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(NASA-CR-137895) CIVIL USES OF REMOTELY
PILOTED AIRCRAFT Summary Report (Lockheed
Missiles and Space Co.) 28 p HC A03/MF A01
CSCL 01C

N77-10048

Unclass

G3/05 08928

CIVIL USES OF REMOTELY PILOTED AIRCRAFT

(SUMMARY REPORT)

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

JULY 1976

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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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1. Report No. NASA CR-137895		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle CIVIL USES OF REMOTELY PILOTED AIRCRAFT				5. Report Date July 1976	
				6. Performing Organization Code	
7. Author(s) Jon R. Aderhold, G. Gordon, George W. Scott				8. Performing Organization Report No. LMSC-D057322	
9. Performing Organization Name and Address Lockheed Missiles & Space Co., Inc. P. O. Box 504 Sunnyvale, CA. 94088				10. Work Unit No.	
				11. Contract or Grant No. NAS2-8935	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Ames Research Center Moffett Field, California 94035				13. Type of Report and Period Covered Contractor Report	
				14. Sponsoring Agency Code	
15. Supplementary Notes Summary Report (Final report is NASA CR-317894)					
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.					
17. Key Words (Suggested by Author(s)) Remotely Piloted Vehicles Mission Analysis Cost-Benefit Safety Requirements				18. Distribution Statement	
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 15	
				22. Price*	

*For sale by the National Technical Information Service, Springfield, Virginia 22151

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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 Aeronautics 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 complete final results of the study are reported in NASA-CR137894.

CIVIL USES OF REMOTELY PILOTED AIRCRAFT

Jon R. Aderhold, G. Gordon, and George W. Scott
Research & Development Division, Lockheed Missiles & Space Company, Inc.

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.

APPROACH

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.

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.

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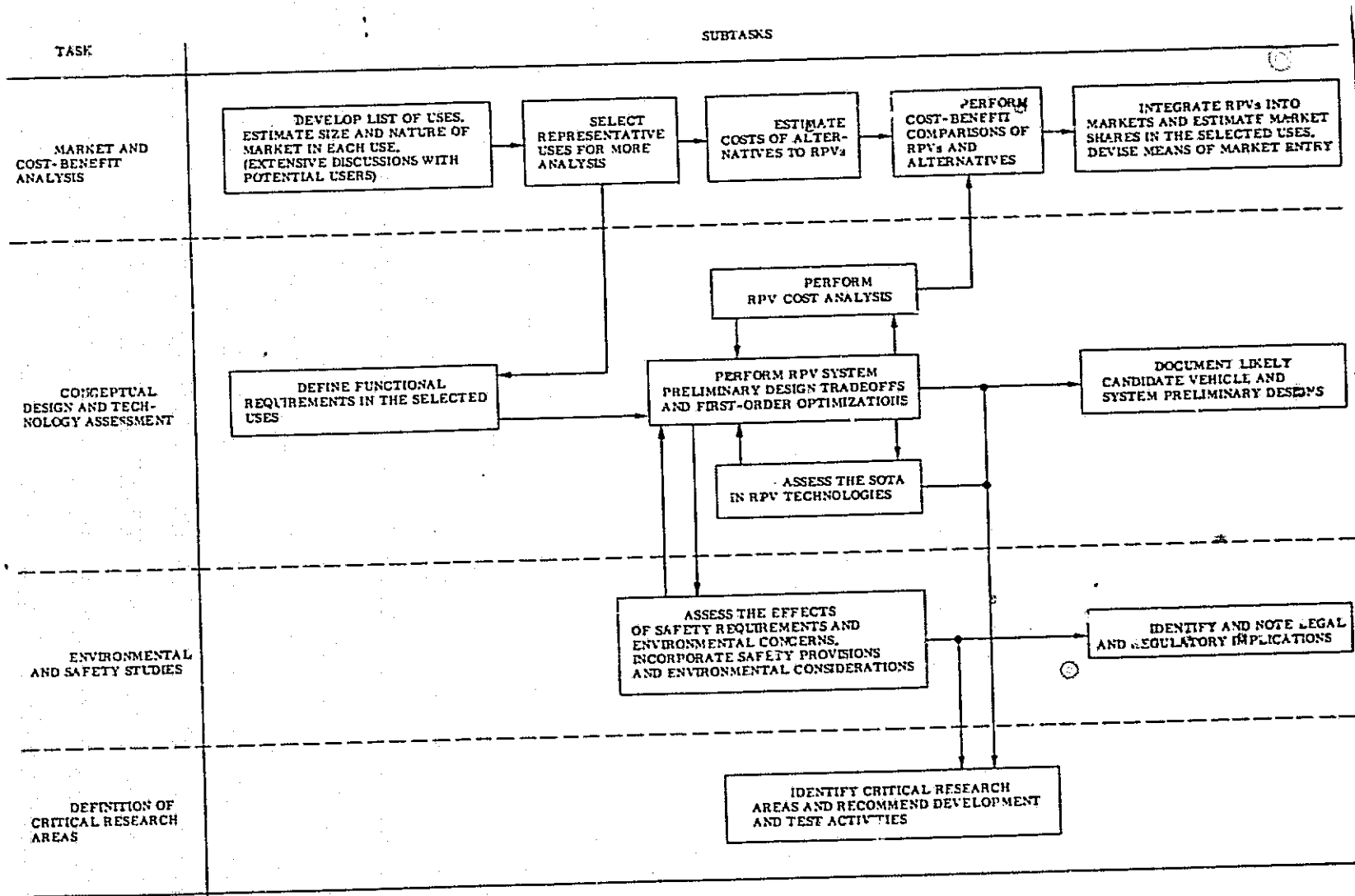


FIGURE 1

Study Flow Diagram

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 assess market size. For those data, it was necessary to turn to government agencies and industry associations that collect nationwide statistics.

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.

Potential uses defined. - 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, there 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.

Selection of representative uses. - 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:

- o Small-area surveillance
 - 1. security of high-value property
 - 2. wildfire mapping

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

TABLE 1.

POTENTIAL USES DEFINED

- o Large-area surveillance
 - 3. wildfire detection
 - 4. fishing-law enforcement
- o Linear patrol
 - 5. highway patrol
 - 6. pipeline patrol
- o Aerial spraying
 - 7. agricultural spraying and crop dusting
- o Atmospheric sampling
 - 8. storm research
 - 9. meteorology

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. 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. Aerial detection of wildfires consists of flying over large areas of forest, brush, or grasslands with infrared sensors to detect and locate small, latent-stage fires such as those started by lightning.

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. 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. Agricultural spraying is done for the control of pests and disease. Extensive research and aerial monitoring of severe storms 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.

Conceptual System Designs

The conceptual designs of RPV systems to satisfy eight of the nine selected uses are based on the functional and performance requirements. 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.

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.

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, speed, altitude, and other requirements were then used to size 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. 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.

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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.

System Conceptual Design Rationale. - 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.

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

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.

Figure 2 illustrates the RPV configurations that were used in the study. They are sized for each use, and their performance capabilities match the requirements that were derived. Tables 2 and 3 summarize the performance and dimension data that apply to the RPVs in each of the eight uses for which systems were devised. No system was devised that could compete satisfactorily with weather balloons in the meteorology mission. Table 4 gives a brief description of the main features of the ground stations that were devised.

Cost comparisons and potential market. - Total system costs are estimated for the RPV systems, as well as for the non-RPV alternatives, in each selected use. The costs are converted to an annualized basis by amortizing the investment costs and adding them to the annual fixed operating costs (insurance, hangar, personnel, and training) and the annual direct operating costs (fuel, oil, periodic inspection, and maintenance). The annualized costs for RPV systems and non-RPV alternatives are compared in Table 5, which also shows the estimated potential market demand for RPV systems in those uses for which RPV systems show a cost advantage. The ranges of potential demand come from two separate market analyses, one considered conservative and one optimistic.

TABLE 5 Cost Comparisons and Potential Demand

	ANNUALIZED COST (\$K)		RPV COMPARISON (%)	POTENTIAL DEMAND FOR RPV SYSTEMS
	RPV	ALTERN.		
SECURITY OF HIGH-VALUE PROPERTY	126	172	-25	1,050 TO 7,500
WILDFIRE MAPPING	69	68	SAME	30
WILDFIRE DETECTION	67	98	-30	50 TO 680
FISHING-LAW ENFORCEMENT	41	11	+115	0
HIGHWAY PATROL	120	186	-35	200 TO 1,500
PIPELINE PATROL	64	28	+130	0
AGRICULTURE	(\$0.35/ACRE)	(\$0.47/ACRE)	-25	400 TO 800
STORM RESEARCH	11	57	-80	20 TO 40
SIMILAR USES	-	-	-	280 TO 300
TOTAL				- 2,000 TO 11,000

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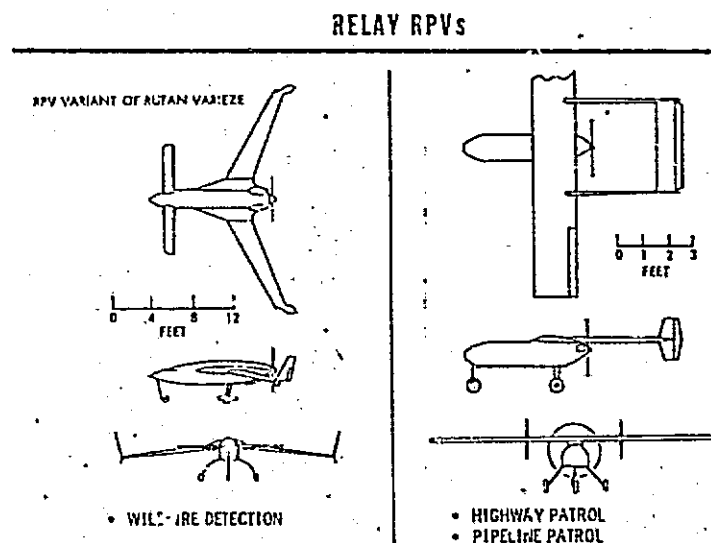
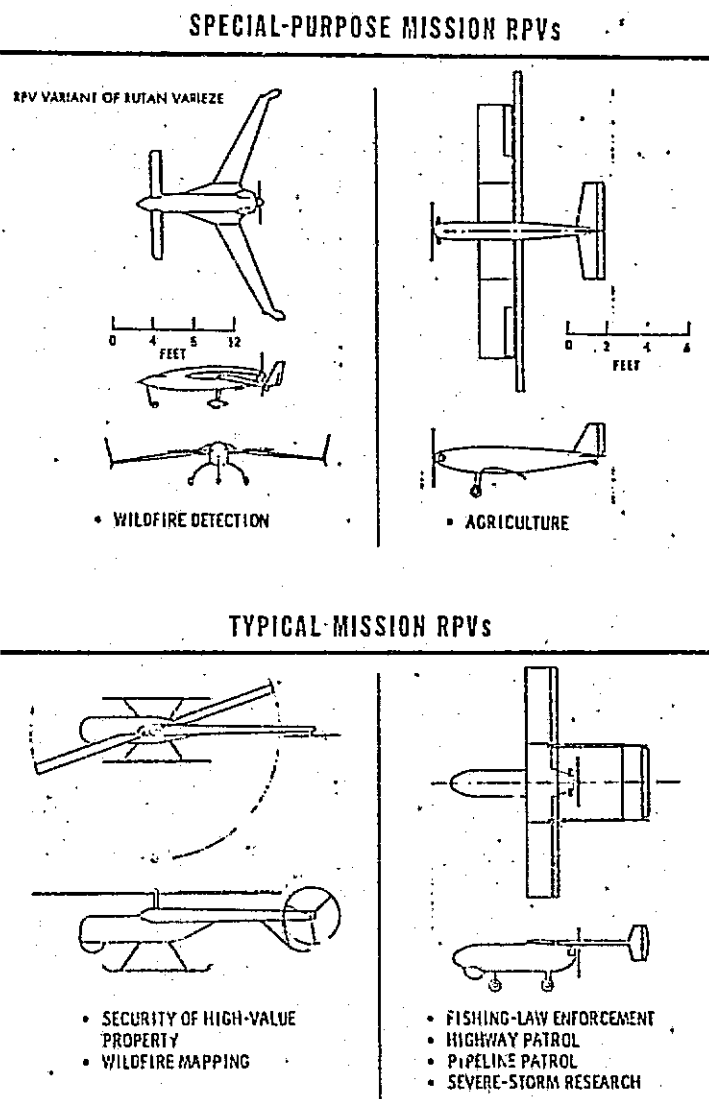


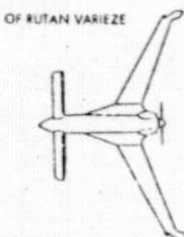
FIGURE 2

RPV CONFIGURATIONS USED

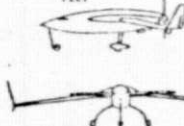
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SPECIAL-PURPOSE MISSION RPVs

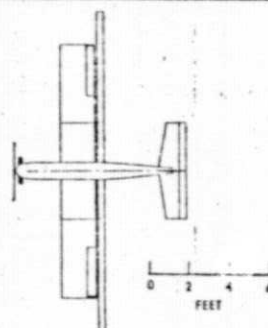
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- WILDFIRE DETECTION

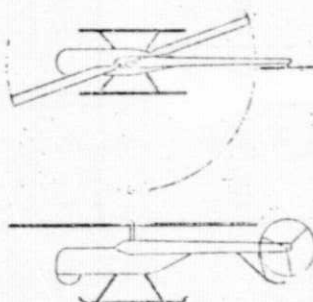


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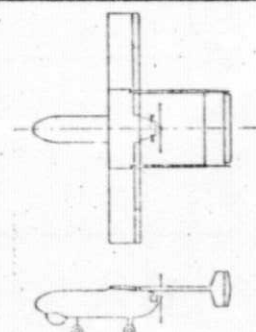


- AGRICULTURE

TYPICAL MISSION RPVs



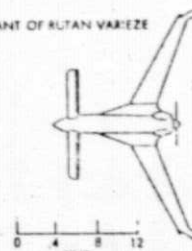
- SECURITY OF HIGH-VALUE PROPERTY
- WILDFIRE MAPPING



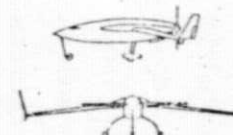
- FISHING-LAW ENFORCEMENT
- HIGHWAY PATROL
- PIPELINE PATROL
- SEVERE-STORM RESEARCH

RELAY RPVs

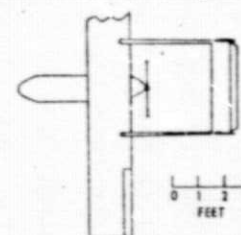
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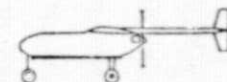
0 4 8 12
FEET



- WILDFIRE DETECTION



0 1 2 3
FEET



- HIGHWAY PATROL
- PIPELINE PATROL

FIGURE 2

RPV CONFIGURATIONS USED

TABLE 2

SUMMARY OF HELICOPTER RPVs

	CRUISE PERFORMANCE						DESCRIPTION						
	PAYLOAD		ENDUR. (HR)	SPEED		CRUISE CEILING		ROTOR DIA.		DISC LOADING		WEIGHT	POWER (BHP)
	(LB)	(KG)		(MPH)(KPH)	(KFT) (KM)	(FT)(M)	(PSF)(KG/M ²)	(LB) (KG)					
SECURITY OF HIGH- VALUE PROPERTY	22	10	1.3	40 65	10 3.0	13.4 4.1	1.17 5.7	165 75	14*				
WILDFIRE MAPPING	22	10	2.0	70 112	16 4.9	13.4 4.1	1.19 5.8	168 76	18				

*18 BHP WITHOUT MUFFLER

TABLE 3

SUMMARY OF FIXED-WING RPVs

	CRUISE PERFORMANCE								DESCRIPTION						
	PAYLOAD		ENDUR. (HR)	SPEED		CEILING		LENGTH		SPAN		WEIGHT		POWER (BHP)	
	(LB)	(KG)		(MPH)	(KPH)	(KFT)	(KM)	(FT)	(M)	(FT)	(M)	(LB)	(KG)		
MISSION RPVs															
• FIRE DETECTION	38	17.3	9.0	200	320	25	7.6	14.3	4.4	22.3	6.8	980	445	100	
• FISHING-LAW ENFORCEMENT	32	14.5	5.5	80	130	16.5	5.0	7	75	2.4	9.0	2.7	146	66	11
• HIGHWAY PATROL	17	9.1	8.5	90	145	9	2.7	7.75	2.4	9.0	2.7	165	75	10	
• PIPELINE PATROL	10	4.5	6.5	80	130	15	4.6	7.75	2.4	9.0	2.7	129	59	10	
• AGRICULTURE	69	31.4	2.2	80	130	—	—	9.3	2.8	16.7	5.1	250	114	25	
• STORM RESEARCH	19	8.6	2.0	90	145	17.5	5.3	7.75	2.4	9.0	2.7	114	52	10	
RELAY RPVs															
• FIRE DETECTION	88	40.0	9.0	150	240	25	7.6	14.3	4.4	22.3	6.8	980	445	100	
• HIGHWAY PATROL	43	19.5	8.5	90	145	16	4.9	8.7	2.7	11.8	3.6	230	105	17	
• PIPELINE PATROL	43	19.5	6.5	80	130	17	5.2	8.7	2.7	11.8	3.6	215	98	17	

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	Shed, 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 4. Ground Control Station Elements

The total estimate of demand includes, in the last entry in Table 5, an estimate for uses which were not examined in detail but which are similar in performance requirements and operating situation to those that were examined.

Note from Table 5 that a typical cost advantage for RPVs is 25-35%, in the uses that show an advantage, and that the total demand is estimated to be about 2000-11 000 systems.

Environmental and safety studies. - 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. Regulatory requirements are examined in both areas, and both are found to present no problems beyond straightforward prudent design.

With regard to safety, there are three areas of concern for RPVs: Positive control, unexpected descent, and collision avoidance. Positive control is amenable to standard design approaches of redundancy, protection of the command link from electromagnetic interference, and provisions for re-establishing a link that is temporarily interrupted. Unplanned descent as a result of a failure requires control of the landing point into the least populated available area, slowing the descent to minimize impact damage to ground objects, and making the final descent path steep to minimize the area of potential damage on the ground. Several design approaches are explored, involving weight penalties from 6-10% for a parachute to 11-14% for stowed-rotor systems or "pitched" wings. Autorotation of helicopter RPVs can be provided, with no weight penalty.

Collision avoidance remains the key technical challenge in the safety area, with the see-and-be-seen philosophy of flight operations in the civil air space. Features for collision avoidance fall into the categories of RPV visibility, precise knowledge of RPV location, air traffic control (ATC), and operation in assigned air space. Lights, paint, etc., can make the RPV as visible as a manned aircraft; the challenge is to make the RPV "see" other aircraft. 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 the proper performance of the mission. In those few uses that do not require precise navigation, collision avoidance may require that it be provided anyway.

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. 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.

ORIGINAL PAGE
OF POOR QUALITY

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, snow-mobile, 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 R/V 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 R/V funds on improving launch and recovery techniques, according to Mr. Thomas Nyman of DDR&E speaking at the National Association for R/Vs 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 R/V to a rotating member and use the R/V'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 military 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 R/Vs. 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 R/V

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.

- o 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.
- o 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.
- o 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.