent total field of view (TFOV) of 120° (nadir $\pm 60^\circ$) with $\pm 10^\circ$ correction for aircraft roll, giving a total equivalent scan of 140°.

3. Meet environmental requirements normally applicable to aircraft equipment.

4. Ability to operate day or night is desirable.

5. Observe background temperature differences of 1 to 2 C°, for adequate terrain feature mapping.

(NOTE: Many sensor-related requirements that can be met potentially by signal processing and display on the ground are discussed in Section D, below.)

C. Air vehicle. -

1. Cruise at 200 mph (90 m/sec) at an altitude of 20,000 feet (6100 m) above mean sea level (MSL), i.e., 15,000 feet (4600 m) above ground level (AGL) over terrain of 5000 feet (1500 m) elevation.

2. Have an endurance of at least eight hours, with reserve fuel for at least one hour.

3. Take off and land in winds up to 30 mph (13 m/sec).

4. Have a top speed of at least 240 mph (110 m/sec) true air speed (TAS).

5. Be maintainable enough to spend eight hours in the air out of every 24 hours, on a steady-state basis.

6. Navigate with sufficient accuracy to follow the mission flight track within ± ½ mile.

D. Ground control station. -

1. Control two air vehicles in the air at any one time (mission + relay).

2. Provide a positively-controlled, preprogrammed patrol flight path for the air vehicle, with manual override capability and provisions for changing the preprogrammed path readily.

3. Control the air vehicle to fly the desired flight path and mission profile with corrections for winds and gusts up to 45 mph from any direction.

4. Provide near-real-time, hard-copy, high quality imagery of the area patrolled. The imagery must display terrain features with enough resolution for a PI to locate fires to the nearest 0.25 mile (0.4 km).

5. Provide automatic target discrimination (i.e., detection), and mark the hard-copy imagery to indicate the location of a discriminated target.

6. Portability is not required.

7. The success of this system depends entirely upon its ability to locate and mark small fire targets on the imagery. The system must discriminate and mark small fire targets with a radiometric power of 1/10 the maximum background variation on the imagery, and at the same time reduce false alarms to near zero. Techniques such as spectral discrimination and scan-to-scan and time correlation must be used to eliminate spurious aircraft noise, navigation pulses, and external radar signals.

8. Slant-range correction (rectilinearization) must correct for changes in aspect ratio from nadir to the edge of the scan. Ground distances measured on the image from nadir to ± 50° must be linear to within two per cent. The average density caused by slant range correction must not vary more than one gray scale across the image perpendicular to the line of flight.

E. Data and control link. - (Covered above, under "Common requirements")

F. Launch and recovery. - Take off and land at an ordinary air field.

G. Support and maintenance. - Provide support and maintenance adequate to keep the air vehicle in the air eight hours out of every 24 hours in a steady-state operation.

Mission 4, Fishing-Law Enforcement. - Fishing-law enforcement by aerial observation and investigation is concerned with detecting illegal fishing in U.S.-regulated coastal waters. The possible use of RPV (remotely piloted vehicle) systems for such observation will become of interest if international conventions extend the limits of regulation from the presently recognized (by the U.S.) 12-mile (19 km) limit to a 200-mile (320 km) limit, since the resulting, sudden, 16-fold increase in area to be regulated could tax the capacity of the U.S. Coast Guard severely. It is envisioned that RPV systems would supplement the Coast Guard's surface ships and manned aircraft patrols by performing the routine large-area surveillance for detection and location of fishing fleets and large fishing vessels. The manned aircraft or surface ships would then spot check at appropriate intervals by close inspection of the type of fishing and the precise locations of the fishing vessels.

The following are tentative top-level performance requirements for an RPV system to supplement manned aircraft and surface ships in fishing-law enforcement. They are derived partly from discussions with U.S. Coast Guard personnel, but do not represent official thinking of the Coast Guard.

A. System capabilities. -

1. Operating from a land base on the coast, be able to cover every point in an offshore area 200 miles by 200 miles (320 km by 320 km) once every day.

2. Detect any ship larger than 100 feet (30 m) in length from operating altitude and determine its location to within CEP = one mile (1.6 km).

3. Estimate the speed of detected ships to within ± 5 knots (± 9 km/hr) and direction of travel to within $\pm 10^{\circ}$

4. Be able to detect and locate ships (item 2, above) and estimate speed and direction (item 3, above) day or night and when there is cloud

cover. The ability to identify a ship, at least by type, day or night and when there is cloud cover is desirable but not required.

5. Plot the locations of all identified fishing fleets and large fishing vessels in the 200 mile by 200 mile (320 km by 320 km) area. Update the plot at least once every day.

6. Takeoff and landing may be from an ordinary air strip, provided proper air traffic control is provided around the air strip to prevent danger to other aircraft.

7. Be able to provide a permanent record of imagery and/or information gathered.

B. Sensor/payload. - Be able to operate day or night and in the presence of cloud cover, with at least the capability to detect and locate ships and to estimate speed and direction. The ability to identify ships, at least by type, at night and in the presence of cloud cover is desirable.

C. Air vehicle. -

1. Cruise at 80 mph (36 m/sec) at an altitude of 15,000 feet (4500 m) above mean sea level (MSL).

2. Have an endurance of at least four hours, with reserve fuel for 30 minutes.

3. Take off and land in winds up to 40 mph (18 m/sec).

4. Have a top speed of at least 100 mph (45 m/sec) true air speed (TAS) (i.e., to return to base at 60 mph (27 m/sec) against 40 mph (18 m/sec) winds).

5. Be maintainable enough to spend four hours in the air out of every 24 hours, on a steady-state basis.

6. Have a (fixed?) forward-looking TV camera for takeoff and landing use.

7. Have a navigation capability to know air vehicle location to within CEP = 0.5 mile (0.8 km).

D. Ground control station. -

1. Control a single air vehicle in the air at any one time.

2. Display a real-time image of what the TV camera in the air vehicle sees.

3. Provide a positively-controlled, preprogrammed patrol flight path for the air vehicle with manual override capability and provisions for changing the preprogrammed path readily.

4. Control the air vehicle to fly the desired flight path and mission profile with corrections for winds and gusts up to 45 mph (20 m/sec) from any direction.

5. Provide a permanent record of the data from the RPV (plus pertinent data such as time, date, and location of RPV).

6. Portability is not required.

E. Data and control link. - (Covered above, under "Common requirements")

F. Launch and recovery. -

1. Take off and land from an ordinary air field.

2. Provide adequate air traffic control around the air field to prevent danger to other aircraft.

G. Support and maintenance. - Provide support and maintenance adequate to keep each air vehicle in the air four hours out of every 24 hours in a steady-state operation.

Mission 5, Highway Patrol. - This mission for RPVs is to patrol stretches of highway that are too remote or too lightly traveled to justify regular patrol by manned aircraft. The RPVs would supplement existing patrols by manned aircraft.

The RPV would carry an electro-optical sensor (e.g., a TV camera) and transmit a real-time image of the scene below to an operator at a ground control station. The objective is to locate accidents, motorists in trouble, stolen or wanted vehicles, and unsafe road conditions such as landslides, flooded stretches, or washouts. Upon discovery of any of the above items, the necessary information would be provided to a dispatcher on the ground, who would direct ground units to take appropriate action.

In the case of stolen or wanted vehicle, the RPV would follow it and keep it under surveillance until ground units could intercept it. A permanent record, by videotape or hard-copy, could be made of the imagery transmitted to the ground control station, for use as evidence if necessary.

The following are tentative top-level performance requirements for an RPV system to perform highway patrol. They are derived partly from discussions with potential highway patrol users.

A. System capabilities. -

1. Operating from a base at or near a highway patrol station, fly daily patrols of highways anywhere in a region within 150 miles of the station, at the discretion of the operator.

2. Operate eight hours per day, 365 days per year, covering approximately 700 miles (1100 km) of path length each day.

3. Distinguish motor vehicles by type, style, and manufacturer from operating altitude.

4. Be able to follow a particular motor vehicle and keep it under surveillance as long as it remains in the open.

5. Determine the location of objects (people, vehicles, etc.) on the the ground with sufficient accuracy to direct ground units to them.

6. Be able to maintain any point in the area under continuous real-time surveillance indefinitely (within the limits of aircraft endurance).

7. Operate at or below 800 feet (245 m) above ground level (AGL) to avoid interference with general aviation. Be able to descend to lower altitude for a closer look.

8. Be able to communicate (e.g., by loudspeaker) to people on the ground, to ask the nature of their problem (e.g., mechanical trouble, injured person, out of gas, etc.), and to tell them what action is being taken to aid them. Voice communication from the people on the ground is not required, but the RPV must be able to transmit a real-time visual image of their sign-language responses to the operator at the ground control station.

9. The ability to operate at night and in fog or bad weather is desirable.

10. Navigate well enough to keep the road in the field of view with a minimum of operator attention. Have provisions for manual correction of drift.

11. Be able to provide a permanent record of selected imagery and information transmitted to the ground control station, when desired by the operator.

In order to patrol 700 miles (1100 km) in a normal operator work shift of eight hours, the patrol speed must be about 90 mph (40 m/sec). Flying at 800 feet (245 m), the image motion using a vertical-pointing sensor would exceed the acceptable level of ~ 0.05 rad/sec and cause blurring. We find that depressing the center of the FOV to an angle of $\beta = 23^\circ$ below the horizontal, and providing a vertical FOV of $\theta_L = 20^\circ$, give a maximum depression of 33° to the line-of-sight from the sensor to an object at the bottom of the FOV. From equation C7, a speed of just over 90 mph (40 m/sec) is allowable without exceeding 0.05 rad/sec image motion.

The time that an object is in the FOV is no longer given by equation C6. With the depression angle $\beta \neq 90^\circ$, the expression becomes

$$T = a \left[\tan \left\{ 90^\circ - (\beta - \theta_L/2) \right\} - \tan \left\{ 90^\circ - (\beta + \theta_L/2) \right\} \right] / V \qquad \text{(C8)}$$

where T = time a point is in the FOV

a = altitude of the aircraft

β = sensor depression angle ($^\circ$)

θ_L = vertical FOV ($^\circ$)

V = speed of the aircraft

For the above values, equation C8 gives a time of $T = 16.9$ sec, which is satisfactory. Thus, a value of $\theta_L = 20^\circ$ is selected.

The expression for the width W of the swath covered on the ground by the center of the FOV is

$$W = 2a \tan (\theta_c/2)/\cos (90^\circ - \beta) \qquad \text{(C9)}$$

where θ_c = the FOV across the flight direction.

If θ_c is selected as 20° to equal θ_L, W = 722 feet, which is adequate. With 600 resolution cells, the resolution per cell is 0.58 mrad, which will resolve an object 1.2 feet (0.37 m) in the center of the FOV and an object 0.85 feet (0.26 m) at the bottom of the FOV. This is adequate for general patrol.

These calculations give the performance requirements below.

<u>B. Sensor/payload</u>. -

1. Have a FOV of 20° by 20° for general patrol.
2. Have resolution sufficient to detect people and vehicles on the ground from an operating altitude of 800 feet AGL, while at the 20° by 20° FOV setting.

3. Have resolution and magnification sufficient to distinguish motor vehicles anywhere in the FOV by type, style, and manufacturer from an operating altitude of 800 feet (245 m) AGL, at the highest magnification setting. Being able to read license numbers from low altitude is highly desirable.

4. Day or night operation with no artificial lighting other than ambient light ordinarily present is desirable, as is operation in fog or bad weather. However, daytime-only operation is acceptable.

C. Air vehicle. -

1. Cruise at 90 mph (40 m/sec) at an altitude of 800 feet (245 m) AGL.

2. Have an endurance of at least eight hours with reserve fuel for 30 minutes, at a cruise speed of 90 mph true air speed (TAS) at MSL.

3. Take off and land in winds up to 30 mph (13 m/sec).

4. Be able to either hover over a point on the ground or turn tightly about the point to keep it continuously in sight.

D. Ground control station. -

1. Display a continuous real-time image of what the sensor payload on the air vehicle sees.

2. Control the pointing of the sensor and the zoom or FOV adjustment.

3. Control the air vehicle to fly the desired flight path and mission profile with corrections for winds and gusts up to 30 mph (13 m/sec) from any direction.

4. Provide hard copy or a videotape record of the sensor's picture (plus pertinent data such as time, date, and location) on demand of the operator.

5. Be operable by one person.

6. Control two air vehicles at any one time.

7. Portability is not required, but is desirable. Repeater screens to display the transmitted images in ordinary highway patrol cars, as well as in the control station, are also desirable.

F. Launch and recovery. -

1. Take off and land from an ordinary airfield.

2. Provide adequate air traffic control around the airfield to prevent danger to other aircraft.

G. Support and maintenance. - Provide support and maintenance adequate to keep each air vehicle in the air eight hours out of every 24 hours in a steady-state operation.

Mission 6, Pipeline Patrol. - Gas and oil pipelines are patrolled to detect and report leaks and potential hazards to the pipeline. Leaks are indicated by stains, changes in vegetation, dead wildlife, gas plumes, etc. Primary hazards are construction and agricultural activities near the buried pipe and excessive soil erosion where the pipe crosses streams and gullies. Another item to be observed is the position of the semaphore indicators that signal a malfunction of the cathodic protection system that protects the pipe against corrosion.

When any of these observables indicates a potential problem, ground personnel are dispatched to prevent or correct the problem.

The following are tentative top-level performance requirements for an RPV system to perform pipeline patrol.

A. System capabilities. -

1. Operating from a base adjacent to a pumping station or dispatch control center, be able to fly along 400 miles (640 km) of pipeline right of way in a day and then land at another base, for refueling, maintenance, and later patrol (next day).

2. Observe the pipeline right of way for leaks, erosion, and cathodic-protection semaphores, and observe a strip of land 0.25 mile (0.4 km) wide for construction and agricultural activity that might endanger the pipe. Be able to detect the observables that indicate these potential hazards and to evaluate them.

3. Be able to maintain a point on the ground under continuous surveillance indefinitely (within the limits of aircraft endurance).

4. Be able to transmit to the operator on the ground a continuous, real-time image of what the airborne sensors see.

B. Sensor/payload. -

1. Have a FOV of 20° vertical by 45° horizontal.

2. Have resolution and spectrum coverage adequate to detect and evaluate the observables described in "System Capabilities", above, and in the mission description.

3. Daytime, clear-weather operation is adequate.

4. Be able to track a surface target well enough to keep it in the field of view, either automatically or by remote control from the ground station.

C. Air vehicle. -

1. Cruise at 80 mph (36 m/sec) at an altitude of 800 feet (245 m) above ground level (AGL), with the ability to descend to lower altitudes for a closer look at things on the ground.

2. Have an endurance of at least six hours, with reserve fuel for at least 30 minutes.

3. Take off and land in winds up to 30 mph (13 m/sec).

4. Have a top speed of at least 110 mph (49 m/sec) true air speed (TAS), i.e., to operate at 80 mph (36 m/sec) against 30 mph (13 m/sec) winds.

5. Be maintainable enough to spend 30 hours in the air out of every week, on a steady-state basis (six hours per day, five days per week).

6. Be able to turn about a point on the surface and/or fly past it repeatedly from any desired direction, to keep it continuously in sight or to take a good look at it.

D. Ground control station. -

1. Control two air vehicles in the air at once (mission RPV and relay RPV).

2. Display, simultaneously, a continuous real-time image of what the sensor payload on the mission RPV sees.

3. Be able to control the pointing of the sensor and the zoom or FOV adjustment remotely.

4. Control the air vehicle to fly the desired flight path and mission profile with corrections for winds and gusts up to 45 mph from any direction.

5. Portability is not required.

E. Data and control link. - (Covered above, under "Common requirements")

F. Launch and recovery. -

1. Take off and land from an ordinary airfield or landing strip.

2. Provide adequate air traffic control around the airfield to prevent danger to other aircraft, if other aircraft are in the area.

G. Support and maintenance. - Provide support and maintenance adequate to keep the air vehicle in the air thirty hours out of every week (six hours per day, five days per week) in a steady-state operation.

Mission 7, Agricultural Spraying and Cropdusting. - Chemical treatment of orchards and crops, forests, grasslands, and ornamental growth is performed for a number of reasons: pest and weed control, disease prevention, application of fertilizers and feeds, and mosquito control. Crop seeding is also accomplished.

The basic requirement is to distribute precisely-determined quantities of active chemical uniformly over a given area on the ground. Normally, this active material is diluted with an inert liquid, i.e., water, and quantities like ten to twenty gallons per acre are dispensed. However, products labeled as Ultra Low Volume (ULV) chemicals are emerging which can be used nearly undiluted in quantities of fractions of pounds, or ounces per acre. Therefore, an RPV with a comparatively light payload capacity could look attractive. Although remote piloting of full-sized conventional agricultural aircraft is a concept that has aroused enthusiasm among some agricultural aviation operators, this set of requirements deals only with small RPVs to deliver small payloads.

A. System capabilities. -

1. Uniformly dispense materials (liquids or solids) over at least thirty acres (twelve hectares) per flight, i.e., have a delivery capacity of 15 to 30 pounds (7-14 kg).

2. Spray at least 150 acres per hour.

3. Spray altitude: ordinarily 2 to 10 feet (0.6 to 3 m) above the crop.

4. Operate off of rough, unimproved, short airstrips.

5. Turn on spray only at designated altitude above the field; turn off spray before lifting out of the field with 15-foot (4.5 m) accuracy.

6. Ability to determine wind drift at the time and at the area that spray operations begin.

7. Avoid any obstacle in or adjacent to the field being sprayed. The heights typically vary from 5 to 50 feet (1.5 to 15 m) higher than the top of the crop or orchard being sprayed.

8. The weather condition limits in which the vehicle is required to operate are moderate and based upon safe aircraft use and satisfactory spray effectiveness. The following are those weather parameters considered most important for aerial spraying:

Fertilizer Application

1.	Cloud ceiling	500 feet (150 m) or greater
2.	Visibility	1 mile (1.6 km) or greater
3.	Precipitation	Less than .05 in (0.127 cm)
4.	Wind	Less than 20 mph (9 m/sec)
5.	Dew	None present

Herbicide Spray

1.	Cloud ceiling	500 feet (150 m) or greater
2.	Visibility	1 mile (1.6 km) or greater
3.	Low-level temperature inversion	Surface inversion desirable
4.	Temperature (air)	Variable; generally between 55° and 80° F. (13° - 27° C.)
5.	Precipitation	None
6.	Wind	Direction; speed less than 10 mph (4.5 m/sec)
7.	Dew	Presence and period

Fungicide & Insecticide Spray and Dust

1.	Cloud ceiling	500 feet (150 m) or greater
2.	Visibility	1 mile (1.6 km) or greater
3.	Low-level temperature inversion	Surface inversion desirable

4.	Temperature (air)	Variable; generally less than 85°F. (29°C.)
5.	Precipitation	None
6.	Wind	Direction; speed less than 10 mph (4.5 m/sec)
7.	Dew	Presence and period

9. Be able to put the system into operation with a minimum response time (estimate no more than 30 minutes), including ferry time if applicable, truck to site and assemble, load chemical, and deploy ground control station. Reasons include quick response to unfavorable near-term weather forecast or rapid spread of plant disease or insects.

B. Sensor/payload. -

1. Carry liquids in one or more tanks in, or mounted on, the RPV.

2. The spray material is pumped into plumbing, usually located near the wing trailing edge, through a series of nozzles. The orifice size of the nozzles for given applications is constant and the amount of liquid or dust is regulated by varying developed pump pressure either controlled manually by the pilot or preset. Changing winds or other factors would require remote control of pump pressure for an RPV.

3. Some material particle sizes are very small and not always visible. A ground controller must be able to determine that system pressure is correct and that proper quantities are being dispensed.

4. Include a fixed forward-looking TV camera to aid in piloting.

C. Air vehicle.

1. Carry at least 15 to 30 pounds (7 to 14 kg) of deliverable spray.

2. Spray at 80 miles per hour (36 m/sec).

3. Minimize wing-tip vortices, to minimize spray drift.

4. Locate the spray nozzles and the propeller relative to one another so as to minimize the backwash effect on the spray pattern, e.g., a puller propeller and nozzles behind the wing trailing edge.

5. Maintain desired altitude to within ± 2-4 feet (± 0.6-1.2 m).

6. Be able to land, reload and refuel, and take off in 3 to 5 minutes.

7. Minimize turning radius.

D. Ground control station. -

1. Control the RPV along a preprogrammed flight pattern to within ± 5 feet (± 1.5 m) cross-track deviation.

2. Control the start and stop of spraying to within ± 15 feet (4.5 m) along the track.

3. Display a real-time TV image from the camera in the RPV.

E. Data and control link. - (Covered above, under "Common requirements")

F. Launch and recovery. -

1. Take off and land from a rough, unimproved dirt strip.

2. Take off in 600 feet (180 m) over 30-foot (9 m) obstacle.

3. Land and taxi to within 25 feet (8 m) of chemical tanker truck located on unimproved road.

G. Support and maintenance. - Provide support and maintenance adequate to keep the air vehicle in the air eight hours per day in a steady-state operation for at least a month at a time.

Mission 8, Severe Storm Research. - The National Weather Service (NWS) of the National Oceanic and Atmospheric Administration (NOAA) conducts an extensive research, monitoring, and measurements program of severe storms (thunderstorms, hurricanes, cyclones, and tornados). The purpose is to analyze storm formation and behavior, and thus provide the public and aviation operations with forecasts of storm activity and potential for a period from 2 to 72 hours in advance.

In addition to storm watch stations, radar, and instrumented weather balloons, aircraft are currently employed to obtain meteorological observations of wind, temperature, pressure, and humidity in the immediate vicinity of tornado vortices and thunderstorms. Manned aircraft, such as the F-100, F-4C, C-120, Queen Air, U-2, and the RB-57F are used.

Two separate missions for RPVs are envisioned. These are:

- Measurements outside the cloud at low altitude including observations in the vicinity of a tornado vortex.
- High altitude monitoring of the growth and decay of thunderstorms.

Because the RPV performance requirements for the "low altitude" mission and the "high altitude" mission are sufficiently different, each is described separately.

A. System capabilities (low-altitude system). -

1. Be sufficiently portable to be transported to remote areas in one or more ground vehicles.

2. Be ready for deployment at any time, 365 days per year.

3. Be capable of continuous controllable flight in the vicinity of small thunderstorms and tornados (a tornado funnel varies from 30 to 300 meters in diameter; when accompanied by, or embedded in, a mesascale cyclone, the total storm diameter varies from 5 to 10 kilometers).

4. Obtain and transmit to a ground station meteorological data at one-minute time periods automatically or on command from ground station.

5. Carry instrumentation to measure temperature, pressure, and humidity.

6. Provide high quality video imagery for the visual observation of the vortex of a tornado, formation and movement of the tornado funnel and adjacent storm, and ground damage.

7. Be capable of maintaining continuous monitoring from an area (space) for no less than a ten-minute period.

8. Be capable of dispensing chaff to provide reflectors for doppler radar determining air motion in space which is precipitation-free.

9. Provide a permanent record of all meteorological measurements and imagery.

10. Be operable by no more than two men (preferably one), not including radar operators, vehicle drivers, etc.

B. Sensor/payload (low-altitude system). -

1. Obtain the following data with the indicated accuracy:

o	Temperature	± 0.5°C.
o	Humidity	± 10%
o	Pressure	± 1 mb
o	RPV altitude	± 1 meter
o	RPV position	± .5 kilometer

- Wind speed ± 2 meters/second
- Wind direction ± 5 degrees

2. Video camera with the following characteristics:
   - 40° by 40° field of view
   - Azimuth control through $\pm 90^{\circ}$
   - Elevation control through $\pm 90^{\circ}$

3. Chaff dispenser: chaff is packaged in separate bundles and released at equal intervals through a 2600-meter column (five bundles maximum).

4. Airborne equipment must continue operating during frequent electrical discharges.

C. Air vehicle (low altitude system). -

1. Maximum airspeed no less than 110 miles per hour (50 m/sec) since the RPV will be operating in wind speeds up to 80 miles per hour (35 m/sec); minimum airspeed at least as low as 60 miles per hour (27 m/sec).

2. Operate at any altitude between ground level and 5000 feet (1.55 km) above ground level, which is approximately 1000 feet (300 meters) above the cloud base.

3. Take off and land in 40 mile per hour (17 m/sec) winds.

4. Maintain a turning radius of no greater than 300-feet (90 m) at maximum airspeed of 110 miles per hour (50 m/sec).

5. An in-flight endurance of one hour is required, with a 30-minute fuel reserve.

D. Ground control station (low altitude system). -

1. Display, and provide permanent record of, real-time TV imagery.

2. Record data transmitted from RPV of temperature, pressure, humidity, RPV position, and altitude, wind speed, and direction.

3. Provide capability for positive and continuous control of TV pointing and zoom adjustment.

4. Provide for control of chaff dispenser at the discretion of the ground station, coordinated with the radar controller.

5. Control only one RPV in the air at a time.

6. Must be transported by ground vehicle and have a self-contained power supply.

7. Provide for continuous altitude and position data; assume radar assist.

E. Data and control link (low altitude system). Operate in the presence of frequent lightning discharges.

F. Launch and recovery (low altitude system). - Take off and land at an unprepared, short surface, or launch from a portable launcher and recover with a portable recovery system.

A. System capabilities (high-altitude system). -

1. Operate from a prepared airfield adjacent to a control radar site.

2. Be ready for use at any time, 365 days per year.

3. Capable of continuous controllable flight over large thunderstorms, obtain and transmit to a ground station meteorological data at one-minute time periods automatically or on command from ground stations.

4. Carry instrumentation to measure the pulsation of the storm top, temperature, and pressure.

5. Provide high-quality video imagery for real-time observation at a ground station of storm formation, movement, direction, and changes in storm intensity.

The NWS is particularly interested in the potential correlation of storm top behavior to storm intensity as measured by surface phenomena. Good video imagery would lead to a relaxation of meteorological measurement requirements.

6. Be capable of maintaining continuous monitoring about an area (space) for no less than a ten-minute period.

7. Provide permanent record of all meteorological measurements and imagery.

8. Operable by no more than two men, not including radar operators. Operation by a single operator is desirable.

B. Sensor/payload (high-altitude system). -

1. Obtain the following data with the indicated accuracy:

o Temperature	± 0.5°C.
o Pressure altitude	± 200 meters
o RPV position location	± 1000 meters

Humidity measurements are not required.

2. Video transmitter with the following characteristics:
   - 40° by 40° field of view
   - Azimuth control through ± 90°
   - Elevation control through ± 90°
   - Self-adjusting to various levels of light intensity (from light haze to heavy overcast); night operations not required.

3. Airborne equipment must continue operating during frequent electrical discharges.

C. Air vehicle (high-altitude system). -

1. Maximum airspeed no less than 110 miles per hour (50 m/sec) since the RPV will be operating in wind speeds up to 80 miles per hour (35 m/sec). Minimum airspeed at least as low as 60 miles per hour (27 m/sec).

2. Operating "on-station" altitude will be 60,000 feet AGL (18 km).

3. Remain "on-station" for at least six hours.

4. RPV range from control radar site will be no greater than 60 miles (100 km).

5. Take off and land in 40 mile per hour (17 m/sec) winds from a prepared airstrip.

D. Ground control station (high-altitude system). -

1. Control the air vehicle to fly the desired flight path and mission profile with corrections for winds and gusts up to 80 mph (35 m/sec) from any direction.

2. Display air-vehicle operating data (e.g., remaining fuel) required for safe operation.

3. Provide hard copy or a videotape record of the sensor's picture (plus pertinent data such as time, date, and location) on demand of the operator.

4. Be operable by no more than two persons. Operation by one operator is desirable.

5. Control one air vehicle at any one time.

6. Portability is required.

7. Provide for control of chaff dispenser at the discretion of the ground station coordinated with the radar controller.

E. Data and control link (high-altitude system). - Operate in the presence of frequent lightning discharges.

F. Launch and recovery (high-altitude system). - Take off and land from a prepared runway.

G. Support and maintenance (high-altitude system). - (Covered above, under "Common requirements")

Mission 9, Meteorology. - The National Weather Service (NWS) employs a variety of techniques to obtain daily meteorological data throughout the U.S. and at sea. These data are used for forecasts and warnings, by the Environmental Data Service to document our climatological history, by travelers to determine the weather existing over their proposed route, for the conduct of air and sea navigation and local operations, for short- and long-range monitoring of the environment, by research laboratories exploring the mechanics of our atmosphere.

Of particular interest for potential RPV applications are two programs which obtain periodic weather data from ground surface to 10,000 feet (3000 m) and 20,000 feet (6000 m), respectively. Manned aircraft are not used to obtain day-to-day routine meteorological data. Rather, weather balloons, tracking radar and other ground based sensors, and visual observation are the most common techniques used. Weather balloons are not recoverable, and a high percentage of the airborne instrumentation packages are lost. The RPV operational requirements have been derived from conversations with the NWS and programs described in Reference 8 . These requirements are based largely on the ability of the RPV to substitute for the balloon as the airborne vehicle. Although there are a number of RPV performance requirements common to both the 10,000-foot and 20,000-foot missions, for convenience, each is discussed separately.

A. System capability (low-altitude system). -

1. Provide data for continuous determination of vertical profiles of wind, temperature, and relative humidity.

2. Minimum value of maximum altitude: 10,000 feet (3000 m) AGL, 15,000 feet (4500 m) MSL.

3. Two flights are normally conducted each day, 365 days per year, at approximately 0900 and 1600 hours. System should be available for additional flights (up to two more per day) if dictated by rapid weather changes.

4. Minimum operational complexity: a goal is to be equivalent to inflating a balloon, attaching prepackaged instrumentation, and releasing the balloon.

5. All-weather capability (exclude severe storms).

6. Be less costly to own and operate than the weather-balloon method.

7. Minimum RPV maintenance (counted in minutes per day).

8. Have a very high probability of RPV recovery at the launch station.

B. Sensor/payload (low-altitude system). -

1. Airborne instrumentation measures temperature and relative humidity. Data are continuously telemetered to ground station. Sensor transmitters and receivers operate at 403 MHz.

2. The weather data payload package weighs approximately five pounds.

C. Air vehicle (low-altitude system). -

1. Rate of climb: 650 feet per minute (3.3 m/sec) with ground station verification capability.

2. Be ready for no fewer than two flights per day, with capability of up to four flights per day.

3. All-weather capability (daytime only); exclude severe storms.

4. Take off and land in an area approximately 100 feet by 100 feet (30 m by 30 m).

5. Have a maximum speed of at least 60 miles per hour (27 m/sec).

6. Be operable by one person.

7. Take off and land in surface winds up to 30 mph.

8. Provide for one hour total flight endurance.

9. Provide for autopilot control during ascent to required altitude, provision for reacquiring a lost data link, and safe (soft landing) recovery in the event of permanent data link loss or power failure.

D. Ground control station (low-altitude system). - The RPV will operate from permanent, fixed ground stations presently located in clear areas away from housing, airports, industry, etc.

Two basic functions will be performed at the ground stations:

- Use the existing systems for receipt and processing of telemetered temperature and moisture data and for radar and/or optical theodolite tracking of RPV drift for wind velocity and direction.
- Provide additional systems for RPV launch, control, and recovery.

1. Use existing ground read-out equipment, located at permanent stations, with minimum, or preferably no, modifications.

2. Use existing radar and optical theodolites to track RPV drift to provide vertical profiles of wind direction and velocity.

3. Control only one RPV at a time.

4. Provide for continuous RPV time-altitude data to correlate with meteorological sampling.

5. Assume all provisions for weather data reception and processing are already available since the RPV is only substituting for the balloon as the airborne platform.

6. Provide for constant rate of ascent or measuring rate of ascent and preprogrammed flight profile requiring no ground operator control after launch.

E. Data and control link (low-altitude system). - (Covered above, under "Common requirements")

F. Launch and recovery (low-altitude system). - Take off and land from a small, clear area with minimum improvements.

G. Support and maintenance (low-altitude system). - Provide capability for maximum support and maintenance of the air vehicle at the weather station, providing for up to four flights per day.

High-altitude Meteorology. -

A. System capabilities (high-altitude system). -

1. Provide data for continuous determination of vertical profiles of wind direction and velocity.

2. Minimum value of maximum altitude, 20,000 feet (6000 m) AGL, 25,000 feet (7500 m) MSL.

3. Between one and three flights conducted each day, 365 days per year. System should be available for additional flights (up to a total of four per day) if dictated by rapid weather changes.

4. Minimum operational complexity: a goal is to be equivalent to inflating a balloon, attaching a small payload, and releasing the balloon.

5. All-weather capability (exclude hurricane force storms and tornados).

6. Be less costly to own and operate than the weather-balloon method.

7. Minimum RPV maintenance (counted in minutes/day).

8. Have a very high probability of RPV recovery at the launch site.

B. Sensor/payload (high-altitude system). - There are no sensor or instrumentation payloads currently used for this mission. Occasionally a small light is attached to the balloon for night operations, since wind data are obtained by tracking the balloon by optical theodolite.

Reference 8 notes the following:

a). A fixed rate of rise (of the balloon) is assumed; and height is determined by timing the ascent.

b). This method of windfinding requires favorable weather conditions. Low clouds and obstructions to vision interfere with visual tracking, while turbulence, precipitation, and icing introduce inaccuracies into the assumed ascent rates.

The use of an RPV, instrumented to provide accurate rate-of-climb data and a capability of being tracked through fog, precipitation, low ceiling, etc., could have considerable advantage over a balloon.

Both airborne and ground station instrumentation to achieve this capability should be considered.

C. Air vehicle (high-altitude system). -

1. Rate of climb, 600 feet per minute (3 m/sec.), with ground station verification capability.

2. Be ready for no fewer than 2 flights per day, with capability for up to 4 flights per day.

3. All weather capability (day and night), excluding severe storms.

4. Take-off and land in an area approximately 100 ft x 100 ft (30 m x 30 m).

5. Be operable by one person.

6. Have an operational ceiling of at least 25,000 ft (7600 m), to operate at 20,000 ft (6100 m) AGL over terrain at 5000 ft (1500 m) altitude.

7. Take-off and land in surface winds up to 30 mph (13 m/sec.).

8. Provide for 1-1/2 hours total flight endurance to permit controlled flight return to launch facility.

9. Provide autopilot control during ascent to required altitude, provision for reacquiring a lost data link and safe (soft landing) recovery in the event of permanent data link loss or power failure.

D. Ground control station (high-altitude system). - The RPV will operate from permanent, fixed ground stations located in cleared areas away from housing, airport, industry, etc.

Two basic functions will be performed at the ground stations:

- Use current system to provide optical theodolite tracking of RPV drift for wind velocity and direction.
- Provide additional systems required for RPV launch, control, and recovery.

1. Use existing ground read-out equipment, located at permanent stations, with minimum modifications.

2. Use existing optical theodolites or the RPV guidance system to track RPV drift to provide vertical profiles of wind direction and velocity.

3. Control only one RPV at a time.

4. Provide for continuous RPV time-altitude data to correlate with meteorological sampling.

5. Assume provisions for wind data observation and processing are already available, since RPV is only substituting for the balloon as the airborne platform.

6. Provide for constant rate of ascent, and a preprogrammed flight profile requiring no ground operator control after launch.

7. Be operable by one person.

E. Data and control link (high-altitdue system). - (Covered above under "common requirements".)

F. Launch and recovery (high-altitude system). - (same as for low-altitude system.)

G. Support and maintenance (high-altitude system). - (Same as for low-altitude system).

APPENDIX D

RPV CONCEPTUAL-DESIGN PARAMETRICS

The parametric curves in this section provide the preliminary sizing of an RPV based on flight requirements. The assumed basic design comprises a conventional fixed-wing, piston-engine aircraft. The method used consists of the following steps:

Step 1. Define the flight requirements.
" 2. Determine the wing loading.
" 3. Size the wing and total wetted area.
" 4. Estimate airframe drag.
" 5. Determine the conditions for maximum lift-to-drag-ratio (L/D) flight.
" 6. Determine cruise horsepower (HP) at max. L/D.
" 7. Determine HP at high speed.
" 8. Determine HP at cruise ceiling.
" 9. Size the propulsion.
" 10. Determine the fuel weight.
Steps 11 - 17. Determine the group weight breakdown.

Step 18. After the group weights and payload have been determined, the design is adjusted, as needed, by iteration through steps 1 - 17, with changes to the vehicle flight requirements or size as judged necessary, to give the desired payload capability and flight characteristics. An acceptable design results from a reasonable balance among flight characteristics—speed, altitude, endurance, payload.

An explanation of the steps and use of the parametric curves to size an example RPV are given in the following paragraphs.

On some of the parametric curves, data points from actual drone, RPV, and manned aircraft are shown for reference. The following aircraft are used:

- AQUILA RPV built by the Lockheed Missiles & Space Company (LMSC) for the U.S. Army.
- AEQUARE RPV built by LMSC for the U.S. Air Force (USAF) and the Defense Advanced Research Projects Agency (ARPA).
- BQM-34A and -34E target drones built by Teledyne-Ryan for the U.S. Navy and USAF.
- Cessna 150 and Cessna 185 single-engine light aircraft (general aviation).
- F-80 jet fighter aircraft built by the Lockheed-California Company for the USAF.
- Harassment drone, built by LMSC for the USAF and ARPA.
- KD2R-5 target drone built by Northrop.
- L-5 single-engine light observation aircraft (high wing, strut-braced, fixed landing gear).

Step 1. Flight requirements.- Establish max density altitudes for flight and launch or recovery operation. Include consideration of maximum terrain elevation and hot-day conditions expected. Select minimum airspeeds, desired cruise flight and launch or recovery. Select endurance or range desired and max speed.

Example: Operate from a 5000 ft (1525 m) field elevation on 90°F (32.2°C) day with flight up to 1500 ft (457 m) above ground. Minimum launch and recovery speed to be not over 40 KTAS (20.5m/sec) and minimum cruise speed not over 65 KTAS (33.4m/sec).

Determine from Figure D-1, density altitudes for launch and flight:

$h_p =$ 5000 ft (1525 m)

$T =$ 90°F (36°C)

$h_\sigma =$ 8000 ft (2440 m) for launch

$h_p =$ 6500 ft (1980 m)

$T =$ 90°F (36°C)

$h_\sigma =$ 9800 ft (2990 m) for cruise flight;
use 10,000 ft (3050 m).

Step 2. Wing loading. - Determine the maximum allowable wing loading that satisfies the minimum airspeeds set for launch and cruise

Example: Require launch speed to be not over 40 kt TAS (20.5m/sec) and cruise not over 65 kt TAS (33.4m/sec).

Using Figure D-2; with the appropriate density altitude, the wing loadings are for launch, W/S = 4.3 lb/ft^2 (21 kg/m^2) max; for cruise, W/S = 5.1 lb/ft^2 max. The launch wing loading is lower and sets the wing area.

Step 3. Size wing and wetted area. - Size the wing area to the vehicle gross weight. Here, the gross weight may be a preferred value, set in the initial requirements or, in lieu of this, an intuitive estimate based on the amount of payload and flight duration. A first estimate may be 5 times payload weight, for longer flights.

Example: Assume payload weight to be 25 lb (11.35 kg), and estimate gross weight to be

W_o = 5 x 25 = 125 lb (56.8 kg)

Then wing area, S = 125/4.3 = 29 ft; use 30 ft (2.79 m^2).

Using Figure D-3, estimate the vehicle wetted area for a wing size of 30 ft^2 (2.79 m^2).

S_{wet} = 130 ft^2 (12.1 m^2)

Step 4. Airframe drag. - Consider the airframe design arrangment and extent of aerodynamic cleaness (exposed payload, landing gear, etc.). Correlate with existing designs.

Example: Assume vehicle has fixed landing gear.

Using Figure D-4, with S_{wet} = 130 ft^2 (121. m^2) and selecting equivalent skin-friction coefficient C_f = 0.010, then

Equivalent parasite area, f = 1.3 ft^2 (0.121 m^2).

Step 5. Maximum lift/drag ratio. - Select a wing span or aspect ratio, A (typically A = 4 to 8). Determine vehicle profile drag coefficient. Determine lift coefficient and max lift/drag ratio.

Example: Assume aspect ratio, A = 5

Then wing span, $b = \sqrt{AS}$

$b = \sqrt{5 \times 30} = \sim 12$ ft (3.66 m)

Profile drag coefficient, $C_{D_o} = f/S$

$C_{D_o} = 1.3/30 = 0.043$

Using Figure D-5, and selecting wing efficiency factor $e = 0.8$ (typical), determine lift coefficient C_L at maximum lift-to-drag, L/D.

For (L/D) max, $C_L = 0.74$

and $(L/D)_{max} = 8.5$

Using Figure D-6, the corresponding flight conditions would be

Dynamic pressure, $q = 5.6$ lb/ft^2 (27.4 kg/m^2).

At 10,000 ft, airspeed V = 47.5 kt TAS (24.4 m/sec).

Step 6. Cruise power for max. L/D flight. - Using Figure D-7, for flight conditions at max L/D, determine cruise power.

Example:

Cruise drag, $W_o \div (L/D) = 125/8.5 = 14.7$ lb (6.67 kg)

Thrust horsepower, THP = 2.1 hp (1.57 kW) at 47.5 kt TAS (24.4 m/sec)

Selecting propeller efficiency, $\eta_p = 0.7$ (typical for cruise)

Then engine horsepower, HP = 3.1 hp (2.31 kW).

If an engine-driven generator exists, then the engine must provide additional power

$HP_{Generator}$ = Watts/500 (generator efficiency = 0.67)

If 400 watts of electrical load is being supplied, for example, then

Engine $HP_{Cruise} = 3.1 + 400/500 = 3.9$ hp (2.91 kW).

Step 7. Power at high speed. - For propulsion sizing, consider the vehicle maximum speed requirement plus any accessory loads. (If no high-speed requirement above crusie speed exists, omit this step.)

Example: Assume 75 kt TAS (38.6 m/sec) is desirable at the maximum operating altitude, 10,000 ft (3048 m).

Using Figure D-8, determine horsepower ratio.

For $V/V_{L/D\ max} - 75/47.5 = 1.58$

Determine $H_P/HP_{L/D\ max} = 2.28$

Then high speed HP = 2.28 x 3.1 = 7.1 hp (5.36 kW).

With generator load of 400 watts, then

Engine HP = 7.1 + 400/500 = 7.9 hp (5.89 kW).

Step 8. Power at cruise ceiling. - For propulsion sizing, consider the maximum operating altitude plus any accessory loads. Provide a rate-of-climb margin at cruise ceiling of RC = 300 fpm (91.4m/min).

$$\text{Engine HP}_{\substack{\text{cruise}\\ \text{ceiling}}} = (\text{THP}_{L/D\ \max} + W \times RC/33000)\ (1/\eta_{\substack{\text{prop}\\ \text{climb}}})\ + \text{HP}_{\text{Gen}}$$

Where: $\text{THP}_{L/D\ \max}$ as determined earlier, step 6

$RC = 300$ fpm (91.4 m/min)

$\eta_{\substack{\text{prop}\\ \text{climb}}} = 0.6$ (typical propeller eff. in climb)

$$\text{Engine HP}_{\substack{\text{cruise}\\ \text{ceiling}}} = (\text{THP}_{L/D\ \max} + W/110)\ (1/0.6)\ + \text{Watts}/500$$

Example: $\text{HP}_{\substack{\text{cruise}\\ \text{ceiling}}} = (2.1 + 125/110)\ (1/0.6) + 400/500$

$\text{HP}_{\substack{\text{cruise}\\ \text{ceiling}}} = 5.4 + 0.8 = 6.2$ hp (4.63 kW).

Step 9. Propulsion sizing. - Determine sea level installed power needed to satisfy the high-speed requirement (step 7) and the cruise ceiling requirement (step 8). Provide an allowance for engine installation losses based on the extent of exhaust manifold, muffler, and air induction cleaner used.

Example: High speed requirement at 10,000 ft (3048 m), Engine HP = 7.9 hp (5.89 kW)

Cruise ceiling requirement, 10,000 ft, Engine HP = 6.2 hp (4.63 kW)

In this example the high-speed power requirement sizes the engine.

Using Figure D-9, and engine horsepower of 7.9 hp, determine sea level installed horsepower to be 11.3 hp (8.43 kW). Assuming a typical installation loss factor of 0.9 (no muffler) requires the engine to have a rated horsepower of 12.5 hp (9.33 kW); 0.8 to 0.7 would be appropriate, depending on the degree of muffling.

Step 10. Fuel weight. - Estimate engine specific fuel consumption (sfc) for the type of engine selected (2-cycle or 4-cycle) with allowance for service degradation and field maintenance conditions. Estimate fuel weight from the range or flight endurance required. Provide a fuel reserve allowance.

Endurance fuel, $W_f = P \times sfc \times t$

Range fuel, $W_f = P \times sfc \times R/V$

Where P = power
t = endurance (time)
R = range
V = speed

(Assuming fuel weight is small compared to gross weight.)

Example: Using Figure D-10, estimate sfc for the selected engine at operating altitude.

For 2-cycle engine at 10,000 ft (3048 m), estimate
sfc = 1.1 lb/hp-hr (3.25 kg/kW-hr).

Assume 2-hour flight time is required at low-speed cruise (max L/D conditions from step 6)

Cruise power = 3.9 hp (2.9 kW)

Fuel $W_f = 3.9 \times 1.1 \times 2 = 8.6$ lb (3.9 kg)

Providing a fuel reserve (10% typical)

Fuel weight, $W_f = 8.6 + .10\,(8.6) = 9.4$ lb (4.27 kg)

(Round up to 10 lb, or 4.54 kg.)

Vehicle group weight estimates. - The basic groups are:

a. Structure
   - wing
   - tail
   - body
b. Launch/Retrieval gear
   - landing gear
   - parachute
   - net engagement
c. Flight controls
   - autopilot
   - actuators, linkages
d. Propulsion
   - engine

  - air induction, exhaust, muffler
  - engine controls
  - propeller
  - fuel system

e. Electrical
  - power supply
  - power conversion
  - wiring

f. Avionics
  - command link
  - telemetry
  - beacons

Vehicle empty weight comprises a summation of the above groups.

$$W_{empty} = W_{struct.} = W_{L/Retrieval} = W_{cont.} = W_{prop.} + W_{elect.} + W_{avion.}$$

Gross weight, $W_o = W_{empty} + W_{fuel} + W_{payload}$

<u>Step 11. Structure weight, W_{struct}</u>. - Select a structural load factor limit for the expected flight usage. Typically:

limit $\eta = 4$

factor of safety $= 1.25$ (unmanned)

ultimate $\eta = 1.25 \times 4 = 5.$

Using Figures D-11 and D-12, determine wing, tail, and body weight.

Example: For wing loading $Wo/S = 4.3$ lb/ft^2 (21 kg/m^2) (from step 2)

then $\eta \times Wo/S = 5 \times 4.3 = 21.5$ lb/ft^2 (105 kg m^2).

Wing wgt $W_{wing}/S = 0.75$ lb/ft^2 (3.66 kg/m^2)

$W_{wing} = 0.75 \times 29$ ft^2 $= 22$ lb (9.99 kg)

Tail wgt $W_{tail}/W_{wing} = 0.3$

$W_{tail} = 0.3 \times 22 = 7$ lb (3.18 kg)

Body wgt $W_{body}/W_o = 0.145$

$W_{body} = 0.145 \times 125 = 18$ lb (8.17 kg)

$W_{struct} = 22 + 7 + 8 = 47$ lb (21.34 kg).

Step 12. Launch/Retrieval gear weight. - Select a concept for launch and retrieval (large weight variations can be expected here for parachutes, landing gear, skids, etc.). Use Figure D-13 for preliminary weight estimates.

Example: Assume a landing gear concept. Then ,

tentatively, $W_{L/Retrieval}/W_o = 0.05$

$W_{L/Retrieval} = 0.05\ (125) = 6$ lb (2.72 kg)

Step 13. Flight controls weight. - Use Figure D-14 for weight estimate.

Example: $W_{cont}/W_o = 0.095$

$W_{cont} = 0.095\ (125) = 12$ lb (5.45 kg)

Step 14. Propulsion group weight. - Use Figure D-15 for propulsion group weight estimate.

Example: For engine rated power = 12.5 hp (9.33 kW) (from step 9)

$W_{prop}/HP = 1.3$ lb/hp (0.79 kg/kW)

$W_{prop} = 1.3\ (12.5) = 16$ lb (7.26 kg)

Step 15. Electrical group weight. - Use Figure D-16 for electrical group weight estimate.

$W_{elect.} = 0.09\ (125) = 11$ lb (4.99 kg)

Step 16. Avionics group weight. - Use Figure D-17 for avionics group weight estimate.

$W_{avionics}/W_o = 0.05$

$W_{avionics} = 0.05\ (125) = 6$ lb (2.72 kg)

Step 17. Group weight summary. - The group weights are summed up to determine empty weight. Weight available for payload becomes:

$$W_{PL} = W_o - W_{empty} - W_{fuel}$$

Example:

Group	Weight
Structure	47 lb
L/Retrieval	6
Flight Controls	12
Propulsion	16
Electrical	11
Avionics	6
Empty wgt	98 lb (44.49 kg)
Fuel	10 lb (4.54 kg)

W_{PL} = 125 -98 -10

W_{PL} = 17 lb (7.72 kg) as compared to the 25 lb (11.35 kg) desired in step 3.

This completes the first iteration. Since W_{PL} is too small, a review of the group weights is made to determine if they are reasonable values compared to the vehicle design concept. Adjustments are made, if required, and another iteration is made through the sizing steps with a change in the initial gross weight or the flight requirements to achieve the desired design.

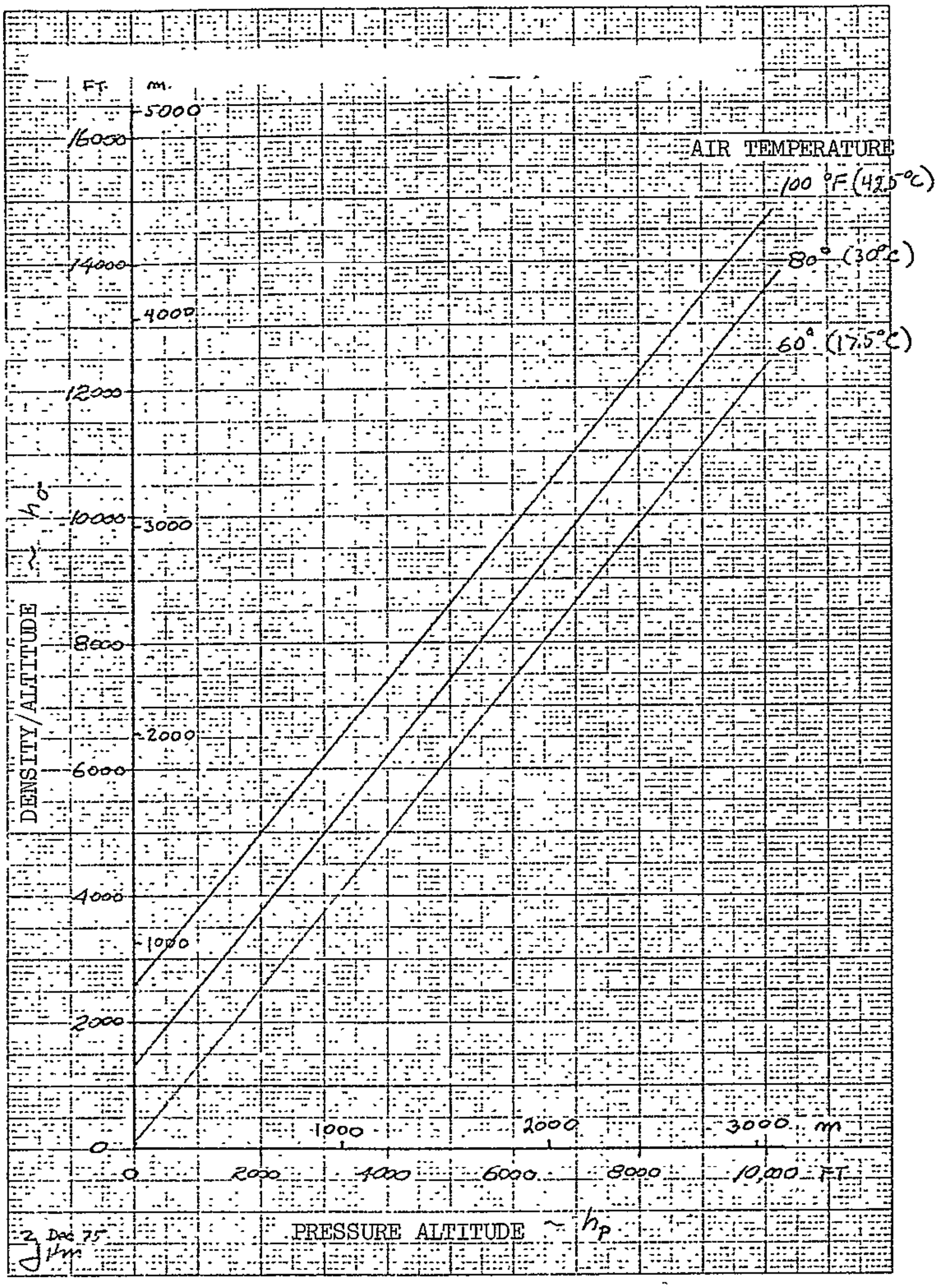


Figure D-1. Density Altitude - Hot Day Conditions

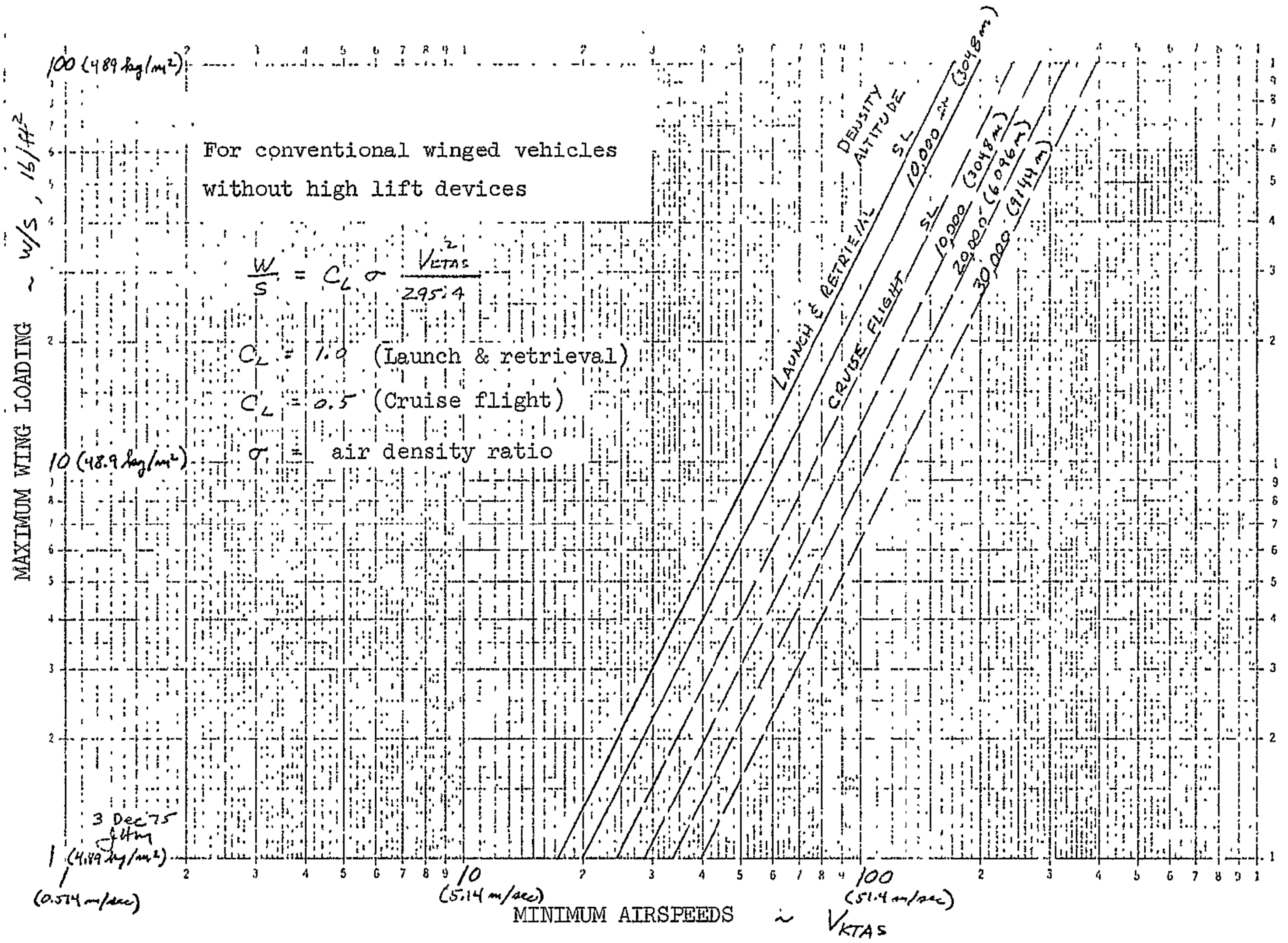


Figure D-2. Preliminary Wing Loading Selection

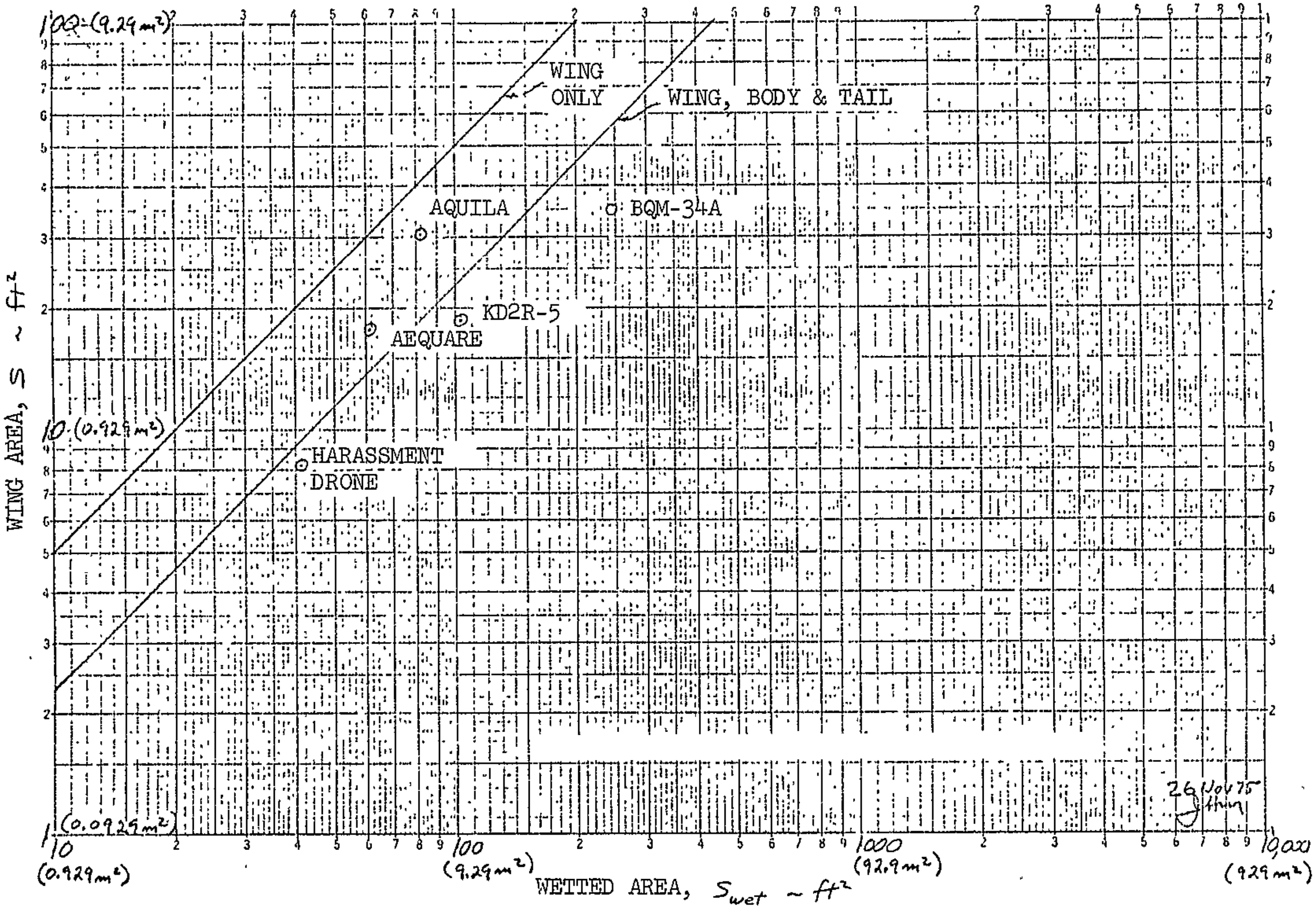


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Figure D-3. Wetted Area Correlation

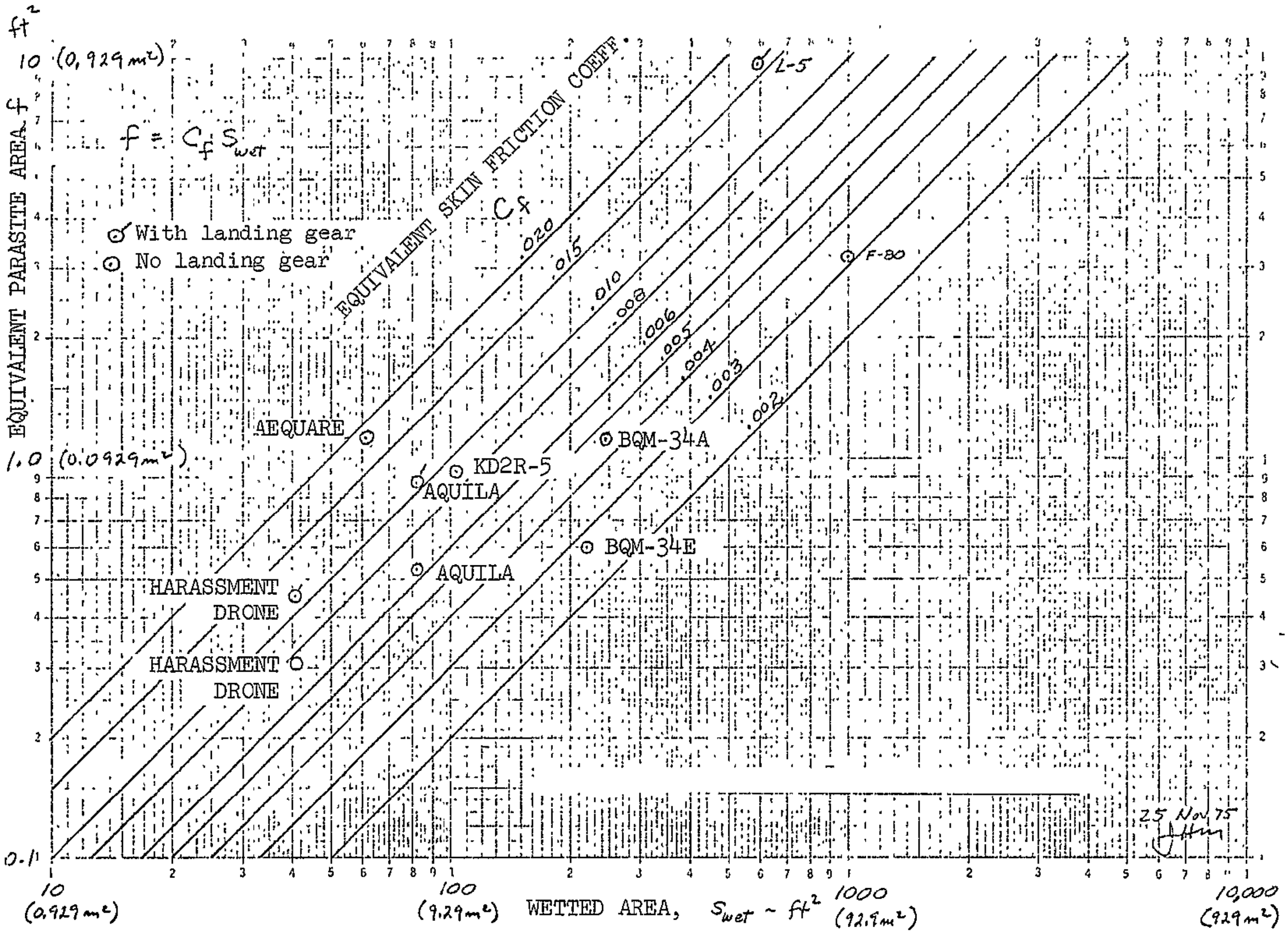


Figure D-4. Parasite Drag Correlation

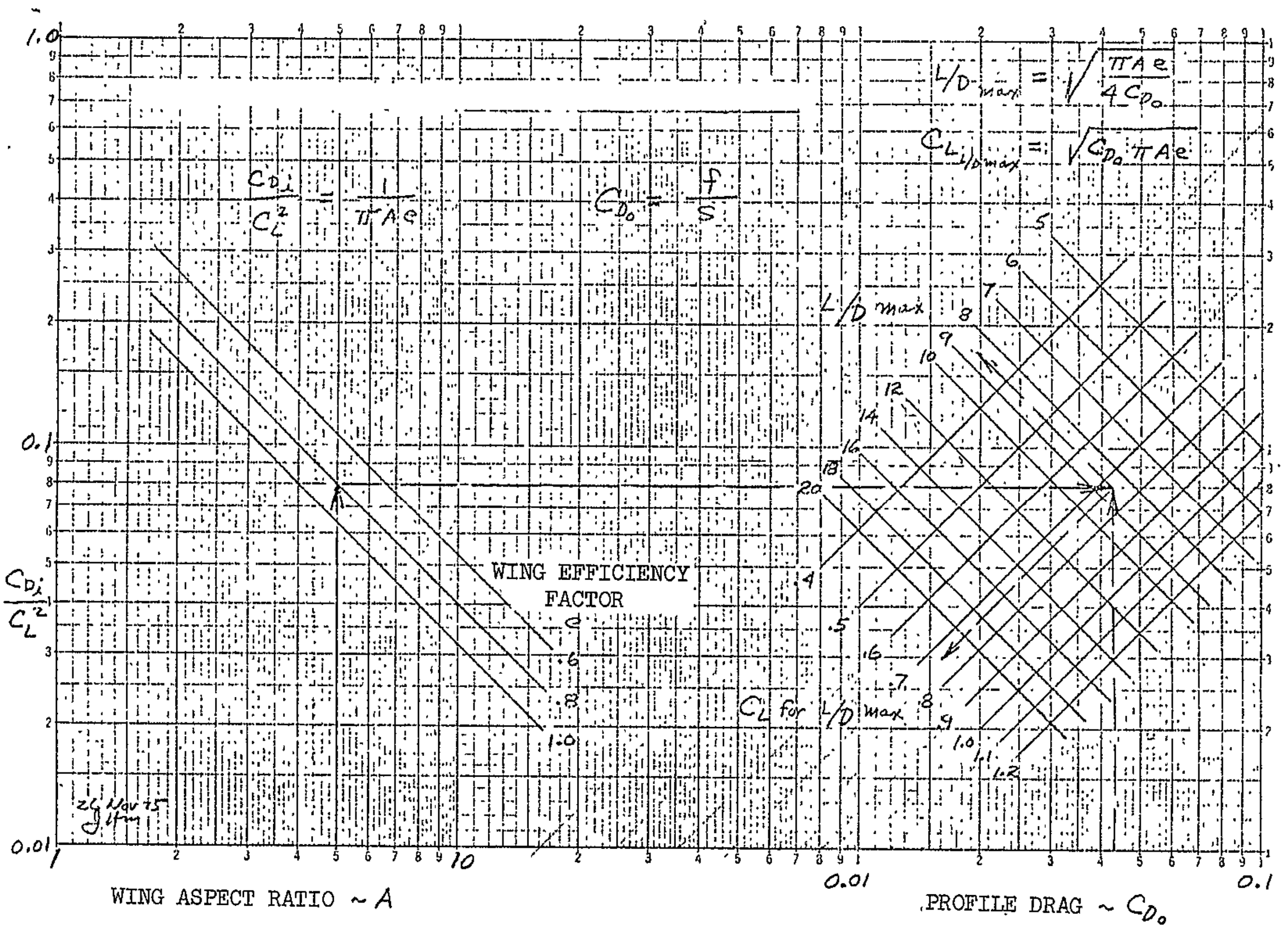


Figure D-5. Maximum Lift/Drag Ratio

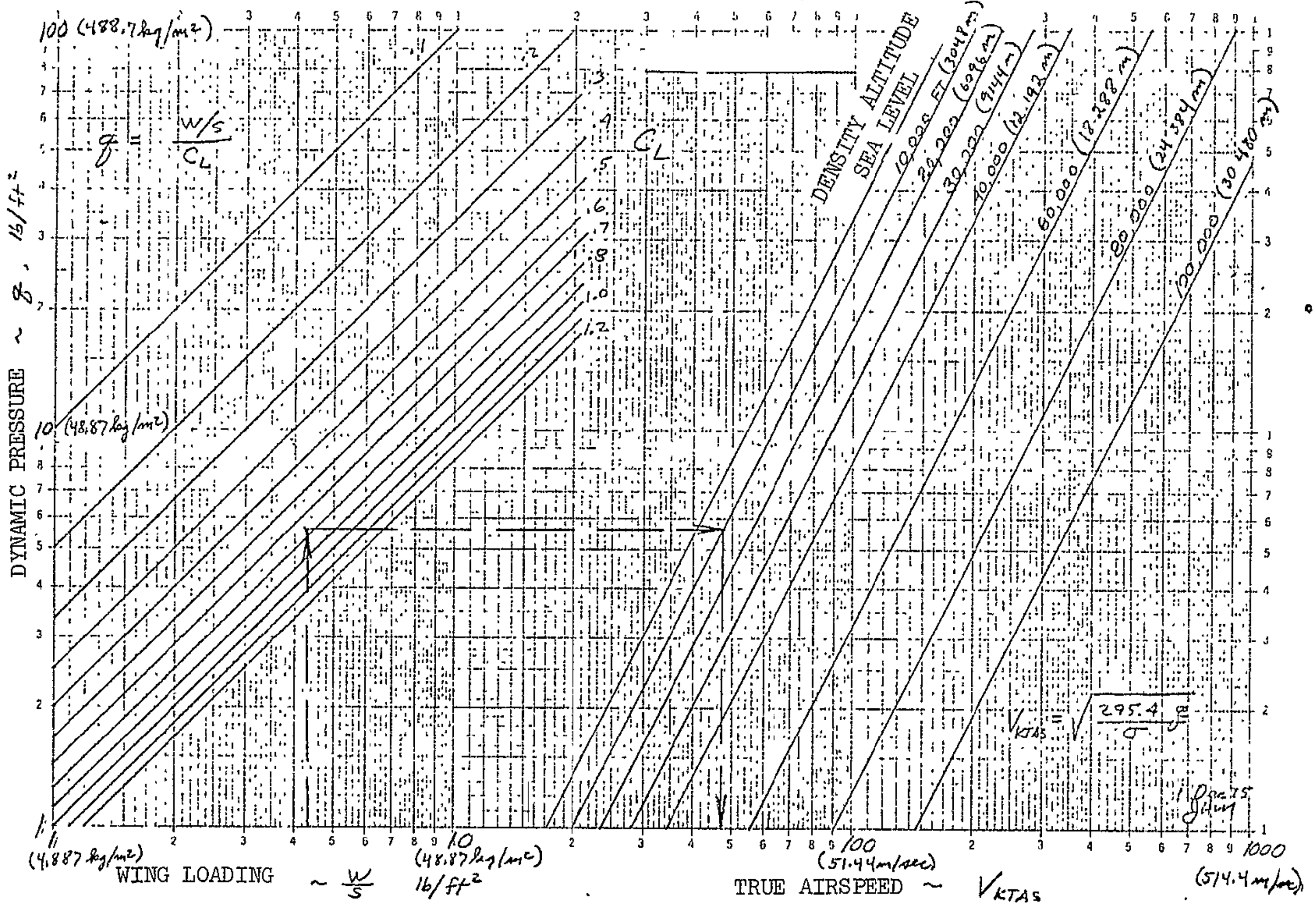


Figure D-6. Flight Speed

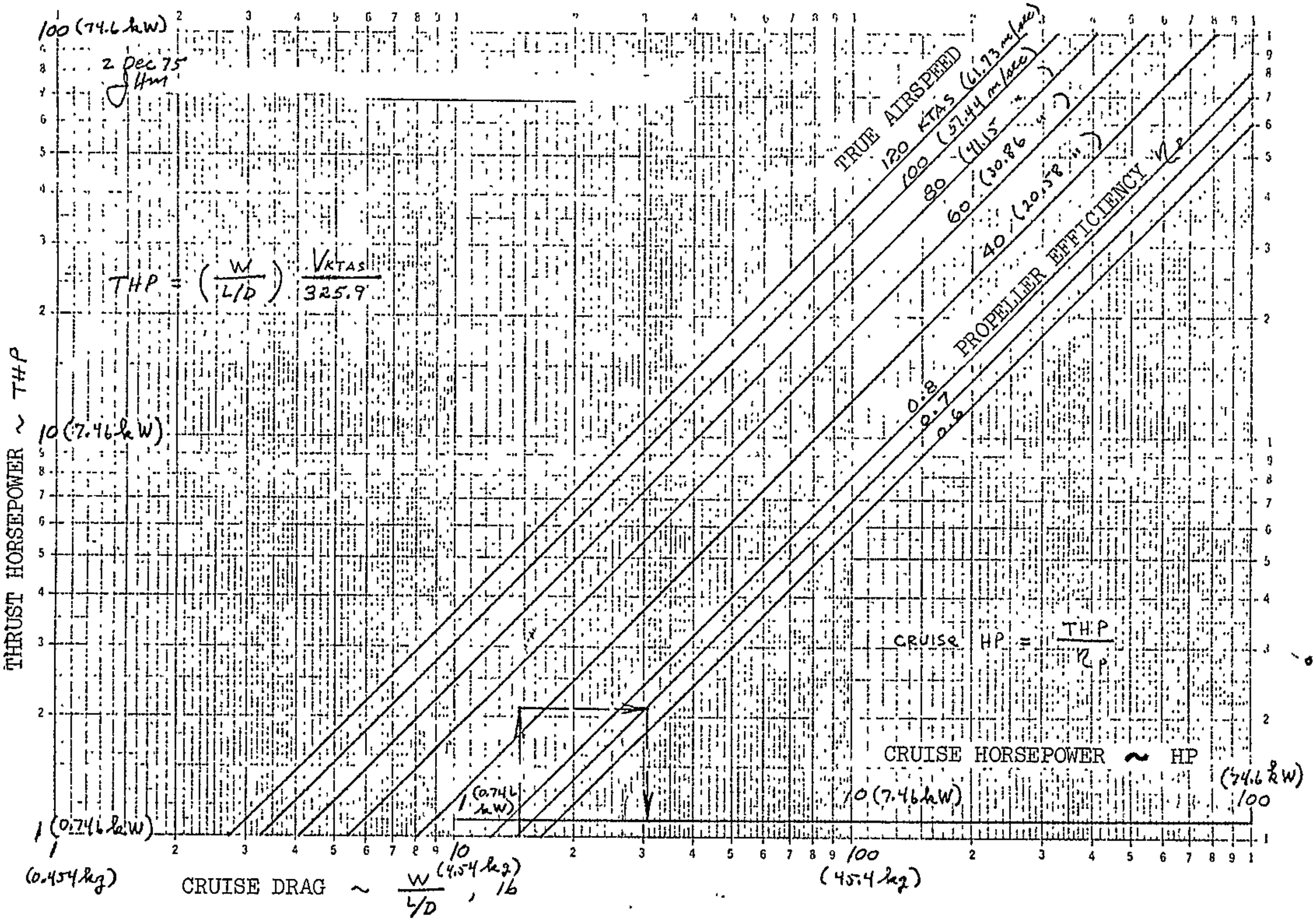
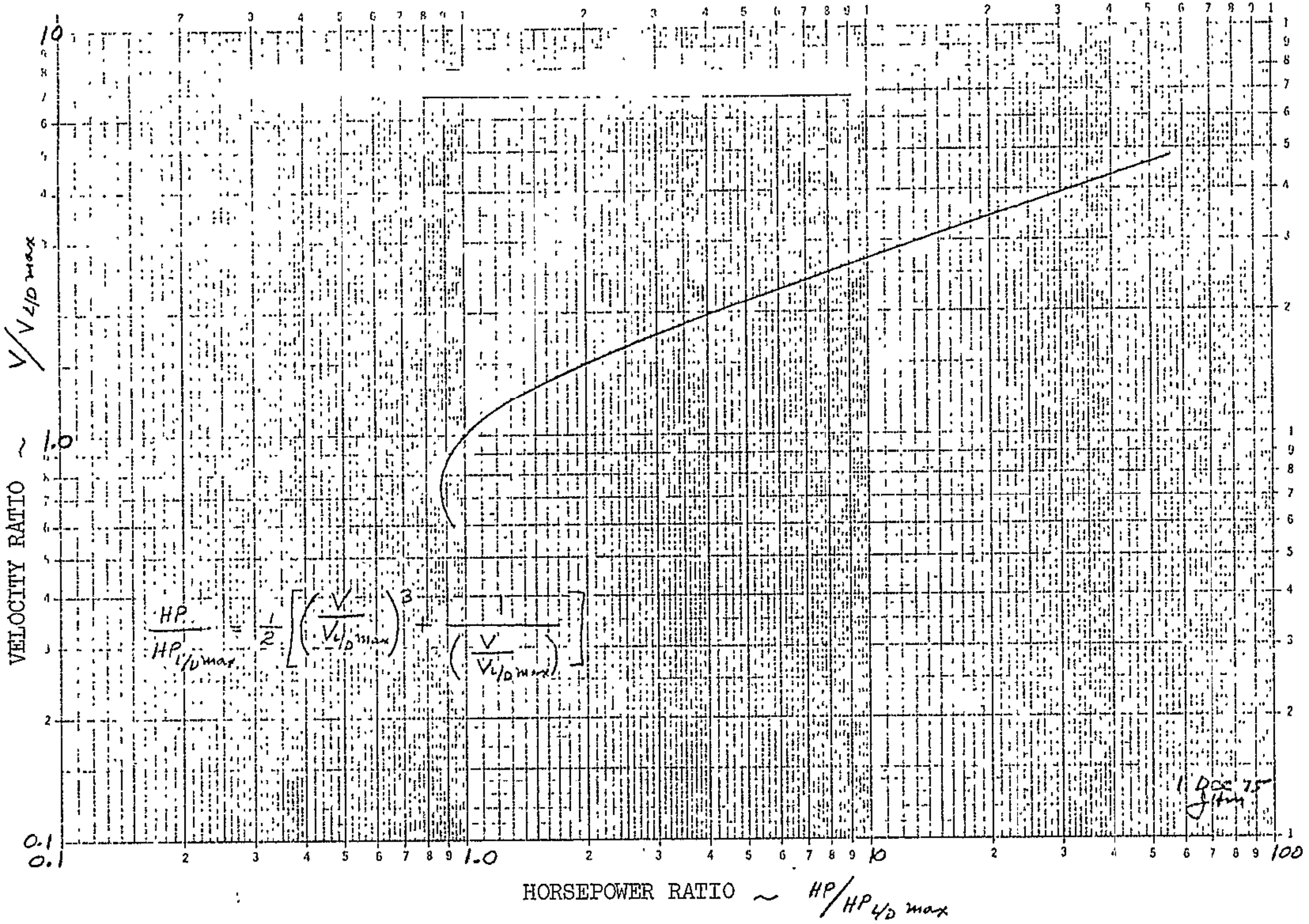


Figure D-7. Cruise Horsepower



$$\frac{HP}{HP_{L/D\,max}} = \frac{1}{2}\left[\left(\frac{V}{V_{L/D\,max}}\right)^3 + \frac{1}{\left(\frac{V}{V_{L/D\,max}}\right)}\right]$$

Figure D-8. Speed - Power Required

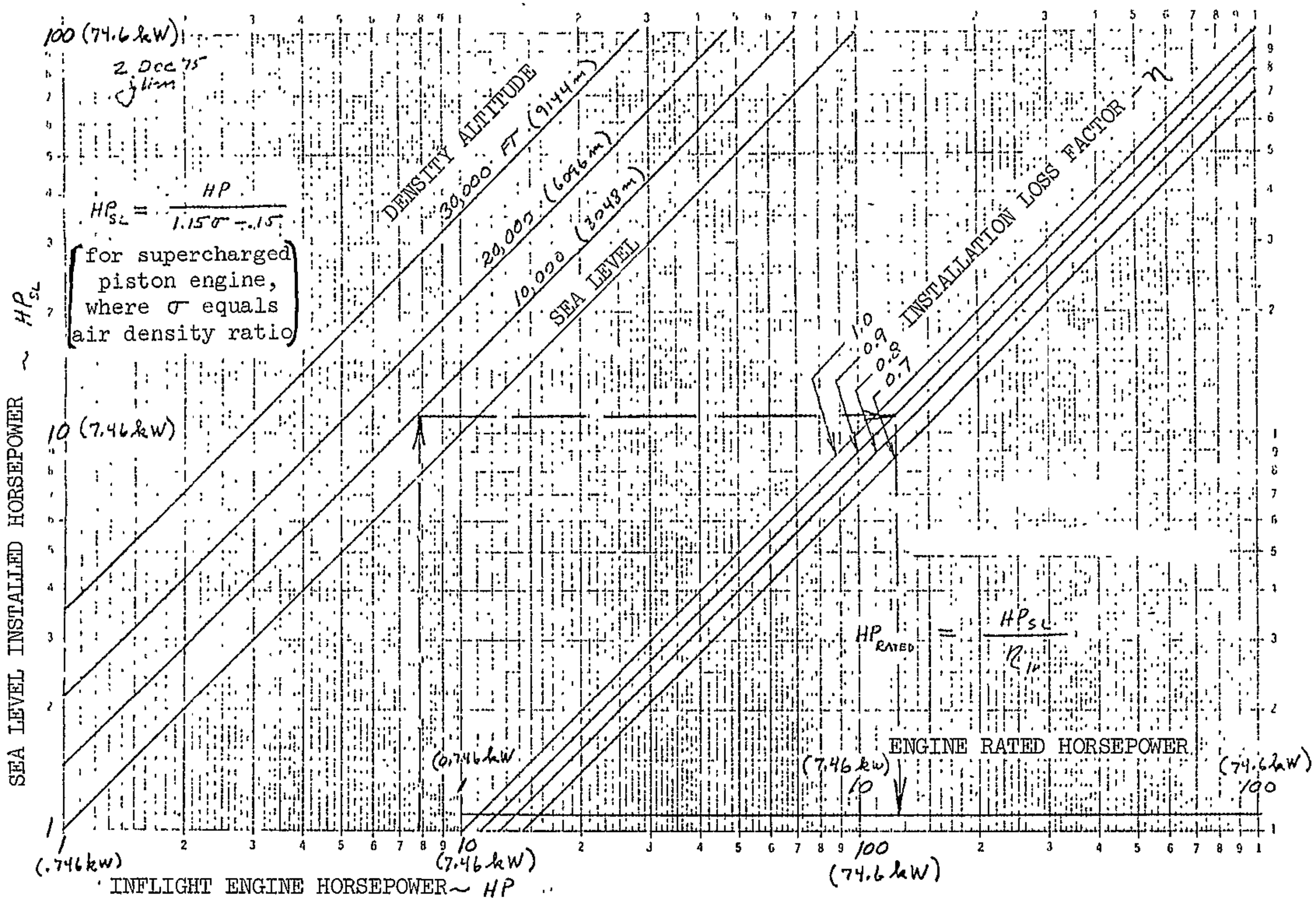


Figure D-9. Engine Sizing

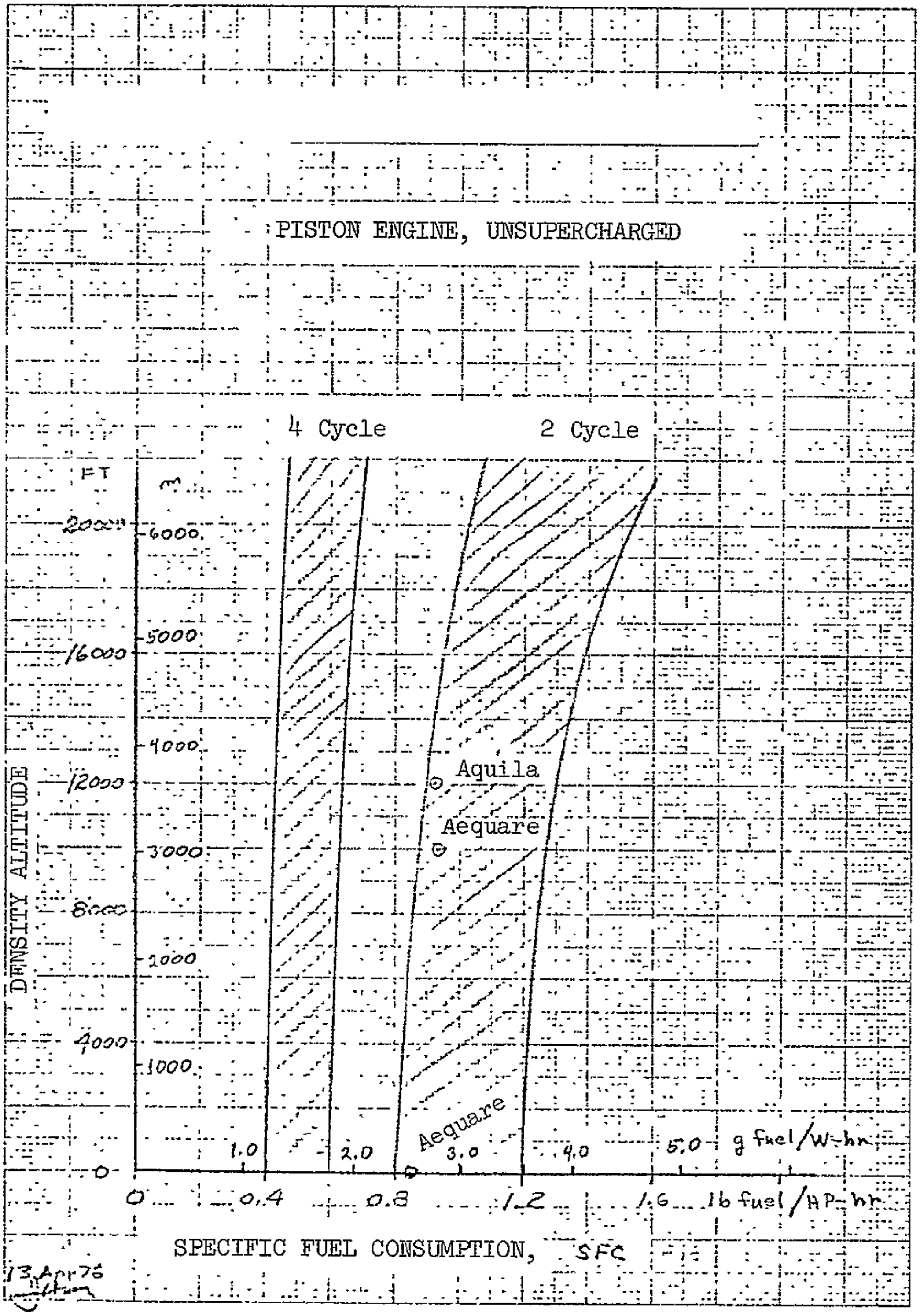
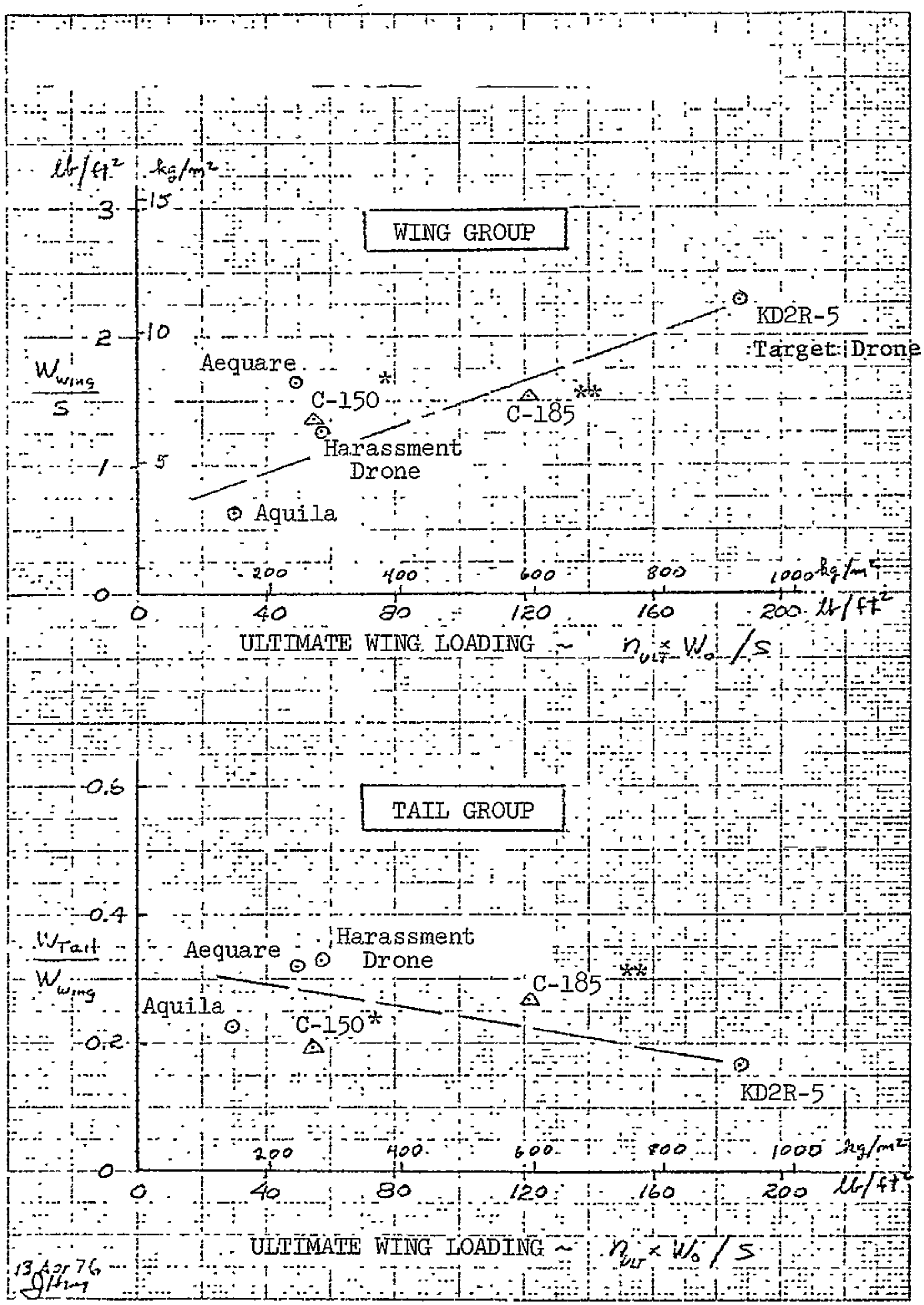


Figure D-10. Specific Fuel Consumption



*Cessna 150
**Cessna 185

Figure D-11. Wing & Tail Structural Weight

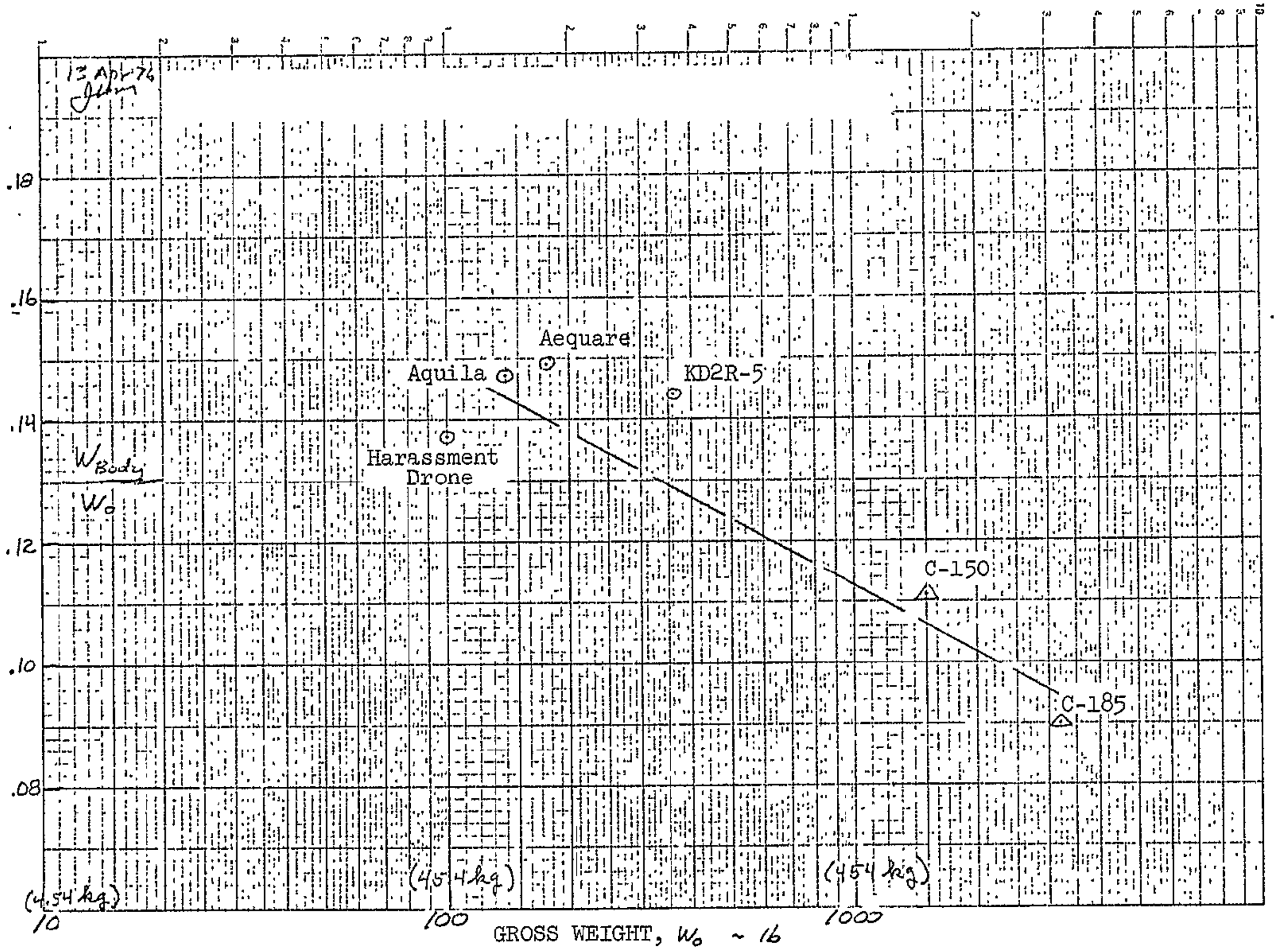


Figure D-12. Body Group Structural Weight

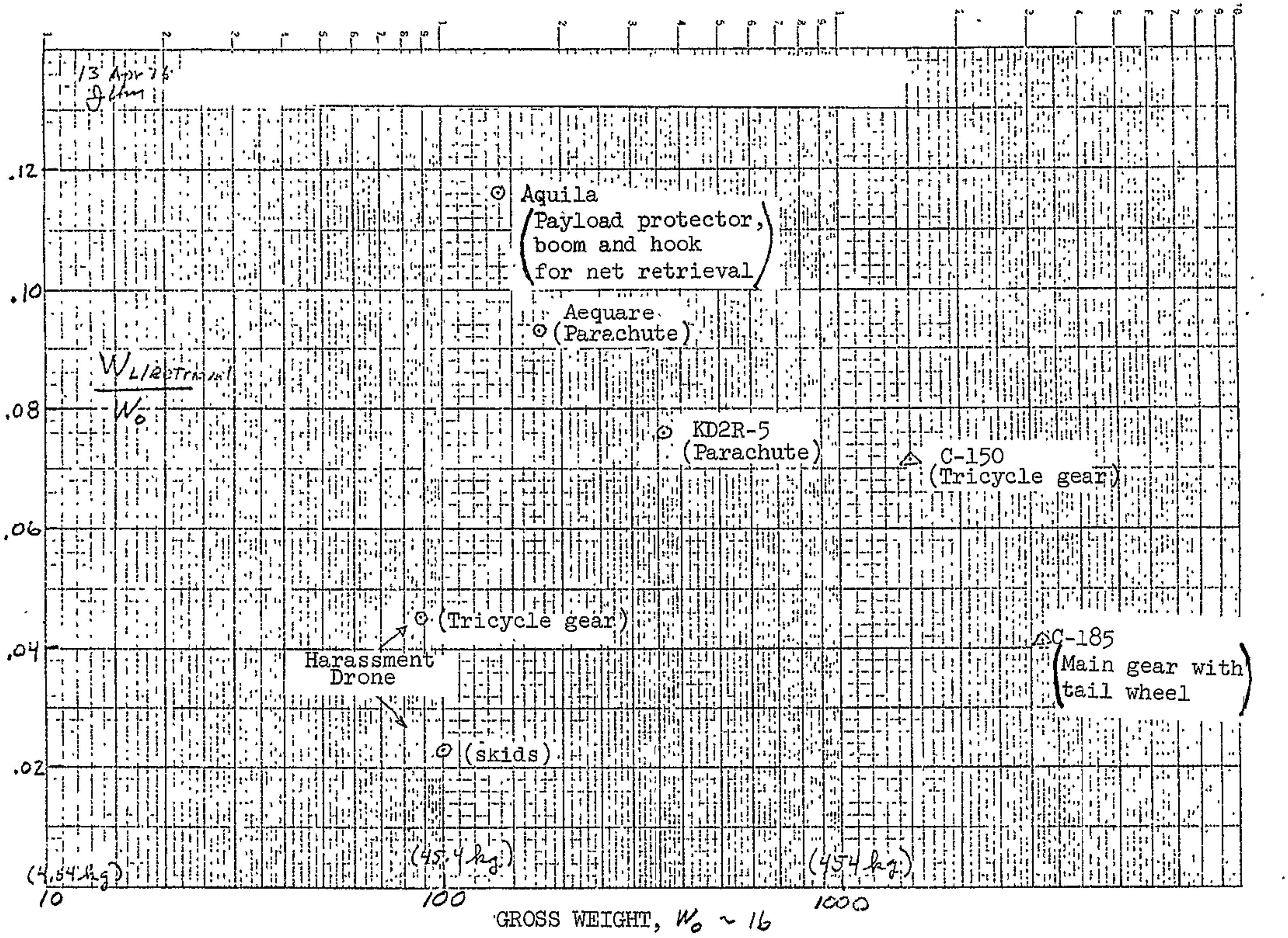


Figure D-13. Launch/Retrieval Group Weight

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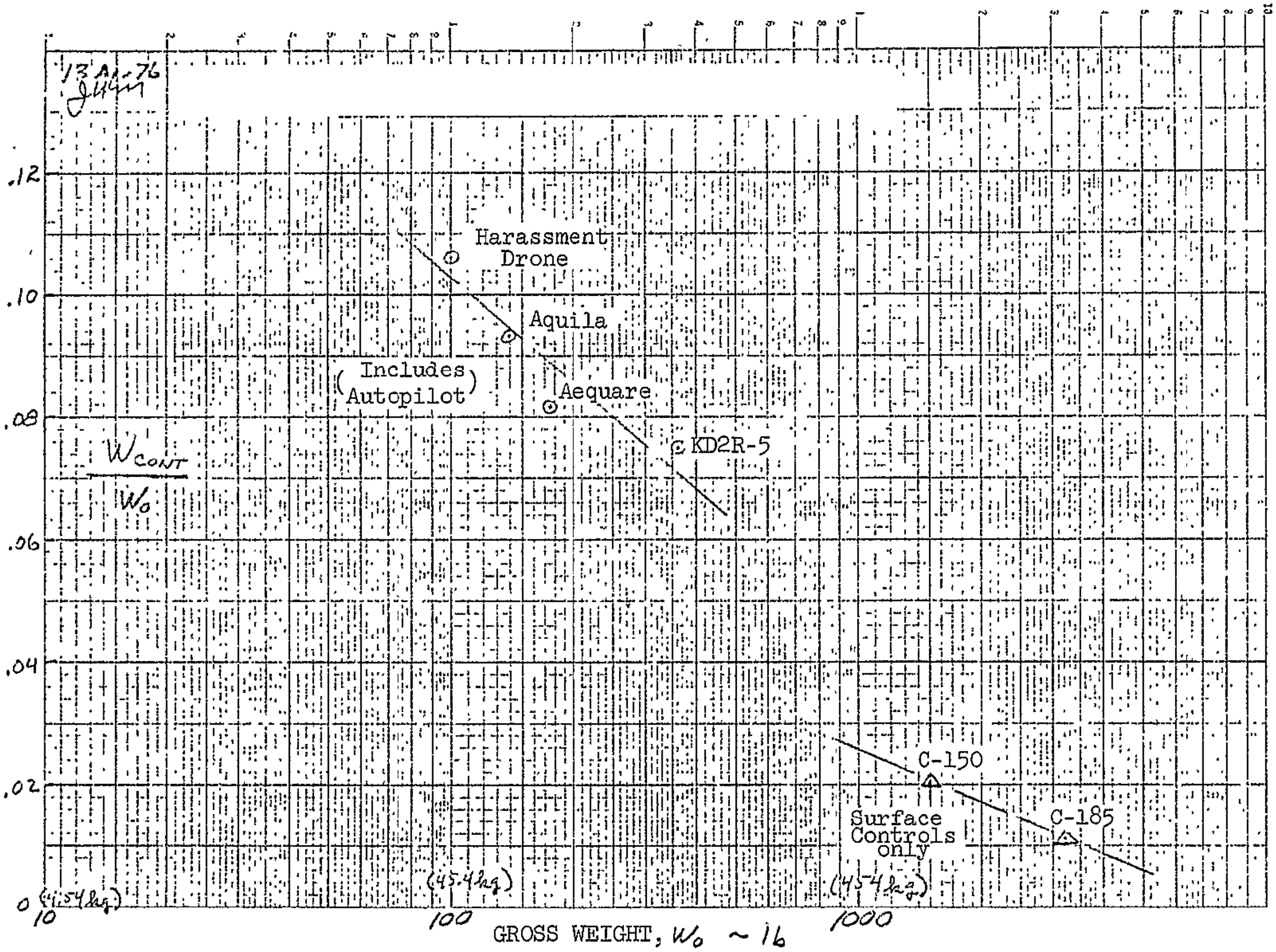

Figure D-14. Flight Controls Group Weight

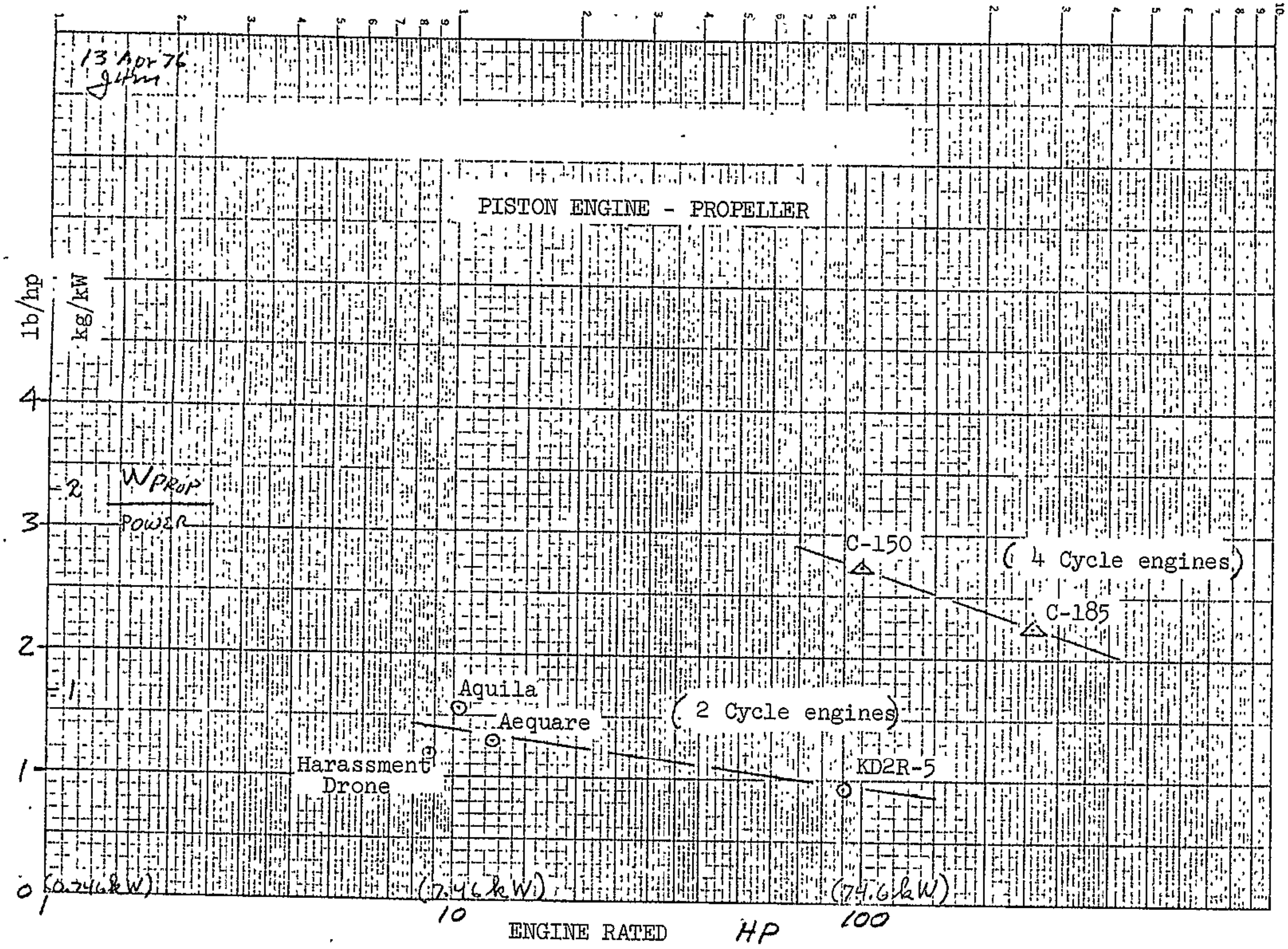

Figure D-15. Propulsion Group Weight

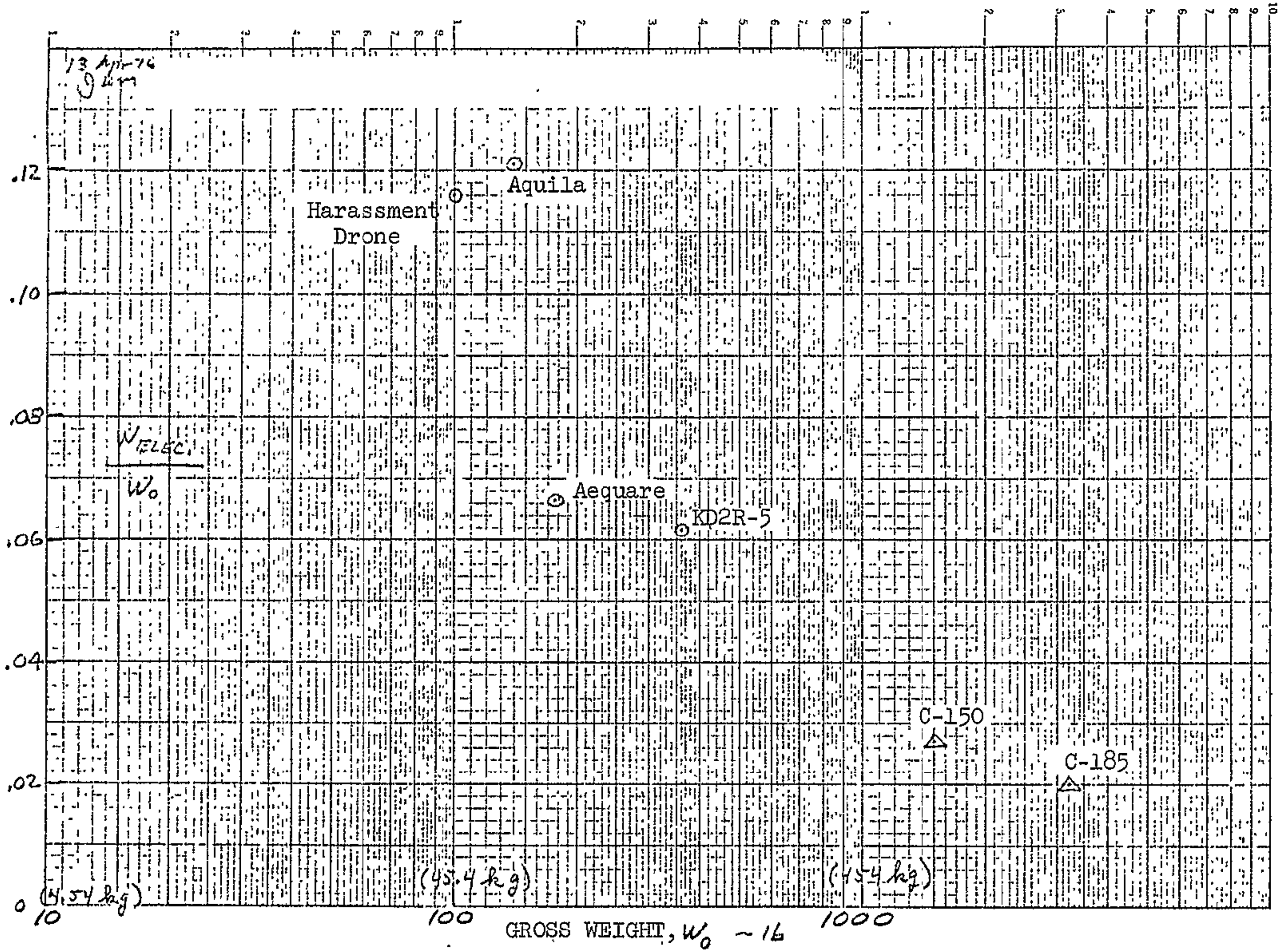

Figure D-16. Electrical Group Weight

Figure D-17. Avionics Group Weight

APPENDIX E
COST ANALYSIS

Introduction

All cost estimates for RPV systems are generated by a cost model modified for this study from an existing mini-RPV cost model. These cost models are based on Lockheed experience in previous aircraft programs and several ongoing RPV programs, as well as on data gathered by a survey of pertinent literature from the RPV community. The cost model used in this study is designated the Lockheed Mini-RPV Cost Model-"C". Cost estimates for alternate methods of accomplishing each mission by means of conventional manned aircraft are determined from published cost data, the market survey and analysis conducted during this study, and from discussions with users and aircraft operating and servicing companies in the San Jose, California, area.

Cost Model

The Lockheed Mini-RPV Cost Model-"C" generates RPV system costs in terms of DDT&E, investment, and operating costs. DDT&E costs are broken down into the following work breakdown structure (WBS) categories:

- Vehicle
- Payload
- Ground Control Station
- Launch/Retrieval
- GSE
- Development Spares
- Flight Test
- Tooling
- Management and Integration

Investment costs are computed for the following WBS categories:

- Vehicle
- Payload
- Ground Control Station
- Launcher/Retrieval System
- GSE
- Spares
- Management and Integration

Vehicle costs are a buildup of the individual costs for Airframe, Engine, Guidance and Control, and Data Link Subsystems. RPV costs include the cost of the Vehicle, Payload, and Integration and Assembly of all subsystems.

The cost model output in Table E-1 displays average unit costs for the various subsystems as well as the investment costs. System investment costs represent the average unit costs multiplied by the number of RPVs and ground control stations required in a single system to perform the mission. The total investment cost for a system can be viewed as the price a user would be required to pay to place a system into operation after it is developed.

The cost model also accounts for the annual operating costs of a system. These costs are displayed in two separate categories; annual fixed costs and direct operating costs. Fixed costs are costs that are incurred each year regardless of system utilization, i.e., the number of hours flown by the system. Direct operating costs are costs that are a direct function of the number of flight-hours. An interim output of the cost model is fixed costs on an annual basis and direct operating costs in dollars per hour. The cost model then sums the two operating cost contributors to give total operating cost per hour and total operating cost per year for the system.

The cost model estimates individual costs by one or more of the methods described below.

Cost estimating relationships (CER's). A CER is an equation of a curve with cost as the dependent variable and physical characteristics, performance, or program parameters as the independent variable. The cost drivers in the equation are established to be some physical or program characteristic or performance capability of the system. The specific function is determined by

```
MISSION NO.


AVERAGE UNIT COSTS (1976 $):

AIRFRAME
ENGINE
GUID. & CONT.
DATA LINK
PAYLOAD
INT. & ASSY.
   TOTAL RPV

GRND. CONTROL STA.

LAUNCHER-RETRIEVAL


SYSTEM COSTS (1976 K$):

VEHICLES/SYSTEM:     GCS/SYSTEM:

SYSTEM ELEMENT          INVESTMENT      DDT&E

VEHICLE(S)
PAYLOAD(S)
GRND. CONTROL STA.
LAUNCHER-RETRIEVAL
GSE
SPARES
FLIGHT TEST
TOOLING
MGMT. & INTEG.
   TOTALS

INVESTMENT SPARES=          TRAINING=


OPERATING COSTS (1976 $):

ANNUAL FIXED COSTS ($/YR)         DIRECT OPERATING COSTS ($/HR)
  DEPRECIATION                      FUEL
  INSURANCE                         OIL
    HULL                            PERIODIC INSP.
    LIABILITY                       MAINTENANCE
    MEDICAL                            AIRFRAME
  AIRCRAFT STORAGE                     ENGINE
  CREW                                 AVIONICS + GCS
  TRAINING
      TOTAL                                 TOTAL

                    TOTAL OPERATING COST/SYSTEM

                              COST/HR       HRS/YEAR
  FIXED
  DIRECT OPERATING
    TOTAL
```

Table E-1. <u>Mini-RPV Cost Model-"C" Output Format</u>

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fitting a statistical curve to the appropriate data points. The data may be historical, coming from previous programs, or be known estimates from other sources.

Analogy. - Cost is determined by comparing the element to be estimated with a similar element whose cost is known. The estimated cost is arrived at by adjusting the known cost to account for increased or decreased complexity of the element being estimated.

Factoring or profiling. - Costs for some elements of a system are sometimes well represented as percentages of other costs or of total program costs. The method of factoring or profiling consists of determining the percentages that apply from previous similar programs that are typical of this relationship.

Vendor estimates. - These are estimates provided directly or indirectly by suppliers. They may be obtained from catalogs or other published sources, by direct query, or by referring to estimates provided by vendors on previous programs. Vendor estimates lack the binding force of formal price quotations, but they do represent the considered opinion of people accustomed to dealing in hardware or service being estimated.

Engineering estimates. - Engineering estimates are usually the result of a combination of all of the above methods. An engineering cost estimate is basically the best guess of competent persons who have previous experience on similar efforts and who have put together the facts that can be gathered to arrive at an estimate.

Cost estimates generated by CERs are computed inside the cost model by inputting the appropriate values for the physical, program, or performance characteristics. Estimates generated by factoring are also computed inside the model by operating on other costs. Estimates arrived at by any of the other methods are input (throughput) to the model.

Methodology and Results

RPV Systems. - Cost model computer printouts which include the total system costs for Mission 1 through 8 are given in Tables E-2 through E-9.

The outputs are designed in a manner that for missions requiring both a mission vehicle and a relay vehicle the costs must be added to identify total system costs. For these missions (Nos. 3, 5 and 6) the costs of hardware and services that are required by the system but are common to both the mission vehicle and the relay vehicle (e.g., Ground Control Station and Training) are included in the mission-vehicle cost output only. For example, in Mission 3, the total DDT&E, Investment, and Operating Costs for the RPV System are obtained by adding the costs of Table E-4a, (Mission No. 3, Mission Vehicle) and Table E-4b, (mission no. 3, Relay Vehicle). An explanation of all other tabulated data is given below.

Average Unit Costs: Average unit costs are shown for the RPV, which includes the Air Vehicle and Payload, and the Ground Control Station. The cost model also provides for the inclusion of a Launcher-Retrieval System cost. However, no Launcher-Retrieval System was required for any of the missions selected in this study. Therefore, this subsystem is identified at zero cost in the cost outputs for all missions.

Average unit costs are obtained by first determining the Theoretical First Unit (TFU) cost for each subsystem. The appropriate learning curve is then applied to each TFU in order to arrive at the average unit cost for the total quantity required. The learning-curve effect reflects the observable phenomenon that unit production cost decreases with increasing production quantity. This phenomenon is caused by a combination of things such as improved worker efficiency due to practice, improved procedures and processes as time goes on, quantity discounts in material prices, etc. One relationship that describes the observed phenomenon well is "doubling the production quantity reduces the average unit cost by a factor k." The formula for this learning-curve relationship is:

$$\bar{C}y = \bar{C}_x \, k \exp [\ln (y/x)/\ln 2], \; 0 < k < 1$$

where $\bar{C}y$ = the average unit cost of y units

$\bar{C}_x$ = the average unit cost of x units

k = the learning-curve factor.

The factor k differs for different kinds of industries, typically falling

Table E-2

```
MISSION NO.1   SECURITY OF HIGH-VALUE PROPERTY


AVERAGE UNIT COSTS (1976 $):

AIRFRAME                          3656.
ENGINE                             913.
GUID. & CONT.,                    4028.
DATA LINK                         2183.
PAYLOAD                           7209.
INT. & ASSY.                      1651.
   TOTAL RPV                     19640.

GRND. CONTROL STA.               12598.

LAUNCHER-RETRIEVAL                   0.


SYSTEM COSTS (1976 M$):

VEHICLES/SYSTEM: 2   GCS/SYSTEM: 1

SYSTEM ELEMENT             INVESTMENT      DDT&E

VEHICLES                      24.86        2685.
PAYLOADS                      14.42         158.
GRND. CONTROL STA.            12.60         600.
LAUNCHER-RETRIEVAL              .00           0.
GSE                            2.59         172.
SPARES                          .00          87.
FLIGHT TEST                     .00         669.
TOOLING                         .00         780.
MGMT. & INTEG.                 3.81         824.
   TOTALS                     58.29        5975.

INVESTMENT SPARES= 2.72     TRAINING= 12.33


OPERATING COSTS (1976 $):

ANNUAL FIXED COSTS ($/YR)              DIRECT OPERATING COSTS ($/HR)
  DEPRECIATION          4162.            FUEL                        1.83
  INSURANCE             5003.            OIL                          .43
    HULL           4355.                 PERIODIC INSP.              4.35
    LIABILITY       600.                 MAINTENANCE                10.98
    MEDICAL          48.                    AIRFRAME            5.45
  AIRCRAFT STORAGE         0.               ENGINE              2.12
  CREW                 64000.               AVIONICS + GCS      3.41
  TRAINING              1256.
      TOTAL            74420.                       TOTAL            17.59

                      TOTAL OPERATING COST/SYSTEM

                                  COST/HR  2920 HRS/YEAR
 FIXED                             25.49          74420.
 DIRECT OPERATING                  17.59          51364.
   TOTAL                           43.08         125785.
```

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Table E-3

```
MISSION NO. 2   WILDFIRE MAPPING


AVEPAGE UNIT COSTS (1976 $):

AIRFRAME                         3656.
ENGINE                            913.
GUID. & CONT.                    4028.
DATA LINK                        2183.
PAYLOAD                         15788.
INT. & ASSY.                     2439.
   TOTAL PPV                    29006.

GRND. CONTPOL STA.              15780.

LAUNCHER-PETRIEVAL                  0.


SYSTEM COSTS (1976 K$):

VEHICLES/SYSTEM: 1   GCS/SYSTEM: 1

SYSTEM ELEMENT             INVESTMENT      DDT&E

VEHICLE                         13.22      2702.
PAYLOAD                         15.79       346.
GPND. CONTROL STA.              15.78       658.
LAUNCHER-RETPIEVAL                .00         0.
GSE                              2.24       185.
SPARES                            .00       101.
FLIGHT TEST                       .00       669.
TOOLING                           .00       780.
MGMT. & INTEG.                   3.29       871.
   TOTALS                       50.32      6312.

INVESTMENT SPARES= 2.35     TRAINING= 12.33


OPEPATING COSTS (1976 $):

ANNUAL FIXED COSTS ($/YP)          DIRECT OPERATING COSTS ($/HR)
  DEPPECIATION        3593.          FUEL                        1.86
  INSURANCE           3632.          OIL                          .44
    HULL         3284.               PEPIODIC INSP.              4.35
    LIABILITY     300.               MAINTENANCE                12.71
    MEDICAL        48.                  AIPFPAME          5.80
  AIPCRAFT STOPAGE       0.             ENGINE            2.12
  CREW               32200.             AVIONICS + GCS    4.79
  TRAINING            1256.
     TOTAL           40680.                  TOTAL              19.36

                   TOTAL OPEPATING COST/SYSTEM

                                 COST/HP  1467 HRS/YEAR
 FIXED                            27.73         40680.
 DIPECT OPEPATING                 19.36         28397.
   TOTAL.                         47.09         69078.
```

Table E-4a

```
MISSION NO. 3   WILDFIRE DETECTION (MISSION VEHICLE)


      AVERAGE UNIT COSTS (1976 $):

      AIRFRAME                    32374.
      ENGINE                       6490.
      GUID. & CONT.               10681.
      DATA LINK                    3575.
      PAYLOAD                     18543.
      INT. & ASSY.                 6579.
         TOTAL PPV                78242.

      GRND. CONTROL STA.          26468.

      LAUNCHER-RETRIEVAL              0.


      SYSTEM COSTS (1976 K$):

      VEHICLES/SYSTEM: 1   GCS/SYSTEM: 1

      SYSTEM ELEMENT           INVESTMENT      DDT&E

      VEHICLE                       59.70      6534.
      PAYLOAD                       18.54       300.
      GRND. CONTROL STA.            26.47      1027.
      LAUNCHER-RETRIEVAL              .00         0.
      GSE                            5.24       393.
      SPARES                          .00       238.
      FLIGHT TEST                     .00      1504.
      TOOLING                         .00      2371.
      MGMT. & INTEG.                 7.70      1979.
         TOTALS                    117.64     14347.

      INVESTMENT SPARES= 5.50     TRAINING= 14.22


      OPERATING COSTS (1976 $):

      ANNUAL FIXED COSTS ($/YR)            DIRECT OPERATING COSTS ($/HR)
        DEPRECIATION       7127.             FUEL                      5.50
        INSURANCE          4014.             OIL                       1.29
          HULL          3666.                PERIODIC INSP.            3.56
          LIABILITY      300.                MAINTENANCE              19.64
          MEDICAL         48.                   AIRFRAME          6.74
        AIRCRAFT STORAGE      0.                ENGINE            1.20
        CREW              13200.                AVIONICS + GCS   11.70
        TRAINING           1512.
           TOTAL          25853.                   TOTAL              29.99

                          TOTAL OPERATING COST/SYSTEM

                                         COST/HP   600 HRS/YEAR
        FIXED                              43.09         25853.
        DIRECT OPERATING                   29.99         17994.
          TOTAL                            73.08         43847.
```

Table E-4b

```
MISSION NO. 3   WILDFIRE DETECTION (RELAY VEHICLE)


         AVERAGE UNIT COSTS (1976 $):

         AIRFRAME                      32374.
         ENGINE                         6490.
         GUID. & CONT.                 10681.
         DATA LINK                     16359.
         PAYLOAD                        3060.
         INT. & ASSY.                   6331.
            TOTAL RPV                  75294.

         GRND. CONTROL STA.                0.

         LAUNCHER-RETRIEVAL                0.


         SYSTEM COSTS (1976 K$):

         VEHICLES/SYSTEM: 1    GCS/SYSTEM: 0

         SYSTEM ELEMENT             INVESTMENT      DDT&E

         VEHICLE                        72.23      4262.
         PAYLOAD                         3.06        50.
         GRND. CONTROL STA.               .00         0.
         LAUNCHER-RETRIEVAL               .00         0.
         GSE                             3.76       216.
         SPARES                           .00       226.
         FLIGHT TEST                      .00      1003.
         TOOLING                          .00         0.
         MGMT. & INTEG.                  5.53       921.
            TOTALS                      84.59      6677.

         INVESTMENT SPARES= 3.95     TRAINING=    .00


         OPERATING COSTS (1976 $):

         ANNUAL FIXED COSTS ($/YR)            DIRECT OPERATING COSTS ($/HR)
           DEPRECIATION       4815.             FUEL                         5.50
           INSURANCE          3560.             OIL                          1.29
             HULL         3260.                 PERIODIC INSP.               2.78
             LIABILITY     300.                 MAINTENANCE                 14.85
             MEDICAL         0.                    AIRFRAME           8.18
           AIRCRAFT STORAGE      0.                ENGINE             1.20
           CREW                  0.                AVIONICS + GCS     5.47
           TRAINING              0.
              TOTAL           8376.                    TOTAL                24.42

                            TOTAL OPERATING COST/SYSTEM

                                          COST/HR    600 HRS/YEAR
           FIXED                            13.96          8376.
           DIRECT OPERATING                 24.42         14651.
             TOTAL                          38.38         23027.
```

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Table E-5

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MISSION NO. 4  FISHING LAW ENFORCEMENT


     AVERAGE UNIT COSTS (1976 $):

     AIRFRAME                      3020.
     ENGINE                         271.
     GUID. & CONT.                 3073.
     DATA LINK                     2735.
     PAYLOAD                       5590.
     INT. & ASSY.                  1348.
        TOTAL RPV                 16037.

     GRND. CONTROL STA.          123531.

     LAUNCHER-RETRIEVAL               0.


     SYSTEM COSTS (1976 K$):

     VEHICLES/SYSTEM: 1   GCS/SYSTEM: 1

     SYSTEM ELEMENT          INVESTMENT      DDT&E

     VEHICLE                      10.45      2838.
     PAYLOAD                       5.59       116.
     GRND. CONTROL STA.          123.53      1218.
     LAUNCHER-RETRIEVAL             .00         0.
     GSE                           6.98       209.
     SPARES                         .00       120.
     FLIGHT TEST                    .00       511.
     TOOLING                        .00       653.
     MGMT. & INTEG.               10.26       906.
        TOTALS                   156.80      6570.

     INVESTMENT SPARES= 7.33     TRAINING= 12.49


     OPERATING COSTS (1976 $):

     ANNUAL FIXED COSTS ($/YR)               DIRECT OPERATING COSTS ($/HR)
        DEPRECIATION       10935.              FUEL                             .79
        INSURANCE           2339.              OIL                              .18
          HULL          1991.                  PERIODIC INSP.                  4.35
          LIABILITY      300.                  MAINTENANCE                    10.72
          MEDICAL         48.                     AIRFRAME               1.14
        AIRCRAFT STORAGE       0.                 ENGINE                  .13
        CREW               32000.                 AVIONICS + GCS         9.45
        TRAINING            1264.
            TOTAL          46538.                          TOTAL           16.04

                         TOTAL OPERATING COST/SYSTEM

                                      COST/HR  1460 HRS/YEAR
        FIXED                          31.88         46539.
        DIRECT OPERATING               16.04         23414.
          TOTAL                        47.91         69953.
```

Table E-6a

```
MISSION NO. 5   HIGHWAY PATROL (MISSION VEHICLE)


      AVERAGE UNIT COSTS (1976 $):

      AIRFRAME                      3020.
      ENGINE                         244.
      GUID. & CONT.                 3073.
      DATA LINK                     1857.
      PAYLOAD                       5692.
      INT. & ASSY.                  1275.
         TOTAL RPV                 15159.

      GRND. CONTROL STA.           20521.

      LAUNCHER-RETRIEVAL              0.


      SYSTEM COSTS (1976 K$):

      VEHICLES/SYSTEM: 1    GCS/SYSTEM: 1

      SYSTEM ELEMENT           INVESTMENT      DDT&E

      VEHICLE                        9.47      2366.
      PAYLOAD                        5.69        95.
      GRND. CONTROL STA.            20.52       894.
      LAUNCHER-RETRIEVAL              .00         0.
      GSE                            1.78       168.
      SPARES                          .00        75.
      FLIGHT TEST                     .00       300.
      TOOLING                         .00       653.
      MGMT. & INTEG.                 2.62       728.
         TOTALS                     40.09      5278.

      INVESTMENT SPARES= 1.87     TRAINING= 14.22


      OPERATING COSTS (1976 $):

      ANNUAL FIXED COSTS ($/YR)          DIRECT OPERATING COSTS ($/HR)
        DEPRECIATION       2616.           FUEL                        1.02
        INSURANCE          1220.           OIL                          .24
          HULL           872.              PERIODIC INSP.              3.56
          LIABILITY      300.              MAINTENANCE                 2.99
          MEDICAL         48.                 AIRFRAME           1.03
        AIRCRAFT STORAGE      0.              ENGINE              .12
        CREW              64000.              AVIONICS + GCS     1.94
        TRAINING           1512.
            TOTAL         69347.                   TOTAL               7.81

                         TOTAL OPERATING COST/SYSTEM

                                     COST/HR  2920 HRS/YEAR
        FIXED                          23.75         69347.
        DIRECT OPERATING                7.81         22801.
          TOTAL                        31.56         92148.
```

Table E-6b

```
MISSION NO. 5   HIGHWAY PATROL (RELAY VEHICLE)


      AVERAGE UNIT COSTS (1976 $):

      AIRFRAME                           5509.
      ENGINE                              903.
      GUID. & CONT.                      3253.
      DATA LINK                          9983.
      PAYLOAD                            2981.
      INT. & ASSY.                       2077.
         TOTAL RPV                      24707.

      GRND. CONTROL STA.                    0.

      LAUNCHER-RETRIEVAL                    0.


      SYSTEM COSTS (1976 K$):

      VEHICLES/SYSTEM: 1    GCS/SYSTEM: 0

      SYSTEM ELEMENT             INVESTMENT      DDT&E

      VEHICLE                       21.73        3036.
      PAYLOAD                        2.98          50.
      GRND. CONTROL STA.              .00           0.
      LAUNCHER-RETRIEVAL              .00           0.
      GSE                            1.24         154.
      SPARES                          .00         106.
      FLIGHT TEST                     .00         440.
      TOOLING                         .00         924.
      MGMT. & INTEG.                 1.82         754.
         TOTALS                     27.76        5463.

      INVESTMENT SPARES= 1.30     TRAINING=    .00


      OPERATING COSTS (1976 $):

      ANNUAL FIXED COSTS ($/YR)            DIRECT OPERATING COSTS ($/HR)
        DEPRECIATION        1580.            FUEL                          1.23
        INSURANCE           1370.            OIL                            .29
          HULL            1070.              PERIODIC INSP.                2.78
          LIABILITY        300.              MAINTENANCE                   4.21
          MEDICAL            0.                AIRFRAME               2.40
        AIRCRAFT STORAGE       0.              ENGINE                  .20
        CREW                   0.              AVIONICS + GCS         1.60
        TRAINING               0.
            TOTAL           2950.                      TOTAL               8.50

                          TOTAL OPERATING COST/SYSTEM

                                       COST/HR   2920 HRS/YEAR
      FIXED                              1.01          2950.
      DIRECT OPERATING                   8.50         24823.
        TOTAL                            9.51         27773.
```

Table E-7a

```
MISSION NO. 6   PIPELINE PATROL (MISSION VEHICLE)


     AVERAGE UNIT COSTS (1976 $):

     AIRFRAME                     3020.
     ENGINE                        244.
     GUID. & CONT.                3073.
     DATA LINK                    1857.
     PAYLOAD                      4788.
     INT. & ASSY.                 1192.
        TOTAL PPV                14173.

     GRND. CONTROL STA.          20521.

     LAUNCHER-RETRIEVAL              0.


     SYSTEM COSTS (1976 K$):

     VEHICLES/SYSTEM: 1   GCS/SYSTEM:11

     SYSTEM ELEMENT           INVESTMENT      DDT&E

     VEHICLE                        9.38      2365.
     PAYLOAD                        4.79        80.
     GRND. CONTROL STA.           225.73      1081.
     LAUNCHER-RETRIEVAL              .00         0.
     GSE                           12.00       176.
     SPARES                          .00        84.
     FLIGHT TEST                     .00       300.
     TOOLING                         .00       653.
     MGMT. & INTEG.                17.63       758.
        TOTALS                    269.53      5496.

     INVESTMENT SPARES=12.59     TRAINING= 28.83


     OPERATING COSTS (1976 $):

     ANNUAL FIXED COSTS ($/YR)            DIRECT OPERATING COSTS ($/HR)
       DEPRECIATION      19014.             FUEL                          .80
       INSURANCE          3548.             OIL                           .19
         HULL         2984.                 PERIODIC INSP.               3.56
         LIABILITY     300.                 MAINTENANCE                  3.24
         MEDICAL       264.                    AIRFRAME           1.02
       AIRCRAFT STORAGE      0.                ENGINE              .12
       CREW              14250.                AVIONICS + GCS     2.10
       TRAINING           2985.
           TOTAL         39797.                    TOTAL                 7.79

                          TOTAL OPERATING COST/SYSTEM

                                       COST/HR  1300 HRS/YEAR
       FIXED                             30.61         39797.
       DIRECT OPERATING                   7.79         10131.
         TOTAL                           38.41         49928.
```

Table E-7b

```
MISSION NO. 6   PIPELINE PATROL (RELAY VEHICLE)


     AVERAGE UNIT COSTS (1976 $):

     AIRFRAME                      5074.
     ENGINE                         903.
     GUID. & CONT.                 3253.
     DATA LINK                     9983.
     PAYLOAD                       2981.
     INT. & ASSY.                  2037.
        TOTAL PPV                 24232.

     GRND. CONTROL STA.               0.

     LAUNCHER-RETRIEVAL               0.


     SYSTEM COSTS (1976 K$):

     VEHICLES/SYSTEM: 1   GCS/SYSTEM: 0

     SYSTEM ELEMENT          INVESTMENT      DDT&E

     VEHICLE                      21.25      2980.
     PAYLOAD                       2.98        50.
     GRND. CONTROL STA.             .00         0.
     LAUNCHER-RETRIEVAL             .00         0.
     GSE                           1.21       151.
     SPARES                         .00       103.
     FLIGHT TEST                    .00       416.
     TOOLING                        .00       877.
     MGMT. & INTEG.                1.78       732.
        TOTALS                    27.22      5309.

     INVESTMENT SPARES= 1.27      TRAINING=    .00


     OPERATING COSTS (1976 $):

     ANNUAL FIXED COSTS ($/YR)            DIRECT OPERATING COSTS ($/HR)
       DEPRECIATION       1550.             FUEL                          1.26
       INSURANCE          1349.             OIL                            .30
         HULL          1049.                PERIODIC INSP.                2.78
         LIABILITY      300.                MAINTENANCE                   4.30
         MEDICAL          0.                   AIRFRAME              2.35
       AIRCRAFT STORAGE      0.                ENGINE                 .20
       CREW                  0.                AVIONICS + GCS        1.75
       TRAINING              0.
           TOTAL          2899.                    TOTAL                  8.64

                            TOTAL OPERATING COST/SYSTEM

                                          COST/HR   1300 HRS/YEAR
      FIXED                                  2.23           2899.
      DIRECT OPERATING                       8.64          11230.
        TOTAL                               10.87          14129.
```

Table E-8

```
MISSION NO. 7   AGRICULTURAL SPRAYING


     AVERAGE UNIT COSTS (1976 $):

     AIRFRAME                     6979.
     ENGINE                       1355.
     GUID. & CONT.                3757.
     DATA LINK                    1857.
     PAYLOAD                      3795.
     INT. & ASSY.                 1629.
        TOTAL PPV                19372.

     GRND. CONTROL STA.          18897.

     LAUNCHER-RETRIEVAL              0.


     SYSTEM COSTS (1976 M$):

     VEHICLES/SYSTEM: 1   GCS/SYSTEM: 1

     SYSTEM ELEMENT           INVESTMENT     DDT&E

     VEHICLE                       15.58     3518.
     PAYLOAD                        3.79       84.
     GRND. CONTROL STA.            18.90      734.
     LAUNCHER-RETRIEVAL              .00        0.
     GSE                            7.91      217.
     SPARES                          .00      127.
     FLIGHT TEST                     .00      806.
     TOOLING                         .00      985.
     MGMT. & INTEG.                 3.23     1035.
        TOTALS                     49.41     7507.

     INVESTMENT SPARES= 2.31     TRAINING=  5.92


     OPERATING COSTS (1976 $):

     ANNUAL FIXED COSTS ($/YR)            DIRECT OPERATING COSTS ($/HR)
       DEPRECIATION       3213.             FUEL                        1.69
       INSURANCE          4521.             OIL                          .40
         HULL           2767.               PERIODIC INSP.              3.56
         LIABILITY      1730.               MAINTENANCE                 4.51
         MEDICAL          24.                  AIRFRAME           1.71
       AIRCRAFT STORAGE    0.                  ENGINE              .30
       CREW              10960.                AVIONICS + GCS     2.50
       TRAINING            615.
          TOTAL          19309.                   TOTAL                10.16

                         TOTAL OPERATING COST/SYSTEM

                                        COST/HR   1000 HRS/YEAR
       FIXED                             19.31        19309.
       DIRECT OPERATING                  10.16        10159.
         TOTAL                           29.47        29468.
```

Table E-9

```
MISSION NO. 8A   SEVERE STORM RESEARCH


      AVERAGE UNIT COSTS (1976 $):

      AIRFRAME                      3020.
      ENGINE                         244.
      GUID. & CONT.                 3073.
      DATA LINK                     1857.
      PAYLOAD                       3975.
      INT. & ASSY.                  1117.
         TOTAL RPV                 13285.

      GRND. CONTROL STA.           16548.

      LAUNCHER-RETRIEVAL               0.


      SYSTEM COSTS (1976 K$):

      VEHICLES/SYSTEM: 1   GCS/SYSTEM: 1

      SYSTEM ELEMENT           INVESTMENT      DDT&E

      VEHICLE                        9.31      2738.
      PAYLOAD                        3.98        88.
      GRND. CONTROL STA.            16.55       672.
      LAUNCHER-RETRIEVAL              .00         0.
      GSE                            7.49       175.
      SPARES                          .00        85.
      FLIGHT TEST                     .00       511.
      TOOLING                         .00       653.
      MGMT. & INTEG.                 2.61       788.
         TOTALS                     39.94      5710.

      INVESTMENT SPARES= 1.87     TRAINING=  5.92


      OPERATING COSTS (1976 $):

      ANNUAL FIXED COSTS ($/YR)          DIRECT OPERATING COSTS ($/HR)
        DEPRECIATION       2635.           FUEL                      .82
        INSURANCE          1157.           OIL                       .19
          HULL            809.             PERIODIC INSP.           3.56
          LIABILITY       300.             MAINTENANCE              5.26
          MEDICAL          48.                AIRFRAME        1.01
        AIRCRAFT STORAGE      0.              ENGINE           .12
        CREW               3480.              AVIONICS + GCS  4.12
        TRAINING            615.
            TOTAL          7887.                    TOTAL           9.83

                           TOTAL OPERATING COST/SYSTEM

                                        COST/HR   200 HRS/YEAR
        FIXED                             39.44          7887.
        DIRECT OPERATING                   9.83          1966.
          TOTAL                           49.27          9853.
```

between 0.85 and 0.99.

Production quantities assumed for the costing calculations are summarized in Table E-10. The TFU for each subsystem is determined either by CER or by direct input of an engineering estimate. It represents the theoretical production status of the hardware as it is postulated to exist at the beginning of the production run for the particular RPV program. In the case of hardware that is considered to be already in production at the start of the RPV program, such as Payload, the TFU is the projected unit production cost at that time, and learning is assumed at a very low rate. In effect, this learning merely represents the cost break that would accrue from a large-quantity buy. Integration and Assembly costs for the RPV covers all activities that cannot be allocated to any one subsystem and includes assembling all subsystems into an integrated vehicle and performing acceptance tests.

System Costs: System costs consist of two categories, DDT&E costs and Investment costs. DDT&E costs include all design, development, test hardware, and test costs required to bring the program to the point where system production can begin. Investment costs comprise the average costs to purchase one complete system ready for operation.

Vehicle DDT&E costs include design, development and fabrication of test hardware. It does not include Payload costs. For missions that require a mission vehicle only, test hardware consists of 20 units, 18 of which are used for flight test. For missions that require both a mission vehicle and a relay vehicle, 15 units of test hardware are assumed for each vehicle, (a total of 30 units), 26 of which are flight test articles. Vehicle investment costs consist of the average unit cost of the vehicle times the number of vehicles in the RPV system.

Payload DDT&E costs represent only the cost of providing the Payload test hardware required by the development program. As in the case of the vehicle, 20 units are assumed to be required for single-vehicle missions and 30 units (15 units of each) are assumed for two-vehicle missions. All other development costs for the Payload are assumed to be already written off (sunk) by the time of RPV development. Investment cost for the Payload is the average unit cost times the number of mission vehicles per system.

TABLE E-10 PRODUCTION QUANTITIES
(Basis of Costing)

Hardware		Missions in which used:	Assumed Production Quantity*
RPVs	Mini, Fixed-wing	4,5,6,7,8	3000
	Mini, Rotary wing	1,2	1500
	Midi, Fixed-wing	3	500
Ground Control Station	Single-RPV	1,2,7,8	2000
	Multiple-RPV	3,4,5,6	2000

*These assumptions were made early in the study, before the market analysis. However, they are within the range of market potential estimated on page 129. Note that the market potential on page 129 is given in terms of RPV <u>systems</u> (e.g., one system for mission 1 is two RPVs plus one ground station), whereas these production quantities are quantities of RPVs and quantities of ground control stations.

DDT&E costs for the Ground Control Station consists of design, development and fabrication of four units of test hardware. Investment costs are the product of the number of Ground Control Stations in the system and the average unit cost.

System cost for GSE (ground support equipment) is derived by factoring other costs and adding the costs of mission-peculiar support equipment. The DDT&E costs include design and development of the GSE plus the hardware required to support the development program. Investment costs include all the initial GSE required to support the operational program. For Mission 7 and 8 the GSE investment costs were augmented to account for the inclusion of specific high-cost ground mobility items.

DDT&E spares cost represents the development spares required to support the test hardware built for and used in the ground-test and flight-test programs. Investment spares cost are displayed in the cost output independent of the total for investment costs. This is because the cost of replacement spares are included in the maintenance costs as part of the operating costs.

All flight-test and tooling costs are charged to DDT&E as a nonrecurring cost. Flight-test costs reflect all efforts required to test the air vehicles and ground control stations as an integrated system and to certify the system for flight. For missions requiring both a mission vehicle and a relay vehicle (Missions 3, 5 and 6), the flight-test plan is modified to account for differences in test procedures and objectives.

The DDT&E costs for Management and Integration include all the systems engineering, systems integration, and program management efforts required to coordinate and direct the development program. Management and Integration cost for investment is the system's pro-rated share of the total cost of this effort for the production program.

Training costs cover the training of a crew for one system. Three training programs were laid out that include estimates of class size, instructor-to-student ratio, training equipment and manuals, training duration, and training sequence. The three training programs are characterized by mission and system operational requirements, i.e.:

1. Single fixed-wing RPV and ground control station
2. Single rotary-wing RPV and ground control station
3. Multiple fixed-wing RPVs and ground control stations, including handoff.

In the cost model output, similar to investment spares, training is shown separately from the total system investment cost because it is included in the annual fixed-costs contribution to the operating costs.

Operating Costs: Operating costs include the two categories of Annual Fixed costs and Direct Operating Costs. The sum of these two costs is the total annual cost of owning and operating a system, except for the amortization of DDT&E costs.

For Annual Fixed Costs, the Depreciation of the air vehicles is calculated in accordance with data developed for manned aircraft. (See following discussion on Alternative Systems). For fixed-wing vehicles, depreciation is 40% of the initial cost over seven years with 60% residual value, i.e., the annual rate is 5.62% of the vehicle average unit cost per year for seven years. For rotary wing vehicles, ground control stations, and GSE, depreciation is 50% of the initial cost over seven years with a 50% residual, i.e., 7.14% of the average unit cost per year for seven years.

Annual Insurance costs consist of costs for hull, liability, and medical insurance. These costs are also calculated in accordance with data developed for manned aircraft. Hull insurance is estimated at 4% of vehicle cost for fixed-wing RPVs (5.6% for agricultural) and 10% for rotary-wing RPVs. Hull insurance also includes an estimate of 1% of the ground control station cost and GSE cost to insure these elements of the system. Liability insurance is calculated at $300/aircraft/year (except Agricultural, which is $1730) and Medical insurance at $15/operator/year. (See following discussion on Alternative Systems)

No costs are included for RPV storage. It is assumed that RPV vehicles required for the missions studied can be accomodated in existing facilities or the "storage" costs for mobile RPV systems are included in the GSE costs.

Crew costs are a function of the number of crew members and the number of hours per year that the system is required to operate. Crew costs are consistent with a consensus of salary and benefit data acquired for pilots with IFR training working in civil aviation. These costs include non-working costs, such as vacation, sick leave, and holidays. A rate of $10.96 per operating hour per operator is used to estimate crew costs. Annual operating hours for each mission is shown in Table E-11.

Training costs are converted to annual fixed costs by amortizing the training equipment costs over a seven year period and all personnel and training manuals over a 10-year period.

For Direct Operating Costs, the fuel and oil consumption rate is determined from the RPV cruise endurance and the amount of fuel carried. Costs are based on $.85 per gallon of fuel and $1.00 per quart of oil.

Periodic Inspection costs and Maintenance costs drew on the Aquila program for estimates of major RPV subsystem maintenance manhours per flight hour. A program was laid out for periodic inspection, airframe and controls maintenance and parts, engine maintenance and parts. This program reflects civil aircraft operator requirements, procedures and labor rates for conducting scheduled and unscheduled maintenance, overhauls and replacement of spare parts.

Periodic Inspection cost rates were established for the class of mini-RPVs and ground control stations represented in this study:

$3.57 per flight hour for rotary-wing vehicles
$2.78 per flight hour for fixed-wing vehicles
$0.78 per flight hour for the ground control station.

Airframe maintenance costs, engine maintenance costs, and avionics and ground control station maintenance costs are estimated in the cost model by using CERs developed for this purpose. The basic avionics and ground control station maintenance costs do not include the maintenance costs for the Payload. A survey was made of various TV systems, LLLTV systems, navigation and guidance systems, and radars to determine maintenance and repair requirements. The examination suggested that for the types of payloads used in Mission 1 through Mission 8, maintenance and repair parts costs amount to about 14% of the initial cost per year. Therefore, it is assumed in this study that all sensor-type payloads are to be maintained at the rate of 14% per year. This cost estimate is added to the avionics and ground control station maintenance costs computed by the cost model.

TABLE E-11 ANNUAL OPERATING HOURS

Mission	Flight Hours Per Year
1	2920*
2	1467
3	600
4	1460 (2190 for manned aircraft)
5	2920*
6	1300
7	1000
8	200

* 8 Hours/Day x 365 Days/Year = 2920 Hours/Year

Alternative Systems. - The alternative fixed wing aircraft and helicopters identified as mission candidates from the market survey are listed in Table E-12. The total system cost data for these alternatives came from LMSC's data bank, the "Aircraft Price Digest", the market survey of present users, and discussions with aircraft owners and fixed base operators in the San Jose, California area.

System Costs: Alternative systems cost consists of vehicle and payload costs only. All development costs for general aviation aircraft are assumed to be sunk costs. Ground support equipment is expected to be available at the airport or facilities from which these aircraft operate. Spares cost is included in the maintenance costs, an element of direct operating costs. Therefore, system cost of the mission-competitive fixed-wing aircraft and helicopters includes the manufacturer's price without interest or carrying charges in 1976 dollars, adjusted for mission-mandatory equipment and other avionics pertinent to the specific missions.

Operating Costs: Similar to RPV Systems, operating costs include the two categories of Annual Fixed Costs and Direct Operating Costs. The sum of these two costs is the total annual cost of owning and operating the aircraft.

For Annual Fixed Costs, the actual Depreciation varies with usage and type of aircraft. For the purposes of this study, the depreciation cost for thirty-two general-aviation fixed-wing aircraft were examined and an average rate determined. All fixed-wing aircraft evaluated were equipped with factory-installed purchaser's options. The examination indicated an annual straight line depreciation rate of 5.62% of the vehicle average unit cost (purchase cost) per year for seven years. A similar examination of ten general aviation helicopters revealed that rotary wing aircraft depreciate fifty percent of their intitial cost in seven years. This results in an annual straight line depreciation rate of 7.14% of the vehicle average unit cost (purchase cost) per year.

Annual Insurance costs consist of costs for hull, liability and medical insurance. Discussions with fixed-base operators and owners of general aviation aircraft suggested the following average rates:

TABLE E-12 MISSION AIRCRAFT ALTERNATIVES CONSIDERED

Mission	Fixed Wing Aircraft	Helicopters
1 Security of High-value Property	Cessna 180 Cessna 182 Cessna 206 Cessna 310 Cessna 337 Cessna 340 Cessna 440	Hughes 300C Hughes 500 Bell 47G Series Bell 206A Fairchild FH-1100
2 Wildfire Mapping	Cessna 180 Cessna 182 Cessna 206	Bell 47G Series Bell 206A
3 Wildfire Detection	Beech B80	
4 Fishing Law Enforcement	Beech B80 Cessna 310Q Cessna 340	
5 Highway Patrol	Cessna 180 Cessna 182 Cessna 206	Hughes 300C Bell 206A Fairchild FH-1100
6 Pipeline Patrol	Cessna 150L Cessna 172M Piper 140	
7 Agricultural Crop Dusting	Cessna 188 Grumman G164A Piper PA-25 RI Thrush	Bell 47G Series
8 Storm Research - Low Altitude	Lockheed L-749 M D F-4C RI (NA) F-100F Beech B80	

Fixed Wing Aircraft

- Single engine - cost less than $40,000: 4% of manufacturer's price (5.6% of manufacturer's price for Agricultural aircraft)
- Single engine - cost more than $40,000: 3% of manufacturer's price (5.6% of manufacturer's price for Agricultural aircraft costing $40,000 to $50,000)
- Light twin engine aircraft: 2% of manufacturer's price
- Business jets and larger aircraft: 1% of manufacturer's price
- There is a deductible clause for general aviation aircraft that may vary from $200 to $1,000, depending on the insurance carrier and the value of the aircraft.

Helicopters

- 10% of manufacturer's price (As the age of the helicopter incrases the hull insurance cost increases. Depending on use, hull insurance varies from 7% to 15% of manufacturer's price.)
- 14% of manufacturer's price for Agricultural helicopters.

For general aviation aircraft liability and property damage - $1,000,000 combined-single-limit insurance are:

- 1-3 place single-engine aircraft: $300/aircraft/year
- 4 place, and over, single-engine aircraft: $450/aircraft/year
- twin-engine aircraft: $4,000/aircraft/year.

For agricultural aircraft, drift liability and aircraft liability are included at the following rates:

- Fixed-wing aircraft: $1730 per aircraft per year
- Rotary-wing aircraft: $2600 per aircraft per year

Current general aviation practice is to carry $5,000 medical for each crew member at the rate of about $15/person/year. The medical insurance cost for agricultural aircraft crew is about $60/person/year.

Aircraft storage depends on aircraft physical characteristics and a cost per square foot per month (typically $0.15, currently charged by fixed base operators at the San Jose Airport, San Jose, California).

Crew costs are consensus of salary and benefit data acquired on working pilots and observers in civil aviation. Pilots and pilot-obsevers are assumed to hold valid private pilot's licenses. Fixed-wing pilots have, at least, some additional instrument training. Crew costs include nonworking costs, such as vacation, sick leave, and holidays. Rates of $10.96 per duty hour per pilot and $8.20 per non-pilot observer were used in the study. In missions 1 and 5, each two-man crew flies four hours out of an 8-hour duty shift, and there are two shifts per day. An exception to crew costs is the expected annual income for an agricultural aircraft pilot. Operator annual costs varied widely with hours flown. An annual crew cost of $50,000 was selected as a best mean estimate on this study. Table E-13 gives annual crew costs.

TABLE E-13 ALTERNATIVE AIRCRAFT CREW COSTS

Mission	Crews per System		Crew Cost	
	Fixed Wing	Helicopter	Fixed Wing	Helicopter
1	Pilot and Observer	Pilot and Pilot-observer	$112,000	$128,000
2	Two Pilots	—	32,200	—
3	Two Pilots	—	13,200	—
4	Two Pilots and Observer	—	66,000	—
5	Two Pilots	—	128,000	—
6	Pilot	—	14,250	—
7	Pilot	—	50,000	50,000
8	Two Pilots	—	4,380	—

No training costs are included for pilots and observers that operate fixed-wing aircraft and helicopters.

For Direct Operating Costs, fuel consumption per hour is based on data from the "Aircraft Price Digest" or calculated from aircraft endurance at the most economical speed and fuel capacity (with reserve). Oil consumption per hour depends on aircraft oil capacity, an assumed consumption rate of two quarts of oil per 100 gallons of fuel, and oil changes every 100 hours. Average fuel and oil costs used on the study are:

Aviation Gasoline	$0.85 per gallon
Jet Fuel	$0.77 per gallon
Oil	$1.00 per quart

Periodic inspection and maintenance costs were developed from data offered by San Jose, California, fixed-base operators, manufacturer's estimates, and information acquired from the market survey. The periodic-inspection and the scheduled-and unscheduled-maintenenance cost analysis included single-engine and twin-engine fixed-wing aircraft, and small, three-to-five seat helicopters. The Periodic Inspection costs for fixed-wing aircraft are shown in Figure E-1, and for rotary wing aircraft in Figure E-2. These curves are the best mean estimates of the available data.

Airframe maintenance and parts costs are shown for fixed-wing aircraft and helicopters in Figures E-3 and E-4, respectively. These curves also are the best mean estimates of the available data.

Engine maintenance and parts costs are based on a used engine being overhauled by a local fixed-base operator. This is the most economical of approaches to engine maintenance costs. Other options include engine replacement with a new engine, engine replacement with a new exchange engine, or engine replacement with a remanufactured engine. The engine maintenance costs are computed from actual data on the average cost of overhaul and installation and dividing by the time between overhaul-engine hours .

Avionics maintenance and parts costs are treated in a somewhat different manner. Discussions with users and fixed-base operators indicated that, normally, communication and navigation instruments are replaced or repaired only when a malfunction occurs. It was assumed for the purposes of this study

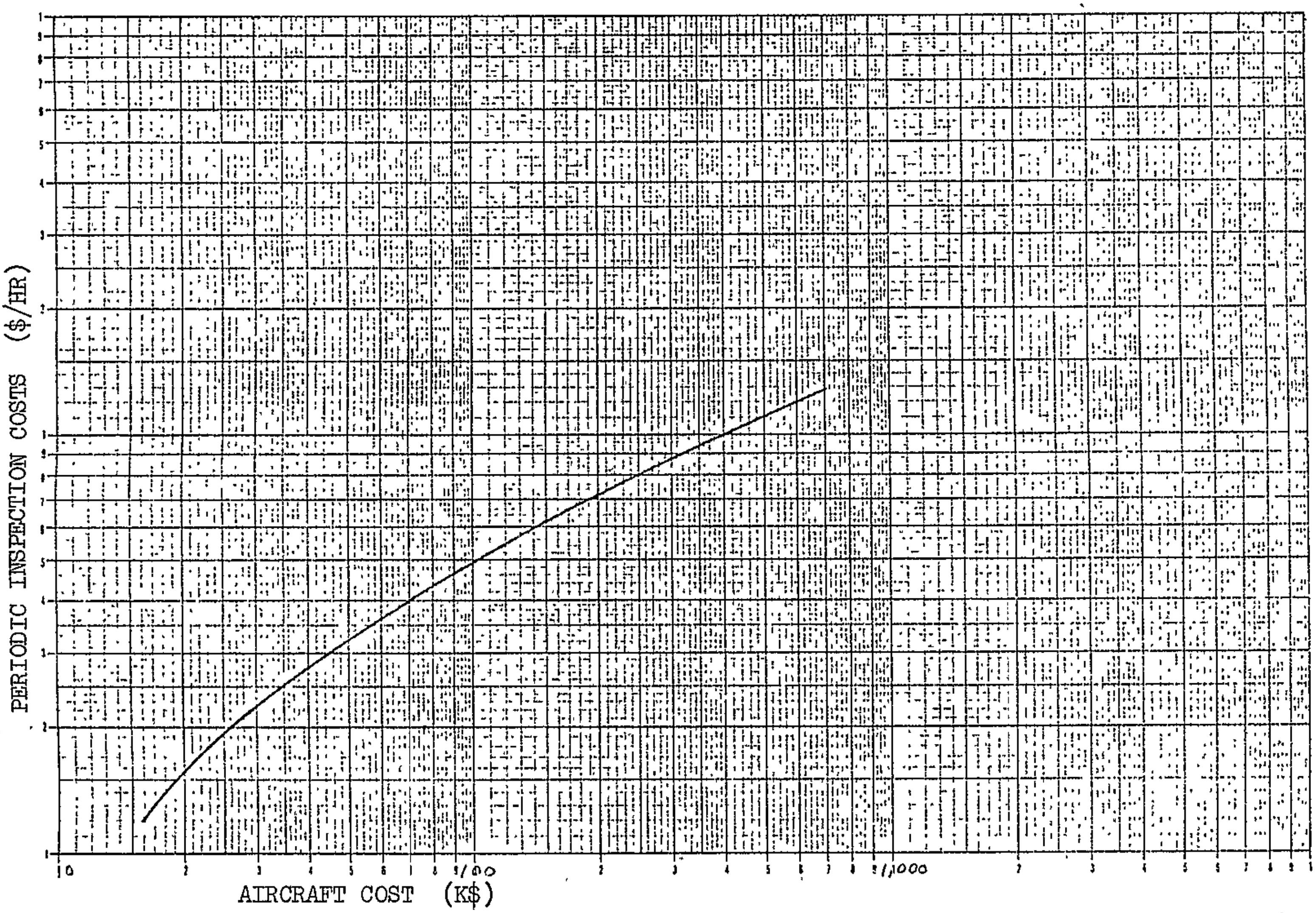

Figure E-1. Periodic Inspection Cost for Fixed-Wing Aircraft

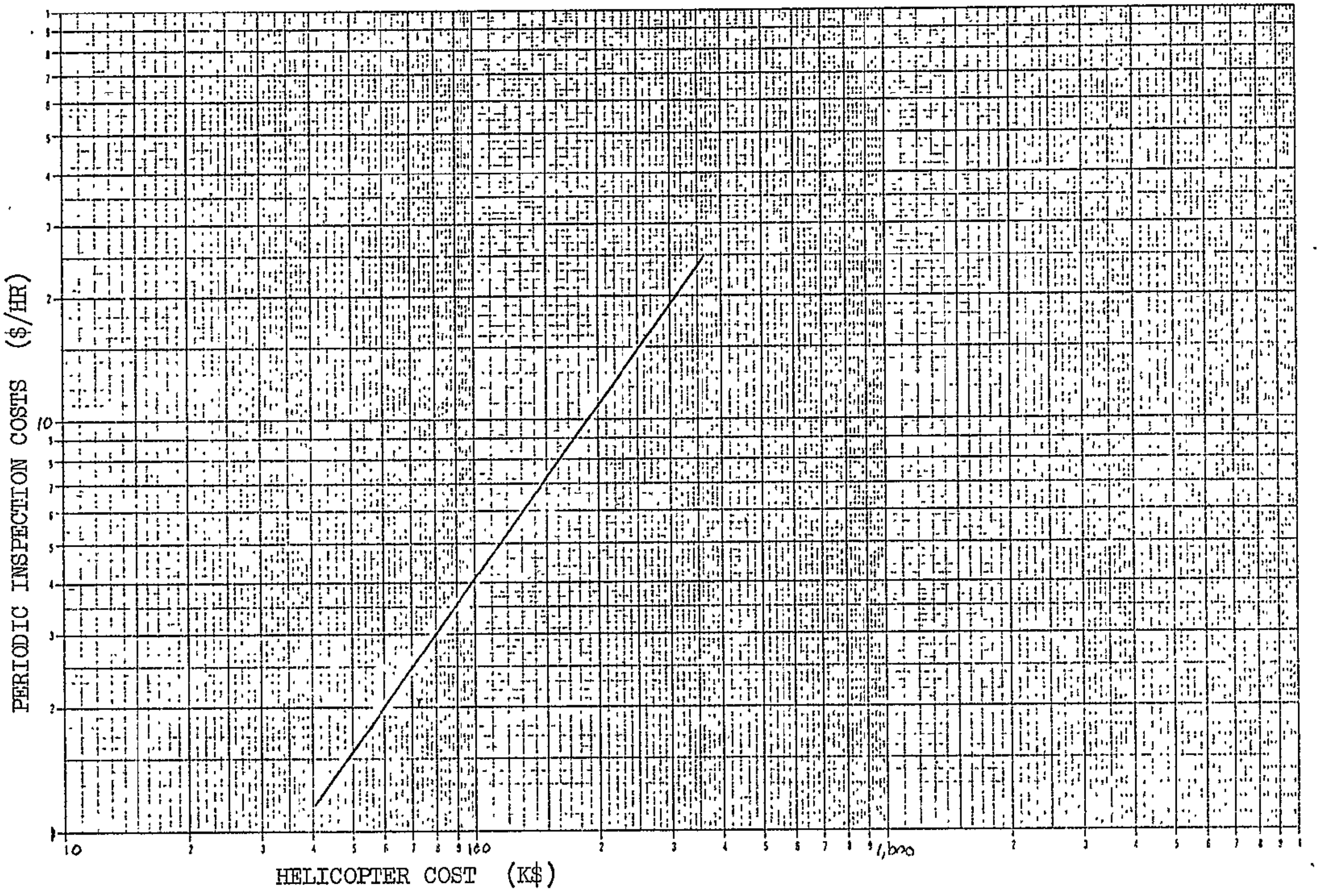

Figure E-2. Periodic Inspection Cost for Helicopters

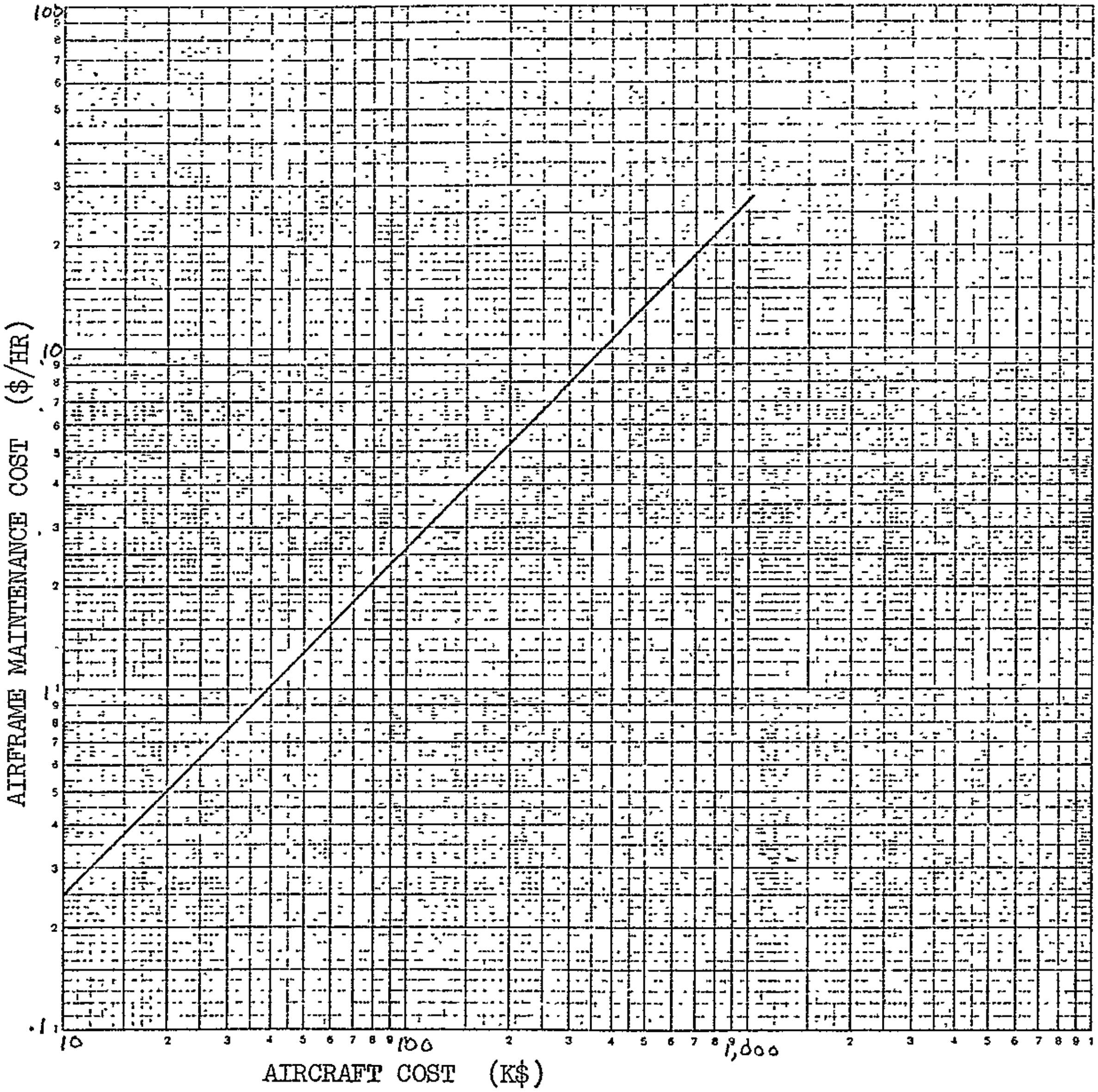

Figure E-3. Airframe Maintenance Cost for Fixed-Wing Aircraft

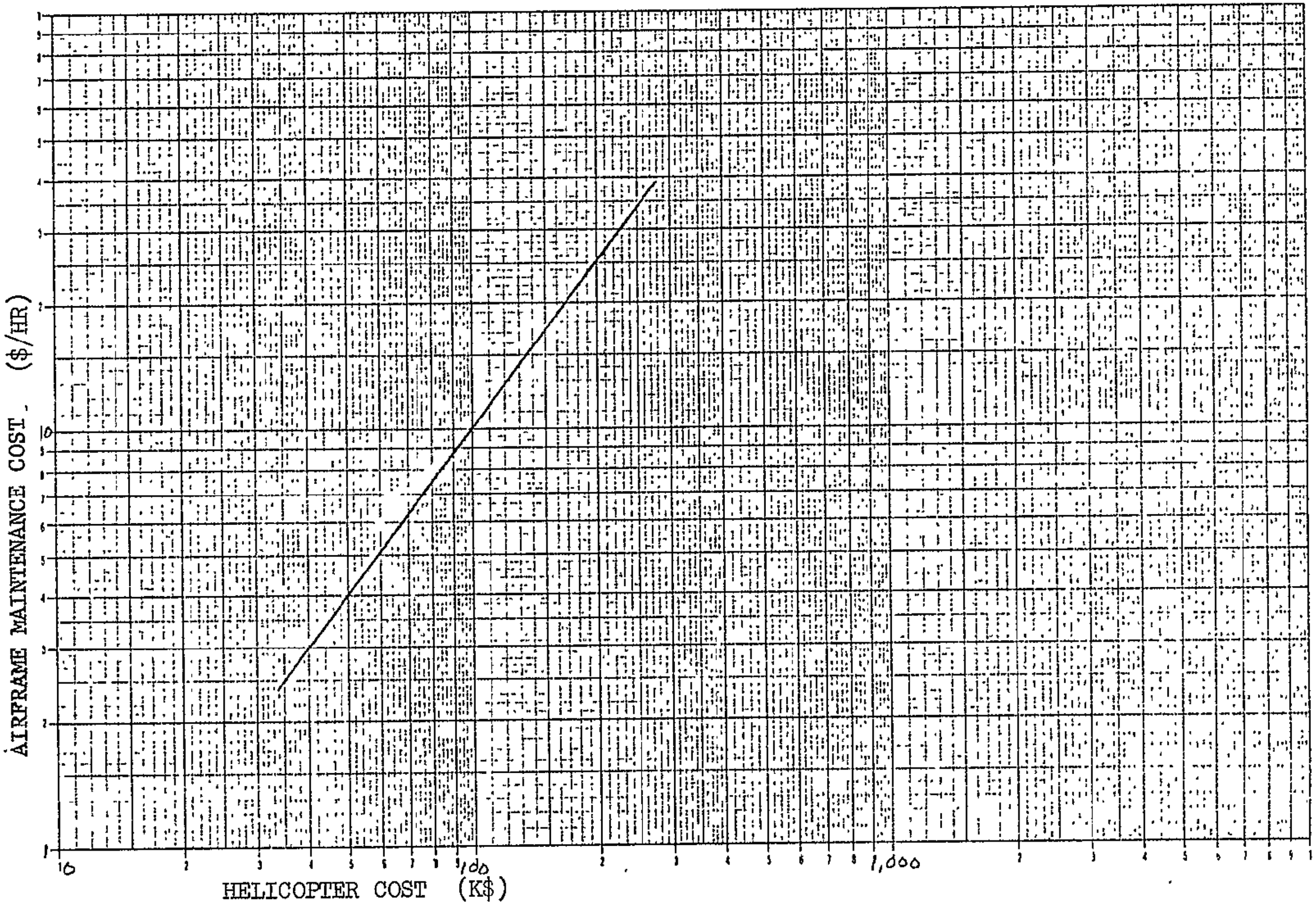

Figure E-4. Airframe Maintenance Cost for Helicopters that basic avionics maintenance costs would be the equivalent to replacing the avionics installations every ten years, based on the life of the equipment, assuming a conservative 600 flying hours per year.

Similar to RPV Systems, the basic avionics maintenance cost estimates do not include the maintenance costs for the sensor payloads. The same 14% of the average unit sensor cost per year, established for RPV sensor payloads, is added to the basic avionics maintenance costs for fixed-wing aircraft and helicopters to account for the maintenance requirements of mission-related sensor systems.

APPENDIX F

RPV STATE-OF-THE-ART ASSESSMENT

This appendix discusses the present state of several technologies that play important parts in the design and functioning of remotely piloted vehicles (RPVs). The topics discussed are:

- Navigation equipment
- Airborne data and command link equipment
- Airborne computers
- Beacon transponders for collision avoidance
- Engines
- Imaging sensors

Navigation

Four kinds of navigation are discussed here. They are trilateration Loran, Omega, and the rho-theta method.

Trilateration. - In its simplest form, navigation by trilateration uses radar ranging to measure ranges from a mobile unit to two or more reference transponders at known fixed locations. The mobile receiver-transmitter interrogates the reference transponders in turn and measures the elapsed time for the round trip of the signal. Three or more reference transponders yield an unambiguous solution for location in three-dimensional space. Trilateration can be used at any range and in any operating area over which line-of-sight can be maintained between the mobile unit and the pre-positioned reference transponders, provided transmitting power and antenna gains combine to give adequate signal strength.

Trilateration systems are available today for position location of survey boats, dredges, seismic exploration drilling trucks, and other such surface units. Although not developed with RPV use in mind, the weights, power requirements, and operating ranges of off-the-shelf units are not far from values usable in RPVs. An example is the Motorola Mini-Ranger III (MRS III) horizontal positioning system. The basic MRS III system consists of a range console, a receiver-transmitter, and two reference stations. The range console and receiver-transmitter units usually form the mobile part of the system and the reference stations are usually set out at fixed known locations. Table F-1 gives the specifications of the basic MRS III. In an adaptation to RPV use, the range console might be integrated into the ground control station (with suitable changes in the display of position information) and the receiver-transmitter unit carried aboard the RPV. Three or more reference stations would be located around the periphery of the operating area.

Table F-1. Motorola Mini-Ranger III System Specifications

SPECIFICATIONS	
Range	37 kilometers (20 nm.) line of sight; 185 km (100 nm.) options available.
Accuracy	3 meter (10 ft) probable range error.
Frequency	5450 to 5600 MHz.
Coding	Four selectable codes using pulse spacing.
RANGE CONSOLE	
Range readout	Displays channels A and B simultaneously with range units available in meters (standard); yards or feet optional.
Output to peripherals	Binary coded decimal, TTL, +8421 parallel.
Operating voltages	115/230 volts AC, 50 - 400 Hz. (Optional: 24 - 30 volts DC power).
Operating temperatures	0° to +50°C
Dimensions	43 x 45.7 x 14 cm. (17 x 18 x 5.5 in.) table mount.
Weights	14.5 kg. (32 lb.) AC power. 12.7 kg. (28 lb.) DC power.
RECEIVER/TRANSMITTER UNIT	
Antenna	Omnidirectional, 25° elevation.
Operating temperatures	–40° to +60°C
Dimensions	15.8 x 23.5 x 16.5 cm. (6.25 x 9.25 x 6.5 in.)
Weight	2.3 kg. (5 lb.) with brackets.
REFERENCE STATIONS	
Antenna	13 dB sector; 75° azimuth, 15° elevation.
Operating voltages	24 - 30 volts DC.
Operating temperatures	–54° to +71°C.
Dimensions	14 x 26 x 16.5 cm. (5.5 x 10.25 x 6.5 in.)
Weight	2.3 kg. (5 lb.) less antenna.

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LORAN-C. - LORAN-C is a pulsed transmission system having a broad spectrum centered at 100 kHz. It is characterized by a highly stable ground wave which can be received accurately up to 2000 km from the transmitting station. Seven chains are currently operational worldwide and cover a substantial portion of the northern hemisphere. U.S. coverage is primarily in the eastern half of the country, although west coast coverage can be achieved if LORAN-D equipment is used rather than LORAN-C. The major disadvantage of LORAN-C is that not all of the U.S. is covered by LORAN; consequently, this system is unusable in some areas. LORAN navigation will work best for those applications covering a large area in which the flight plan is not necessarily predictable or repetitive.

Omega. - Omega is a very low frequency system that operates at 10.2 kHz, 11.3 kHz and 13.6 kHz. It is a worldwide system using eight transmitting stations. These stations are operating and Omega navigation can be used throughout the U.S. Ambiguities occur at various distances depending on the number of frequencies used by the receiver. This occurs every 24 miles if a single-frequency receiver is used, and every 72 miles if a three-frequency receiver is used. Propagation corrections can be determined and transmitted to the RPV, which greatly improves accuracy. As in the case of LORAN, Omega is most logical for use in those applications requiring wide area coverage.

Rho-theta. - Rho-theta navigation uses the pointing azimuth (theta) of the ground antenna, the range (rho) from antenna to RPV measured by timing a round-trip signal, and the altitude measured by the RPV's altimeter. All calculations are done at the ground control station, and commands sent to the RPV for heading, speed, and altitude.

Table F-2 summarizes the size, weight, cost and accuracy of the airborne equipment for the four navigation methods.

Airborne Data and Command Link

Table F-3 shows estimates of the size, weight, and cost of transmitting and receiving equipment suitable for RPVs. Present values and predictions

Table F-2

Airborne Navigation Equipment

Navigation Method	Weight 1976	Weight 1985	Volume 1976	Volume 1985	Cost(1) 1976	Cost(1) 1985	Accuracy, CEP 1976	Accuracy, CEP 1985
Trilateration	(2)	5 lb/2.3 kg	(2)	375 in^3/6100 cm^3	(2)	$5000(4)	(2)	∠20 ft/ ∠ 6 m
LORAN-C	3 lb/1.4 kg	3/1.4	120 in^3/1950 cm^3	100/1600	$3000	3000	1000 ft/300 m	1000/300
Omega	3/1.4	3/1.4	125/2050	100/1600	3000	3000	6000/1800	3000/900
Rho-theta	(3), (4)	(3), (4)	(3), (4)	(3), (4)	(3), (4)		6 m rad in θ, 100 ft in rho (5)	

(1) Constant 1976 dollars; production quantity = 1000 units

(2) Not available in RPV configuration in 1976

(3) No additional airborne equipment

(4) Requires ground equipment for computation and interrogation

(5) Independent of range

Table F-3

Airborne Data and Command Link

	Weight 1976	Weight 1985	Volume 1976	Volume 1985	Cost(1) 1976	Cost(1) 1985	Power Required 1976	Power Required 1985
Receiver	6 oz/0.17 kg	4 oz/0.11 kg	8 in^3/131 cm^3	4 in^3/66 cm^3	$1100	$ 700	0.6 W	0.4 W
Video transmitter	20/0.57	12/0.34	16/262	10/164	1500	900	100	40
Encoder/decoder	16/0.45	8/0.23	16/262	8/131	1100	550	0.5	0.5
Antenna	1/0.03	1/0.03	1/16	1/16	35	35	–	–
Total	43/1.22	25/0.71	41/671	23/377	~ 3700	~ 2200	~100	~40

(1) Constant 1976 dollars; production quantity = 1000 units

are based on discussions with representatives of three avionics manufacturers who supply RPV electronics equipment, but should not be considered as performance claims or price quotes. The three manufacturers are Aacom, Inc., Resdel Engineering Corporation, and the Conic Corporation.

The three basic performance characteristics assumed for the equipment are:

- Bit error rates less than 10^{-3}
- Video signal quality greater than 20 dB (rms/rms)
- Standard video information bandwidth
- Telemetry bandwidth is 1000 Hz; command bandwidth is 500 Hz.

Airborne Computers

One of the applications of the airborne computer is that of replacing much of the analog and digital flight control circuitry. This has the advantage of reducing weight and size, and adds flexibility in that it is then possible to make major modifications in a design by reprogramming a memory rather than designing new circuitry. A single design may be used for a number of different vehicles. With microcomputers, the central processing unit is usually on a single chip, so the primary volume requirement is the space allotted for the memory. A large memory is desirable, in order to be able to store calibration data and mathematical look-up tables, as well as special routines.

A criterion for computer evaluation is the ease and speed of addressing data in memory. If several levels of indirect addressing are required to reach much of memory, then any instruction requiring memory access will be more time-consuming. The type of memory should also be considered. Core provides the most flexibility, since it is non-volatile (no data loss with power loss) and can be rewritten over and over again. However, it also requires the most power. Semiconducter Read Only Memory is non-volatile but permanent. Semiconductor Random Access Memories can be read or written, but are volatile. Programmable Read Only Memories can be erased fully and rewritten over and over again, so offer a possible compromise between ROMs & RAMs.

Within the area of Random Access Memory, there are two different types. Static RAMs use flipflops for storage, while dynamic RAMs rely on charging the input capacity of field-effect transistor (FET). Static RAMs require less associated circuitry, are easier to handle, but consume more power and are generally slower. Dynamic RAMs have very low standby power and consume less power than static RAMs even when accessed, but must have their charge refreshed at least every 2 milliseconds, requiring additional logic circuitry. Also, when used in conjunction with a CPU, the CPU clock rates must be modified to allow for the refresh cycles. However, the reduced power consumption of the dynamic RAM makes it an attractive candidate for large memory systems where memory power can be high. A small battery can be used as standby power for a dynamic RAM array in order to preserve stored data when main power is removed.

Other applications of an on-board computer are in navigation and guidance systems. In the processing of Omega navigation signals, the computer can provide many functions such as timing, calculations, calibrations, and digital filtering. Some of the guidance functions can be transferred from ground computer to the airborne computer, in order to decrease dependency on the RF data link for reliable operation.

Since subroutines will have wide usage, it is desirable that the computer have provision for nesting of many subroutines. Although a 16-bit word length is desirable, cheaper and smaller 8-bit microcomputers can be used at less than their normal speeds to form 16-bit words. When handling flight control data, update commands do not have to be given often compared with computation speeds, so the 8-bit machines may indeed be the most efficient solution.

A major computer selection area is between a microcomputer, which is composed of a single- or few-chip microprocessor and auxiliary circuitry, and a minicomputer, which is a small computer enclosed in a housing. The advantage of a minicomputer is its greater ease of operation, speed, and amount of software support available. Also, the minicomputer is a fully defined unit, while the microcomputer is a collection of computer elements made either by the manufacturer of the integrated circuits, a separate supplier, or the user. However, the microcomputer speed may be sufficient for many applications, and its cost, size, and weight reduction over the minicomputer make it the prime candidate for airborne RPV applications. Besides the decreased volume, since microcomputers are fabricated at the circuit level, these cards may be assembled to fit more restrictive and more irregular volume allotments than the minicomputers.

What cannot be fully explored in this summarized survey is the time required by each computer to perform all the functions intended for the on-board computer. This can only be determined by a detailed definition of the requirements, well beyond the scope of this survey, and a detailed study of the architecture of the computer candidates. The space and power required will depend strongly on the amount of memory required and the amount of hardware necessary for interfacing with all the devices with which the computer will interact. The cost of using a given candidate will be heavily dependent on the software support for the tasks to be performed.

Microprocessor technology is advancing rapidly, with many new devices being announced from a variety of manufacturers, and speed and capabilities being increased. Table F-4 describes a representative microcomputer system.

Table F-5 summarizes some significant characteristics of three microcomputers and two minicomputers. The first listing is the size of the basic instructions set. Generally, a larger instruction set permits more speed and flexibility of operation; however, the usefulness of given instructions must also be considered. A shorter word length means that more time must be consumed in handling 16-bit data. Subroutine nesting capability is important because it permits the computer to handle many repetitive tasks efficiently and intersperse them with other programs. The times required to do addition and to shift data give an indication of the effective speeds of the various computers. A built-in hardware capability speeds multiplication and therefore many computations. In the absence of such a capability, ROM table look up, external hardware, repeated add and shift, or a combination of these can be used. Direct Memory Access permits rapid access to the computer memory for high speed peripherals. Minicomputers are primarily constructed with TTL CPUs, faster than most currently available microporcessors which utilize primarily MOS for their CPUs, although interfaces are TTL-compatible. Minicomputers are generally easier to program and have more available software

Table F-4. Representative Microcomputer System Based on INTEL 8080 CPU

MCS-80 Capabilities

8-bit parallel central processor, using 8080 chip.
2.5 μ sec instruction execution time.
78 basic instructions.
Direct addressing to up to 65 K bytes of any speed ROM, PROM, or RAM.
Virtually unlimited subroutine nesting.
Seven working registers: six 8-bit general purpose registers and one 8-bit accumulator.
256 x 8-bit PROM.
Separate 16-bit address bus, 8-bit output bus and 3 multiplexed 8-bit input busses for I/O input, memory input, and interrupt data.
Direct addressing of 256 input and 256 output ports.
Four 8-bit input and twelve 8-bit latching output ports.
All busses TTL compatible.
1 K of 8-bit static RAM or 4 K of 8-bit dynamic RAM capability.
All circuitry on one 6" x 8" card, approximately 0.5" thick.

IN-40 Memory System Capabilities

32 K x 9 dynamic Random Access Memory.
Cycle Time: 650 nanoseconds.
All circuitry on two 8" x 10.5" x 0.5" circuit cards.
Power Requirements: 24 watts
Temperature: 0°C to 50°C operating, -40°C to +125°C non-operating.
Altitude: Up to 10,000 ft operating, up to 5,000 ft non-operating.
Field expandable.

	1976	1985
Volume	600 cu in	200 cu in
Weight	12 lbs	8 lbs
Power	100 - 200 W	50 - 100 W
Unit Cost (1)	$5,000	$3,000

NOTE: Includes 32 K words x 16 bits or 64 K x 8 bits of memory. Power consumption depends on mix of ROM, PROM, dynamic RAM, static RAM

Does not include DC supplies which may be shared with other portions of the system.

(1) Hardware costs only, in constant 1976 dollars; production quantity = 100+.

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		Bendix (Mini) BDX-920	Intel 8080 Series Microcomputer	National PACE Microcomputer	HP 2100 Mini-computer	Motorola 6800 Micro-computer
No. of Instructions		40	72	45	80	72
Basic Word Length		16	8	16 + 8	16	8
Subroutine Nesting Ability		Not Given	Very Good	Good	Very Good	Very Good
Min. Instruction Times (μ sec) (S = No. of Shifts)	Add	2	4	8.5	2	2
	Long Shift	1 + S/2	2 S	10.5 + 6 S	1 + S/2	2S
Direct Memory Access for I/O		Yes	Yes	Yes	Yes	Yes
Memory		Core or Semic. Up to 32 K core. 512 words directly addressed.	Semic. Up to 65K x 8 words can be directly addressed.	Semic. Up to 65K x 8 can be addressed directly.	Core, Up to 32K x 16	Semic Up to 65K can be addressed directly.
CPU Technology		TTL	NMOS	PMOS	TTL	NMOS
Software Support		Yes	Yes	Yes	Yes	Yes
No. of General Registers		16	6	4	2	2
Built-In Hardware Multiply		Yes	No	No	Yes	No

TABLE F-5 Comparative Computer Parameters support. The number of general registers is also an important evaluation criterion, since too few will result in data bottlenecks which in turn will slow down processing and make programming less efficient and more complex.

Beacon Transponder

Upcoming legislation will require a Collision Avoidance System (CAS) on all aircraft by the late 1970's or early 1980's. At the present time, the primary candidate CAS is the Litchford Semiactive BCAS* System. The BCAS requires an Air Traffic Control Radar Beacon System (ATCRBS) Mode C transponder currently in use by aircraft operating from Class 1 terminal control areas plus a yet-to-be-defined escape-maneuver decoder. The ATCRBS Beach System consists of a transponder and an altimeter.

The BCAS system is envisioned to operate in the following manner: the transponder, when interrogated by ground base radar, responds with an assigned identification code and the altitude of the aircraft. The ground base station, along with secondary radar stations, triangulates the aircraft position and tracks all aircraft in the air space under supervision. In the event of possible danger of collision, the ground base radar transmits instructions to each endangered aircraft as to action to be taken to avoid collision via the beacon/radar link.

The airborne BCAS hardware, with the exception of the escape-maneuver decoder, presently is available from all of the major avionics equipment manufacturers. The typical beacon/transponder meets the following:

Size: 64 in^3
Weight: 3 lb
Input Power: 18 watts
Cost: $600

The altimeter is described by:

Size: 6.5 in^3
Weight: 0.6 lb
Input Power: 1 watt
Cost: $600

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*BCAS - Beacon Collision Avoidance System

The forecast of improvements in the beacon system will be three areas: (1) the microwave power source; (2) altimeter; and (3) processor electronics. The microwave source is presently using a cavity triode. Solid state sources using TRAPATT diodes would reduce the size and improve cost, life, and power consumption. The altimeter will be replaced by a solid-state transducer along with a microporcessor to correct the non-linearities which are inherent with the solid-state pressure transducer. This will improve on size and cost. The processor circuit will probably be mechanized in large scale integrated (LSI) circuit technology and will also use the altimeter microprocessor to provide control functions. These techniques would provide improvements in cost and size.

With the implementation of these forecasted improvements, the 1985 beacon systems, with the altimeter and escape maneuver decoder, could meet the following:

Size: $40\ \text{in}^3$
Weight: 2 lb
Input Power: 12 watts
Cost: $2000

Engines

The engines available for RPVs are mostly designed and built for powering other devices such as chain saws, go-carts, snowmobiles, etc. One or two, by Kolbo and by DH Enterprises, were developed for RPVs. Table F-6 summarizes the main characteristics of a number of candidate engines.

Imaging Sensors

Table F-7 summarizes some of the main features and characteristics of a number of imaging sensors that are, or are expected to be, available and suitable for RPV programs.

Table F-6 Some RPV Engine Candidates

ENGINE	NO. OF CYLINDERS	STROKES/ CYCLE	DISPLACEMENT		POWER		WEIGHT		COST 1976 $	PRESENT APPLICATION
			IN.^{3}	CM^3	HP	kW	LB	KG		
KOLBO D2118	2	2	11.8	193	18	13.4	11	5.0	$1000	RPV
" D2100	2	2	9.8	160	13	9.7	9.25	4.2	1000	RPV
" D274	2	2	7.4	121	10	7.5	9.0	4.1	1000	RPV
MC CULLOCH MC-101	1	2	7.5	123	10	7.5	12	5.5	125	GO-KART
HOMELITE 650	1	2	6.0	98	7	5.2	8EST	3.6	100	CHAIN SAW
CHRYSLER 820	1	2	8.2	134	8	6.0	13.5	6.1	150	GO-KART
DH ENTERPRISES DVAD274	2	2	16.7	274	16	11.9	12.6	5.7	1000	RPV
JLO ROCKWELL L230	1	2	13.6	223	15.5	11.6	29	13.2	120	SNOWMOBILE
KOHLER K440-2AS	2	2	21.6	354	42	31.3	64	29.1	—	SNOWMOBILE
STIHL 090	1	2	8.36	137	8.5	6.3	12EST	5.5	—	CHAIN SAW
AVCO-LYCOMING DIV 0-235-CIB	4	4	—	—	115	85.8	213	96.8	—	LIGHT AIRCRAFT
JLO ROCKWELL LR440/2	2	2	25.2	413	35	26.1	62	28.2	225	SNOWMOBILE
FRANKLIN ENGINE CO., INC. 2A-120	2	4	—	—	60	44.8	133	60.5	—	LIGHT AIRCRAFT
TELEDYNE CONTINENTAL MTRS 0-200-A	4	4	—	—	100	74.6	200	90.9	—	LIGHT AIRCRAFT
BARKER ENGINE (VW CONVERSIONS)	4	4	98.1	1607	55	41.0	136	61.8	1255	SPORT AIRCRAFT
" "	4	4	112.4	1842	70	52.2	136	61.8	1435	SPORT AIRCRAFT
" "	4	4	120.1	1968	80	59.7	138	62.7	1575	SPORT AIRCRAFT
LON STEVENS CO. MODIFIED MERCURY OUTBOARD ENGINE (LIQUID COOLED)	4	2	44	721	80	59.7	72EST	33EST	700	AUTO & BOAT RACING
WILLIAMS WR24-6 TURBOJET	N/A	JET	—	—	121 LB THRUST	55 KG THRUST	30	13.6	—	AIRCRAFT

TABLE F-7 Imaging Sensors

SENSOR TYPE	WEIGHT		SIZE (IN.)		COST(1) EST. $K		1975									1977
							POTENTIAL SOURCES	AVAIL. IN 1976 W/O DEVELOPMENT COSTS	IFOV(4) MRAD LINE	RESOLUTION TV LINES PICTURE HT.		FOV DEG.	BW (MH$_z$)	COOLER ENDUR.	COOLER WEIGHT (LBS.)	RESOLUTION TV LINES PICTURE HT.
	1976	1985	1976	1985	1976	1985				HORIZ.	VERT.					
DAY SENSORS																
1 CCD CAMERA - BURIED CHANNEL	1.6	1.0	3DIAx1.87	2DIAx1.5	3	0.5	FAIRCHILD	YES	0.5	142	244	5	2.0			284x488
2 CCD CAMERA - SURFACE CHANNEL	2.5	2.0	2.75x4.5x5.87	2x3x4	2	0.5	RCA	YES	0.5	320	512	11	4.0			320x512
3 CID CAMERA - CHARGE INJECTED	2.9	2.0	2.25x4.37x7.5	2x4x6	6.8	1.0	GE	YES	0.5	244	248	8	3.0			500x500
4 PAN & TILT CCD CAMERA & DOME	10	7	13DIAx16	8DIAx10	9	6	HONEYWELL/ FAIRCHILD	NO	0.5	142	244	5	2.0			284x488
5 PAN & TILT CCD CAMERA & DOME	10	7	13DIAx16	8DIAx10	8	6	HONEYWELL/RCA	NO	0.5	320	512	11	4.0			320x512
6 PAN & TILT CID CAMERA & DOME	10	7	13DIAx16	8DIAx10	12.8	6.5	HONEYWELL/GE	NO	0.5	244	248	8	3.0			500x500
7 PAN & TILT - VIDICON CAMERA & DOME	18.5	14	13DIAx16	11DIAx12	8	6	HONEYWELL	YES	0.15	450	600	ZOOM 5 to 32	4.5			- - -
8 PAN & TILT - VIDICON CAMERA & DOME	34	16	18DIAx12	8DIAx10	19	7	WESTINGHOUSE	YES	0.2	450	600	5, 12, 20	4.5			
9 PAN & TILT - VIDICON CAMERA & DOME	20	14	12DIAx16	11DIAx12	8	6	AERONUTRONIC- FORD	YES	0.15	400	600	ZOOM 3 to 16	4.5			
10 TILT - VIDICON CAMERA $\left\{ {+10^\circ \atop -80^\circ} \right.$ EL	3.5	2.0	9.8x3 8x1.8 6.5x3x2.3	3DIAx5	2	1	LMSC/SONY TV	YES	1.4	450	600	30	4.5			
DAY/NIGHT SENSORS																
1 MINI FLIR; 2 FOVs, PAN & TILT & DOME	19	10	5DIAx7(DOME) 9DIAx17	5DIAx7(DOME) 6DIAx10	19 to 30	7 to 15	AERONUTRONIC FORD	YES	0.2	262	350	3x4(2) 30x40	3.0	N_2 BOTTLE CRYO 3 HOURS	0.5	
2 MINI-FLIR; 2 FOVs, PAN & TILT & DOME	15	10	18.6x7(DOME) 21.5x7.5x71	9.3x7(DOME 21.5x7.5x36	20 to 25	15 to 20		YES	0.25	160	214	13x18(2)	2.0	N_2 BOTTLE CRYO 3 HOURS	0.5	
3 MINI-FLIR; 2 FOVs, PAN & TILT & DOME	12	8	8DIAx4(DOME) 8DIAx11.3	8DIAx3(DOME) 8DIAx8	10 to 30	10 to 20		NO	0.1	174	233	1x1.7 30x40	2.0	N_2 BOTTLE CRYO 4 HOURS	1.5	
4 FLIR(3) MONOLITHIC FOCAL PLANE ARRAY		5		10DIAx15				NO	0.1	174	233	1x1.7(2) 10x13	2.0	CRYO ENGINE	1.0	
5 PYROELECTRIC VIDICON PAN & TILT	18	14	14DIAx28	12DIAx20	10	4	LMSC/PHILLIPS	NO	0.5	150	200	4x5	1.0	NONE		

NOTES: (1) 1976 Dollars; on quantities of 1000; and NOT official estimates from the companies. (2) With stabilization. (3) In development - available in 1980. (4) IFOV = Instaneous Field of View

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TABLE F-7 Imaging Sensors (Continued)

SENSOR TYPE	Comments		
DAY SENSORS			
1 CCD CAMERA - BURIED CHANNEL	o LOW-LIGHT LEVEL OPERATION - WITH COOLING	o ON-CHIP COLUMN ANTI-BLOOMING	o 1000:1 DYNAMIC RANGE - COOLING
2 CCD CAMERA - SURFACE CHANNEL	o LOW PROJECTED COSTS IN PRODUCTION	o HIGHEST RESOLUTION AVAILABLE IN CCDs	o TV MONITOR COMPATIBLE o SCENE LIGHT DOWN TO 0.1 FT-CANDLES
3 CID CAMERA - CHARGE INJECTED	o LOW BLOOMING	o RANDOM ACCESS - ANTI-JAM DATA LINK	o FREEDOM FROM TRANSFER INEFFICIENCIES
4 PAN & TILT CCD CAMERA & DOME	o LOW-LIGHT LEVEL OPERATION - WITH COOLING	o ON-CHIP COLUMN ANTI-BLOOMING	o 1000:1 DYNAMIC RANGE - COOLING
5 PAN & TILT CCD CAMERA & DOME	o LOW PROJECTED COSTS IN PRODUCTION	o HIGHEST RESOLUTION AVAILABLE IN CCDs	o TV MONITOR COMPATIBLE
6 PAN & TILT CID CAMERA & DOME	o LOW BLOOMING	o RANDOM ACCESS - ANTI-JAM DATA LINK	o FREEDOM FROM TRANSFER INEFFICIENCIES
7 PAN & TILT - VIDICON CAMERA & DOME	o LOW PROJECTED COSTS IN PRODUCTION	o DEVELOPED FOR AQUILA RPV PROGRAM	
8 PAN & TILT - VIDICON CAMERA & DOME	o HEAVY IN PRESENT PACKAGE	o GOOD FLIGHT TEST DATA IN MANNED AIRCRAFT	
9 PAN & TILT - VIDICON CAMERA & DOME	o DEVELOPED FOR ARPA RPV PROGRAMS	o LOW PRODUCTION COSTS PROJECTED	
10 TILT - VIDICON CAMERA $\binom{+10^\circ}{-80^\circ}$ EL	o USED ON SEVERAL RPV PROGRAMS		
DAY/NIGHT SENSORS	NIGH SENS		
1 MINI FLIR; 2 FOVs, PAN & TILT & DOME	o LARGER FLIR (86 LB) - SAME DESIGN - USE BY FOREST SERVICE IN HELICOPTER		
2 MINI-FLIR; 2 FOVs, PAN & TILT & DOME	o QUANTITY PRODUCTION BACKLOG ON MANY OF THE MODULAR PARTS NEED FOR THIS FLIR		
3 MINI-FLIR; 2 FOVs, PAN & TILT & DOME	o GOOD PRODUCTION POTENTIAL 1976-1977		
4 FLIR(3) MONOLITHIC FOCAL PLANE ARRAY	o DUE OUT IN 1980-1985	o SENSOR MAY BE EXTRINSIC SILICON	
5 PYROELECTRIC VIDICON PAN & TILT	o FLIGHT TESTS BY LMSC R&DD 1975	o GOOD RESULTS - SMALL AREA SURVEILLANCE APPLICATION	

APPENDIX G

DATA AND CONTROL LINK DESIGN RATIONALE

The starting point for the design of each data and control link is the range over which it must operate, as determined by the geometry of each mission. These geometries are described in Appendix C and summarized in Figure G-1. The second determinant is the data rate (in Hertz) and data quality (in signal-to-noise ratio (SNR)) to be provided, as determined by the information to be transmitted in each direction. This, too, is determined by the mission. Beginning with these requirements and a chosen frequency, a link analysis provides transmitter powers, antenna gains, receiver noise figures, and bandwidths for proper operation. The size, weight, cost, and electrical-power requirements of equipment with these characteristics are then estimated and used in the conceptual system designs and the system costing.

Frequency: It is desirable to keep the frequency as low as possible (in the UHF region) to keep the transmitter costs down and avoid high range losses. Lower frequency means both lower component costs and better efficiency. A frequency of 800 MHz was used, assuming it to be possible to get the Federal Communications Commission to assign several UHF television channels between channel 70 and channel 80 for use by RPVs in any given region.

Data rates: The required data rate for the command (control) link from the ground is estimated at 500 Hz in all systems but Mission 7. Because of the tighter control required for precision flying during crop spraying, Mission 7's command-link bandwidth was increased. For the data downlink it is estimated at 500 Hz for telemetry, 4.5 MHz for video or FLIR, 0.2 MHz for infrared line scanner, and 0.25MHz for synthetic-aperture radar.

The system bandwidth was selected by assuming frequency accuracy of the transmitter and receiver of 0.005% (within 40 KHz of f_o each) and adding the

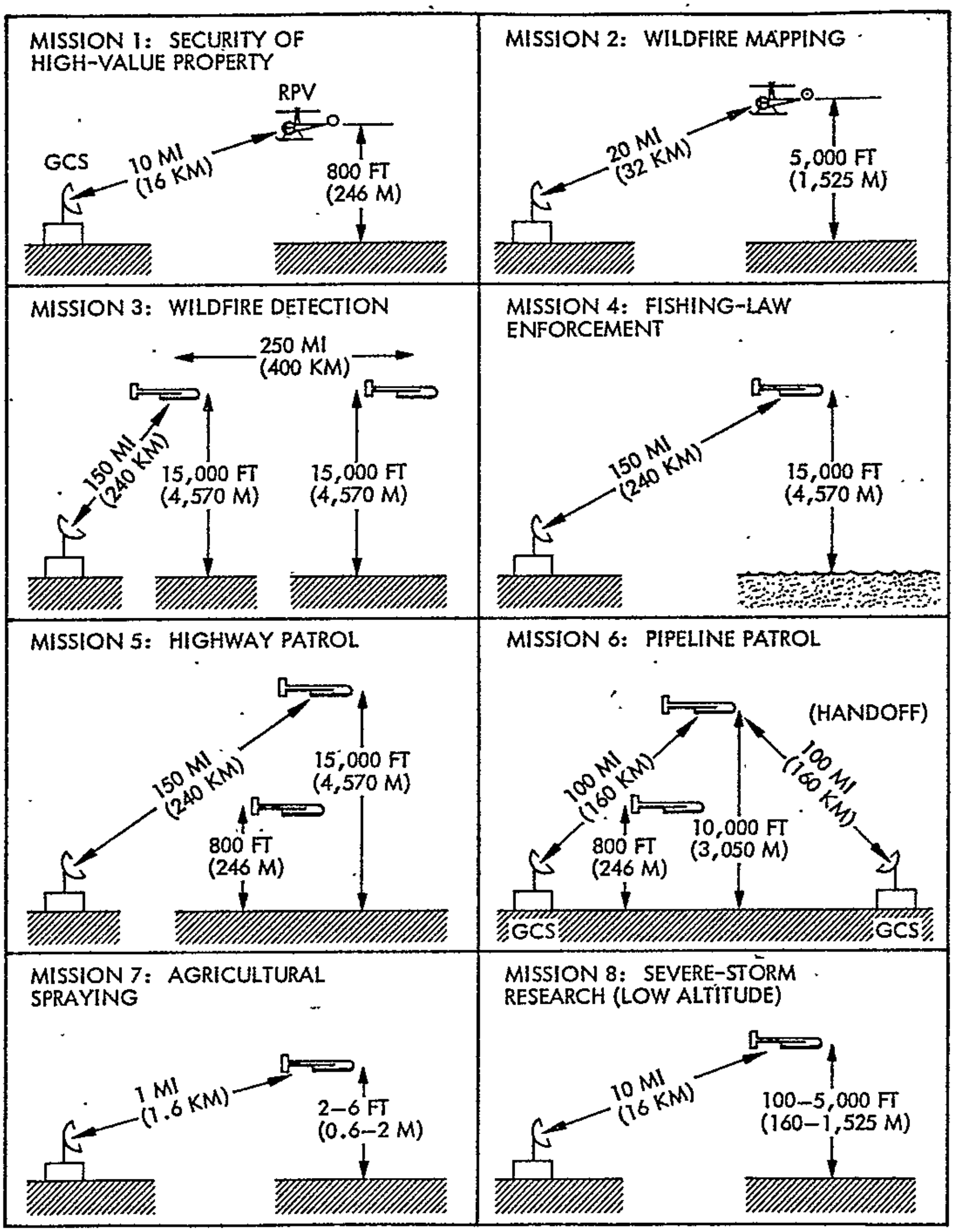


FIGURE G-1 Data and Control Link Geometries bandwidth required by the signal. A rigorous analysis of signaling technique to be used was not done for each system.

Link analysis: The link analysis was performed on all systems; the results are displayed in Table G-4 The SNR result does not include the effects of frequency-modulation (FM) and pre-emphasis improvement. The are possible and can be calculated from the following equations:

$$\text{FM improvement} = 10 \log 3\beta^2, \quad \beta = f_d/f_m$$

where f_d = deviation frequency

f_m = modulation frequency

$$\text{pre-emphasis improvement} = 10 \log [(2\pi f_m \tau)^2/3]$$

where τ = the de-emphasis time constant

Using the criterion that bit error rate must not exceed 10^{-5} in the digital links, a SNR of 14 dB is required. All links provide margins considerably above this figure. Video links should have a SNR of at least 20 dB, and mission 1 has the least margin (4 dB). However, that margin is satisfactory.

A basic set of system-performance and equipment quality values were determined first for the requirements of missions 1 and 8, as shown in Table G-4. The other systems were developed as variations from this system. In this system and the system for mission 2, navigation is by the rho-theta method, in which the RPV encoder is bit-locked to the command decoder to get a range (rho) output by measuring the phase difference between the telemetry signal and the command signal and calculating travel time of the signal. The pointing angle (theta) of the ground antenna is measured for azimuth from the ground station to the RPV, and the RPV altimeter measures altitude. Position is calculated from these three parameters. The angular accuracy can (with some care) be measured to one-twentieth of a beamwidth and the command and telemetry phases measured within 3 microseconds. Thus, the RPV position can be resolved to approximately 150-meter cells at a range of 10 mi (16 km).

Mission 2 has the same basic link except there is an additional 6 dB of range loss. By replacing the 8 dB antenna with a 14 dB antenna, the 6 dB is regained.

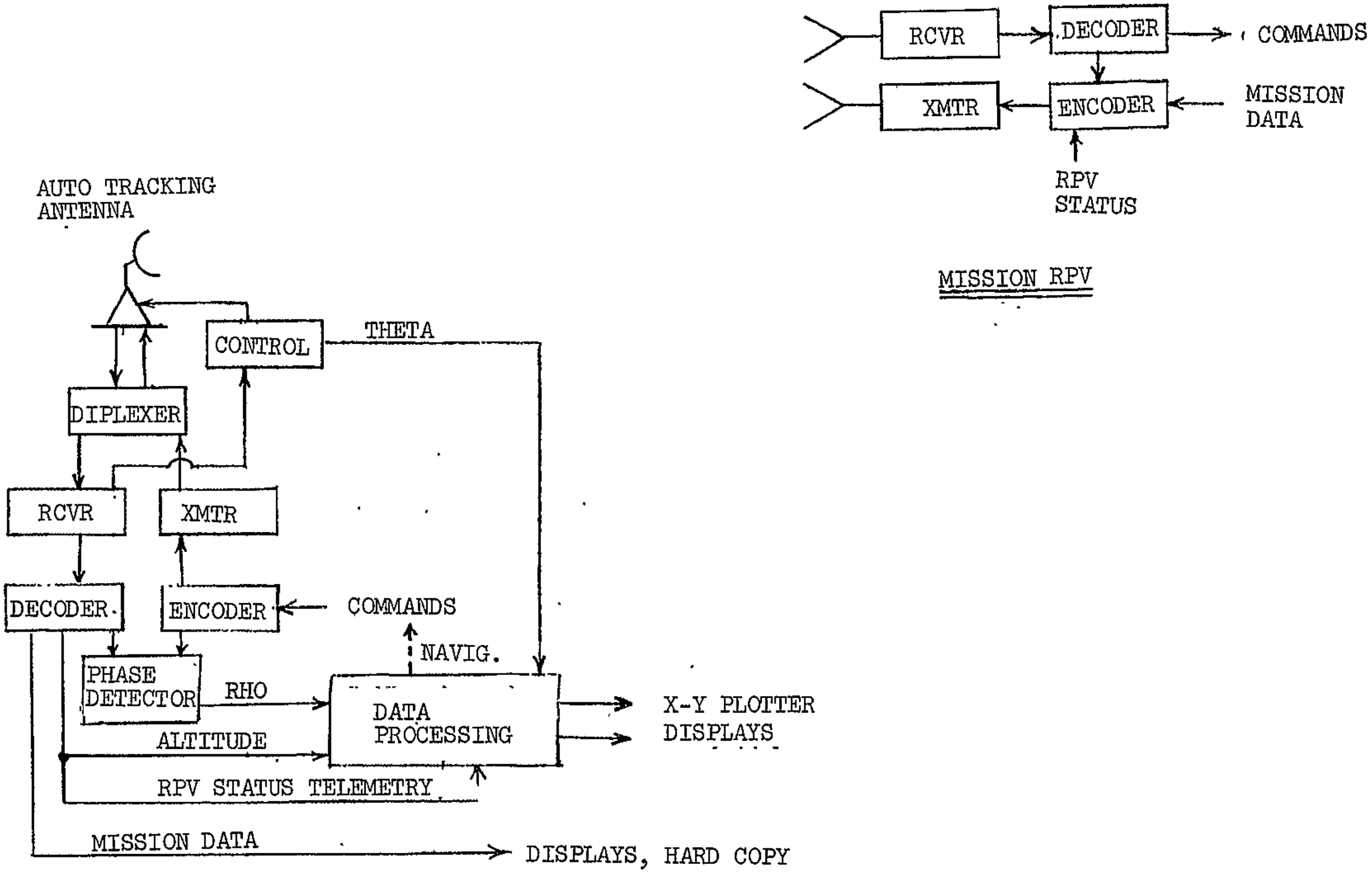
TABLE G-4 SUMMARY OF LINK ANALYSIS FOR ALL SYSTEMS

MISSION	LINK	RANGE MI. (KM)	TRANSMITTER		RECEIVER		SYSTEM BANDWIDTH	SNR
			POWER	ANTENNA GAIN	ANTENNA GAIN	NOISE FIGURE		
1 and 8	Command	10 (16)	1 W	8 dBi	0 dBi	10 dB	0.1 MHz	36 dB
	Data	10 (16)	2	0	8	5	10.0	24
2	Command	20 (32)	1	14	0	10	0.1	36
	Data	20 (32)	2	0	14	5	10.0	24
3	Command: grnd - relay	150 (240)	4	23	0	5	0.1	38
	relay - RPV	250 (400)	4	12	3	5	0.1	26
	Data: RPV - relay	250 (400)	4	3	12	3	0.5	21
	relay - grnd	150 (240)	4	0	23	5	0.5	31
4	Command	150 (240)	4	25	3	3	0.1	45
	Data	150 (240)	4	3	25	3	1.0	35
5 and 6	Command: grnd - relay	150 (240)	4	23	6	5	0.1	44
	relay - RPV	3 (4.8)	1	0	0	10	0.1	38
	Data: RPV - relay	3 (4.8)	2	0	0	5	10.0	26
	relay - grnd	150 (240)	8	6	23	3	10.0	29
7	Command	1 (1.6)	1	15	0	10	0.5	56
	Data	1 (1.6)	1	0	15	10	10.0	43

Mission 3 requires a relay system due to the long ranges (over-the-horizon). As transmitter power is a costly method of gaining range performance (23 db more than mission 1 between the relay and the ground), the antenna gain was increased by 15 dB, the command receiver noise figure decreased by 5 dB, and the transmitter power increased by 3 dB. This provides the same command link performance out to the relay RPV as mission 1. To provide the command link to the mission RPV, power, antenna gains, and receiver noise figure had to be improved. Response on the downlink was assumed to require less than 500 KHz of IF bandwidth.

The systems for missions 4, 5, and 6 are variations of the above systems. Mission 7 is extremely difficult, as it requires very tight control. Data rates were increased to provide high sample rates of all RPV data and a higher command rate.

Figures G-2 through G-5 illustrate the main elements of the airborne and ground-based parts of the links.



MISSION RPV

GROUND STATION

FIGURE G-2 Data and Control Links for Missions, 1, 2 and 8

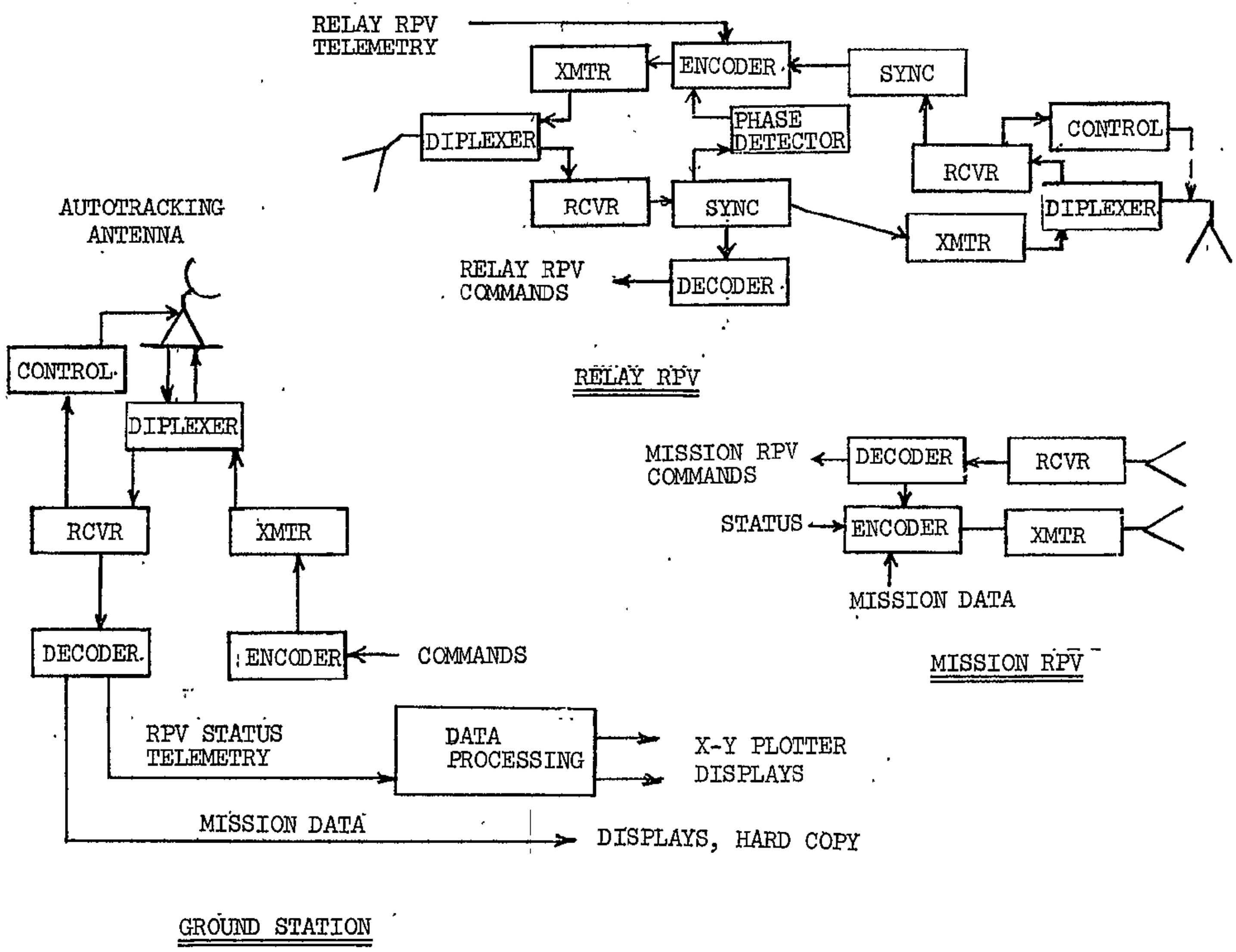


FIGURE G3 Data and Control Links for Missions 3, 5, and 6

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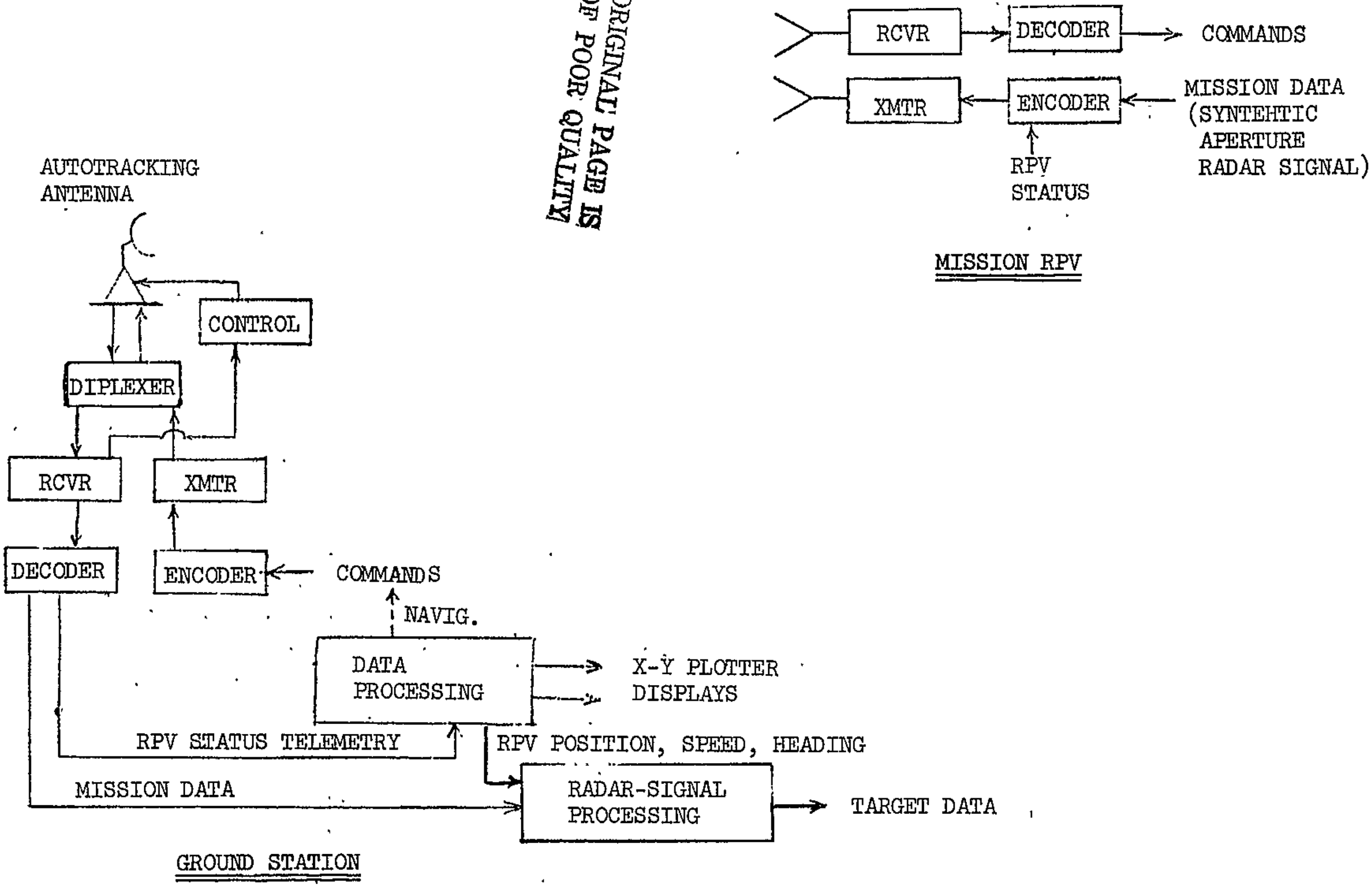
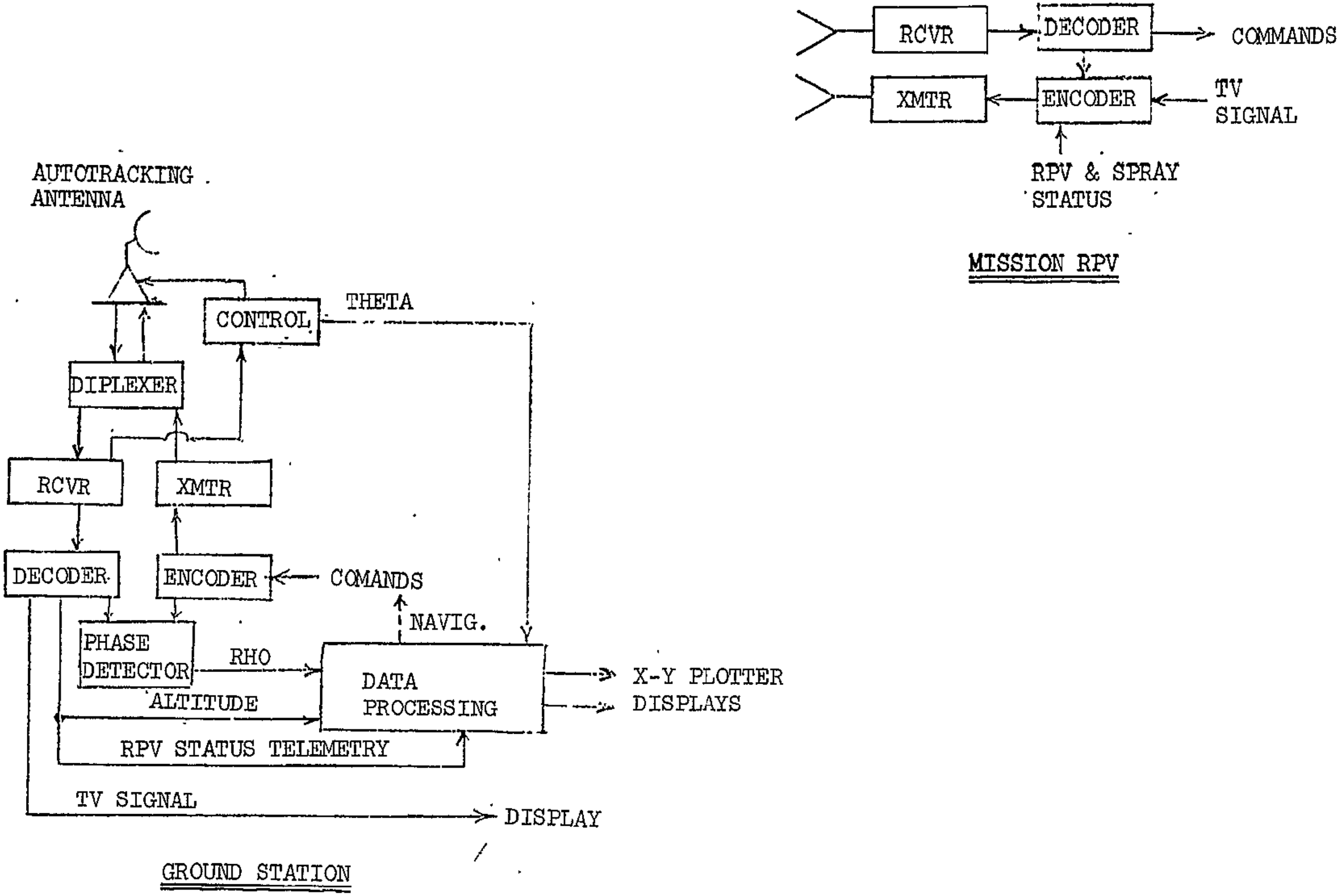


FIGURE G-4 Data and Control Links for Mission 4



MISSION RPV

GROUND STATION

FIGURE G-5 Data and Control Links for Mission 7