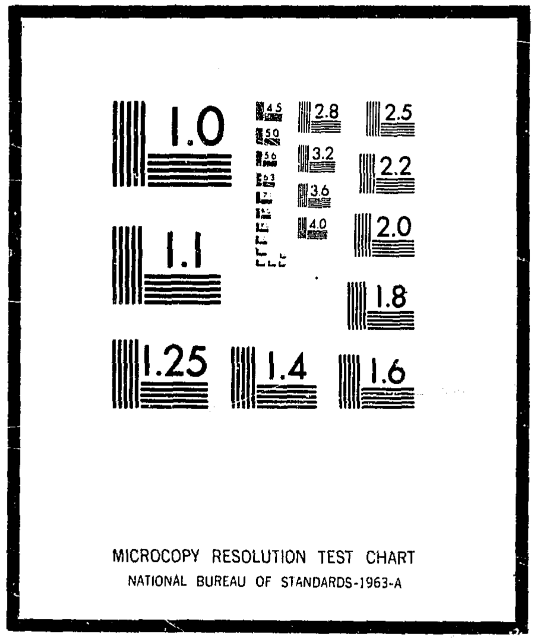

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Revision A

EQUIPMENT SYSTEMS IMPROVEMENT PROGRAM--DEVELOPMENT

EVALUATION OF AERIAL VEHICLES FOR LAW ENFORCEMENT APPLICATION

December 1973

Law Enforcement Development Group
THE AEROSPACE CORPORATION
El Segundo, California

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EQUIPMENT SYSTEMS IMPROVEMENT PROGRAM -- DEVELOPMENT

EVALUATION OF AERIAL VEHICLES FOR LAW ENFORCEMENT APPLICATION

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ABSTRACT

The performance, cost, and safety of various aircraft which are applicable to law enforcement operations such as surveillance, patrol, search-rescue, and traffic control are described and compared in this report. Unique vehicles such as blimps and autogiros are also included in the study and discussed in detail in Appendix A. The report reviews police mission requirements and then proceeds to evaluate various candidate vehicles in light of these requirements.

Helicopters have been the mainstay in police air operations and the implication is that their hovering and vertical takeoff-landing (VTOL) capability is a necessity in most applications. However, the projects cited and reviewed in this report do not fully support this conclusion since most of the police air operations can generally be performed by airplane as well as helicopters. The main qualitative argument favoring helicopters is relative safety in an emergency or during poor weather. Federal Aviation Administration (FAA) safety regulations for low-altitude airplane flights and flights below cloud ceilings limit the police airplanes. Helicopters are not similarly constrained. Nevertheless, the studies reported here indicate that airplanes malfunction only a third as often per flying hour as do helicopters. Unfortunately no hard facts exist relating to the safety of various aircraft under typical police conditions (60 to 80 mph at 800 to 1200 feet altitudes), and additional study in this area is recommended.

It is shown that the principal cost of aerial operations is personnel; cost reduction studies should consider this important factor. Estimated 1973 operating costs range from $95/hour for a Bell helicopter jet Ranger, and $74/hour for a smaller piston-engine helicopter, to $47/hour for a Cessna 172 STOL airplane. Comparable cost for a patrol car is $36/hour. One of the more promising low-cost, low-fuel-consumption aerial vehicles for future law enforcement use is the remotely piloted blimp (RPB). This is a miniature low flying lighter-than-air (LTA) vehicle equipped with color television zoom camera, searchlight, autopilot, etc. One ground-based police officer-pilot could safely operate several RPBs in 200 to 400-foot altitude patrol cruises or "park" them anywhere at will.

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PREFACE

Aircraft are being used by a number of police agencies for a wide variety of functions. The introduction of the helicopter to urban police departments has resulted in the recent rapid expansion in the size of the total law-enforcement fleet. Through 1971 the fleet had attained the size of 163 aircraft; by the end of 1972 it had grown to 234.

This growing aerial fleet is being composed primarily, if not exclusively, of helicopters. Obviously, the relatively high cost of helicopters has not outweighed the concern that buying anything less than a helicopter's capabilities might represent risking a failure to satisfy mission requirements.

To appreciate these requirements, law enforcement missions should be broken down into elements that can, in turn, be categorized by frequency and importance. The "importance" or weight of each element, and the efficiency with which each aircraft is able to perform each element, when expressed numerically, is essential to overall measurements of that aircraft's effectiveness.

Unfortunately, mission elements expressed as numerical factors are not available and may not become available within the next few years. Nevertheless, a guide is needed to assist law enforcement administrators and operational personnel in their selection of available aerial vehicles and equipment most appropriate for their particular needs.

One purpose of this study was to develop a framework within which aerial vehicles could be evaluated as tools for accomplishing law enforcement missions or mission elements. A secondary objective was to assist in ranking various mission elements in accordance with their importance to the overall mission so that broadest possible acceptance and usefulness can be achieved.

The use of the report varies with the intent and background of the user:

- The novice will find a checklist of questions to ask and the terminology by which he can communicate with technical representatives from industry.
- Municipal accounting groups will find a checklist of cost items making up the overall cost of an aerial operation along with typical levels at which these costs run.
- Operating groups will find definitions of the characteristics required for an aircraft to attain the various mission element capabilities.

This report, in and of itself, makes no attempt to resolve the question of mission-element importance. Rather, it accepts the existence of present and proposed aerial roles and missions and evaluates the relative acceptability of various vehicles considered for these roles and missions. The

report does provide an indication of the comparative cost for carrying out a mission element with one aerial vehicle versus another.

Even with this modest goal, much of this report is of an interim nature. It will have served its purpose if it establishes a broader understanding of the problems and a nomenclature that will allow the law enforcement aircraft builders and user groups to communicate with each other. When more universal agreement is achieved on the operational requirements for mission elements, and when a ranking of importance of mission elements is finally determined, an extension of this study can present more definitive alternatives to the present use of helicopters.

The Aerospace Corporation wishes to acknowledge the assistance of the many law enforcement and general aviation industry representatives and other individuals listed in Chapter IX, who directly and indirectly contributed to the preparation of this report. Special thanks are due to Captain James Beall, Commander of the Los Angeles Police Department Helicopter Section and former president of the Airborne Law Enforcement Association for his helpful comments and criticism.

This study was conducted by members of the Aerospace staff during 1972 and 1973. The principal investigator was Mr. John B. Nichols.

SUMMARY

Scope. Use of aircraft in police operations has increased significantly. Both helicopters and airplanes are employed in patrol, surveillance, search and rescue, traffic control, and as airborne command posts. The most significant advantage is shortened response time and extended field of view. Since today's law enforcement aerial fleet is composed primarily of helicopters, high costs are usually attributed to use of such aircraft. In actuality, however, the greatest cost is personnel.

The present study comprises a review of overall police missions and related vehicle requirements, evaluation of various candidate vehicles in light of these requirements, and an analysis of principal costs. Consideration was also given to the matter of safety and auxiliary equipment requirements. This report is organized into these general categories, comprising five relatively independent chapters, so that individual topics may be pursued separately.

Since law enforcement aircraft selection is usually made at the local level, the principal choice has been aircraft for which comparitive police performance data are available. This, again, is the helicopter, partly because reasonably accurate data relating to other vehicle options are lacking. Nevertheless, other promising aircraft types are available to police agencies, and this report provides data to assist in their evaluations.

Methodology. This study was originally aimed at evaluating the autogiro as an alternative to the helicopter. Evaluation of blimps and fixed-wing aircraft was added later, and the addition prompted the study approach to be broadened from a detailed investigation of one specific aircraft to a parametric evaluation of generalized aircraft types. A novel computer performance analysis methodology was developed to ensure objective treatment for all types of aircraft, regardless of the state of development or off-the-shelf availability. Unfortunately, time did not permit detailed analysis of the Tempe, Arizona Police Department Blimp Study (by Goodyear) or the miniature Remotely Piloted Blimp (RPB) proposed by the Development Sciences, Inc. (DSI)/Goodyear Aircraft Co. team.

Findings. A noticeable controversy has existed regarding the relative merits of airplanes and helicopters in police applications. Federal Aviation Administration regulations enter into the controversy in a significant way. Current regulations stipulate that airplanes must maintain an altitude of 1,000 feet or more above ground over congested areas. This limitation is apparently based solely on safety considerations, and helicopters are not included. Apparently no adequate data exist to indicate that airplanes are indeed less safe than helicopters at altitudes below 1,000 feet. In fact, this study indicates that the probability of a helicopter malfunction is about three times as great as that of an airplane. On the other hand, the helicopter is safer to land after a serious malfunction. Another

pertinent FAA regulation affecting airplane operations relates to weather. In essence, this regulation prohibits airplane flights over congested areas when cloud ceilings are less than 1,500 feet above the surface. In reality, however, this is a very safe situation, especially for instrument-rated pilots. In many areas this regulation can seriously affect the number of hours a police airplane can fly. Here again, the regulations do not apply to helicopter operations.

It is clear that the FAA weather and minimum-altitude regulations could have a strong bearing on the choice of helicopter or airplane for police applications. While these regulations are founded primarily on safety considerations, there appears to be no tangible evidence clearly indicating that helicopters are, indeed, safer than airplanes under actual police operating conditions. One must also bear in mind the important fact that the majority of police operations do not require flight much below 600 to 800 feet above the surface.

A factor of great importance in the evaluation of aerial operations is personnel costs, which are usually more significant than aerial vehicle costs. Personnel costs, in fact, can comprise over 75% of the total cost of maintaining an airborne police capability. Consequently, one would expect that a significant reduction in personnel might justify an increase in vehicle and equipment cost, if such a tradeoff were possible. Vehicle cost-effectiveness analyses are complex and depend among other factors on urban geometry, weather, vehicle type, and missions. Costs, by themselves, are not too difficult to determine, and some general figures have been summarized below. Assessing the effectiveness of various vehicles is very difficult, however, and more often than not this assessment hinges on subjective factors. The following figures should, therefore, be considered only a part of the cost-effectiveness question:

Vehicle Type	Approximate Cost Per Hour of Service (2 Men)
Large mixed-helicopter fleet	$95
Small helicopter fleet	$74
Small airplane fleet	$47
Patrol car fleet	$36

Conclusions. The following paragraphs summarize the major conclusions derived from the study.

The rate at which aircraft are being added to the country's law enforcement fleet is higher than ever before; however, the total number of aircraft added per year is still small. There is no immediate risk that a nonoptimum choice of aircraft type will result in a significant economic drain; the risk, if any, can be eliminated by the purchase of popular off-the-shelf aerial vehicles with ready resale market. The major cost of maintaining an aerial capability is not associated with the vehicle but with the cost of personnel to man the system.

A large number of police missions can be accomplished by aerial vehicles of less complexity and cost than the helicopter. For larger fleets it would appear that a mix between helicopters and fixed-wing airplanes is more cost-effective. Helicopters appear more appropriate in large, dense, city urban areas; while airplanes appear more appropriate in less dense, extended areas (county and state), or in small communities. Fixed-wing vehicles would be more attractive if they were allowed to fly lower than the 1000-foot minimum and, also, under lower cloud minimums than specified by the FAA. This problem must be evaluated more carefully in a follow-on study. Other types of aircraft -- autogiros, blimps, remotely piloted blimps, etc. -- have particular advantages that would make them useful for police work, if they were available. However, without more extensive cost-effectiveness studies, one may not be justified in initiating expensive research and development work on these vehicles.

Recommendations. Based on the findings of the study, the following are offered:

The choice of aerial vehicles for law enforcement applications should be made on the basis of careful field evaluation programs and under a consistent set of well-defined measures of effectiveness. Representative candidates of all aircraft types should be evaluated as they become available. Although no autogiro of a suitable size is in production, at least two certified machines suitable for field evaluation could be obtained.

Law Enforcement Assistance Administration should establish a centralized aviation bureau the purpose of which would be to collect, organize, and analyze data obtained from all the law enforcement agencies employing aircraft.

Law Enforcement Assistance Administration should commission studies aimed at more detailed examination and analysis of the safety and low-altitude question. These future studies should include careful examination of malfunction probabilities and most-probable pilot responses (e.g., pilot errors). In addition, careful account should be taken of topography and weather statistics in representative metropolitan areas. The studies should be coordinated with, and have the assistance of the FAA and knowledgeable aerial police agencies. If appropriate, the results of this future study should be submitted as evidence to support proposed FAA regulation changes for the benefit of law enforcement vehicles.

Several preliminary design studies of specialized police aerial vehicles should be supported by Law Enforcement Assistance Administration to generate standards against which to evaluate proposed vehicles. One such vehicle offering many potential benefits is the remotely piloted blimp (RPB). This current report has covered the basic types, i.e., airplanes, helicopters, autogiros, lighter-than-air craft (LTAs and hybrids), and the critical parameters of these types have been established and examined extensively.

CHAPTER I. INTRODUCTION

A. Study Objective

The use of aircraft in police operations has increased significantly in the past few years. Both helicopters and airplanes have been employed in patrol, surveillance, search and rescue, traffic control, and as airborne command posts. Probably the most significant single advantage of aerial vehicles in law enforcement is the shortened response time (Reference 1-2). Another obvious advantage is the unique and relatively unrestricted and extended field-of-view the aerial vehicle can provide.

Aerial vehicles have introduced police departments to an entirely new level of surveillance capability. They have also been introduced to an entirely new level of vehicle costs - both initial and operational. Since today's law enforcement aerial fleet is composed primarily of helicopters, high costs are usually attributed to use of such aircraft. In actuality, however, the greatest cost is personnel, and this factor is relatively independent of the vehicle type employed, with possible exception of RPBs.

The primary objective of this evaluation was to compare existing aerial vehicles in their capabilities to perform current and projected missions of airborne law enforcement. Vehicles with payloads between 500 and 5,000 pounds were considered candidates. Even though no suitable autogiros or lighter-than-air (LTA) craft are currently in production, they exhibited certain desirable qualities and were, therefore, included in the study.

This study was originally aimed at evaluating use of the autogiro as an alternative to the helicopter, but other vehicle types were subsequently added. The study itself comprised a review of overall police missions and their related vehicle requirements, evaluation of various candidate vehicles in light of these requirements, and an analysis of principal costs. Some consideration was also given to the matter of safety and, to a lesser extent, auxiliary equipment requirements (e.g., radios, navigation equipment, spotlights, etc.). These general categories comprise five individual chapters, and each chapter is reasonably independent of the others so that individual topics may be pursued separately.

The selection of most law enforcement aircraft is usually made at the local level. It is significant that even though there is wide variation in geographic, climatic, political, and demographic factors throughout the United States, the principal choice has been the helicopter. This situation probably exists in part because reasonably accurate comparitive material relating to other vehicle options is lacking. On the other hand, objective evaluation of vehicle alternatives would be expensive and time consuming and would require specialized personnel, not usually available at the local level. Nevertheless, other aircraft types are often offered to police agencies and, since these vehicles appear to have promising features, they should be evaluated. It is hoped that this report will contribute to this ev-

This study also provides a response to the question of whether a more cost-effective aerial capability can be attained and maintained with aerial vehicles other than the helicopter. Still another objective is to assist police agencies in ranking various mission elements in accordance with their importance to the overall mission. It is evident that consistent and pertinent numerical measurements of effectiveness are needed in order to evaluate operational strategies and tactics and to select specific pieces of equipment.

The use of the report varies with the intent and background of the user:

- For the novice it provides a checklist of questions to ask and the terminology to use when communicating with technical industry representatives.
- For the operating group it defines the characteristics required to attain the various mission element capabilities.
- For the city manager it explains operational, financial and safety aspects of police aerial operations.

Finding the answer for each use involves different steps; and these steps are presented in rational order within the appropriate section. Essential data are also tabulated or plotted as required. Background data are supplied in a separate technical appendix. Additional data, if not available in the Appendices, will be provided by The Aerospace Corporation upon request.

As a primer, therefore, it is intended that the main body of the report should be self sufficient and independent of the need for technical explanatory material.

B. Background

A vehicle frequently offered as an alternative to the helicopter is the autogiro. This suggestion was apparently made frequently enough to prompt the Law Enforcement Assistance Administration (LEAA) to authorize the study reported herein. Evaluation of blimps and fixed-wing aircraft were later added to this study, and the addition prompted the study approach to be broadened from a detailed investigation of one specific aircraft to a parametric evaluation of generalized aircraft types. This necessitated development of a novel performance analysis methodology to ensure objective treatment of all types of aircraft, regardless of the state of development or off-the-shelf availability. A computer model and program was developed to assist in this endeavor. Consequently, by using the resulting computer model, The Aerospace Corporation or the Law Enforcement Assistance Administration can in the future provide an aircraft performance evaluation service to any local law enforcement agency involved in aircraft procurement studies.

A noticeable controversy has existed regarding the relative merits of airplanes and helicopters in police applications. Arguments usually center on questions of the capability to perform designated missions, costs, and safety. Noise, relative comfort, and passenger fatigue have also

entered the argument, though in a more subjective form. A preliminary police mission analysis conducted by other organizations indicates little need for the helicopter's hovering and vertical takeoff and landing (VTOL) capability. It would appear that specially equipped airplanes designed for short-field takeoff and landing (STOL) and slow flight (35 mph) would consequently offer a natural alternative to a helicopter.

Federal Aviation Administration regulations enter into the helicopter vs airplane controversy in a significant way. Current regulations stipulate that airplanes must maintain an altitude of 1,000 feet or more above the ground over congested areas. The only exceptions occur during takeoff and landing. This limitation is apparently based solely on safety considerations, and helicopters are not included. Unfortunately there does not appear to be adequate data indicating that airplanes are indeed less safe than helicopters below 1,000-foot altitudes. Chapter VI of this report, in fact, indicates that the probability of a helicopter malfunction is about three times as great as that of an airplane. On the other hand, the helicopter would probably be safer to land after a serious malfunction. Here again, however, the matter is not clear, since aircraft have a greater gliding range and, hence, a greater choice of landing spots. Emergency landings at night might leave both types of aircraft in an equal dilemma.

Another pertinent FAA regulation which has an effect on airplane operations relates to weather. Essentially all police flight operations are conducted under visual flight regulations (VFR), and these regulations require the pilot of a fixed-wing aircraft to stay more than 500 feet below, 2,000 feet laterally of and 1,000 feet above the clouds. In essence, this regulation prohibits airplane flights over congested areas when cloud ceilings are less than 1,500 feet above the surface. In reality, instrument-rated pilots operate in such situations very safely, but the regulation can significantly affect the number of hours a police airplane can fly in many areas. Furthermore, there are visibility restrictions that apply to VFR airplane operations during takeoff and landing. Here again, these regulations do not apply to helicopter operations.

It is clear that the FAA weather and minimum-altitude regulations could have a strong bearing on the choice of helicopter or airplane for police applications. While these regulations are founded primarily on safety considerations, there appears to be no tangible evidence clearly indicating that helicopters are, indeed, safer than airplanes under actual police operating conditions. One must also bear in mind the important fact that the majority of police operations do not require flight much below 600 to 800 feet above the surface.

Unfortunately, time did not permit a more careful Aerospace Corporation evaluation of the impact of these FAA regulations on the question of police aerial vehicle selection. It is recommended that such questions be treated in a follow-on study.

A factor of great importance in the evaluation of aerial operations is the matter of personnel costs, which are usually more significant than aerial

vehicle costs. Personnel costs can comprise over 75% of the total cost of maintaining an aerial police capability. Consequently, one would expect that a significant reduction in personnel might justify an increase in vehicle and equipment cost, if such a tradeoff were possible. This fact also suggests consideration of unmanned vehicles; although, unfortunately, no measures of effectiveness are available against which the cost effectiveness of such unmanned vehicles (e.g. RPB) might be tested in law enforcement activities.

Vehicle cost-effectiveness analyses are complex and depend among other factors on urban geometry, weather, vehicle type, and missions. Costs, by themselves, are not too difficult to determine, and some general figures have been summarized in Table 1-1. Assessing the effectiveness of various vehicles is very difficult, however, and more often than not this assessment hinges on subjective factors. For example, the figures developed in Chapter V and summarized in Table 1-1 indicate that the cost per hour of service for a two-man patrol car is approximately $36 (Reference 3-8), while a small two-man helicopter would cost $75 per hour. It is obvious, however, that the helicopter can respond more rapidly, cover a greater area, and offer a unique field of view compared to the patrol car. The following figures should, therefore, be considered only a part of the cost-effectiveness question:

Table 1-1. Cost Summary

Vehicle Type	Cost Per Hour of Service (2 Men)
Large mixed-helicopter fleet, 3 and 5 passenger, 24-hour/day	$95
Small helicopter fleet 3 passenger, 16-hour/day	$74
Small airplane fleet, 3 to 4 passenger, 16-hour/day	$47
Patrol car fleet 24-hour/day	$36

These factors, as well as others which came to light during the course of this study, represent the background against which the study was undertaken. The end result of this study disclosed several areas of promising potential quite different from the original expectations. Specifically, the performance analysis work, in the section dealing with LTA craft, identified a family of remotely piloted blimps (RPBs) as future candidates for police aerial vehicles. This synthesis was based on their endurance, speed capability competitive with helicopters, and potentially low operating costs. The principle advantage of the RPB is the fact that several (3 to 4) RPBs can be operated by a single ground-based pilot/observer thus significantly reducing operating cost. Fuel consumption is very low and potential safety is high. The RPB is in fact a mobile remote TV monitor.

The result of the studies reported herein indicate that, in the immediate future, either STOL type airplanes or helicopters now on the market are capable of performing the majority of police missions under generally favorable weather conditions. Federal Aviation Administration regulations, however, give more operational freedom to helicopters and, in some areas of the country, this latitude could be very significant. Additional studies are necessary to reveal more clearly whether helicopters are indeed more capable and safer to operate than airplanes at altitudes and weather conditions typical in police operations. Airplane engines and airframes have historically proven extremely reliable, and it may result that airplanes are relatively safe at altitudes above 500 feet. If this is in fact the case, relaxation of FAA regulations for police vehicles may be possible. The matter requires further study.

In the more distant future, autogiros, blimps, hybrids, or special remotely piloted blimp (RPB) may offer cost-effective alternatives to manned vehicles. Remotely piloted vehicles may become feasible because of recent advancement in airborne electronics, optics, television, and data transmission equipment. Unmanned vehicles might perform such police functions as traffic control, patrol of industrial and vacant areas, disaster warning, and fire detection.

C. Conclusions

The following paragraphs summarize the major conclusions derived from the study.

1. Trend. The rate at which aircraft (primarily helicopters) are being added to the country's law enforcement fleet is higher than ever before; however, the total number of aircraft added per year is still small. For this reason there is no immediate risk that a nonoptimum choice of aircraft type will result in a significant economic drain. In fact, the risk, if any, can be eliminated by the purchase of popular off-the-shelf aerial vehicles with ready resale market.

The risk becomes progressively greater as the fleet expands, more specialized mission capability is added to the vehicle and its equipment, and crews become trained in the use of this equipment. It is therefore important that a solid basis for mission planning and equipment purchasing be established now, during the low-risk period, in order to have the maximum effectiveness in reducing future risk.

2. Costs. The major cost of maintaining an aerial capability is not associated with the vehicle itself but with the cost of personnel to man the system.

Vehicle costs, both initial and operational, are substantial. Reductions are well worth pursuing. It is quite possible that overall cost savings may result from the introduction of more sophisticated (and expensive) hardware rather than by the introduction of more austere equipment, if this sophisticated equipment will allow a significant reduction in personnel costs. The RPB is one possible solution.

3. Vehicles. A large number of police missions can be accomplished by aerial vehicles of less complexity and cost than the helicopter. For larger fleets in particular, it would appear that a mix between helicopters and lower-cost, fixed-wing airplanes would represent a more cost-effective operation than a fleet composed exclusively of helicopters. Helicopters appear more appropriate in large, dense, city urban areas; while airplanes appear more appropriate in less dense, extended areas (county and state), or in small communities.

4. FAA limitations. Fixed-wing vehicles would be more attractive if they were allowed to fly lower than the 1,000-foot minimum and also under lower cloud minimums. This problem must be evaluated more carefully in a follow-on study.

5. Future vehicles. Other types of aircraft, autogiros, blimps, hybrids, and remotely piloted blimps have particular advantages that would make them useful for police work, if they were available. However, without more cost-effectiveness studies, one may not be justified in initiating research and development work with these vehicles so long as there is an adequate selection of off-the-shelf helicopters and fixed-wing aircraft.

6. Cost reduction. Since personnel represent a large portion of the cost for maintaining an aerial operation, systems which can operate with a small staff are obviously attractive. Remotely operated vehicles offer a potential for cost savings by reducing personnel requirements. Effectiveness

and safety considerations require further study before the extent of such savings can be assessed. A miniature version of the lighter-than-air craft, as defined by this study, offers promise in solving the safety problem.

7. Criteria. Without an overall system measure of effectiveness, data generated on aerial vehicles (or any other topic) cannot be related on a rational basis to other elements of the total system. Therefore, the choice of one vehicle over another involves a number of nonquantified factors, and as long as this situation exists it will be difficult to avoid a certain dependence on subjective inputs.

D. Recommendations

Based on the findings of the study, the following recommendations are offered:

1. Vehicle selection. The choice of aerial vehicles for law enforcement applications should be made on the basis of careful but deliberate field evaluation programs established under a consistent set of pertinent, well-defined measures of effectiveness that include results as well as costs. Representative candidates of all aircraft types should be evaluated as they become available. For example:

- Remotely piloted blimps (discussed on page 52) promise substantial fuel and cost savings as well as safety advantages and should be carefully considered.

- Several new fixed-wing airplane designs offer features of particular advantage to police applications because of their performance and/or configuration. These, too, warrant consideration, provided they are certified by their builders (or that such certification would not be too costly).

2. Data bureau. Law Enforcement Assistance Administration should establish a centralized aviation bureau, the purpose of which would be to collect, organize, and analyze data obtained from all the law enforcement agencies employing aircraft. The goal of this operation would be to establish accurate statistical records regarding costs of aerial operations and to provide a centralized clearing house of information regarding aircraft and equipment recommendations, deficiencies, corrective actions, and optimum usage techniques. Such a central information bureau would prove invaluable in increasing the effectiveness of individual agencies, because they would benefit from the cumulative experience of all other groups. It would also be useful to agencies that are instituting their first aerial operations by providing them with a basis for formulating a realistic operational and financial plan.

3. Low altitude and safety. Law Enforcement Assistance Administration should commission studies aimed at more detailed examination and analysis of the safety and low-altitude question. These future studies should include careful examination of malfunction probabilities and most probable

pilot responses (e.g., pilot errors). They should also look at small, inexpensive, Jet Assisted Take-Off (JATO) auxiliary rocket motors that fire for about a minute and lift the airplane 500 feet or more. The present 1,000-foot rule applies to all fixed-wing aircraft equally, whether they have a gliding ratio of 3:1 or 30:1. It would seem, however, that this rule should take into account such variations between aircraft as it does for the differences between fixed-wing and rotary wing aircraft. If such permission were granted, a whole new array of possibilities would be open for consideration to law enforcement agencies. In addition, careful account should be taken of topography and weather statistics in representative metropolitan areas. The studies should be coordinated with, and have the assistance of, the FAA and knowledgeable aerial police organizations. Results of the future study could be submitted as evidence to support proposed changes in FAA regulation for the benefit of law enforcement vehicles.

4. Future designs. Preliminary design studies of specialized police aerial vehicles such as remotely piloted blimps should be supported by Law Enforcement Assistance Administration. This report has covered the basic current types; i.e., airplanes, helicopters, autogiros, lighter-than-air craft (LTAs and hybrids), and the critical parameters of these types have been established and examined extensively.

5. Noise. Aircraft noise is one of the most annoying aspects of airborne law enforcement operations so far as the average citizen is

concerned. Consequently, whenever possible, police agencies design their flight operations to minimize noise and incorporate noise-reduction devices. Unfortunately there are no completely adequate noise-muffling devices, and the present alternative is to fly at higher altitude.

Helicopters generate the most noise, followed by airplanes, then (probably) manned blimps of the type being studied in Tempe, Arizona. The least noise is generated by small remotely piloted blimps.

CHAPTER II. MISSIONS AND REQUIREMENTS

A. Mission Elements

Complex and varied as aerial missions appear from an operational point of view, they generally resolve into a few basic mission elements, with occasional variations as to the order in which they are carried out. For example, a typical surveillance mission may be interrupted by the need to chase a speeder. Subsequent to apprehension of the speeder (by aerial direction of a patrol car to make the interception), the aircraft returns to its assigned surveillance area to complete its shift. In aircraft terminology, this common police mission would involve the following elements:

- Takeoff with required payload (crew and equipment)
- Climb to cruise altitude
- Cruise to surveillance area
- Decelerate to loiter speed for surveillance operation
- Maintain loiter speed during surveillance or patrol
- Attain top speed (to pursue speeder)
- Cruise back to surveillance area
- Maintain loiter speed during surveillance
- Cruise back to home base
- Let down at home base
- Land at home base.

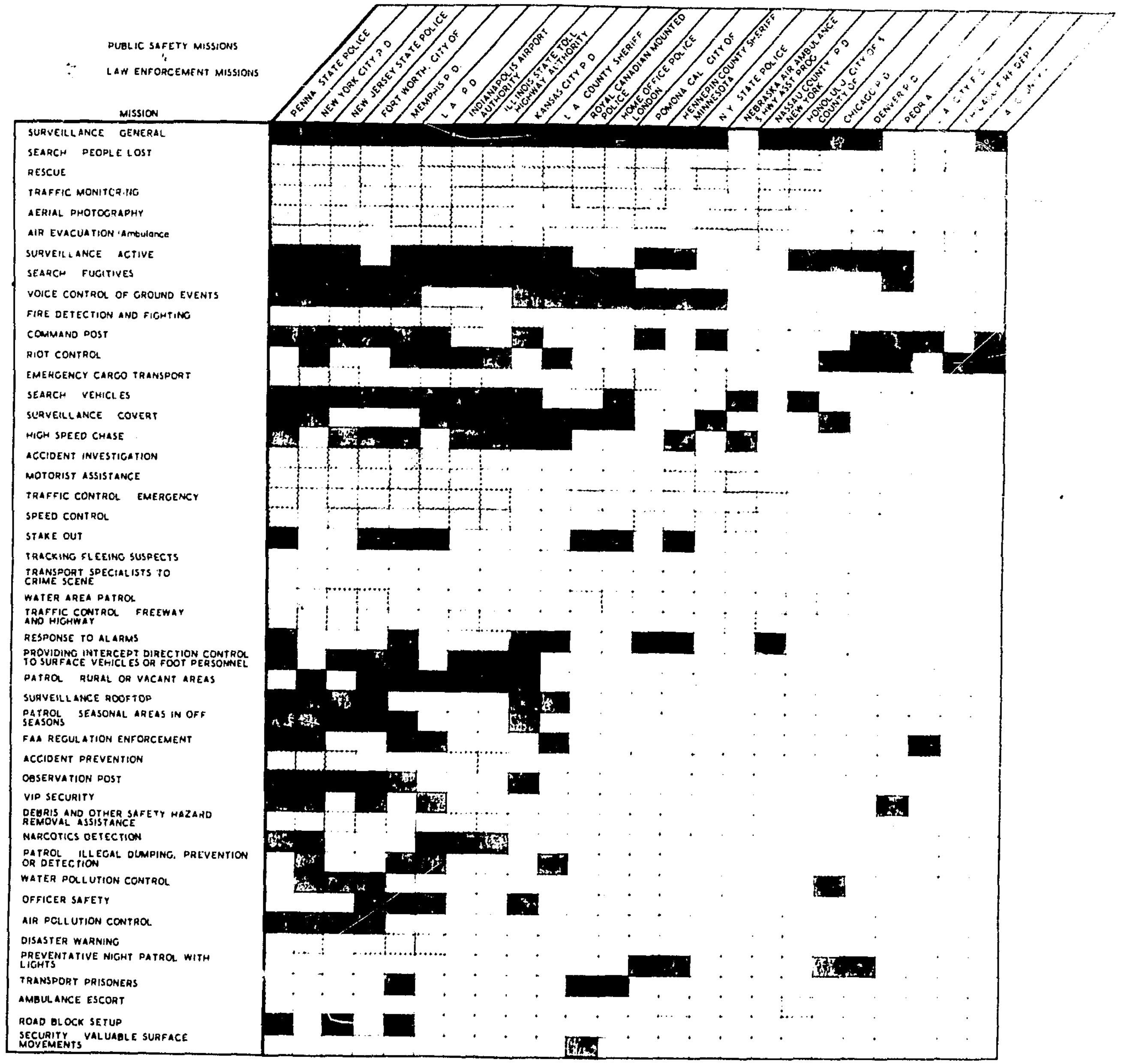
B. The Present Situation

Probably the most dramatic impact aerial patrol has had on law enforcement is to reduce response times while providing support to traditional ground units. From these aerial command posts, ground units previously at a disadvantage in locating fleeing suspects, stolen vehicles, or lost people, can now be guided either directly to the object of the search or to a more promising search area.

Not only has air mobility re uced crime potential by reducing the time required to conduct rooftop surveillance over suspected residential, recreational, and commercial areas, but it has enabled aerial operations to save more lives and property as more and more missions of ever-broadening variety have been incorporated.

To illustrate, Table 2-1 data were extracted from a similar table in the NILECJ report, "Utilization of Helicopters for Police Air Mobility" (Ref. 1-1) and reformatted to enable the reader to identify those agencies whose operations meet requirements comparable in scope and complexity to his own. The 46 missions are listed in descending order of prevalence (top to bottom) among the 24 user agencies, and the agencies are listed in descending order (left to right) according to the variety of missions they fly. Law enforcement missions are designated by the solid blocks; public safety missions are designated by the cross-hatched blocks. "Surveillance - General" and "Search - Lost People", for example, are performed by 80 percent of the agencies listed; whereas, only 8 percent included a mission called

Table 2-1. Law Enforcement and Related Missions Performed by Helicopters for Selected Agencies



"Security - Valuable Surface Movements" in their repertory. Furthermore, "Penna. State Police" perform 32 of the 46 missions listed, while the last three agencies listed perform only 5 each.

Several evaluation programs have been or are being carried out to determine the effectiveness of fixed-wing aircraft in police operations previously assigned to helicopters. The Dade County (Florida) Short Takeoff and Landing (STOL) program employing a Helio Courier STOL aircraft has been reported in considerable detail in Ref. 1-2. The Santa Monica (California) Police Department is presently evaluating a Cessna-172 with the Mid-America STOL conversion kit. Both of these programs have shown the fixed-wing aircraft to be effective in the majority of police aerial missions, particularly surveillance. In the Dade County tests, the cost effectiveness of the relatively expensive Helio Courier vs the helicopter was not established. However, Santa Monica's converted Cessna-172 is a lower-cost machine and its present cost compared to the helicopter's cost appears to offer significant cost advantages.

It is evident, therefore, that work has been and is being done to evaluate aircraft other than helicopters for police operations. The uncorrelated nature of these investigations has produced an interesting result. Practical applications have often preceded or supplanted theoretical systematic considerations which could lead to new vehicle specifications. There are several reasons for this:

- First, typical police budgets do not provide for extensive research required to derive optimized solutions.
- Second, even if research had been funded, there is little likelihood that subsequent funding for developing the optimized machine would have become available.
- Third, off-the-shelf hardware appears to have done the job in the majority of police aerial missions scheduled to date.
- Fourth, police missions have been designed to suit available capability.

C. Dade County Results

The Dade County report (Ref. 1-2a) in conjunction with the CAL report (Ref. 1-2b) represent the first comprehensive and objective comparison made between aircraft types in a police operation. In the past, when law enforcement agencies were becoming convinced that airborne surveillance was effective, the helicopter was the natural choice of individuals and organizations who were not only unfamiliar with aircraft but, also, unfamiliar with the exact tasks that could be performed. The helicopter, of course, was the one existing vehicle capable of operating from facilities on small city lots. Furthermore, helicopters provided both the vertical take-off and landing (VTOL) and hovering capabilities that were originally considered necessary to respond rapidly to the increasing number of mission demands, especially when a police department had only one aircraft. The LEAA grant, therefore, made it possible for Dade County to acquire and evaluate data collected during police operations and to compare the efficiency of the aircraft types.

Although an accident reduced the total test time available, and although the evaluation did not prove to be conclusive, the results are discussed in this section to give the reader an indication of the factors involved in present and future planning exercises.

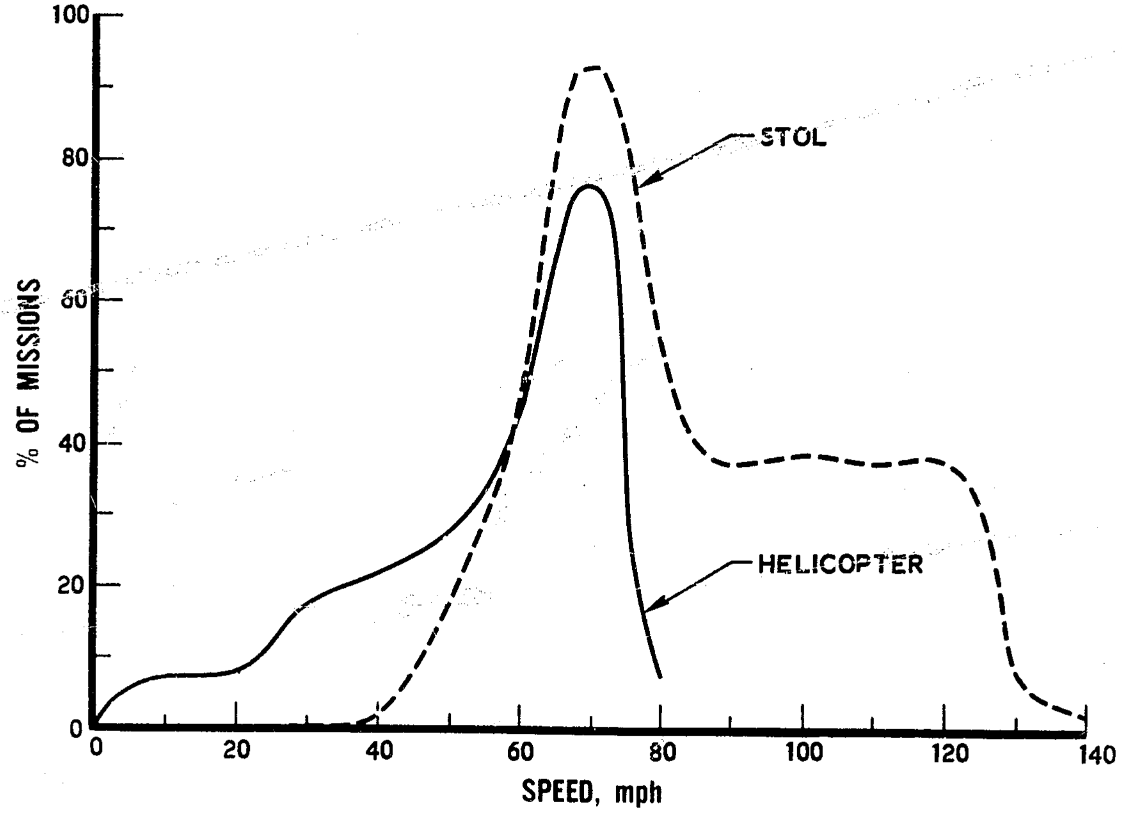


Figure 2-1. Speeds Maintained in STOL/Helicopter Missions[*]

Figure 2-1, shows the various speeds maintained by a Helio Courier STOL aircraft and a helicopter flying identical types of police missions. Note that the greatest percentage of missions were flown at speeds between 60 and 70 mph, which occurs near the top of the helicopter range and at exactly midpoint in the STOL range. While up to 20 percent of the missions occur below 40 mph, where the STOL does not usually operate, almost 40 percent of the missions were performed above 80 mph, beyond the usual range of the helicopter (especially meaningful in high-speed chases, rescues, etc.).

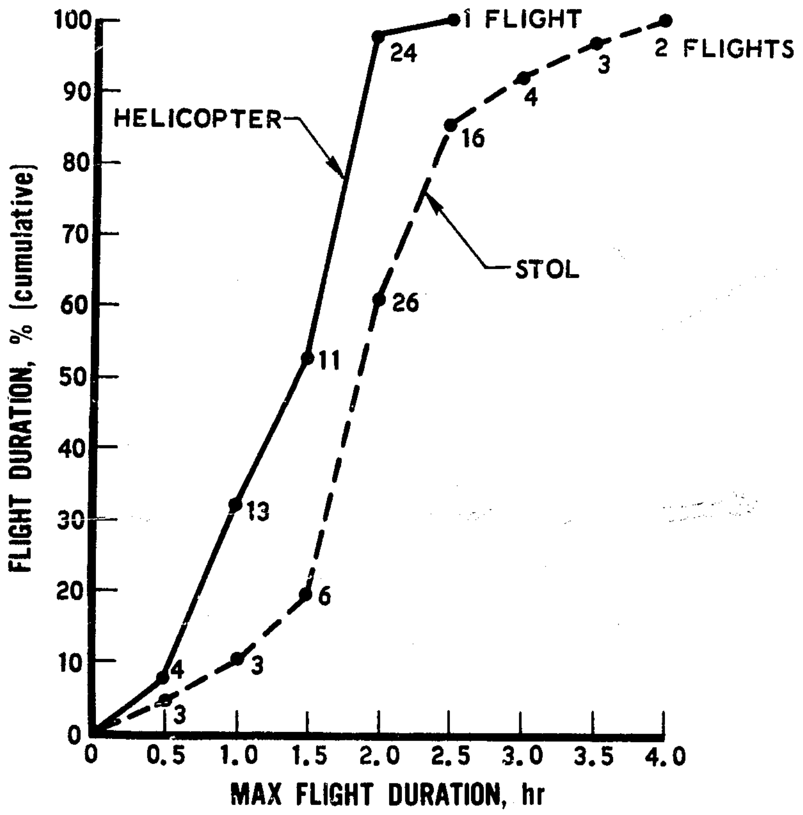


Figure 2-2. STOL/Helicopter Endurance Comparison[†]

Figure 2-2 compares flight endurance requirements. Eighty percent of the helicopter missions were generally between 1.5 and 2 hours long. Only one flight lasted 2.5 hours. Half of the STOL missions lasted between 1.5 and 2 hours, and only 25 percent were between 2 and 4 hours in length.

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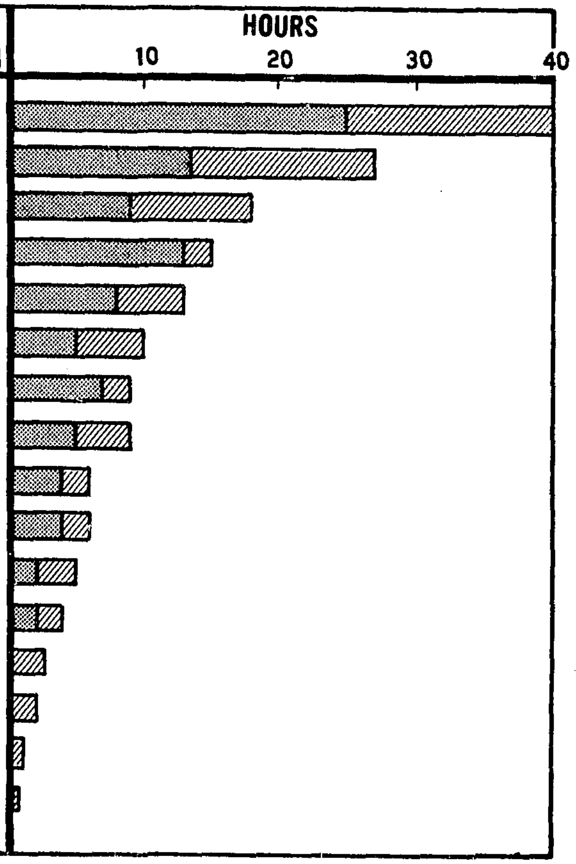
[*] From Table 7-7 in Appendix

[†] From Table 7-8 in Appendix C

Table 2-2 compares STOL and helicopter effectiveness in identical missions (168.1 hours, 16 different types) evaluated in the Dade County program. Of this total, 155.5 hours could have been flown by either aircraft. More than half of the General Surveillance missions was flown by STOL; Civil Disturbances, Rooftop Surveillance, and Traffic Control missions were equally divided; and other types were shared as shown between STOL

Table 2-2. STOL/Helicopter Effectiveness Comparison[†]

MISSION	HOURS FLOWN
GENERAL SURVEILLANCE	40.0
* CIVIL DISTURBANCE	27.1
TRAFFIC PATROL	18.0
LIGHTED PATROL	15.0
WATER PATROL	13.0
ROOFTOP SURVEILLANCE	10.0
* SEARCH FOR STOLEN VEHICLES	9.0
RECREATIONAL AREA PATROL	9.0
* RURAL AND VACANT AREA PATROLS	6.0
* ILLEGAL DUMPING	6.0
FIRE DETECTION	5.0
WATER POLLUTION	4.0
* PHOTOGRAPHIC **	2.9
* NARCOTICS	2.0
DROWNING **	0.6
ARMED ROBBERY**	0.5
TOTAL HOURS FLOWN	168.1



* INVOLVED OFF-AIRPORT LANDINGS
** UNSCHEDULED MISSIONS

▨ STOL
▨ HELICOPTER

[†] From Tables 7-3 and 7-4 in Appendix C

(solid bars) and Helicopter (cross-hatched bars). It should be noted that during helicopter flights (both scheduled and unscheduled) 30 off-airport landings were made in response to 11 types of incidents:[§]

• Recover stolen and/or abandoned vehicles	8
• Narcotics investigations	5
• Civil disturbances	4
• Investigate persons in remote areas	3
• Illegal discharge of weapons	
• Illegal dumping	3
• Drownings	2
• Photography at scene of crime	1
• Update mission information	1
• Investigate car stripping	1
• Demonstrate a helicopter	1
• Accident to the aircraft	1
Total off-airport landings	30

Helicopters also landed during fire detection, water patrol, and traffic patrol missions, demonstrating that a flexible system provided by combining rotary wing and fixed-wing aircraft does enhance aerial police operations.

It should be noted, however, that most city police departments (e.g., Los Angeles) do not permit their helicopters to land at other than heliports or airports except under extraordinary conditions, since this negates the prime advantage of aerial vehicles. Furthermore, state laws usually prohibit

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[§] From Tables 7-1 and 7-2 in Appendix C nonemergency landings at unprepared locations, except by prior approval. Another reason why police tactics have not developed around an off-airport landing capability is undoubtedly due to the fact that few neighborhoods are amenable to safe landing sites.

The airplane is being exploited primarily to supply the surveillance and control capability provided by its superior and relatively stable vision. This capability is rarely enhanced by the ability to hover, since flying an airplane in a circular pattern at loiter speeds is relatively effective in the surveillance application. Proponents of airplanes also point out the smoothness of an airplane, compared to the vibration experienced by most helicopters, providing a better platform from which observers using high-powered binoculars can survey more area in less time and with less fatigue.

These data point up the fact that mission requirements not only dictate hardware, but the availability of hardware suggests new missions and tactics. It would be unrealistic to expect a single solution to solve a requirement once and for all. The fact that many police missions involve considerable flight time at low (loiter) speeds suggests that not only fixed-wing but other vehicles should be considered. Autogiros and lighter-than-air (LTA) craft (e.g., blimps) automatically come to mind. The autogiro offers low-speed flight capabilities combined with the helicopter's safe autorotational capability at a possible reduction in first cost and a significant reduction in maintenance costs. The blimp, or some modern descendant therefrom, offers the possibility of extremely long-duration missions with its ability to remain aloft

with minimal fuel expenditure. Obviously, there are disadvantages; their effects on police applications will be discussed later in the report.

The problem, therefore, is a dynamic one, and static solutions are useful only for brief periods. Agencies should be prepared to evaluate and reevaluate their positions and needs as developments dictate. From the data already available and from a permutation and combination of the mission elements already discussed, the most complex missions can be synthesized, as will be discussed later.

D. Summary of Mission Requirements

Airborne vehicle mission requirements have been determined through a selected review of current and past law enforcement airborne vehicle programs. Basic missions were identified and translated into technical parameters relevant to the design of a particular system. Although these parameters contain a range of expected values, it is implied that the full range of all mission requirements may be difficult to achieve operationally.

From a requirements viewpoint, mission priorities are greatly dependent upon the exact utilization approach taken by various user groups. Because of the different role each chooses, only the user can establish specific mission priorities when designing a new system. It is further apparent that the topic of airborne vehicle mission requirements should be reviewed on a continuing basis.

Table 2-3 lists the specific requirement areas as a function of the various expected missions. The first three parameters describe the ratio of flying activity to element time anticipated in the fulfillment of the missions listed. The total mission (element) time is a summation of these components. (See also Figure 2-2, page 23).

Observation details are meant to describe the kind of observation needed to derive useful mission data. "Recognize personnel" means that the pilot or observer can deduce that a human being is engaged in some activity. The positive identification in law-enforcement terms (i.e., court evidence) is not considered a valid airborne requirement, since ground personnel action is usually needed to complete the total mission.

An important requirement is the capability to identify human activity during hours of darkness. This is accomplished using a powerful searchlight or, when appropriate, using night vision aids and normal skylight or street lights.

The communication needs are broken into two categories. One, called local, is a communication capability between the airborne vehicle and ground vehicles (i.e., tied to the local police network with multichannel radio capability). The second category, multi-agency, combines local coverage with a capability to talk to other pertinent agencies in the area (fire, state police, FBI, secret service, etc.) as needed in missions indicated.

Table 2-3. Requirements Parameters vs Mission Types

Mission	Loiter Speed Time MPH/Hour	Cruise Speed Time MPH/Hour	Maximum Speed Time MPH/Hour	Nominal Mission Time, hr	Altitude, ft	Number of Personnel	External Noise	Observation Capability	Communications
Command Post	35-60/3	N/A	N/A	3	500-1500	2-3	D or N/C	Personnel	Multi-Agency
High Speed Chase	N/A	N/A	100-150/0.5	0.5	1000	2	D	License Plate	Multi-Agency
Patrol - Rural	35-60/.25	85/1.75	N/A	2	500-1000	2	ND	Personnel	Local
Patrol - Urban	35-60/.25	50/2.75	N/A	3	500-1500	2	ND	Personnel	Local
Burglary and Robbery	35-60/0.5	N/A	100-150/0.5	1	500	2	ND	Personnel	Local
Covert Surveillance	35-60/1	60/1	N/A	2	1000-2000	2-3	ND	Personnel	Local
Tracking Vehicles	35-60/.5	65/1.5	N/A	2	500-1000	2-3	ND	License Plate	Multi-Agency
Tracking Personnel	35-60/1	N/A	N/A	1	500-750	2-3	ND	Personnel	Local
Nighttime Patrol	35-60/1	60/2	N/A	3	750-1000	2	ND	Personnel	Local
Security	35-60/1.5	60/.5	N/A	2	500-1000	2-3	D	Personnel	Multi-Agency
Rescue	N/A	N/A	100-150/1	1	0-750	2	N/C	Personnel	Multi-Agency
Traffic	N/A	85/3	N/A	3	750-2000	2	N/C	Personnel	Local

Key:
N/A - Not Applicable
N/C - Not Critical
D - Desirable
ND - Not Desirable

CHAPTER III. EVALUATION OF CANDIDATE AERIAL VEHICLES

A. Candidates

Only a few of the many models of helicopters and airplanes are serious candidates for extensive use in law enforcement, and the study efforts were concentrated on these vehicles. Vehicles with payloads above 5,000 pounds are not considered serious contenders, nor are single-passenger vehicles.

The study was not limited strictly to readily available vehicles. Had it been, autogiros and lighter-than-air vehicles could have been dismissed. Instead, vehicles which might be made available, and which represent current state of the art, were included so that each vehicle type could be compared on equal terms. This approach also permitted the selection of parameters for each aircraft type by which it could be identified as an initial candidate. Within these parametric boundaries, each type could then be optimized for police missions and compared with other types or against some standard or "ideal".

For one example, no suitable production autogiros exist, so autogiro proponents can assume current best practice in describing a proposed design. On the other hand, all helicopters presently flying in police operations represent vehicles designed to military specifications and do not reflect new designs that consider police requirements.

The lighter-than-air (LTA) types were retained for consideration by extending the definition of LTA to include hybrid aircraft which are not vertical take-off and landing (VTOL) vehicles but which can accomplish the low-speed loiter mission with less power than other types. In their pure state, LTAs (blimps) violate too many of the existing criteria for effective police aerial vehicles: they are expensive, require extensive ground facilities, are hard to handle, and require a large ground crew. Furthermore, they are too slow for many mission elements.

By overloading LTAs and shaping the lifting "bag" into a more effective wing shape, some of these objections can be eliminated or minimized, with the following results:

- The use of dynamic lift requires a takeoff run, but it also means that a pilot can land without a ground crew (except in unusually bad weather).
- The huge, unwieldy volume of the blimp is dramatically reduced, though not to within sizes comparable to heavier-than-air types.
- Efficient low-speed flight and the crash-safety feature of "slow crashes" are maintained.
- Speed capabilities to meet the stated requirements can be attained with "limp" construction using modern materials and structural techniques. However, consideration should be given to the use of a rigid (dirigible-type) structure as it appears to provide a higher speed potential with less weight and lower cost.

In summary, all initial candidates have been retained in the sense that each one, by proper parameter choice and design, can be shown to be technically capable of performing many mission elements. Therefore any choice must be made on the basis of operational suitability factors and cost effectiveness.

1. Measures of effectiveness. This study has generated and assembled a substantial amount of technical and cost data to define the basic characteristics of the candidate vehicles. If vehicle cost were the only issue, it could be stated that the overwhelming majority of police aerial mission elements (as defined in Table 2-1, page 19) could be accomplished by vehicles other than helicopters. But such is not the case. Mission cost effectiveness is the end objective, and the operational features of the several candidates must be considered.

The numerical requirements that presently define the mission are mere requirements, not criteria. Requirements separate qualified candidates from nonqualified candidates (i.e., noncandidates); however, once the qualified candidates are identified, the role of the requirements has been fulfilled, and criteria are applied in ranking the candidates. The quality of execution of any mission element now becomes the important factor, and this quality is measured not by the number of mission-hours flown, but by the results obtained. However, the shortage of operational data from the field and proper analyses of such data have resulted in few numerical measurements of quality. Without some established measures of effectiveness, a numerical ranking is impossible; however, a few observations of a qualitative nature can be stated:

- Fixed-wing aircraft look good from cost, top-speed, and reliability viewpoints; but minimum-altitude regulations sometimes reduce their effectiveness in surveillance missions.
- Hybrids provide the most efficient low-speed loiter but require the most elaborate and unusual ground system.
- Autogiros provide the greatest safety (of single-engine machines) and the smoothest observation platform (considering all types of weather).
- Helicopters provide the greatest versatility by ensuring that a maximum of unusual mission elements can be accomplished. Their hovering and VTOL capabilities further provide a rescue capability and a formidable threat to the criminal who respects the ability of a helicopter to land and its crew to participate in action on the ground. An autogiro with a good jump-takeoff capability or an intermittent hovering capability (compound helicopter) is the only other candidate with the potential to provide this versatility.
- Remotely piloted blimps promise substantial cost and fuel savings.

- A compound helicopter would probably represent the ultimate in police-vehicle capability if cost were no object. Discounting development costs, the compound helicopter could represent a cost-competitive machine, making up for its higher first cost with reduced maintenance costs.

In themselves, these observations do not provide the quantitative measurements needed to justify the choice of one vehicle over another. It is not possible to make an objective choice until: it is known how valuable the hovering capability can be in preventing crime, how much a shorter response-time is worth in apprehending offenders, or just how much more effective an aerial system can be compared to another system. As in the previous qualitative observations, the emphasis can only be on subjective comparisons of operation factors that tend to favor one vehicle or another. However, when and if criteria are established for measuring mission values and successes, the parametric-performance/cost data developed in this study represent sufficient technical inputs for an optimization computation. Unfortunately the missing inputs have political and sociological implications, to which many are reluctant to assign numerical values.

B. Definitions

The various factors to be considered are listed here for the purpose of providing a checklist and establishing definitions used throughout this report.

- Altitude/Temperature.[*] The primary effects of higher temperature or altitude on police missions are higher loiter speeds and longer takeoff distances. Cities at high altitudes may have to pay a premium to maintain performance for a few hot days per year; however, consideration should be given to reducing mission time and fueling more often, or to some other approach for maintaining minimum size and cost of aircraft.
- Commonality. In comparing two aircraft which will accomplish any set of missions, the lowest-cost aircraft will generally be the one in the highest production. If the aircraft is so versatile as to attract other customers and thus generate a sizeable market, the price will be considerably lower than for a more specialized aircraft. Unlike automobiles, aircraft are very low production items and have a steeper production learning curve. An increase in the number of sales can reduce prices more dramatically than an austere design, and it is much more satisfying to the user.
- Configuration. Primarily concerned with internal arrangement as necessary to accommodate the crew and mission equipment. A most important aspect of configuration would be the visibility provided for the observer.

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[*] Aircraft are usually compared on the basis of performance stated at sea level standard (SLS).

- Emergency Landing Requirement. A factor that has not had enough consideration or rational treatment. Surveillance altitudes are now established by FAA requirements rather than functional efficiency. The FAA requirements are fixed according to aircraft type rather than the aircraft's actual capabilities and the availability of emergency landing areas. The effect of technical factors such as multiple engines, flotation gear, glide ratio improvement, etc., must be considered if a truly cost-effective solution is to be developed for police aerial operations.
- Cruise Speed (V_{cr}). Theoretically that speed which provides maximum range. It is the speed for maximum aerodynamic/propulsive efficiency. In actual practice, the cruise speed is set by a long-life rating for the engine. For reciprocating engines this is usually a 75-percent power setting; for turbines, 80 to 90 percent, depending on the manufacturer and service history of engine. Cruise distance or time must also be specified.
- Loiter Speed (V_L). Speed at which surveillance and observation missions are to be carried out. In general, this should be the maximum endurance speed (the minimum power speed) since this is most economical of fuel. Loiter duration must also be specified.

- Maximum Speed (V_{max}). Speed that is attained at maximum continuous rating of engine. This is the speed which one specifies for pursuit. The length of pursuit in miles or time (duration) must also be specified. For this report it is assumed that top speeds do not conflict with the structural limit speed, V_{NE} (never-exceed speed).
- Minimum Speed (V_{min}). Minimum flying speed as determined by lift and power capability. Note that minimum speed does not correspond to minimum power or maximum endurance. Low-speed STOL operation or hovering requires considerably more power than flying at maximum endurance speed and will involve increased costs. Minimum speeds derived in this report may be lower than V_C, the minimum speed at which adequate control is available. The margin between V_C and V_{min} required for safe flight depends upon the particular aircraft.
- Payload (PL). Consists of the crew including pilot, observer(s), and others; police communications equipment; aircraft electronics (only if it exceeds standard visual flight regulations (VFR) equipment); floodlights and special power supply, loudspeakers binoculars, weapons, and other special police equipment.
- Takeoff and Landing Distances. Important to police operations particularly if an airport is not available as a home base for the

aircraft. For consistency these distances are stated to be for takeoff or landing over a 50-foot obstacle. A stringent landing and takeoff specification probably will contribute more to police aircraft costs than any other factor with the exception of extended loitering at zero speed (hovering).

- Takeoff and Landing Speeds. Probably meaningless for police operations. Stall speed usually sets landing condition; maximum rate of climb determines the takeoff.
- Useful Load (UL). The sum of the payload plus the fuel load. The useful load plus the aircraft empty weight (EW) add up to the gross weight (GW).

C. Aircraft Design Fundamentals

Any law enforcement mission can be synthesized from a number of mission elements, as noted in the previous chapter. The ability of the aircraft to accomplish any mission element is determined by fundamental physical laws. The user need not be familiar with these laws but can appraise aircraft solely by means of clearly defined specifications. It is helpful, however, if the user becomes familiar with the rudimentary fundamentals discussed in this section so that he can understand the feasibility limitations they impose on specifications and the impact of specifications on cost. Additional technical discussion is contained in the Appendices.

The classical aircraft mission is a payload/range mission, illustrated in Figure 3-1. An aircraft differs from most other vehicles in the fact that weight is such an overriding factor affecting its ability to accomplish its mission. This in turn makes it more sensitive to geographic and atmospheric variations.

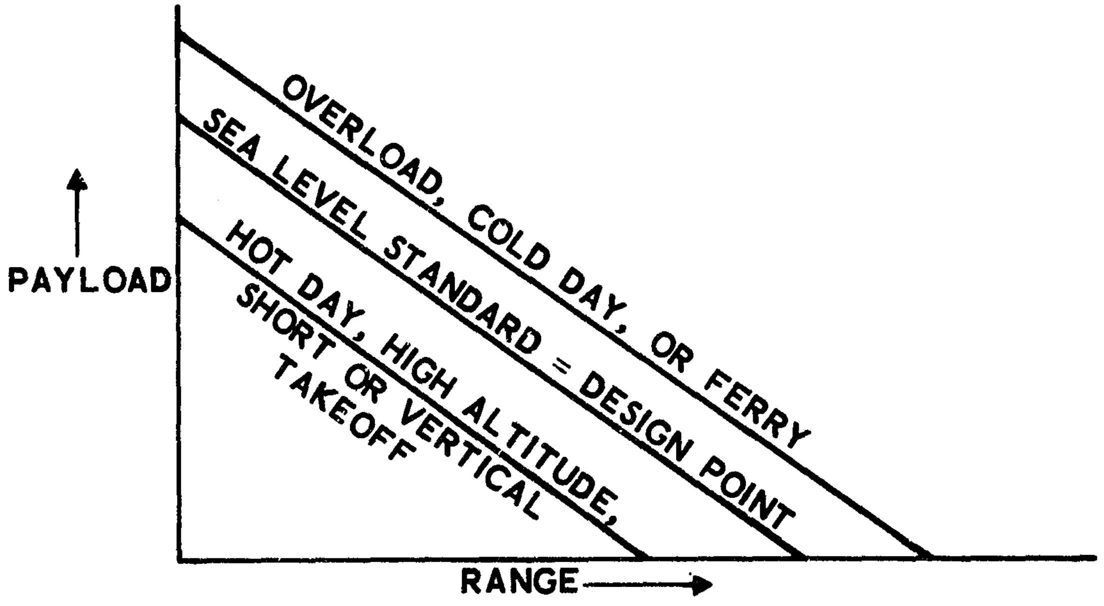

Figure 3-1. Aircraft Payload/Range Diagram

In Figure 3-1, the middle line shows the design performance, defined at sea level on a standard 60°F day. An aircraft can trade fuel for payload and, at the same takeoff weight, accomplish a high-payload/short-range mission or a low-payload/long-range mission. When all the payload has been displaced by fuel and pilot, the maximum (ferry) range or maximum endurance capability is obtained, depending upon whether one flies at cruise speed or minimum power, respectively.

Under special conditions the aircraft may be overloaded to allow a higher takeoff weight. This is done occasionally to lift higher payloads;

however, it is done more frequently for ferry missions where the overload of fuel is burned off early in flight, leaving the majority of the mission to be carried out at design-stress levels or less.

Any lines above the design-point line are probably of academic interest to police operations, while lines in the area below the design point are frequently encountered. Specifically, any operation requiring takeoff on hotter days or at higher altitudes than standard will reduce the payload/range capability. Also, the requirement for STOL or VTOL takeoff performance reduces the payload/range productivity. One can attain STOL, for example, by reducing the payload/range capability or, conversely, by "buying more airplane" to do the same payload/range job. For straight-line payload/range curves, (a close enough approximation for this discussion) the maximum ton-miles is obtained at the midpoint, illustrated in Figure 3-2, with the transportation productivity obviously falling to zero when the range is zero or the payload is zero.

It should therefore be clear that two aircraft of equal efficiency should be able to attain the same zero-payload/range. At lesser ranges, size alone determines payload for equally efficient aircraft. In general, larger airplanes are more efficient than smaller ones; they not only have a larger payload but a longer range.†

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†The cube-square law states that for exactly similar geometries, the smaller machine is more efficient but, in practice, the law is broken by advanced technology applied to the larger machines (i.e., designs are not exactly similar).

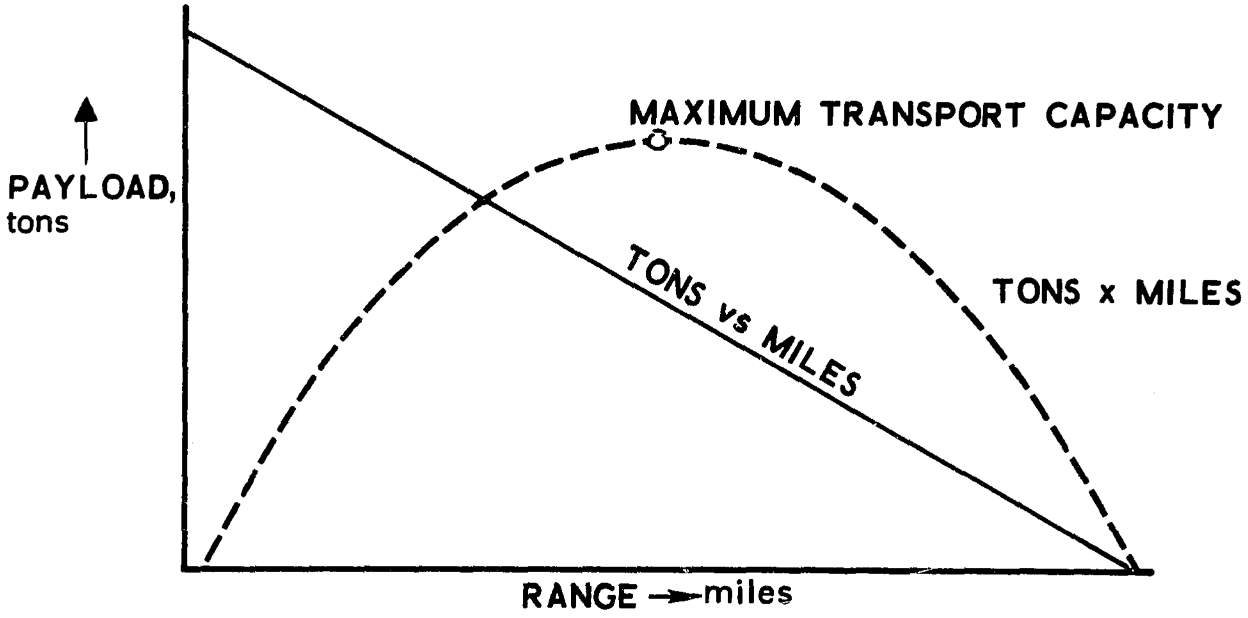

Figure 3-2. Maximum Transport Capacity

Maximum ferry range is the fundamental indication of efficiency, as defined by the lift/drag ratio; however, it is not the best indicator of aircraft for the user because it does not properly account for aircraft weight. Sophistication in aircraft design is aimed at reducing drag and airframe weight; in proper balance they yield the maximum productivity in terms of ton-miles per dollar. Not only do different aircraft types have different payload/range characteristics, but aircraft of even the same type differ according to the designer's philosophy and skill.

Figure 3-3, illustrates typical power requirements for the performances of various candidates considered in this report. There is a rough correlation between the complexity and power requirements of an aircraft.

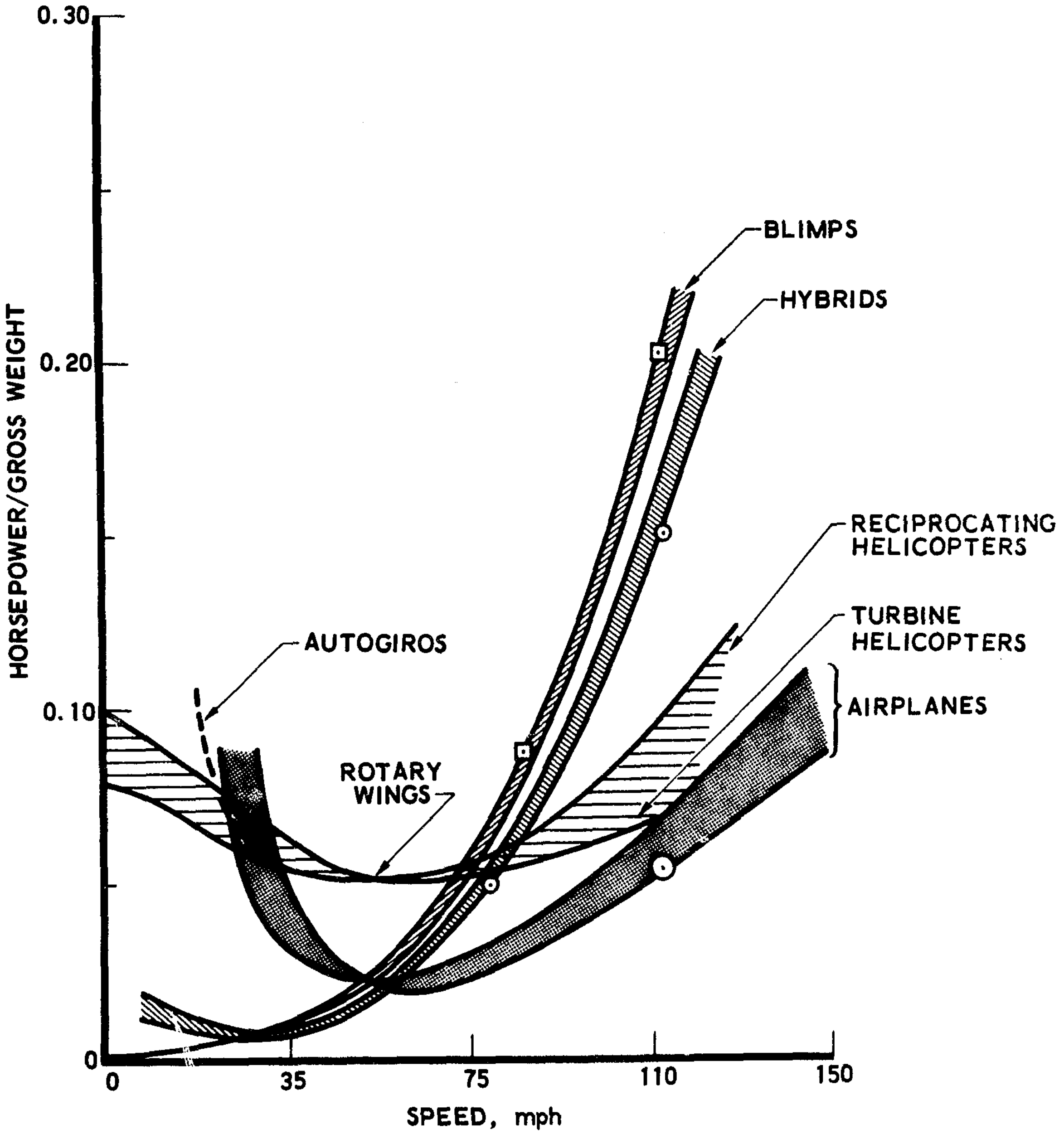

Figure 3-3. Typical Power Requirements for Candidate Aircraft

This correlation is illustrated by the additional power requirements of helicopters vs airplanes over a major portion of the speed spectrum of interest in law enforcement applications. At very low speeds, the power requirements of fixed-wing airplanes exceed those of helicopters or autogiros. A rather exotic STOL kit or special design is needed for a fixed wing to fly as slowly and as safely as an autogiro. Blimp and hybrid types can fly very slowly at negligible power levels; higher speeds are attained at the expense of a considerably higher power requirement and, probably, a significant airframe complexity compared to lower-speed models. Appendix A contains additional detailed discussions of LTA and autogiro design.

D. Aerial Vehicle Types

The preponderance of aircraft now in law enforcement service are helicopters; consequently, they were one of the basic types to be studied. The helicopter is probably the one existing vehicle capable of accomplishing all police aerial missions. It can hover, land in congested areas, and carry out surveillance missions at any desired loiter speed. Furthermore, current turbine models can attain the pursuit speeds required to carry out a chase of any common ground vehicle. The only performance deficiency, compared to a light airplane for example, is the shorter range due to its poorer lift-to-drag ratio. This characteristic results in a greater power (and thus fuel) requirement. The primary criticism leveled against the helicopter is not its capability but its cost.

The source of criticism is the suspicion that the aerial surveillance situation can be improved. If so, improvement could be in several areas:

- Reduce the cost of owning and operating helicopters.
- Find a direct replacement for the helicopter that is cheaper.
- Reexamine requirements to determine if a less capable but lower-cost machine can accomplish the most important and most frequent missions, thus eliminating the need for helicopters or reducing the number required to an absolute minimum.

With regard to the possibility of reducing the cost of owning and operating helicopters, it is obvious that the scope of this report allows little more than a cursory review. Every helicopter manufacturer has a continuing program to reduce costs. It would be highly unlikely that, in this brief report, a significant solution could be developed for a problem which has concerned the entire helicopter industry for 25 years.

On the other hand, it should be recognized that every helicopter flying today (with rare exceptions) is the result of a development program aimed at satisfying the needs of a military customer. Therefore, the possibility exists that as configurations, design practices, specifications, etc. are optimized for commerical or police operations they might lead to more cost-effective solutions.

The alternate approach, finding a direct replacement for the helicopter, is likewise an improbable outcome of this study. Direct replacement would imply a hovering capability and this indicates vertical takeoff or landing

(VTOL). Expensive as the helicopter is, no VTOL is known to be cheaper. The possibility of attaining low-cost VTOL or hovering capabilities with LTA crafts is intriguing, possibily because few people today have first-hand familiarity with their characteristics, costs, or operating problems. Modern structural techniques, materials, and propulsion technologies probably can offer significant improvement in the performance/cost picture of LTA craft and this is discussed in Appendix A. Perhaps the optimum police aircraft calls for employing elements of both the heavier-than-air and lighter-than-air systems.

The primary contribution of The Aerospace Corporation study is in the third area, which provides the background and methodology for making tradeoffs between mission and aircraft requirements in numerical form that are both rational and possible. One end product of this study is a computer model useful in evaluating aircraft performance and estimating "should cost" figures. With numerically defined requirements and this computer model, aircraft characteristics can be specified more realistically. This should lead to better procedures for buying off-the-shelf aircraft or, alternately, to the definition of practical programs for developing the required type.

The basic aircraft types chosen for consideration in this study cover the entire spectrum, with the exception of high-performance jet aircraft. These aircraft are described in order to ensure uniformity of nomenclature. The various aircraft are listed under the headings in general use in the aircraft field.

1. Heavier-than-air craft. Discussed in this category are: fixed-wing aircraft, rotary wing aircraft, compound aircraft, VTOL/STOL aircraft, and flying platforms, respectively.

a. Fixed wing. Airplanes and fixed-wing aircraft are synomymous in that there are no other forms of fixed-wing aircraft than airplanes, unless one chooses to categorize airplanes by wing arrangement (monoplanes, biplanes, triplanes, sesquiplanes, canards etc.). Such categorization was meaningful in the experimental days of aviation, but there appears to be no need for it today when even the sight of a biplane is a rarity. The overwhelming majority of contemporary aircraft are conventional subsonic airplane designs. Parameters vary widely between the light private airplane and the heavy transport, but the fundamentals are identical. The airplane represents the standard of comparison for all aircraft types. Indeed, in this report, the role of the airplane as a standard has been emphasized, and all other aerial vehicle types have been reduced to their nearest "equivalent airplane" role, wherever feasible.

b. Rotary wing. Rotary wing aircraft consist of two types, helicopters and autogiros. They display many family resemblances, but they also exhibit some major dissimilarities in characteristics due to the fundamentally different manner in which they are operated. The autogiro rotor is not powered but dragged through the air like an airplane wing. The air flows upward through the autogiro rotor and turns it like a windmill. The turning rotor acts in almost all respects like an airplane wing, and the training for an autogiro pilot is essentially the same as that for a fixed-wing aircraft pilot.

On the other hand, the helicopter rotor is powered. It is not dragged through the air but drags the rest of the aircraft through the air. To do this it must be tilted forward, directing the airflows downward through the rotor. In this respect it differs most from the autogiro rotor, because of its effect on the blade-angle distribution: At high forward speeds the retreating blade of the autogiro rotor starts to stall from the hub rather innocuously; whereas, the helicopter's retreating-blade stall starts at the tip, thus producing major effects on drag, power, roughness, and control. The powered helicopter rotor results in a torque-reaction problem, hence the need for a tail rotor.

In case of a power failure the helicopter must pass through a transition phase from where the air flows downward through the rotor to where it flows upward and establishes the autorotational process. At certain speeds and altitudes this transition period can become a dangerous condition. Such conditions define the "dead man's curve" for the helicopter, a hazard that does not exist in the autogiro because it is always in autorotation and there are no such transitional flight modes. However, the helicopter can hover. This capability has been a major factor in making it the dominant aircraft choice which, to date, has been produced in quantity hundreds of times greater than that of the autogiro, even though it was developed a score of years later.

c. Compound aircraft. This term generally defines a rotary wing aircraft having a wing to unload the rotor in forward flight (aerodynamic compounding) or a separate propulsion system to relieve the rotor of its need to tilt forward when providing forward propulsion (power compounding). Both types of compounding are usually employed at the same time. Today, the old winged autogiros would be defined as compound aircraft.

d. VOTL/STOL aircraft. Vertical takeoff and landing (VTOL) aircraft and short takeoff and landing (STOL) aircraft are differentiated from conventional takeoff and landing (CTOL) aircraft not so much by type as by performance capability. Vertical takeoff aircraft may be helicopters, compounds, tilt rotors, tilt wings, pure jets, or LTAs. Short takeoff aircraft can be fixed-wing airplanes with high-lift devices on the wings and/or high-powered engines, autogiros, or overloaded VTOLs.

Every VTOL aircraft degenerates to STOL performance if it is overloaded; however, the converse is not true. Reducing the weight of a STOL does not allow it to become a VTOL even though it may have the power to hover. Operation of a VTOL involves very low speed flight wherein the flow over fixed aerodynamic surfaces (such as rudders, ailerons and elevators) is not enough to provide control forces or damping. Special provisions must be made for the control and stability of VTOL aircraft; if these are missing a STOL cannot be used in the VTOL mode no matter how much power or lift it can generate.

e. Flying platforms. Flying platforms are a special VTOL case. They may be driven by propellers or rotors (shrouded or unshrouded), turbofans, or turbojets. Their primary advantage is their compactness, but this compactness dictates high-disk loadings and is paid for by high power, high cost, and short range or endurance. If compactness is sacrificed to attain higher efficiency, the flying platform evolves towards a helicopter. Such fictional police missions as suggested for flying platform vehicles by the

Dick Tracy series, for example, are feasible provided mission endurances are defined in minutes rather than hours.

2. Lighter-than-air craft. Rigid and semirigid (zeppelin and dirigibles), nonrigid (blimps), balloons, and hybrid aircraft (including LTA craft) are discussed in these paragraphs.

a. Rigid and semirigid. The shapes of such LTAs as zeppelins and dirigibles are defined by their metallic structures. The lifting-gas bags are separate internal elements, and they may be full or slack (depending upon altitude and state of gas expansion) without affecting external rigidity or shape. The rigid method of construction (as opposed to the nonrigid) provides greater efficiency. Of the LTA craft intended as work vehicles, the dirigible provides the lowest empty weight ratios.

b. Nonrigid. This type of LTA is represented by the blimp, which has no rigid structure outside of the gondola or "car" and maintains its shape by a slight internal overpressure. Expansion and contraction of the lifting gas is accommodated by internal ballonets that are filled with air or evacuated as required to maintain proper gas pressure. Blimps historically have been constructed of a rubberized cloth; however, modern plastics (Mylar, etc.) possessing greater strength, lighter weight, and lower permeability have been applied with a high level of success to high altitude, weather research, logging, tethered "aerostats", and hot-air sports balloons. These applications may suggest improvements to the state of the art, particularly if a market potential were to justify development of advanced LTA vehicles.

c. Balloons. Balloons are generally of a more elemental or natural (spherical) shape than blimps in keeping with their primary function of providing vertical lift rather than forward motion. Natural shapes for enclosing a gas result in lower weights and simpler structures in keeping with the desire for minimum cost. Balloons employing hot air for bouyancy have made a noticeable, if not spectacular, comeback as sporting devices, primarily as a result of the availability of new materials for the envelope and of reliable, responsive burners for generating hot air.

Aerostats, modern versions of the barrage balloon, have also been developed to withstand severe winds of velocities beyond the operating speeds of existing blimps. Use of modern materials and judicious use of metallic stiffening at the nose has allowed maintenance of streamlined shapes at blimp airspeeds for envelope weights significantly less than those associated with present blimps.

3. Hybrid Aircraft. This term denotes aircraft having both heavier-than-air and lighter-than-air lifting elements defined on a structural basis. A hybrid could be classified as an aircraft that employs both static lift and dynamic lift; however, this would cause confusion because a simple blimp, which is defined as a "pure" LTA, is quite capable of taking off with a considerable overload by flying with an angle of attack and using forward velocity to provide dynamic lift. To be a true hybrid, an aircraft would have to have a wing or rotor dynamic element to always share the lift with the static lift element. The question arises as how to define a wing-shaped aircraft designed to carry a considerable fraction of its weight by dynamic lift but

which maintains its shape with helium, like a blimp, rather than by rigid members, like an airplane wing. Is this a pure LTA or a hybrid? That it is an inflated structure and is inflated with a lifting gas is immaterial. As long as the aircraft cannot get off the ground by static lift alone, and the operation of the vehicle is enhanced by the special shaping provided by the structure, inflated or otherwise, it would be defined as a hybrid; its structure defines a dynamic lifting shape.

4. Remotely-piloted mini-blimp (RPMB). The RPMB is a new vehicle proposed by Developmental Sciences, Inc. in partnership with Goodyear Aerospace Corporation. It is essentially a remotely controlled miniature blimp equipped with a television camera having light-enhancement for night operations and capable of serving as the airborne eyes of the ground-based pilot. The RPMB is capable of more than 15 hours endurance on 6 gallons of fuel at speeds ranging from 15 to 70 knots and it can carry a wide range of equipment in addition to the TV camera(s). At low power levels and altitudes above 200 feet, the RPMB is practically silent. This vehicle could have many applications in the law enforcement and private security field including freeway, harbor, and industrial area patrol; search and rescue; airborne command post; riot control, etc.

The RPMB measures approximately 55 feet in length and 13.5 feet in diameter. The helium envelope is constructed of rugged 5 oz/yd^2 Mylar-coated Dacron material and has a simple, automatically operating balonaise to compensate for envelope superheat and altitude changes.

It is fitted with horizontal "straked" fins, which enhance aerodynamic lift and reduce induced drag.

The fiber-glass car, which is flush-mounted to the belly of the envelope and supported by external cateneries, carries the equipment and propulsion packages. The propulsion system consists of a muffled 35 horsepower, two-stroke engine driving a ducted propeller.

The RPMB is equipped with a simple off-the-shelf, autopilot-system vehicle which permits "hands-off" operation, automatic station keeping, and altitude hold. Simplified controls are proposed, which only require the pilot to steer the vehicle in the desired direction; it is not necessary that the operator be a pilot or have pilot's skills in order to fly the RPMB. An automatic system limits maximum altitude to 500 feet above the surface, in keeping with FAA preliminary recommendations relating to RPMBs. As a result, one operator can control up to four RPMBs simultaneously and still carry out effective surveillance over a considerably large area. A mooring-tower system allows the RPMB to be "parked" when not in use and still remain ready to fly in seconds. Even without the docking tower, one man can recover the RPMB.

Two FAA regional offices, which have reviewed this concept, expressed their support of this type of operation because of the intrinsic safety of the RPMB. Frequency allocations to accommodate the necessary microwave video transmission are not unusual and would probably not pose a problem for most cities. Another feature of the RPMB is that when (inevitably) somebody tries to shoot it down, it will descend very slowly and safely. Patching of bullet holes in present Goodyear blimps constitutes a routine maintenance chore. An Emergency Location Transmitter (ELT) permits rapid retrieval of the downed vehicle.

E. Selection Criteria

When overall and well-defined system measures of effectiveness are not available to provide a basis for a system or subsystem optimization, as is the case here, a logical alternate criterion is one based on minimization or risk. The following list of factors should prove useful in minimizing risk:

- Retain versatility. Avoid the selection of specialized or single-purpose machines which appear to meet all the currently identified requirements but are incapable of responding to new situations.
- Retain reversibility. Reversibility is another term for maintaining the option of changing one's mind at a minimum cost. This means buying a popular vehicle which enjoys a wide market, both new and used, and which allows one to sell out and start over if a mistakes has been made.
- Balance-the-Portfolio. In other words, don't concentrate too much on one system to the exclusion of others. Introduce new types gradually into existing successful operations so that direct comparisons can be made.

- Exploit R&D. Both vehicular and operational R&D should be supported by both government agencies and private industry.

Before applying the above rules to any situation ensure that the vehicle or system in question at least provides functional suitability for the missions as presently defined. As far as a vehicle is concerned, this utility is defined by one of the following three functions:

a. Transport occupants from one point to another, whether for business or pleasure

b. Carry an individual who is performing a service, i.e., observation or surveillance (or equivalent remote "vision").

c. Carry inanimate objects or loads, e.g. supplies, aerial insecticides, etc.

Any vehicle operated for business, government, or personal use is performing one of these three functions. Ideally, it should perform these functions safely, quickly, and economically.

It is acknowledged that the helicopter, barring city ordinances, performs "a." almost as well as the automobile; in certain cases it outperforms the automobile. The autogiro accomplishes function "a." almost as well as the helicopter, but cannot duplicate its performance because of its inability to sustain a hover.[†] However, both rotorcraft offer significantly greater capability than the fixed wing in performing function"a.". For pure performance (speed, range, and payload), given the same power plant and gross weight, the fixed wing provides a better capability.

With the same horsepower and gross weight, the autogiro is approximately 25 percent better than the helicopter in terms of speed and range; payload considerations are about equal. Rates of climb are also comparable.

In function "b.", the advantages of rotorcraft are distinct in observation and surveillance roles. The ability of rotorcraft to fly slowly, turn rapidly at low speeds and altitudes without fear of stalling, even in gusty conditions, combined with their overall high degree of maneuverability, make their use most appropriate. As for the comparison between the two rotorcraft in the observation/surveillance function, hovering is not as essential to function "b" as it is to function "a.", where an actual touchdown is required. The autogiro, therefore, performs the total aspect of observation/surveillance more effectively. It can maneuver at speeds from 25 mph to "never exceed speed" with the same quickness and agility as the helicopter (without the pilot having to monitor r.p.m.). At low altitude, when considering engine failure, it can perform more safely than the helicopter, because it is already in autorotation. Also, while the helicopter pilot must keep both hands on the controls (collective and cyclic) in order to maneuver and remain alert

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[†] The old low-disk-loaded autogiro of the thirties did land on top of commercial buildings to deliver mail. However, the size of the building top area could be reduced to where the autogiro could not compete with a helicopter under power. Nevertheless, the autogiro matches the helicopter's confined-area landing capability in engine-out conditions.

in the event of engine failure, the autogiro pilot can operate safely with one hand (the collective is unnecessary in flight), utilizing the other hand for other activities.[§] Because of these operational advantages, the autogiro performs observation and surveillance as well as the helicopter. And, certainly, both rotorcraft handles are superior to the fixed wing in this function.

The final consideration, ability to carry, deliver, or disperse inanimate objects, is somewhat of a corollary of "a." and "b.". Both rotorcraft are better than fixed-wing aircraft and carry their loads nearer the point of destination or, if necessary, disperse it in flight (as an aerial application). The superior ability to land on site and the higher degree of maneuverability have already been discussed.

1. <u>Functional Suitability</u>. Functional suitability defines a machine's ability to do what it was bought to do regardless of the "classical" performance figures. Functional suitability is a measure of the design's quality and the designer's true appreciation of the mission requirements. For example, if

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[§] In the event of an engine failure, the autogiro pilot can conduct a full emergency, from start to touchdown, with one hand. In a high-inertia system he may pull collective at touchdown, though he can make a most satisfactory landing without employing collective. Helicopter observation/surveillance roles usually require two people because of the extra activity of the pilot; as this additional requirement is absent in autogiro operations, there is a possibility of reducing personnel in the aircraft by one. This is particularly pertinent when considering that the growing complexity of the police surveillance operation has resulted in consideration of the use of 2 or even 3 observers in addition to the pilot. Autogiros being operated today for radio and TV are using just the pilot -- who, among other things, operates the motion picture camera. The lower levels of vibration of the autogiro also make it a better platform for filming.

the payload requirement includes an internal stretcher, it is not only important that the 200 pounds or so lift capability be provided but that the stretcher can be inserted and removed easily and quickly without disturbing the patient and that proper internal provisions have been made for an attendant (or for inflight access to the patient by a crew member). Also, if maintenance is to be done in remote areas, a maximum of access and a minimum of special tools might be more important than a few pounds saved.

Following is a checklist to be considered in the evaluation of a police aerial vehicle:

- In addition to meeting classical sea-level performance will it perform adequately in the user's environment of climate and altitude?
- Is cabin space suitable for the crew? Does the observer have the field of view required? Are instruments located and lighted properly for rapid and accurate viewing? Is the canopy "glass" distortion-free?
- Are controls, switches, etc., within easy reach? Are they comfortable to operate? Do they activate in the "logical" direction, and are they arranged logically for interpretation? Is there a safety system to prevent inadvertant actuation of any critical switch or control?
- Are handling qualitites suitable to the mission? Does the pilot ever need hands-off control to accomplish a mission? Is a Stability Augmentation System (SAS) desirable? Is Instrument Flight Rule (IFR) a requirement?

- Have proper provisions been made for permanent communications gear and for specialized mission gear which must be removable? Does auxiliary equipment fit into logical and convenient locations and not interfere with the freedom of movement of crew members when operating other pieces of equipment?
- Are there properly located hard points for mounting external equipment and stores such as loud speakers, lights, hoists, etc? Has proper provisions been made for supplying power to such auxiliary equipment?
- Are crew comfort and safety adequate; i.e. seating comfort, vibration, noise, cabin heating, ventilation, cooling? Are flight controls easy to operate; i.e., nontiring? Is crash safety and survivability adequate? (This important factor is discussed in greater detail in Chapter VI.)

While extensive data could be analyzed, evaluated, and discussed, the end result would undoubtedly show that in terms of pure utility, the helicopter is the present leader, with the autogiro very closely matching its capability. The combination of the two in a compound represent the ultimate. As for performance, based upon the same power and gross weight, the fixed-wing aircraft provides better capabilities in the area of speed, payload, range, and rate of climb. Of course, performance depends upon wing (or disk) and power loadings, which can be varied greatly, causing considerable variations in these performance elements. Whether it be considerations of utility and its accompanying factor, performance, the vehicle chosen must fulfill the objectives of safety and utility at an acceptable cost. This has been the primary complaint against the helicopter. Its utility is outstanding but its costs, both initial and operational, have been considered by many to be excessive.

It is not difficult to understand why such costs are higher for the helicopter. The additional dynamic components -- principally required for hovering -- are costly by definition. They must be made of costly alloys, for lighter weight, and machined to closer tolerances. The sum total equals a more expensive machine.

Because the autogiro has somewhat fewer dynamic components, its initial cost is lower. However, it is not as low as some believe. The real cost saving for the autogiro is in the area of operational costs. Operational-cost differentials between the autogiro and the helicopter are more pronounced than their initial cost differential. Operational costs of the autogiro are estimated to be about half that of the helicopter, or approximately the same as for other STOLs. The lower costs result from a lower power setting to achieve the same cruise speed (less fuel and oil), fewer inspections (labor service costs), and higher overhaul time on the engine (e. g. , overhaul time for the Lycoming 0-360, 180-horsepower engine is 750 hours for helicopters vs 2, 000 hours for both the autogiro and the fixed wing).

There are also savings in the indirect-cost area due principally to the fewer number of limited-life components in the autogiro and, consequently,

less unscheduled maintenance and lower hull-insurance rates (the autogiro's approaching those of the fixed wing). All of these factors reduce the autogiro's total operational costs.

In summarizing the cost picture, the final relative results would accord the least initial cost to the fixed wing, the next higher to the autogiro, and the highest to the helicopter. Operational costs would be in the same order. However, data presently available show that the operational costs of the autogiro are comparable to those of the fixed wing. In other words, the autogiro would be almost as expensive as the helicopter to buy, and almost as cheap as the fixed wing to maintain. It appears to offer potential for police work and should be given as much consideration as helicopters and fixed-wing STOLs in future evaluations. While no autogiros have been developed specifically for police work, and none are in production, operational models of certified designs are extant and available for demonstration.

The hybrid vehicles also have interesting characteristics. For manned vehicles their bulk and unwieldiness detract from their positive virtues; but, for small-payload RPVs, the LTA and hybrid types offer distinct advantages in safety and public acceptance. Since the general aviation community is usually acquainted with these unique vehicles, they and blimps are discussed in more detail in Appendix A.

3. Maintainability. Maintainability includes a number of factors. Some are associated with the vehicle type itself and some with the design features of a particular vehicle. Obviously, the maintenance of a blimp gas

bag has no counterpart in the helicopter or fixed-wing aircraft, but the fuselage of an airplane or helicopter does have a counterpart in the car of a blimp.

As stated in Chapter V , the primary maintenance costs of an aircraft are associated with the moving parts (engines, gear boxes, etc). These endure a steady wearing operation and provide only a limited life compared to static structures. For this very reason, highly efficient systems have been set up to handle the repeated engine overhauls; whereas, there is far less organization in the repair of sheet metal structures less subject to steady wear than to intermittent accidental damage.

In light of this fact, a standard popular engine would have to be deemed much more maintainable than any of the airframes in which it was used. On the other hand, spare parts problems could be far greater for an old or rare-model engine than for an old airframe, which would probably be repaired with the same techniques and materials as a newer model.

Although this example represents an extreme case it illustrates the need for retaining a certain amount of flexibility in maintenance operations. If it is at all possible to employ a vehicle model of wide appeal and useage in the operation, maintainability is enhanced tremendously. Not only does it provide the benefits of mass production in vehicle first-costs and parts costs, but it further provides the benefits of a widespread system of trained personnel, supply sources, and communications that enhance maintenance capabilities.

Widespread parts availability not only has an obvious direct effect on maintainability and maintenance costs, but it has implications on indirect

costs involving spare parts purchases and storage requirements. With local supplies and a fast delivery system, the spare parts inventory can be reduced to an absolute minimum, which means savings in storage space, interest costs, and bookkeeping.

3. Facilities Requirements. The facilities requirements associated with the vehicle include the home base, hangaring, and repair facilities plus any remote bases and fueling stops required in the particular region covered. The type of vehicle being employed has a major effect on the size and sophistication of the facilities needed. It is this area of consideration that would have the greatest bearing on the functional suitability of LTA and hybrid vehicles. The helicopter exhibits marked advantages in this area, since its hangaring and maintenance facility requirements are no greater than they are for the fixed-wing aircraft, and landing strip and approach zone requirements are reduced to a minimum.

The LTA and hybrid types appear to present a distinct disadvantage in this area. Even the "pure" LTA types require a run-on landing to maintain some control, unless there is a wind. Landing-distance requirements are equal to or more than that those required for any reasonable STOL, but this is not so much of a problem as the large ground crew needed to handle LTAs. The docking and launching of LTAs are very critical operations, particularly in bad weather or when the ship is "light."

Since one of the motivations behind this study was to reduce the high cost of police helicopter operations, and since one of the highest cost elements of police aerial operations is that of personnel, it would seem that the need for a large ground crew to handle LTAs would militate against their use. Add to this problem the need for a huge hangar in all but a few favorable climates (a pure LTA for a 2-man crew will be at least 90 feet long), a helium supply (and possibly purification) unit, and a specialized repair facility for gas-sealed structures, and it becomes clear that the rapid escalation in costs could put LTAs beyond the reach of most police agencies.

The hybrid aircraft seems not only to be a better solution but also a variant needed to make the LTA practical. Not only is the size reduced to manageable proportions, but, by being somewhat heavier than air, the hybrid can negotiate a landing without need for a ground crew to "hold it down." Even so, the light wing loadings of the hybrid types may preclude their use in heavy weather.

CHAPTER IV. SUPPORT EQUIPMENT REQUIREMENTS

This section is concerned principally with avionic and other supporting electronic equipment which may be appropriate for use in police air vehicles. A short discussion of accessories suitable for use in fire and rescue emergencies, riot control, and surveillance is also included.

A. Avionics Equipment Specification Guidelines

In order to establish guidelines for specifying avionics equipment in police air vehicles, one must be aware of the following factors:

- Most major cities underlie positive control airspace, in which air traffic is often heavy due to movements into and out of hub airports. Operations beneath this airspace are restricted by altitude limitations. Radar identification and control from the ground is a feature of positive control airspace.
- Airport traffic control zones extend 5 miles in radius from the center of the airport and upward in altitude to 3,000 feet. All pilots are required to be in radio contact with the control tower when flying within this airspace. Furthermore, many uncontrolled airports which do not have control zones nevertheless serve significant numbers of aircraft and often provide a UNICOM advisory service for communicating favored runway and traffic information.

- VHF navigational facilities are plentiful in and around most cities, with reasonably good signal quality available a short distance above the ground, and often at ground level. Low-frequency beacons (200 to 400 KHz) are located near most large airports, and many cities have a number of broadcast-band (550 to 1700 Hz) stations. Signal quality is usually adequate for navigation down to ground level.
- Many cities are subjected to reduced visibility conditions due to smog, making navigation by pilotage (landmarks) difficult. This is particularly true in Special Visual Flight Rule (SVFR) conditions, when visibility is between one and three miles. Under these circumstances, difficult-to-see fixed-wing aircraft searching for landmarks or for an airport represent a potential collision hazard. Helicopters often continue normal operations in SVFR conditions, since they are permitted to operate VFR down to conditions where visibility is only 1/2 mile and the aircraft is clear of clouds.
- Flights from one location within a city to another may be facilitated if a simple VHF navigational receiver and/or Automatic Direction Finder (ADF) is available on board the aircraft. The occasional need to fly beyond the normal operating sphere of the vehicle is certainly facilitated with a system which provides navigational guidance.

- The need for flying helicopters under Instrument Flight Rule (IFR) is minimized relative to that for fixed-wing aircraft. Helicopter VFR permits operations under conditions as poor as 1/2 mile visibility and clear of clouds, because the vehicle has hover and extreme slow flight capability. Thus, an IFR capability is usually only useful if operations are anticipated in areas subjected to heavy fog, and then only in order to penetrate the fog to reach VFR conditions on top of clouds, or to leave VFR conditions on top in order to make a landing at a specified location. If cross-country flight in clouds is anticipated as part of the helicopter's mission, then, of course, an IFR capability is mandatory.

Thus, it appears that the minimum level of avionics equipment on board aircraft which fly in and around cities should consist of a VHF communications transceiver and some form of navigational receiver. This level of capability is desirable even if flight is planned in VFR conditions, notwithstanding the fact that such flights may be legally conducted without communications, so long as positive-control airspace is avoided. The communications equipment carried should be capable of operating in all tower-control frequencies and in most approach-control frequencies.

The navigation receiver should drive a simple converter/indicator display, enabling the pilot both to determine his precise position and to navigate to any other position within the range of the ground station. Beyond this minimum avionic capability, any additional avionic equipment, such as a transponder, may be chosen on the basis of the type of operation planned and the degree of sophistication deemed necessary to provide the pilot with a platform adequate to perform his assigned mission.

For police missions, an FM transceiver is needed in the aircraft to communicate with a dispatcher and other ground units. Clearly, the same transducer (microphone, headphone, loudspeaker) would be used for police and for air traffic control communications, thus leading to a requirement for a control panel enabling central control of all avionics equipment. Such a central control facility could be expanded to permit intercommunications between pilots or between pilot and observer (particularly useful in a noisy environment) and could be designed so that each pilot was able to hear both sides of a conversation. Furthermore, ancillary electronic equipment, such as a public address system, could also be centrally controlled.

Thus, avionic configurations may vary in sophistication depending upon missions, local meteorological conditions, and proximity to controlled airspace. General aviation avionics manufacturers have recently moved strongly toward use of solid-state devices and advanced circuit techniques, which have brought prices down, resulting in relatively small and compact packages and greatly increased reliability. For example, single-unit VHF communications transceivers and navigation receivers with 360 communication transceivers (presently adequate for <u>all</u> air traffic control communications) and 200 navigation channels (adequate for <u>all</u> terminal and enroute VHF facilities for the foreseeable future) are literally commonplace. Furthermore, some general aviation avionics equipment has reached levels of sophistication approaching that specified by airlines (but at far lower prices), and the range of equipment available includes every known component which could be needed for any specified mission. It remains only to carefully specify the air vehicle scenario in order to select the proper avionics equipment.

B. Basic Aircraft Avionics

Federal Aviation Regulations (FARs) spell out in detail the equipment which must be carried in VFR and IFR aircraft. The regulations show that an aircraft which will fly only in VFR conditions is required to carry only an Emergency Crash Locator Beacon, an airspeed indicator, an altimeter and a magnetic compass. Gyro equipment is not required since flight will be by reference to the actual horizon. Communications equipment is not required so long as no flights are planned in positive control airspace.

Upgrading to IFR can often be accomplished with relatively minimal equipment additions over that needed for VFR. A gyro panel must be added so that full control of the aircraft can be maintained strictly by reference to instruments. A communications transceiver must be added to make possible flight under conditions of positive control from the ground. A navigation receiver must be added in order that the pilot may determine his position and navigate his aircraft to other specified positions. Under certain conditions this requirement could be waived and navigation performed by the ground-controller vectoring the aircraft. In fact it is even possible to make relatively precise approaches to certain airports under conditions where navigational instrumentation have filed (the so-called GCA (or Ground Controlled Approach). Under these conditions the pilot maintains control of his aircraft by reference to needle-ball-and-airspeed and uses his magnetic compass for heading. The quality of instrumentation and aircraft systems available today is, however, such that these procedures are rarely used and then only under emergency conditions or as part of a training or proficiency-maintenance program.

Some 350 airports in the United States are served by air traffic control towers, and all aircraft using these ports must be capable of two-way radio communications, even though most users do so only under VFR conditions. Additionally, several thousand UNICOM (airport advisory) systems are in use at uncontrolled airports.

Recently, three manufacturers made available simple, low-cost, reliable, solid-state communications transceivers capable of simplex operation on all 360 communications channels in the aircraft band. A unique feature of these radios is that the receiver portion is shared by a navigation function capable of receiving all 200 channels planned for the navigation band. A navigation converter/indicator is included in the same package, thus enabling the pilot to locate his precise position and to navigate as needed from that position to any other position. Such a capability is ideal when strictly VFR flight is contemplated, where simultaneous use of both the communications and navigation capability is not required. This type of transceiver may be applicable in many police air vehicles which operate in and out of controlled airspace but only occasionally require a navigational function. Of course,

several 360-channel communications transceivers without a navigational function are also available. These have the advantage of even more compact packaging and may offer sufficient VHF capability for many police air vehicles. Prices for these NAV/COM sets range from $600 to over $1, 000.

For operations in IFR conditions, the communications transceiver circuitry must be separate from the navigation-receiver circuitry so that these components may operate independently. Thus, a pilot may communicate with air traffic control while continuing to precisely navigate his aircraft. There are available a host of so-called 1-1/2 systems which contain a communications transceiver and separate navigation receiver in a single package. (The NAV receiver in a 1-1/2 system is interrupted when the microphone is keyed, whereas the so called 1 + 1 system eliminates this deficiency, but at additional cost.) A navigation converter/indicator in a separate package is required to present the navigational information to the pilot. A single 1-1/2 system and an accompanying navigation converter/indicator essentially represent the price of entry into the air traffic control system, assuming that the aircraft's panel also contains adequate instrumentation for control without visual references. These prices range from $750 to over $2, 000.

Enroute navigation with a single receiver can be accomplished with relative ease; although, of course, there is no backup capability in case the single receiver fails. In the terminal area, navigation with a single receiver is more difficult. The FAA recognizes this fact by publishing several different approach minima at most airports, in order to account for the level of equipment available in the cockpit, as well as for the availability of ground instrumentation. For example, a localizer approach often requires that the terminal route leading to the localizer course be set on one system while the localizer itself is set on the second system, thus permitting an intercept without ground guidance. Furthermore, a Marker Beacon Receiver is needed to accurately locate critical transition points on the localizer course. Finally, the localizer system may also contain a glide slope and an array of lights just before the touchdown zone.

An aircraft with minimal IFR capability may be required to have the runway in sight from an altitude of 400 feet above the ground, while another better-equipped aircraft approaching the same airport may be permitted to descend to 200 feet above the ground while searching for the runway.

Requirements for flying helicopter IFR are substantially different from those for fixed-wing aircraft. Because of their hover and slow flight capability and their ability to operate safely at low altitudes, helicopters are permitted to operate VFR under conditions where fixed-wing aircraft must operate IFR. Thus, the need for IFR capability in a helicopter is reduced. On the other hand, visibility is not the only pertinent factor involved because, for some missions, it may be desirable or even necessary to penetrate a cloud cover.

The FAA has taken a hard line with respect to helicopter IFR. It considers these vehicles to be basically unstable, thus requiring the pilot's constant attention. In IFR flight, the pilot's attention is often diverted while copying clearances, reading approach plates, studying maps, finding intersections, communicating, and so forth. Thus, the FAA requires that helicopters operating IFR must be equipped with a fully functioning stability augmentation system. Whereas fixed-wing aircraft are certified for IFR operation on the basis of type, most helicopters must presently be certified for IFR operation on an individual unit-by-unit basis. The cost of installing stability augmentation systems, and the effort required to achieve certification, have put a damper on helicopter IFR operations. Stability augmentation may, however, be of considerable importance in police vehicles where some missions require the pilot to divert his attention from flying to surveillance or other matters. Furthermore, such systems also provide a short-term autopilot capability, another positive aspect not to be lightly dismissed.

An indication of the types of avionic equipment required to achieve various levels of aircraft capability is included in Table 4-1. In general, the purchaser has a good choice of equipment from a number of manufacturers. Since manufacturers offer different features on their products, as well as various levels of quality, the installed costs shown in the table are average values for good quality but standard general aviation equipment. The weights shown are relatively low because the equipment is essentially all solid state. Most general aviation avionics on today's market are reaping the benefits of the revolution in electronic technology, so that one finds highly complex systems included in small packages. Consequently, space and weight requirements, which at one time represented a very serious problem in small aircraft, is today only a minor problem.

Table 4-1 does not represent an exhaustive survey of capabilities. For example, one may conceive of even more sophisticated IFR systems, including weather radar (useful if much enroute IFR is planned), fully coupled three-axis autopilots, or additional equipment redundancy. Also, some VFR missions may be greatly enhanced by an area navigation system, permitting straight-line flight from one point to another, possibly a very useful function in police applications. The system most appropriate for a particular vehicle is, therefore, a function of that vehicle's intended mission and must be suitably tailored to that mission.

Table 4-1. Avionics Equipment

Capability	Equipment	Installed Cost $	Weight, #
Minimum VFR	• Single Integrated COM/NAV, 360/200 Channels, Shared COM and NAV Receiver, Converter/Indicator included	1200	6
Good VFR	• Single 1 1/2 COM/NAV, 360/200 Channel • Separate NAV Converter/Indicator	2500	10
Minimum IFR	• Single 1 1/2 COM/NAV, 360/200 Channel • Separate NAV Converter/Indicator • Three-light Marker Beacon RCVR.	3000	12
Good IFR	• Dual 1 + 1 COM/NAV, 360/200 Channel • Dual Separate NAV Converter/Indicator • Three-light Marker Beacon RCVR. • 4096 - Code ATC Transponder	7000	25
Excellent IFR	• Dual 1 + 1 COM/NAV, 360/200 Channel • Dual Separate NAV Converter/Indicator, One With Cross Pointers • Three-light Marker Beacon RCVR. • Glide Slope RCVR. • 4096 - Code ATC Transponder with Altitude Reporting Altimeter • Single Axis (Minimum) Autopilot • Distance Measuring Equipment • Automatic Direction Finder • Central Mixer Control Panel	18000	60

C. Specialized Police Avionics

A major component of the avionics equipment carried in police air vehicles is an FM communications transceiver operating in the two frequency bands set aside for public safety communications. Generally, the number of channels in use at any one time varies from two to ten within these bands; however, one police agency has indicated it can use as many as 29 channels.

Police aerial vehicles have generally been forced to utilize FM communications transceivers designed for use by ground vehicles. Queries to several manufacturers of airborne communications hardware yielded responses to the effect that the current market for police communications transceivers is not sufficiently large, and they, therefore, have no plans for building equipment designed for police use.

At this writing, however, a manufacturer new to the aircraft avionics field has announced the availability of an airborne public safety radio. The fully solid-state device comes in two units, with the panel-mounted module requiring only a small amount of space. Since the radio is designed to operate in an aircraft environment (i.e., high noise, high vibration levels, small enclosed space shared with other heat-producing equipment) it may offer a degree of reliability not presently available in modified ground units. The first model of this radio has 4-channel capability. Its cost is presently unknown but may be expected to be higher than the cost of modified ground equipment, which averages about $1,000 per installed unit.

An important accessory in a police air vehicle is an audio-mixing and equipment-switching unit, designed to greatly simplify the interface between the pilots and the various VHF, FM, public address, and other electronic equipment aboard the aircraft. At least one aircraft-quality mixer has been designed and is presently available for police communications use. In addition to merely aiding the switching between various equipments, the mixer permits one transceiver to be used while several others are being monitored; allows each pilot to hear both sides of all conversations; provides intercom capability between the pilots (a very necessary element in the noisy environments of most police air vehicles); can even channel messages from a ground station into the aircraft's public address system for broadcast through the aircraft's external transducers; and permits the temporary connection of external devices, such as tape recorders, which the pilots may find useful during their tour of duty. Cost and weight of the mixer are moderate.

Several avionics manufacturees have recently made available an airborne telephone system by means of which ordinary telephone calls may be placed through a mobile operator on the ground. Present installed costs of the equipment run from $2, 500 to $4, 500. Weight is under 14 pounds, while the need for such systems in police air vehicles has not yet been established, telephone systems do offer an interesting option for further consideration.

D. Extended Capability Equipment

Electronics can be exploited to provide an extension to human visual acuity. The use of optical systems to gather more light, subsequently

CONTINUED

1 OF 3

magnified, in a video electronic system can greatly extend the visual capability of an observer. Television cameras that are equipped with image-intensifier vidicons or orthicons, or with Secondary Electron Conduction (SEC) tubes, can provide adequate viewing at light levels equivalent to those at starlit scenes. Television cameras are available with tubes designed to operate in daylight conditions, resulting in a system which functions over a very large dynamic range of lighting conditions. Total weight of the camera-gimballing system and viewing screen is estimated to be 40 pounds. Power consumption is on the order of 50 watts. Costs of a system appropriately modified for aircraft installation is estimated to be $25, 000. The same equipment used for ground surveillance tasks under low light level conditions is estimated to cost between $10, 000 and $20, 000, indicating the magnitude of installation costs in aircraft. Systems that operate at higher light levels and, therefore, use more conventional equipment, can be installed in an aircraft at an estimated cost of $10, 000.

Another area in which an extended capability is possible is in the field of data transmission. For example, it may be desirable to transmit the video output from an aircraft television system to a ground station. Technical feasibility of the technology has been established by some commercial television stations which presently transmit data but over restricted geometries. Providing a system that would operate reliably at arbitrary look angles while the aircraft is maneuvering does represent a formidable technical problem in both the airborne and ground station equipment. Bandwidth usage is up about 30 dB over that for a voice channel. Channels allocated for such operations are considerably higher in frequency than voice channels.

Narrow-band digital data transmission can be accomplished on existing police channels with the simple addition of appropriate encoding and decoding modules. Equipment presently under development for mobile use could be adapted to the aircraft environment without a severe penalty in weight or power, since the equipment is being designed with compactness as a goal.

E. Additional Support Equipment

Accessory equipment, designed to support missions such as fire control, rescue, riot control and surveillance, in which police air vehicles may become involved, encompass a very broad range of items. Much of the equipment has not been designed for specific use in, or delivery by, an aircraft. Thus, equipment weight has not been minimized and compact packaging has not been a design consideration. Table 4-2 provides a partial list of accessory equipment, some, or all, of which could on occasion be carried aboard police air vehicles. Because of the accelerating use of air vehicles by police agencies, some of the equipment noted in Table 4-2 is becoming available as specifically designed flight hardware. For example, a number of spotlights specifically designed for the airborne environment have recently come on the market. Furthermore, armour protection is being designed into some air vehicles destined for police use. Clearly, significant additional work needs to be done before a range of airborne accessory equipment becomes generally available.

Table 4-2 . Support Equipment

Function	Accessory
Fire	Water Tank Extinguisher, CO_2 Gas Masks Hand Tool, Axe
Rescue	Litter Life Rafts Life Preservers Oxyacetylene Equipment Resuscitation Equipment Ropes Cargo Net Winch Flares
Riot Control	Armor Protection Riot Gun Semiautomatic Rifle Gas Guns PA System
Surveillance	Spot Lights Low Light Level TV IR Scanner Camera Equipment

CHAPTER V. COSTS OF AERIAL VEHICLE MISSIONS

This section presents a simple and rapid method for defining the costs required to accomplish the aerial tasks of any law enforcement mission. The large number of manufacturers and the variety of products available provide enough statistics, if properly interpreted, to enable reasonable prices to be determined for the equipment required to accomplish any realistic and well-defined mission. Commonly available price data provide suitable boundaries and checkpoints for hardware costs, while a rational technical analysis has been employed to provide the link between mission requirements and hardware. In order for tradeoff analyses to be realistic, consistency is as important as accuracy, perhaps more so. Absolute-accuracy errors can be corrected easily; relative-accuracy errors require going back over all tradeoff calculations.

The method used in this section is to break down and isolate the various cost factors, to indicate what these factors depend upon, and to give representative cost figures to illustrate relative values. Finally, the relationships and quantities derived are used in several examples to illustrate how they may be applied in practice. Where possible, the analytic results are compared with empirical data to indicate the relative accuracy of this approach. As an exercise, the costs of a typical airborne law enforcement mission were derived. The mission was defined as a two-shift, seven-day-week patrol. The costs include the purchase of the fleet, the costs of maintaining and repairing the aircraft, the crew salaries, and expenses. By way of comparison, the exercise was performed twice; once assuming a fixed-wing fleet and again for a helicopter fleet. It should be noted that an optimum fleet configuration may be a mix of these aircraft based upon local conditions and requirements. A summary of the cost data resulting from the exercise is shown in Table 5-1.

Table 5-1. Cost Summary for a Two-Shift Surveillance Fleet

	Fixed Wing	Rotary Wing
Total Hardware Related Costs	$ 64,643	$221,680
Total Salary and Administrative	211,584	213,184
Total Operating Costs	$276,227	$434,864
Vehicle Purchase Costs	$ 42,000	$172,000
Equipment Purchase Costs	60,000	80,000
Total Purchase Costs	$102,000	$252,000
Hourly Rate for Hardware (per flight hour)	$11.08	$37.90
Overall Hourly Rate (per flight hour)	$47.30	$74.40

A. Fixed-Wing Aircraft

1. First costs. For the surveillance-type mission a realistic basis for cost is the "useful-load times complexity factor" parameter for any "class" of aircraft. Each aircraft class has its own characteristic cruise speed, so that speed is not a valid complexity factor unless the specifications require a major deviation (higher or lower) from this characteristic speed.

While the turbine is indisputably the superior power plant for large aircraft, the economic advantage for smaller machines is still in question. This is indicated by the fact that the turbine models have not yet displaced the reciprocating-engine models of smaller size in the commercial market for either fixed or rotary winged types, although they have on all the larger machines. Unfortunately, since most law enforcement operations involve smaller types of aircraft, this power plant problem becomes an important consideration.

For law enforcement work, size and top-speed requirements are not great. The real opportunity for realizing an economic advantage appears to be attained by aircraft specifications that relax the requirements at the lower-speed end of the spectrum. The economics, if any, must be attained by a careful choice of aircraft type and the associated equipment required to fulfill the actual mission. Furthermore, when considering the total spectrum of missions and the practicalities of operating a fleet of mixed vehicles, it should be borne in mind that lowest overall cost is not always attained by the use of the lowest-cost vehicle specialized for a single mission. For low-production vehicles like airplanes, low cost is attained by versatility, which allows a longer production run of a single multipurpose design. Life is also made easier for the fleet owner, who must maintain and operate aircraft, if the number of types is held to a minimum.

With these considerations in mind, a rational pricing system must be devised which correlates hardware quantity and complexity with mission requirements. It should be recognized from the outset that the system may not exhibit as strict a conformity with existing price statistics as would be desired, but this is because manufacturers and sellers of small aircraft do not sell productivity as do the manufacturers of large commercial airliners. Lifewise, the customer does not buy small aircraft on the basis of productivity, else there could not be the spread in general aviation aircraft prices, which gets wider as the size gets smaller.

In the smaller price ranges it is evident that there are many clearly overpriced and many clearly underpriced aircraft. The underpriced aircraft are generally not low in price because of the experience and efficiency of the manufacturer, but they are more often the products of inexperienced manufacturers who have not yet learned their true costs. Time will invariably result in either an increase in price or a bankrupt operation.

As stated previously, capability for the surveillance mission is defined by a productivity that is a function of useful-load and complexity factor(s). The complexity factors in turn represent meaningful refinements applicable to mission accomplishment and may consist of:

- Fuel efficiency (aerodynamic design, cleanliness, speed, etc.)
- Observation capability (low-speed capability, low-altitude safety, smoothness, etc.)
- Emergency rescue capability (hovering, landing, etc.)
- Crew comforts (cabin arrangement, stability, noise, etc.)

In Ref. 3-6 the complexity factor that best allowed costs to be correlated with empty weight was cruise speed. This was true for a given class of aircraft, but a new curve was required for each class and, in that study, four basic aircraft of only three classes were included, each with precisely defined performance characteristics. In this present study the purpose is to determine cost as performance requirements are varied. In other words, an infinite number of aircraft "classes" must be considered and related to each other. "Class" variation is now defined more by the minimum loiter speed capability than by gross configurational differences such as airplanes (can't hover) vs helicopter (can hover). Furthermore, it was desired to relate cost to mission capability (useful load, etc.) rather than empty weight, which does not give proper credit to a lightweight, efficient structure. In order to accomplish this relationship it was necessary to establish single values of empty weight/useful load (EW/UL) ratios for each class of aircraft and to correlate them with the complexity factors. A relatively modern, efficient structure was assumed for all types in choosing a favorable value of EW/UL as represented by values already attained in practice for each type.

The complexity factor was the result of an extensive statistical analysis for determining the basic cost-correlation factors. A number of false leads were followed based on previous studies emphasizing speed as the primary complexity factor. The present approach, by recognizing speed as a basic characteristic of type, isolated complexity factors more pertinent to police applications.

By taking this approach it has been possible to provide a pricing guide that is rational and technically sound and is, therefore, a basis for the buyer and seller to communicate meaningfully regarding the cost of providing a desired capability.

a. The pricing equation. The form for the pricing equation is:

$$\frac{\text{Price}}{\text{EW}} = \$10\left(\frac{\text{UL}}{1000}\right)^{0.15} \text{(Complexity factor)}$$

The value of $(\text{UL}/1000)^{0.15}$ is given in Figure 5-1, while Table 5-2 provides the complexity factor and empty-weight ratios.

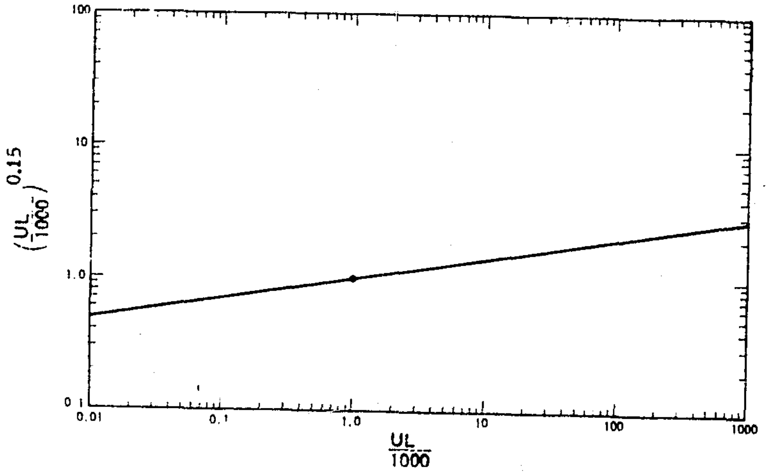

Figure 5-1. $\left(\frac{\text{UL}}{1000}\right)^{0.15}$ Factor

b. Examples of the pricing equation. Several examples of the use of the prior equation and table are:

- Example 1: Twin-turbocharged, piston-engine airplane (one can assume retractable gear and pressurized cabin)

Table 5-2. Complexity and Weight Factors

Basic Aircraft Types (nonjet) & Special Features	Complexity Factor	$\frac{EW}{UL}$	Characteristic Cruise speeds and Factors*
• Austere Sport and Training Airplanes	1.0	1.3	100 to 130 mph
• Standard, Single-Engine, Airplane (Fixed gear, recip. engine)	1.3	1.0	130 to 160
• Basic Rotary Wing Aircraft	5.2	1.0	80 to 120
• Special Features			
Retractable landing gear	1.3	1.12	1.25
Turbocharged Engine(s)	1.13	1.0	1.25 (1.07)*
Twin Engines	1.3	1.25	1.25
Turbine Engines	2.0	0.80	1.20
Pressurized Cabin	1.4	1.15	1.15
Water Takeoff/ Landing	1.0	(1.3 airplane) (1.23 VTOLs)	0.80
V/STOL Capability (nonhelicopter type)	$1+2\left(\frac{V_{\text{min.}}}{50}-1\right)^2$	1.2	1.20

*Characteristic speeds are those typical of today's designs. These can vary. For example, turbocharging and turboprops are usually associated with increased speeds and with cabin pressurization but they could as easily be associated with attaining lower speed flight for V/STOL. Note that turbocharging when added to a single-engine airplane is associated with a significant speed gain (25%) while when added to a twin-engine airplane it adds little (7%) because twin-engine airplanes usually already exhibit a 25% speed increase over single-engine machines.

	Complexity Factor	$\frac{EW}{UL}$
Basic Airplane Factor	1.3	1.0
Retractable Gear	1.3	1.12
Twin engines	1.3	1.25
Turbocharging	1.13	1.0
Pressurization	1.4	1.15
Overall Complexity Factor = (Product of Subfactors)	3.47	1.61

For an airplane of 3000-lb useful load:

$$\frac{\text{Price}}{\text{EW}} = \$10(3.0)^{0.15}\ (3.4) = \$41/\text{lb EW}$$

$$\frac{\text{Price}}{\text{UL}} = \frac{\text{Price}}{\text{EW}} \times \frac{\text{EW}}{\text{UL}} = 41 \times 1.6 = \$66/\text{lb UL}$$

$$\text{Price} = 66(3,000) = \$200,000$$

These figures can be compared to the Piper "Pressurized Navajo", a twin-engine, pressurized, piston aircraft with a retractable landing gear and a useful load of 2,900 pounds. It sells for $216,000.

- Example 2: STOL Airplane, Single Recip Engine, UL = 1000, Minimum flying speed = 40 mph

$$\text{Complexity factor} = 1.3 \times \text{V/STOL factor}$$

$$\text{V/STOL Factor} = 1 + 2\left(\frac{40}{50} - 1\right)^2$$

$$= 1 + 2\ (1.2)^2$$

$$= 1 + 0.08$$

$$\text{Complexity factor} = 1.3 \times 1.08 = 1.4$$

$$\text{Price/EW} = \$10(1)\ (1.4) = \$14.0/\text{lb EW}$$

$$\text{Price/UL} = \$14.0 \times 1.2 = \$16.80/\text{lb UL}$$

$$\text{Price} = \$16,800$$

This corresponds to the Maule M-4 220C Strata-Rocket which has a useful load of 1,050 pounds, a minimum control speed (MCS) of 40 mph, and sells for $16,495.

The method derived herein may be used to define an approximate should-cost figure for heavier-than-air craft that is quite suitable for planning purposes and for judging the relative values between offerings from various manufacturers.

The vehicle itself represents only the platform. The mission is accomplished by the personnel and equipment carried by the platform, and mission requirements continuously become more demanding. This situation will continue to get worse, with the result that equipment will be routinely modernized, updated, or replaced as necessary either to relieve a problem or to improve capabilities. As air traffic becomes more dense, and as more police missions are attempted in inclement weather, the navigation and stabilization requirements are also likely to increase, bringing a concurrent increase in the variety, complexity, and cost of the installed equipment. It is not unusual for present police aerial vehicles to have a complement of special police mission equipment costing (mostly in the form of communications gear) in excess of $20,000. Within 10 years the typical value will probably be closer to $50,000.

2. Operating costs. Vehicle maintenance, equipment maintenance, facility acquisition and maintenance, crew costs, and administrative and supervision costs are discussed in this section. An example is given wherein annual costs are estimated for setting up an operation to fly two 8-hour shifts 7 days a week.

a. Vehicle maintenance. The primary cost of maintaining any vehicle is associated with the power plant and the power train (in other words, the moving parts). These are subject to constant wear and result in the primary costs; while the static structure generally enjoys a relatively long, trouble-free life (accidents, excepted).

The life of a wearing part (e.g., an engine), is determined by the severity of its use, and the FAA establishes the TBOs (time between overhauls) on actual experience of a particular engine in a particular airframe observed over a period of time. In the beginning, for example, an engine may be allowed only a 600-hour life. But, if the service experience is good, this may be gradually increased to, say, 1,200 hours or more.

Police operations are not too often subjected to a heavy dust environment, so the lives of mechanical parts are more a function of the mode of operation than of geography. The establishment of TBOs by FAA involves surveillance of a piece of equipment over a period of time by

a number of users. In general, a TBO is established for the entire community of users, since it would be difficult to differentiate the careful user from the careless operator who "pushes" his equipment. A credit might be given to the careful user with a creditable service record, but only in the case of a fleet operation large enough to establish a statistical base. This is not presently the case for police operations, and the police will have to rely on data compiled by other general aviation users of similar equipment. There is a significant cost saving to be made for the major percentage of all police operations, if a truly "typical" police operation were to be defined for any particular type of aircraft. If the police operation, which is basically surveillance, can be shown to represent a "loafing" operation compared to those of other users, then the TBO for police operations might be extended. If patrol car experience were an indicator of the severity of police aerial vehicle usage vs other fleet usage (which it is not), just the opposite field experience would be expected, and police operators would be required to pay a penalty in maintenance costs.

The point to be made is that the police mission involves a considerable amount of loitering; and, if the engine and other wearing parts were to be given credit for operating primarily at the 50-percent power setting, the maintenance cost factors could be reduced, depending on the wear-rate characteristics. On the other hand, if police operations required a considerable amount of time at higher or very low-speed flight, or in high-speed pursuit where maximum power is required, engine life might be reduced to the extent that the maintenance cost factor would be increased. Since a complete police operation involves mixtures of both mission modes, the effect on maintenance life is impossible to predict without obtaining considerably more operational data from the field. Even then, a close similarity must be established between the operations of various law enforcement agencies before the basis can be found for a ruling that would make TBOs for police operations differ from those observed in general aviation as a whole.

Direct operating costs including fuel, oil, inspection, maintenance, and overhaul have been reported by manufacturer's representatives as follows:

Sky Sentinel:	\$8.68/hour
Cessna Skyhawk:	\$6.46/hour
Maule M4-210:	\$7.48/hour

These figures are approximate and highly dependent upon items such as fuel costs, which are quite variable. For budgetary purposes an average figure of \$7.54/hour is reasonable.

b. Equipment maintenance. Equipment maintenance costs will differ somewhat from vehicle maintenance costs, in that there will be a more continuous updating of equipment accomplished as an integral part of the maintenance program. In fact, if private light-airplane experience is valid, the vehicle maintenance will take the form primarily of replacement of worn parts and secondarily of updating parts (correcting deficiencies);

whereas, in the case of the instruments and electronic equipment, updating costs may equal or exceed the required maintenance.

While the situation may exhibit extreme variations between police operations, equipment updating cannot be ignored as a real cost. For a lack of a better way to handle the situation, and because it is a gradual process, this upgrading has been included in equipment maintenance. A modest amount of updating would increase this to \$50/lb/year.

For 50 pounds of specialized police radio gear, therefore, one should expect an annual cost of something on the order of \$2,000 to \$2,500. Reduced to an hourly operating cost it may be assumed that:

$$\text{Equipment cost} = \$1/\text{hour operation} \tag{1}$$

Other classes of equipment probably will involve less maintenance than electronics. This statement is made on the basis of present knowledge and experience, however, and there is nothing to preclude the development of some novel, highly effective (and expensive), specialized police gear for aerial vehicles which would be fully as sophisticated as any electronic gear.

The point to be made is that the specialized equipment is no less important to mission accomplishment than the vehicle itself, and its maintenance requirements are not insignificant. The trend is certainly in the direction of more capability, and it is difficult to imagine any capability improvement which will not have an impact on the maintenance situation.

c. Hangar rent. While hangar rents vary widely with size and value of aircraft, a representative figure is:

$1,000 per aircraft per year (2)

d. Depreciation. The present conventions appear to be as follows:

Fixed-wing 5 years 50-percent Residual (3)

e. Insurance: (hull and liability). Fixed-wing insurance rates presently approximate 5 percent for hull insurance and $100 per seat for personal liability and public damage. As a rule of thumb, one can assume a yearly cost of about 6 percent of the new value of the aircraft as the total insurance expense for a fixed-wing aircraft. Typical premiums would be $1,200 to $1,500 per year for a four-place STOL.

f. Spares inventory. Were factory delivery of spares to be immediate and reliable, there would be no need for an inventory. But this is not the case, and the lack of immediate spares can result in very high costs of extended downtimes, of maintenance personnel waiting around for parts, of reduced aircraft availability, and of missions not undertaken. At the very least, complete replacements for known-life units (engines, gearboxes, etc.) should be ordered and available well before replacement is scheduled.

For a single aircraft the spares inventory should represent probably 50 percent of the cost of the ship; while, for a 10-ship fleet,

this may safely drop to an average of perhaps 10 or 15 percent and still have most emergencies adequately covered.

Until a spare part is used, it is not charged to maintenance. On the other hand, it should not be kept in stock long enough to suffer depreciation as does a complete aircraft. The most logical approach is to consider spare parts as prepurchased maintenance with the cost showing up as the interest on their monetary value until that part is transferred to maintenance. At that time it will be charged to maintenance (but replaced with new spares from the manufacturer).

On this basis, the cost of maintaining spares will be simply the interest rate times the percentage of the value of the vehicle maintained in spare parts. A schedule has been chosen running from 50 percent spares for a 1-ship fleet to 10 percent spares for a 10 (or more)-ship fleet to determine the annual costs for spares maintenance shown in Figure 5-2. For example, a 1-ship fleet consisting of a $30,000 aircraft would require an annual spare parts cost of $1,500 if a 10 percent interest rate were assumed. If the fleet consisted of 10 aircraft the cost would be:

1% × $30,000/ship × 10 ships = $3,000

g. Facility acquisition and maintenance. Requirements for this item are a function of the size and characteristics of the territory being covered by the vehicle. In a small city, with a local airport, this expense may be zero, since the aircraft will always operate from the home airport.

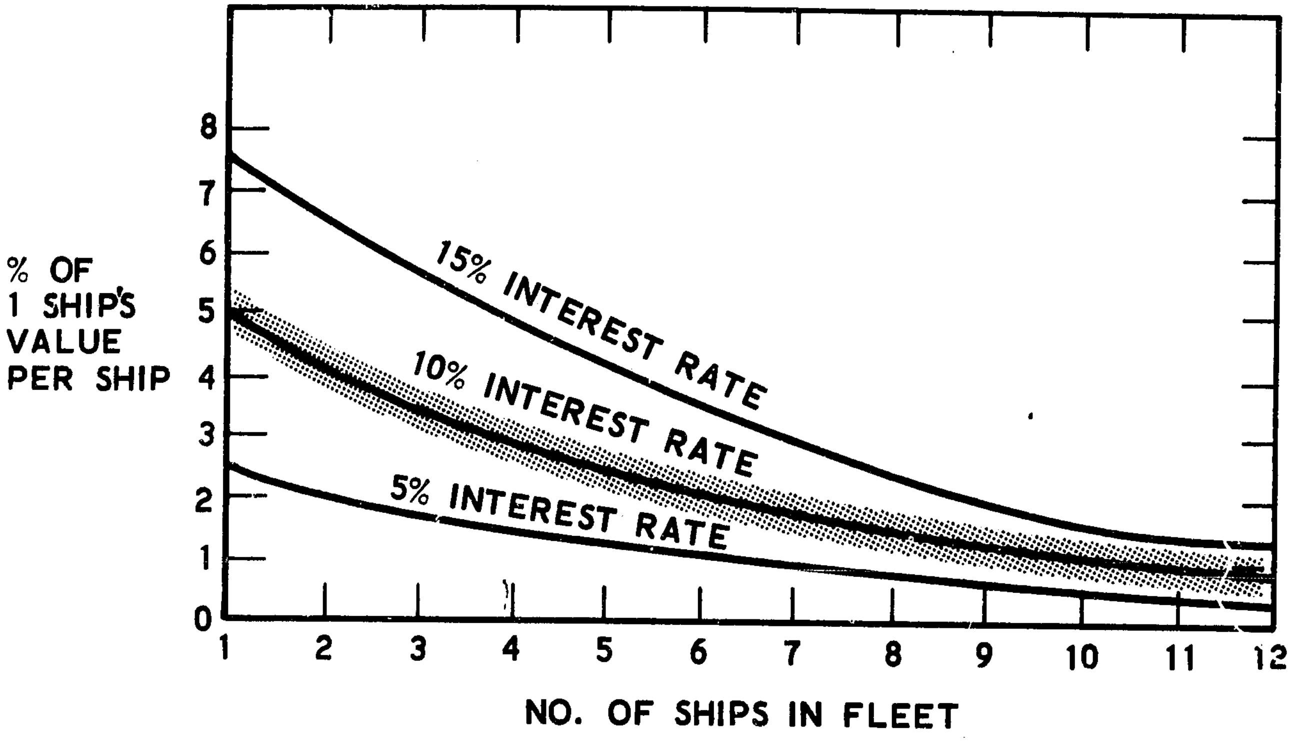

Figure 5-2. Annual Cost of Spare Parts Maintenance

Needs vary so much from situation to situation that it would be difficult to define one that is typical. Instead, it has been assumed that each aircraft in a system (regardless of type) will generate the need for one remote landing and/or fueling facility:

Facility Cost = $1,200/year (4)

(including acquisition, rent, improvement, etc., as the case may be).

h. Crew costs. Personnel annual salaries are assumed as follows, based on a 40-hour week:

Patrolman	$10,500/year
Sergeant	$14,500/year
Lieutenant	$15,500/year
Clerk	$5,000/year

Direct crew costs cover annual salaries for the pilot and one or more observers. Pilots and observers will be considered on the patrolman level, but the pilot's position will carry a skill premium of approximately 15 percent.

Pilot	$12,500/year
Observer	$10,500/year

One full shift, 365 days per year, totals 2,920 hours; but, since a flight crew member typically flies four hours per day and typically works 220 days per year, or 1,760 hours (accounting for holiday, sick leave, etc.), he flys only 880 hours per year. This means that each crew position requires 2,920/880 = 3.3 men to accomplish full manning for one full shift (administration, supervision, and fringe benefits are assumed to be part of indirect, or fixed, costs).

Costs for a two-man crew (one pilot and 1 observer) amount to the equivalent of 3.3 (1.15) + 3.3 = (3.8 + 3.3) = 7.1 patrolmen; for a three-man crew (two observers) the cost would equal (7.1 + 3.3) = 10.4 patrolmen, etc.

Since fractional men are difficult to schedule, a police department maintaining one aircraft in the air during a single 8-hour shift all year long would require four pilots and four observers. (Of course, it must be assumed that 2 or 3 aircraft are available, depending upon whether one assumes a 1,460-hour or a 973-hour annual utilization capability).

On the basis of the salaries quoted for pilots and observers, the hourly costs are shown in Figure 5-3.

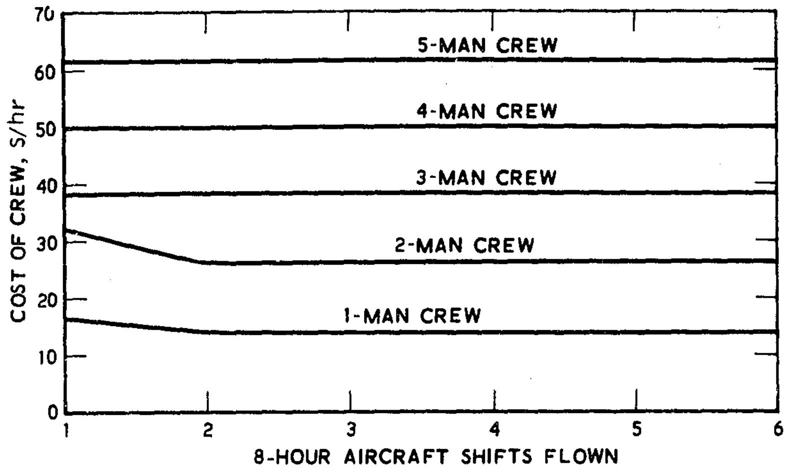

Figure 5-3. Crew Requirements

i. Administration and supervision. While the organizational arrangement will vary from operation to operation, and some operations require the pilot himself to have sergeant rank, it will be assumed that the supervision of an aerial operation will reflect the salary of a ground patrolman (each patrolman requires 1/8 of a sergeant and 1/16 of a lieutenant) on the basis of the salaries presented under Crew Costs. This amounts to an additional

$$\frac{14,500}{8} + \frac{15,500}{16} = \qquad (5)$$

$$1,810 + 970 = \$2,780/\text{crew member}$$

For a two-man crew, the cost per full 8-hour shift, 365 days per year will require approximately 1.7 times the above cost per crew member (to account for time off, vacations, sickness, etc.)

$$\text{Supervision} = \$2,780 \times 1.7 = \$4,830/\text{year}$$

Figure 5-4 provides the Administration and Supervision costs for various crew sizes.

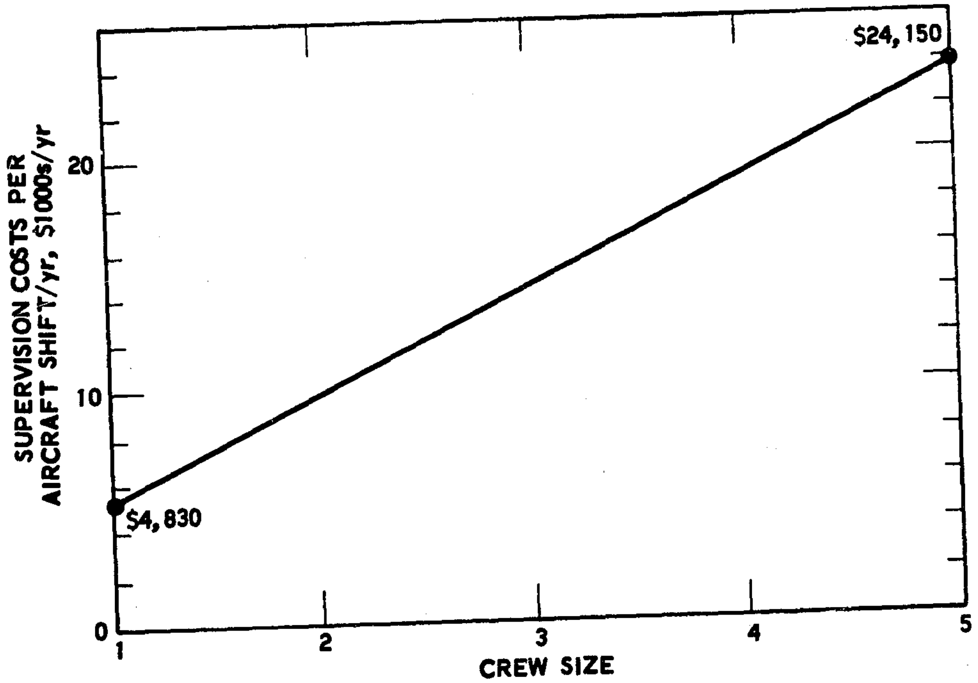

Figure 5-4. Supervision Costs per Aircraft Shift/Year

In addition to this overhead expense, each aircraft in the fleet will generate enough need for typewritten reports, records, etc., as to require at least 1/5 the time of a clerk typist:

$$\text{Clerk/Typing Cost} = \$1,000/\text{aircraft/year} \qquad (6)$$

Added to the foregoing, the total cost of administration and supervision will be:

$$\text{Adm. \& Super. Cost} = \$4,830 \text{ per crew member} + \$1,000/\text{aircraft/year} \qquad (7)$$

(1) Fringe benefits. Personnel requirements were established to cover full shifts, 365 days per year, taking into account vacations, time off, sick leaves, holidays, etc. While such items are generally charged to fringe benefits, these costs have already been covered by the cost of the extra crew-member requirements. The fringe benefits to be covered here are thus restricted to those not represented by lost working time, including retirement plans, health insurance, etc. These presently average approximately 20 percent and must be included not only for the crew members but for the administrative and supervisory personnel.

(2) Office costs. These include office, rent, furniture, light, heat, telephone:

$$\text{Office} = \$1,200 + 400 \times \text{number of aircraft in fleet} \qquad (8)$$

- Example. This example estimates the costs of setting up an operation to fly two 8-hour shifts 7 days a week, year-round (5,840 flight hours). The example is for a single-engine, piston-powered airplane (moderate STOL capability with kit).

- Useful load shall consist of:

Crew (2 @ 200-lb each)	400 lb
Special Equipment (primarily electronic communications gear)	50 lb
Fuel (2 @ 400-lb each)	400 lb
Total	850 lb

- First Cost

Complexity factor: 1.4

$$\text{Price/EW} = \$10 + \left(\frac{850}{1000}\right)^{0.15} \times 1.4 = \$13.65/\text{lb}$$

$$\frac{EW}{UL} = 1.2$$

$$\text{Price/UL} = \$13.65 \times 1.2 = \$16.40/\text{lb}$$

$$\text{Price} = \$14,000$$

This price could be compared with that of the MAULE M-4 220C, which is $16,495. This aircraft has a useful load of 1,050 pounds.

The flying schedule will require three fixed-wing ships to provide coverage: assuming one ship in the air, one ship on the ground for daily inspection and maintenance, and one ship in major overhaul or as backup.*

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*It is reasonable to assume that a well-run maintenance program would accomplish this mission with two aircraft, and such operations have been reported. In this context the estimates made are conservative.

- First Cost: Airplanes $42,000
- Equipment: (3 ships) $60,000
  (approximate)
- Operational Costs (Direct)
- Vehicle Operation: $7.54 × 5,840 = $44,033/year
- Equipment Maintenance and Modernization:

  From Equation 6: 5,840 hr × $1/hr = $5,840
- Hangar Rent:

  $1,000 × 3 = $5,850
- Depreciation:

  $$\frac{0.50 \times 42{,}000}{5} = \$4{,}200$$
- Insurance: $42,000 × 0.06 = $2,500
- Spares Inventory:

  From Figure 5-2: (assume 10% interest rate) 0.035 × $42,000 = $1,470
- Facility: $1,200 × 3 ships = $3,600
- Crew Costs: From Figure 5-3: Salaries:

  $26 × 5840 = 152,000/yr
- Supervision:

  Supervisor: $9,660 × 2 shifts = $19,320
  Clerk: $1,000 × 3 ships = $ 3,000
  Total $22,320

- Fringe Benefits: (20% total salaries)

  Fringes = ($152,000 + 22,320) × 0.20
  = $34,864
- Office Costs: From Equation 10:

  1,200 + (400 × 3) = $2,400

Total operational costs are summarized in Table 5-3.

Table 5-3. Operational Costs for a Two-Shift, Fixed-Wing Fleet

Vehicle Operation	$ 44,033	
Equipment Maintenance	5,840	
Hangar	3,000	
Depreciation	4,200	
Insurance	2,500	
Spares Inventory	1,470	
Facility	3,600	
Total Hardware-Related Costs		$ 64,643
Crew Costs	$152,000	
Supervision	22,320	
Fringe Benefits	34,864	
Office	2,400	
Total Salary and Administrative		$211.584
Total Operational Costs		$276,227

The total cost would correspond to a rate of $47.30 per flight hour.

B. Rotary Wing Aircraft

1. First costs. Table 5-2, page 87 , lists the basic aircraft complexity factor for a helicopter as 5.2, as compared to 1.3 for a standard fixed-wing aircraft. This difference is due to the fact that, for a given useful load, a rotary wing aircraft costs three to four times as much as a fixed-wing aircraft.

One of the most important reasons for this price difference is the higher cost of helicopter transmissions. The helicopter probably represents one of the most difficult of all power-transmission problems in the fact that high power is required at relatively low rotational speeds. High power at low speed defines high torque, and high torque in a mechanical transmission requires large, heavy gears. In addition, since every action has an equal and opposite reaction, the shaft torques must be reacted. This requires either a tail-rotor system for the shaft-driven helicopter or alternate designs with two oppositely turning main rotors. These have not found much favor except for special applications.

A gas turbine employed to drive the rotor turns tens of thousands of r.p.m. , while useful rotor speeds are on the order of several hundred r.p.m. Gear ratios of the order to 100:1 are common, and gearing required includes both high-speed/low-torque stages and low-speed/high-torque stages--all high-precision gearings and all very expensive.

Light helicopter transmissions will weigh from 1/4 to 1/2 pound per horsepower transmitted and will cost $8 to $15 per horsepower. A

200- to 300-horsepower helicopter will thus have $3,000 or more in its transmission system, and this constitutes a major contribution to its high initial cost. Add to this the fact that maximum gear life is only 1,000 to 1,200 hours and it can be seen that the gearbox is also a major contributor to operating costs.

The pricing equation can be used to relate cost to capability for helicopters in the same manner as for fixed-wing aircraft. As an example, consider a useful load of 1,000 pounds for a piston-powered helicopter.

$$\text{Complexity factor} = 5.2 \times 1.0 = 5.2$$

$$\text{Price/EW} = \$10(1.0)^{0.15}(5.2) = \$52.00/\text{lb EW}$$

$$\text{Price/UL} = \$42.0 \times 1.0 = \$52.00/\text{lb UL}$$

$$\text{Price} = \$52.00 \times 1{,}000 = \$52{,}000$$

These figures can be compared with the Bell 47G-5A, which has a useful load of 1,162 pounds and costs $53,350.

Equipment for communication, navigation, etc., will be similar for the rotary and fixed-wing aircraft and can be assumed to cost about $20,000 per aircraft at the present time.

2. Operating costs. Operating costs for rotary wing aircraft include vehicle and equipment maintenance, hangar rent, depreciation, insurance, spare parts, facilities, crew and administrative salaries, fringe benefits, and office costs. An example is given in this section of methods and costs for providing helicopter coverage for two 8-hour shifts per day, 7 days per week on a year-round basis.

a. Vehicle maintenance. Low-performance aircraft structures (such as those used in law enforcement applications) have essentially infinite lives; however, high-performance aircraft, including helicopters, have several items of critical "static" structure that may be subjected to high enough fatigue loads as to result in a finite life. There is at least one case where the installation of a better inlet-air filter doubled the life of a helicopter engine. The same engine type in an airplane was attaining a 1,200-hour life. In the helicopter, however, which spent a large percentage of its time near the ground under dusty conditions, the engine was experiencing a 600-hour engine life, until the filter was installed. This dust-erosion condition has been particularly severe for turbine engines on military helicopters required to operate from unprepared surfaces. Furthermore, since the turbine engine takes in more air than the piston engine, it is more difficult to provide it with a suitable filter. The weight, size, and cost become significant.

In general, direct operating costs for helicopters appear to run about three to four times the cost of a fixed-wing aircraft of comparable useful-load capacity. Some reported figures are as follows:*

Hughes 300 C:	$25.22/hour
Bell 47G-5A:	$29.83/hour
Bell 47G (LAPD)	$30.49/hour
Bell 206A (LAPD)	$44.29/hour

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*R. E. Ropelewski, "Police Find Helicopters Effective," Aviation Week and Space Technology, July 17, 1972.

b. Equipment maintenance. Since the basic equipment costs were assumed to be the same for fixed and rotary wing aircraft, the equipment maintenance costs will also be the same (i.e., about $1 per hour of operation).

c. Hangar rent. A representative figure for hangar costs is $1,000 per aircraft per year.

d. Depreciation. Based on a 30 percent residual value, depreciation for rotary wing aircraft was estimated on a 5-year basis.

e. Insurance. Helicopter insurance runs 15 percent for hull and liability. The hull insurance is the overwhelming insurance item, and one may assume such values as:

$$\text{Helicopters} = 15\% \text{ of new value of aircraft} \qquad (9)$$

Typical premiums would be $6,000 to $8,000 per year for a three-seat, piston-engine helicopter.

f. Spares inventory. Spares inventory for helicopter fleets conform to the same rules that apply for fixed-wing and can be described by Figure 5-2, page 96.

g. Facilities. For most helicopter operations, the minimum cost will be for a heliport and a simple fueling system at the home base (police department, city hall, etc.). Frequently, remote heliports and refueling systems will be required if the territory is large and if such intermediate refueling stops can save expensive returns to the home base.

As an estimate, a facility cost of $1,200 per year for each aircraft is reasonable. This is a rather high estimate in the case where a police helicopter can share the use of a public heliport, but it would be a low estimate where a special landing area is required.

h. Crew costs. Flight crew requirements and costs can be considered independent of the type aircraft flown. Hence, the costs can be related to mission time requirements as shown in Figure 5-3, page 98.

i. Administrative. Administrative and Supervision costs are related to crew size, as shown in Figure 5-4, page 99. When combined with clerical costs the following relation can be used:

Administrative and Clerical = $4,830 per crew member
+ $1,000 per aircraft per year

j. Fringe benefits. These costs are estimated at 20 percent of personnel salaries.

k. Office costs. $1,200 + $400 × N where N = number of aircraft in fleet.

- Example. This exercise illustrates the methods for developing cost estimates for providing helicopter coverage on a two 8-hour shift, 7-day week on a year-round basis. A useful load of about 850 pounds will be assumed for a piston-engine helicopter.

$$\text{Complexity factor} = 5.2 \times 1.0 = 5.2$$

$$\text{Price/EW} = \$10(0.85)^{0.15}(5.2) = \$50.80/\text{lb}$$

$$\frac{EW}{UL} = 1.0$$

$$\text{Price/UL} = \$50.80 \times 1.0 = \$50.80/\text{lb}$$

$$\text{Price} = \$50.80 \times 850 = \$43,000$$

The Hughes 300C with a useful load of 861 pounds has a price of $42,000.

The flying schedule will require 5,840 flight hours per year. Since 1,500 hours per year appears to be the maximum a helicopter can be expected to fly, the schedule indicates a fleet requirement of four ships. The first cost will therefore be:

$43,000 × 4 = $172,000

Equipment costs will be:

$20,000 × 4 = $80,000

Operational costs will be:

Vehicle Operation: assume $25.00/hour

$25.00 × 5,840 = $146,000

Equipment Maintenance

5,840 hrs × $1/hr = $5,840

Hangar Rent

$1,000 × 4 = $4,000

Depreciation

$$\frac{0.70 \times 172,000}{5} = \$24,080$$

Insurance

$172,000 \times 0.15 = \$25,800$

Spares Inventory. Assume 10% interest rate.

$0.03 \times 172,000 = \$11,160$

Facility

$\$1,200 \times 4$ ships $= \$4,800$

Crew Costs

Salaries $\$26 \times 5,840 = \$152,000$

Supervision

Supervisor $\$9,660 \times 2$ shifts $= \$19,320$
Clerk $\$1,000 \times 4$ ships $= 4,000$
$23,320

Fringe Benefits: (20% of total salaries)

$(152,000 + 23,320) \times 0.20 = \$35,064$

Office Costs

$\$1,200 + (\$400 \times 4) = \$2,800$

These costs are summarized in Table 5-4 and can be expressed as approximately

$$\frac{\$423,864}{5,840} = \$74.40\text{/flight hour.}$$

Table 5-4. Operational Costs for a Two-Shift Rotary Wing Fleet

Vehicle Operation	$146,000	
Equipment Maintenance	5,840	
Hangar	4,000	
Depreciation	24,080	
Insurance	25,800	
Spares Inventory	11,160	
Facility	4,800	
Total Hardware-Related Costs		$221,680
Crew Costs	$152,000	
Supervision	23,320	
Fringe Benefits	35,064	
Office	2,800	
Total Salary and Administrative		$213,184
Total Operating Costs		$434,864

The total cost would correspond to a rate of $74.40 per flight hour.

In 1971 the Los Angeles Police Department reported a value of $69.20/flight hour for their helicopter operation (based upon 14,543.8 flight hours). In 1972 the corresponding figure was $95/flight hour. The increase was due in part to: the addition of more expensive, turbine-powered helicopters; the transfer of observer and maintenance personnel to the helicopter section; general inflation effects.

C. Remotely Piloted Mini-Blimp (RPMB)

Because the RPMB is unique, and there is no historical data or organizational background (except military), a representative case was chosen for illustration purposes.

Direct operating costs were estimated on the basis of operating four RPMBs on a 16-hours/day basis, 365 days/year. It was assumed that 1.5 man/shift would be required for actual vehicle operation and an 0.5 man/shift for ground handling, etc. Thus, two men would be continually assigned to the RPMB operation each shift. At a burdened labor rate of $16.00/man hour, the labor cost is $186,880/year. This comes out to about 5.6 man-years and provides 23,360 blimp-hours. Hull insurance, maintenance, and fuel were estimated at $3/blimp-hour, giving a total of $70,080. The total direct operating cost over the year was then found to be $257,000 for the entire operation, or roughly $11.00 per blimp per hour.

To compute capital costs per hour, the same operating schedule was used. It was assumed that 6 blimps (2 spares) would be purchased at

$40,000 per blimp,[*] along with 6 docks at $2,000 each, and a complete ground station at $30,000, giving a total capital investment of $282,000. Assuming that the investment is amortized over a period of 5 years, with no residual value, this works out to a capital cost (for operating an hour) of about $2.40/RPMB-hour. Note that blimp operation and maintenance plus capital cost alone, excluding operating personnel, amounts to $5.40/blimp-hour.

Thus, the total operating cost will be about $13.40/RPMB-hour. It should be noted that this amounts to a total operating cost for <u>all four</u> RPMBs of $312,000/year for 16-hours/day surveillance.

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[*] According to the vendor, in production this number would correspond to a first-class equipment package. Prices could be as low as $30,000/unit, depending on options.

CHAPTER VI. SAFETY

A. Fixed-Wing Aircraft

1. Accident records. An accident is considered a situation in which a person (or persons) suffers death or serious injury or in which the aircraft receives substantial damage. "Aircraft destroyed" accidents involve complete loss of the aircraft; casualty, as used in this analysis, is defined as anyone receiving injury as a result of the aircraft operation.

Since the objective of the study was to evaluate hazards to the general public, it was necessary to limit consideration to those accidents occurring in off-airport areas. Crashes at airport or landing-field areas were assumed to not affect the general public. A review of accident location data for general and commercial aviation indicated the following percentage of accidents occurred away from airports in 1968:

	General Aviation	Commercial Aviation
All Accidents	50%	58%
"Aircraft Destroyed" Accidents	90%	80%

Historical data are shown in Table 6-1 for general aviation and commercial aviation for the years 1968 through 1971. The data show relatively constant accident rates for general aviation and a downward trend for commercial aviation.

Table 6-1. Aircraft Accident Statistics

General Aviation (All Operations)	1968***	1969*	1970**	1971**
Aircraft Hours Flown	24,053,000	25,351,000	26,000,000	26,400,000
Accidents				
Total	4,968	4,767	4,640	4,686
Fatal	692	647	622	651
Accidents/100,000 hours				
Total	20.6	18.8	17.8	17.8
Fatalities	2.90	2.55	2.39	2.47
US Air Carrier (All Operations)				
Aircraft Hours Flown	6,400,000	6,612,000	6,470,000	6,210,000
Accidents				
Total	71	63	55	47
Fatal	15	10	8	8
Accidents/100,000 Hours				
Total	1.109	0.953	0.850	0.757
Fatalities	0.234	0.151	0.124	0.129

* Reference 1-31
** Reference 1-32
*** References 1-33 and 1-34

Additional data are provided in Table 6-2 for general and commercial aviation and for the Air Force. The 1968 data, used in this analysis because of its availability and better definition of accident statistics by aircraft type, are considered representative of the current and near-future situations.

Table 6-2. Aircraft Accident Statistics Fixed-Wing Aircraft 1968

	General Aviation*	U.S. Air Force**	Commercial Aviation (U.S. Air Carrier)***
	Small Fixed Wing Aircraft	Utility Aircraft	All Aircraft
Hours Flown	23,314,932	544,869	6,486,252
Total Accidents	4,621	34	69
Aircraft Destroyed Accidents	1,040	22	14
Accidents/100,000 Hours Flown			
Total	19.82	6.24	1.06
Aircraft Destroyed	4.46	4.04	0.22

* Reference 1-34
** Reference 1-35
*** Reference 1-33

Using these data, the number of off-airport accidents per year which can be expected from flight operations required to maintain one aircraft airborne on an around-the-clock basis were calculated. The results of this calculation are shown on Line 3 of Table 6-3 for Commercial and General Aviation. Air Force statistics were not included since they are within the values defined by Commercial and General Aviation.

Table 6-3. Hazard Summary Based on "Aircraft Destroyed" Accidents for Fixed-Wing Aircraft

	General Aviation	Fixed Wing
1.	Number of "Aircraft Destroyed" Accidents/ 100,000 hours	4.46
2.	% Accidents "Off-Airport"	0.90
3.	"Off-Airport" Accidents/100,000 hours	4.01
4.	Average Casualty Expectation per accident	0.063
5.	Casualty Expectation per Fixed Wing Aircraft per year	0.022

Line 3 of Table 6-3 indicates the "Aircraft Destroyed" accident rate for manned aircraft. In general, the contributions of the pilot to the accident situation are those associated with (1) his actions which cause or contribute to the hazardous situation and (2) his actions which prevent an incident from becoming a hazardous situation or which ameliorate the effects if a hazardous situation occurs.

It is known that a substantial part of the accidents involve the pilot (errors or related factors). However, it is also apparent that the on-board pilot can contribute in many ways to avoiding potentially hazardous situations through his experience, sensory perception, etc. These capabilities cannot be duplicated by any mechanical system. No basis could be established for quantitatively evaluating the difference in this respect that might exist for a manned vs an unmanned system; therefore, it was assumed for this analysis that there would be no significant difference.

Other studies have indicated the pilot's effectiveness in avoiding losses of aircraft after a hazardous situation develops. Reference 1-36 indicates that the pilot's effectiveness in this respect varies from about 30 percent to more than 90 percent. This effectiveness will certainly vary with the pilot's capability and training.

The hazard in terms of the expected casualties was evaluated assuming that each of the accidents resulted in a crash with a random-impact location. The casualty expectation is the average number of people who would be a casualty as a result of the crash. It is a function of the population characteristics (i.e., population density in the area of interest) and the vehicle characteristics. One characteristic of interest is the vehicle's physical size, since this is related to the land area directly affected by the impact of the vehicle (or its debris). This area is called the casualty area, and a value of 1,000 square feet was estimated for small aircraft.

In this analysis, the hazard was evaluated only for persons who are considered to be unprotected from impacting objects by structures, etc. In this connection, Western Test Range (WTR) Safety estimates that, on an average, approximately 920,000 people in Los Angeles out of a total 2,478,000 would be unprotected. Using these data, the average unprotected population density for Los Angeles is 2,340 persons per square nmi based on an area of 393 square nmi.

If it is assumed that the aircraft (casualty area: 1,000 sq. ft.) impacts at random in the area of interest with its average population density of 2,340 persons per square nmi, the casualty expectation would be:

$$\frac{2,340 \text{ persons/nmi}^2 \times 1000 \text{ ft.}^2}{37,000,000 \text{ ft.}^2\text{/nmi}^2} = 0.063 \text{ persons}$$

Thus, in any aircraft accident in Los Angeles, it can be expected that an average of 0.063 persons on the ground will be injured. It should be noted again that the casualty expectation is an average value; in reality, there is some chance that the crash will occur in an area where there are no people, and there is some chance that it will occur in a very congested area and affect many people. (See Appendix B for a detailed hazard analysis.)

The casualty expectation associated with keeping one vehicle airborne on an around-the-clock basis is:

$$4.01 \times 10^{-5} \text{ accidents/hour} \times 8760 \text{ hours/year} = 0.35 \text{ accidents/year}$$

$$0.35 \text{ accidents/year} \times 0.063 \text{ casualties/accident} = 0.022 \text{ casualties/year}$$

2. Operational safety factors. The greatest single cause of fatal and serious aviation accidents is the loss of lift and control (the stall). This loss of aerodynamic pressure on both lifting and control surfaces has been responsible for more fatal "pilot error" accidents in commercial and general aviation than any other single cause.[*]

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[*] The recent crash of a Trident in the United Kingdom was caused by the pilot retracting flaps prematurely after takeoff, thus causing a stall. Such stall accidents are even more frequent in general aviation.

As one reviews FAA accident reports and statistics, the all-too-frequent commentary is "pilot failed to maintain sufficient flying speed." The accident is then conveniently attributed to "pilot error." While these conclusions are partly true, one might ask the fundamental question. "Is it possible to design an aircraft type which removes the stall condition and, thereby, eliminates this primary cause of serious accidents?" The clue can be found, partially, in a review of FAA statistics. These statistics show that the stall and resulting accidents are associated solely with the fixed wing.[†]

The majority of these fixed-wing stalls occur during approach, departure, or when the pilot is loitering at low altitude and low speed. It is understandable since the pilot during these types of operations is, in fact, in a contradictory condition. He is trying to decelerate for touchdown or to avoid overshoot (or attempting to fly slowly for better observation or surveillance) while trying to maintain sufficient speed to avoid the stall.[‡] It is this characteristic of the fixed-wing that imposes an operational requirement on the pilot, one that all too often exceeds his abilities. No matter how ardent the proponents of fixed wing may be, 50 years of flight history and approximately

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[†] While rotorcraft can experience blade stall, it is only encountered at the extreme end of the performance spectrum and seldom results in fatal accidents. The only distant analogy to the fixed-wing stall in rotorcraft is found in the helicopter, when loss of r.p.m. results in coning and consequently, reduces lift and control. Even here degradation of lift and control is not as abrupt as the stall in a fixed wing. It shall be shown later that the autogiro experiences neither the fixed-wing stall nor the helicopter's loss of r.p.m., thus providing a distinct safety advantage over both.

[‡] The loss of lift is critical enough in itself; however, it is accompanied by a loss of control that imposes a serious consequence and will be discussed later.

30 years of carefully recorded accident statistics provide conclusive and unfortunate evidence. On the other hand, the fixed-wing aircraft has more positive stability than a helicopter. The inherent stability characteristics vary with each model.

While stability and particularly control characteristics are the two most important aspects of operational safety, there is yet another major consideration. It relates to the speed at which any vehicle must be operated and the consequence of such speeds on human reaction. The greater the ground speed of a vehicle while performing its function, the greater the possibility of an accident. Aircraft are no exception. The ground-roll speed of a fixed-wing during takeoff and landing is higher than that of rotorcraft with their near-zero, ground-roll speed (particularly in the case of a helicopter). Consequently, fixed-wing aircraft impose a somewhat greater requirement on the pilot with the resulting greater number of accidents.[§]

FAA statistics show that the second greatest single cause of serious and fatal accidents is inclement weather. Again, this problem rests with fixed-wing pilots who falter into weather that neither they nor their aircraft are equipped to handle. Such accidents are infrequent in rotorcraft because the pilot can slow his speed in accordance with weather conditions, maneuver tightly at low altitudes and speeds, and land in a relatively tight area when necessary.

[§] FAA statistics show that the principal cause of all types of accidents (non-serious and serious) relate to pilots failing to control their aircraft during the takeoff and landing roll.

There is also a psychological disadvantage working against the fixed-wing pilot that is absent in the mind of the rotorcraft operator. Many inclement-weather accidents involving fixed-wing aircraft could have been avoided had the pilot executed a landing on a pasture, park, or even a road surface. However, being trained that all landings must be made at prepared areas (i. e., airports), there is an often-unfortunate attempt to reach such airports when weather closes in. Many reports have shown that pilots who flew into mountains or "spun out of clouds" had available roads or open fields greater in length than the very airports they were desperately trying to reach.[**] For the rotorcraft pilot, off-airport landings are not unusual.

FAA requirements dictate a minimum of 1,000 feet for fixed-wing types while allowing rotary-wing types to operate below this altitude. The logic of course, is the ability, in the case of an engine failure, of the rotary wing types to autorotate and flare to a spot landing with relative safety. The exclusion of fixed-wing airplanes from this nap-of-the-earth operation is made totally without regard to the specific capabilities of any particular airplane. The airplane with a high-aspect-ratio wing and a gliding ratio of 30:1 is treated, by this regulation, with no more consideration than a stub-winged racer with the gliding characteristics of a brick.

Assuming that a high level of safety for a particular police airplane was proved, a simple dispensation from the FAA for the police to

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[**] Flying Magazine, Feb. 1972, draws attention to this psychological problem of fixed-wing flying.

operate an airplane at a 500-foot altitude, say, rather than 1,000 feet could save millions of dollars in premium costs for purchase of aircraft that are legal below 1,000 feet.

3. Emergency operation. Surveillance altitudes are now established by FAA requirements rather than functional efficiency. The FAA requirements are fixed according to aircraft type rather than the aircraft's actual capabilities and the availability of emergency landing areas. The effect of technical factors such as multiple engines, flotation gear, glide ratio improvement, etc., must be considered if a truly cost-effective solution is to be developed for police aerial operations.

If any single mission element is unique to police aerial operations, it is the need to fly flowly for extended periods of time during surveillance assignments. It takes considerably more power to fly very slowly or to hover than it does to fly forward at moderate speeds. Slow flying represents a dangerous situation because recovery requires acceleration and (as opposed to the low-power landing condition) there is no power margin for such acceleration, because the airplane is already being operated at a high power level. In case of power failure, the aircraft is flying at a speed lower than the power-off stalling speed.

The consequence to the fixed-wing pilot who allows himself to get into the stall when close to the ground (where statistics show they usually occur) is all too well known. Details of the consequence are not difficult to understand. As noted, the stall results in not only loss of lift and in high rates of descent, but also in a loss of control power. Thus, the final impact, due to asymmetrical pressure and loading, often occurs at one point or another along the aircraft's axis. This high concentration of energy is the cause of serious and fatal injury. If the pilot could control the aircraft and achieve a flat impact, energy distribution and, consequently, absorption would be optimized. Unfortunately, loss of control prohibits this.

B. Rotary Wing Aircraft

1. Accident records. Table 6-4 provides data on accidents associated with helicopters that are considered representative of the current situation. Table 6-5 presents a hazard summary of helicopter-related operations.

Table 6-4. Aircraft Accident Statistics Helicopters 1968

	General Aviation*	U.S. Air Force**	Commercial Aviation***
Hours Flown	616,967	207,562	27,861
Total Accidents	250	15	2
Aircraft Destroyed Accidents	70	8	2
Accidents/100,000 Hours Flown			
Total	40.52	7.23	7.19
Aircraft Destroyed	11.35	3.86	7.19

* Reference 1-34
** Reference 1-35
*** Reference 1-33

Table 6-5. Hazard Summary Based on "Aircraft Destroyed" Accidents for Rotary Wing Aircraft

Item		Rate
1.	Number of "Aircraft Destroyed" Accidents/ 100,000 hours.	11.35
2.	% Accidents "Off-Airport"	0.90
3.	"Off-Airport Accidents/100,000 hours.	10.22
4.	Average Casualty Expectation per Accident	0.063
5.	Casualty Expectation per Helicopter per year	0.0565

In analyzing 950,000 flight hours, 450,000 fixed-wing and 450,000 helicopter, the U.S. Army (circa 1966) determined that there were three times the number of accidents with the helicopter due to material failure than there were with fixed-wing aircraft. Since then better materials, production methods, quality control, and maintenance training have undoubtedly improved this ratio.

The number of serious helicopter and autogiro accidents during approach, touchdown, and departure from the same area in which a fixed-wing operates, are fractional. We emphasize "same area" so as not to confuse those rotorcraft accidents which occur on landing or departure from the more-confined areas from which rotorcraft often operate (i.e., we tend to force a vehicle to operate constantly at its maximum level of capability when considering area and terrain, and this is not always consistent with safety).

In comparing the autogiro with the helicopter, it is apparent that the autogiro, with its unpowered rotor and consequent absences of pitch and power-attitude changes during descent and departure, is less imposing on the pilot. However, this occurs during approach and departure. At the moment of touchdown, the helicopter provides an advantage with its ability to hover momentarily. Weighing the advantages of the autogiro's approach and departure characteristics against the helicopter's actual touchdown advantage is difficult. However, it is apparent that both rotorcraft provide an easier approach, touchdown, or departure from the same type of area than does the fixed-wing aircraft.

Though there are other considerations relative to requirements vs ability, the ones discussed are the most important. To summarize the relative position of the three aircraft it is apparent that, in terms of serious and fatal accidents, one of the distinct advantages of the autogiro (as compared to the fixed wing or helicopter) is the lesser operational demand placed on the average professional and nonprofessional pilot.

2. Operational safety factors. In case of a power failure the helicopter must pass through a transition phase from where the air flows downward through the rotor to where it flows upward and establishes the autorotational process. At certain speeds and altitudes this transition period can become a dangerous condition. Such conditions define the "dead man's curve" for the helicopter, a hazard that does not exist in the autogiro because it is always in autorotation and there are no such transitional flight modes. However, the helicopter can hover. This capability has been such a major factor

in making it the dominant aircraft choice that, to date, it has been produced in a quantity two orders of magnitude greater than that of the autogiro, even though it was developed a score of years later.

The helicopter's and the autogiro's inherent control characteristics provide the most significant and important safety advantages. As dynamic pressure (the essence of lift and control) does not depend on forward speed (as it does in the fixed wing) control power is, for all practicality, as great at zero as it is for speeds between zero and V_{NE}. The only time lift and control become inadequate is when there is a serious loss of rotor r.p.m. Here the autogiro holds a distinct advantage over the helicopter because its unpowered rotor does not impose either an operational or a monitoring requirement on the pilot. The chances of high rates of descent or sluggish control are not inherently part of autogiro operations. Considering that the autogiro neither suffers the stall condition of the fixed wing (consequently removing the largest single cause of fatal and serious accidents) nor the rotor-r.p.m. loss of the helicopter, the continuing interest in this type of aircraft can be understood and appreciated.

As compared to the helicopter, the autogiro has a better level of stability due to its unpowered rotor (a contributing factor) and its more pronounced empennage system. The autogiro's stability characteristics are thus more closely associated with those of the fixed wing. While empirical data and analyses readily confirm this fact, it suffices here to say that the relative order of stability lies with the fixed wing, autogiro, and helicopter, in that order.

An important natural-element safety consideration relates to the gust sensitivity of the rotorcraft and fixed wing. Due to their high blade loading (analogous to the airplane's high wing loading), rotorcraft are relatively insensitive to gusts. Also, since the rotor blades are always turning at a high speed, they do not depend upon the forward speed to sustain lift and control. Gust velocities represent an insignificant percentage of the blade velocity, unlike the case of a slowly flying, fixed-wing airplane that demands more pilot attention to ensure that the sharp variations of pressure caused by gusts on the lifting and control surfaces do not throw the aircraft into a stall condition.[†]

There is little question that rotorcraft can better cope with natural elements while performing their operations. When comparing the two rotorcraft, the helicopter's ability to hover gives it somewhat of an advantage over the autogiro.

Helicopters have had a particular problem with their inherently high-maintenance factor. This is acknowledged within the industry itself and is one of the major limitations of this versatile machine, now being widely sold. Not as a matter of choice, but to compensate for the helicopter's high-maintenance factor, the industry and its companies have consistently tried, and are yet trying, to raise the level of maintenance abilities and facilities in the field. While costly, it has been barely satisfactory.

[†] Such a typical accident occurred in 1972 when a Twin Otter carrying 18 passengers crashed on takeoff. The accident, which was fatal, was attributed to stall resulting from a severe gust.

The difference between the helicopter and the autogiro in the area of maintenance is due to its powered dynamic components; i.e., those components needed primarily for sustained hovering ability. Because of its fewer dynamic components, the autogiro has maintenance characteristics similar to those of a fixed-wing aircraft. Certainly the fixed wing has the best field maintenance factor of any type of aircraft.

Again, the autogiro with its unpowered rotor and consequently fewer dynamic components, ensures that the aircraft is flying in what might be called a comfortable state. It sees none of the high transient loads of the helicopter or the effects of torque on its components. In fact, with its teetering or flapping blade, it experiences none of the bending loads on the wing of a fixed wing (particularly in an articulated rotor where bending loads are cancelled at the flapping hinge). While total certificated-autogiro[††] hours are considerably lower than those of the helicopter and the fixed wing, they are sufficient at this time to indicate that the rate of material failure per flight hour is more comparable to that of the fixed wing than to the helicopter.

3. Emergency operation. It is in this area that rotorcraft provide a significant safety advantage. When a helicopter loses rotor r.p.m. it also experiences relatively high rates of descent. Its consequence would be

similar to that of fixed wing, with one exception: the rotation of the blades is never so slow as to preclude controlling the attitude of the aircraft's impact.

As for the unpowered rotor of the autogiro, as discussed previously, the pilot cannot mismanage r.p.m., thus the condition of high rates of descent caused by rotor r.p.m. loss is, for all practical purposes, not experienced in the autogiro. The only occasion when an autogiro pilot might experience a relatively hard impact is after a high flare during landing, particularly if he is attempting a full-stop touchdown. However, by definition, he is not falling from a significant altitude, as would be the case in a fixed-wing stall or during a helicopter's loss of r.p.m.

The advantages of the helicopter and autogiro in the power-loss condition are well known and need not be discussed at great length. They lie in the ability of these aircraft to maintain full control down to zero-forward speed, their significantly slower approach speed during an emergency landing, their ability to execute a landing in a relatively confined area, and their rapid deceleration on touchdown due to the aerodynamic braking of the rotor. The sum total provides a substantially safer condition after engine failure.

A more meaningful comparison lies between the two rotorcraft themselves: First, as every helicopter pilot and instructor knows, the entrance into the initial phase of autorotation is the most critical for the helicopter. Ironically, the helicopter must convert to an autogiro to execute a safe landing. Failure of the pilot to make this conversion rapidly (by

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[††] The word "certificated" is emphasized here. The rates of experimental autogiro accidents are high due to a combination of inadequately developed designs built and flown by inexperienced hobbyists. The FAA rules for such home-built "experimental" machines cannot be compared with the very stringent requirement it imposes on legitimate companies undergoing full certification of an aircraft.

depressing the collective pitch stick and holding it fully depressed) results in a loss of r.p.m., coning, and those consequences just discussed. The autogiro, which is already in autorotation, eliminates this critical procedure. Second, control application in the autogiro at the moment of power loss is minimum. There is no vigorous application of control to compensate for the loss of torque. Third, the rate of descent in the power-off condition is significantly slower in the autogiro because of its generally lower disk loading, untwisted blade, and the absence of power drain by a tail rotor. Finally, the familiarity of the autogiro pilot with unpowered landings (while the unpowered landing is an emergency procedure for the helicopter, it is a normal procedure for the autogiro) is an important advantage during emergency situations.

The helicopter and autogiro offer an important safety advantage to the public on the ground. The number of fatalities to the public on the ground, due to the high touchdown speeds a fixed wing must maintain to avoid stalling, is all too well known. Injury to the public by a rotorcraft making an emergency landing is almost nonexistent. The reasons are the rotorcraft's high degree of maneuverability during an unpowered descent[§§], its controllability at touchdown, and its negligible speed at touchdown.

As any responsible pilot rated in all three aircraft will attest, concern for an engine failure in a rotorcraft is considerably less than while piloting a fixed wing, particularly when over populated congested areas of rough terrain.

[§§] Assuming the steering apparatus has not malfunctioned.

CHAPTER VII. APPENDICES

The appendices are divided into three separate sections and contain information that supplements the discussion in the main body of this report. Appendix A goes into a relatively detailed discussion of LTAs, autogiros, and RPVs. This is included here because information about such aircraft is relatively unknown in the general aviation community. The natural derivation of the hybrid vehicle combining the attractive features of both lighter-than-aircraft and heavier-than-aircraft is also presented.

Appendix B extends the discussion relating to aircraft safety. More specifically, Appendix B examines the question of aircraft crash hazards in greater detail and develops some quantitative data relating to fatility probabilities. An aircraft collision model is also developed and discussed.

Appendix C contains ten tables extracted from References 1-2 relating to a comparison of the relative effectiveness of helicopters and airplanes. The essence of the information contained in these tables has been summarized and presented in Chapter 2, "Mission Requirements." However, much of the information contained in the tables of Appendix B are qualitative in nature, and an accurate summary of their contents is therefore difficult and subject to ambiguity. In view of this, it was felt that the information contained in these tables should be included in their entirety, and they are therefore presented in this appendix.

APPENDIX A. FUTURE VEHICLES

A. Lighter-Than-Air (LTA) Craft

1. Historical background. With the exception of a few improvements in materials for balloons and aerostats, the LTA art has been essentially static for almost 40 years. The few powered LTA aircraft extant (blimps) represent pre-WWII technology. They are also so expensive that, if these represent the typical costs of LTA vehicles, there is no wonder that they haven't met with more acceptance.

The advantages of obtaining substantial amounts of lift with no power are self evident. The subject deserves considerably more attention in light of modern structural techniques, the greater availability of helium, and the development of serious ecological and energy supply problems which promise only to become more severe in the future.

Airships, in one form or another, offer a real potential as major tonnage freighters not only for dense cargos but for transporting large enough quantities of gaseous fuels as to contribute meaningfully to the alleviation of that shortage. At the other end of the size spectrum are applications for low speed aerial vehicles which are now being fulfilled by STOL airplanes and helicopters. In certain of these applications the use of buoyant lift would result in an increase in efficiency, reduced fuel requirements, and a major reduction in noise.

The major objections to LTA craft are really the results of several independent situations which, unfortunately, have been combined into an integrated case against LTA's, particularly dirigibles. In perspective the development of this situation is easily traceable. It is a rational political and sociological picture but it is not technically sound. A certain amount of historical background might shed some light on the subject.

The original objective of Count Von Zeppelin was to provide to Germany a strictly military vehicle. As fate would have it, the first acceptance of the dirigible was for commercial passenger transportation; and 5 years before World War I the German DELAG service's five Zeppelins made 1600 scheduled commercial flights totaling more than 100,000 miles, without a single injury to the 30,000 passengers, all the time employing "dangerous" hydrogen. Almost 100 Zeppelins were built by Germany during WWI.

The Graf Zeppelin built in 1928 made 590 flights covering over a million miles and survived a number of very severe storms (including frequent lightning strikes). It was retired after 9 years of service. Its predecessor, the U.S. Navy's Los Angeles, also served out its 8-year life to retirement, while the helium-filled U.S.-built Akron and Macon both broke up in storms of severity which were survived almost routinely by the

German-built craft. The fact that the German builders had warned the U.S. about inadequacies of the Akron and Macon's tail structure indicates a level of knowledge, even then, which more justified confidence in proper design practice rather than condemnation of dirigibles, which received their death blows from the unfortunate proximity of the Akron, Macon, and Hindenburg disasters all within a four-year period. The coup de grace was provided by the initiation of WWII, which saw the Graf Zeppelin II cut up (to convert its aluminum into airplanes) and the U.S. Navy's LTA program concentrated on blimps for ASN duty also, partly, as a measure to save aluminum for airplane production. In light of the above history, one can examine the various objections raised against the dirigible with a little more objectivity.

2. Safety factors. In view of the past history of LTA craft, future designs would have to address the primary hazards: fire, structural frailty, and gust sensitivity.

a. Fire danger. There is no question that the use of an inflammable lifting gas is a hazard. When helium is available or practical, the problem is totally eliminated. But there are attractive applications which require the use of inflammable lifting gases, such as when such gases represent the cargo. The dirigible in this case is a flying tanker and probably no more hazardous than seaborne tankers. Rather than emphasizing the Hindenburg disaster (in which twice as many survived as were killed - 62 vs 35), one should equate this event to the Apollo Program where the safety procedures in handling highly volatile liquid hydrogen and oxygen resulted in only one disaster (and that one on the ground), but this mishap did not prevent the flawless execution of over a dozen moon shots nor planning for future space exploration. Modern materials design and safety procedures could easily prevent a recurrence of the Hindenburg disaster, even while using inflammable gases.

When the pre-World War I safety record of hydrogen-filled dirigibles is considered in light of the low level of experience and safety procedures available at the time, one finds it less irrational to believe the recent evidence suggesting sabotage in the case of the Hindenburg. Even more so is this probable, considering the frequent lightning strikes on the Graf Zeppelin without incident over a 9-year period.

b. Structural frailty. The structure of a dirigible, as for any other aircraft, must be very light. Stresses are complex and much of the structure is redundant and difficult to analyze. Nevertheless, most dirigibles built by the German pioneers demonstrated a structural integrity enviable even by today's standards and at a weight lower than the American-designed craft which failed. Even after a lapse of 40 years, the useful load ratios of the German machines would be highly acceptable today, thus providing an added strength margin equal to the amount that materials have improved in 40 years, and with no change in design whatsoever! Add to this, up-to-date techniques for analyzing structures, backed up by a computer capability of actually performing a complete stress analysis, and there should be no question as to the ability to attain a fully airworthy design that could provide all-weather scheduled service.

c. Gust sensitivity and ground handling. One cost area a modern airship service probably could not bear is the need for 100-man ground crews to aid in the docking and undocking of such giant machines. This function would have to be fully automated. Furthermore, unless the airship can be designed for docking out in the worst of weather, the hangar must be designed for swiveling. A common schedule delay in the old airship days was one caused by a crosswind which was not severe enough to prevent flight but would prevent removal of the ship from its hangar for fear of it being damaged as it was buffeted against the hangar on its way out.

The modern solution to this problem would be a hybrid design somewhat heavier than air and employing some aerodynamic shaping to obtain the total lift required. While this would eliminate the hovering capability and would require some runway for operation, it would allow a positive landing operation by the flight crew without help from a ground crew. Also, if tethered on a freely swiveling mast, it could be left outside to weathercock into the wind. Automatic stabilization equipment and controls would be left operative while masting out in order that the aerodynamic control surfaces could compensate for winds and gusts that might tend to change the horizontal attitude in pitch or roll.

3. Analytical factors. With the above considerations in mind, it appears that the next step would be to develop the optimum parameters for further consideration.

a. Light gases. The buoyancy of a gas is simply the difference in density between air and the lifting gas. Several of the lighter gases are listed below with both their densities and the ideal lift provided per 1,000 ft^3 of the gas.

Gas	Density (lbs/ft^3)	c_p	γ	Lift per 1,000 ft^3
Air	0.0765	0.24	1.4	0
Hydrogen	0.0053	3.41	1.41	71
Helium	0.0106	1.25	1.66	66
Neon	0.0533	0.246	1.64	23
Ammonia	0.0451	0.52	1.32	31
Methane	0.0423	0.59	1.3	34
Natural Gas	0.0514	0.56	1.27	25

A perusal of these data makes it quite evident why the most common lifting gases are hydrogen and helium. No other gas is comparable. The 7% lift loss of helium also seems a small price to pay for its nonflammability compared to hydrogen. The other nonflammable gas, neon, gives a poor lift performance. The remaining flammable gases are all commercial and, while they provide little useful lift capability for payload, they can easily lift themselves and thus suggest aerial transportation by LTA vehicles.

b. Hot air. One other gas, hot air, is commonly employed for lift, particularly in sport balloons. Its use is popular for the obvious reason that it is easily available. While not a factor in its choice, the low c_p of air also makes it cheaper to heat than, say, methane or helium. The

lifting capability of air is directly proportional to the density difference between the hot lifting air and the outside free air, and this is given by the following:

$$\text{Lift}/1{,}000\ \text{ft}^3 \text{ for Air} = 76.5 - 76.5\,\frac{T_o}{T_o + \Delta T} \qquad \text{(A-1)}$$

$$= \frac{76.5\ T_o + 76.5\ \Delta T - 76.5\ T_o}{T_o + \Delta T}$$

$$= 76.5\,\frac{\Delta T}{T_o + \quad T} = \frac{76.5 \times \Delta T}{520 + \Delta T} \qquad \text{(A-2)}$$

For a temperature increase of 152° (to a gas temperature of 212°F = boiling water)

$$\text{Lift}/1000\ \text{ft}^3 = \frac{76.5\,(152)}{672} = 17.3\ \text{lb}$$

A 1,000°F temperature rise will yield a lift of approximately 50 pounds, while a 2,000°F rise is required to provide 61 pounds. A temperature increase requirement of approximately 3,400°F is required to obtain 66 pounds, the lift of helium.

The energy required to heat the air is given by:

$$\text{Btu/lb lift} = T_o c_p$$

This equation states that each pound of lift costs the same in energy input regardless of the temperature level. For air at sea level standard temperature, (T_O = 520°) and Cp = 0.24 the required energy input is:

$$\text{Btu/lb lft} = 520 \times 0.24 = 125$$

If we are to assume that this heating is obtained by burning a liquid hydrocarbon of 18,550 Btu/lb costing 6¢ per lb (36¢/gallon) then the cost of lift by hot air is $6 \times \frac{125}{18,550} = 0.05$ per lb of lift, or \$0.0004. At a price of \$70/1,000 ft^3 helium costs \$1.06 per pound of lift. Helium therefore costs

$\frac{1.06}{0.0004} = 2,650$ times as much as a charge of hot air for the same lift.

c. Purity. The characteristics given earlier for lifting gases are those of pure specimens. In actual practice one cannot depend upon "laboratory pure" quality in industrial quantities. One must accept a certain amount of dilution of the gas by impurities, primarily air. This is particularly true of helium, which can diffuse through the most dense of materials. In the typical blimp gas bag there is not only a loss of helium by leakage outward but a leakage of air inward. The loss is probably less trouble than the dilution which ultimately requires the expensive replacement of the diluted helium, and which requires an expensive local facility. Modern materials, such as Mylar, are lighter, stronger and less permeable than the older rubberized cloth construction of the typical blimp. Nevertheless, some consideration must be given to the fact that the lifting gas is not pure. An impurity factor of 7 to 6 percent is reasonable.

d. Expansion space. Changes in external air pressure due to temperature or altitude variations result in the contained helium (or other gas) expanding or contracting to maintain an equal pressure. Provisions must be made to allow this expansion in order that the helium will not burst its envelope.

In rigid LTAs (dirigibles) the external shape is firm. The lifting gas is contained in a number of cells that are only partially filled. The "slack" provides expansion space to permit operation at higher altitudes. The altitude at which the cells become full is the critical altitude, and operation above this altitude requires valving off of valuable helium, a practice which is avoided except in emergencies.

In the case of nonrigid LTAs (blimps) a slight internal overpressure is required at all times to maintain the shape of the aircraft. The expansion requirements of the lifting gas are provided by the use of small internal "ballonets" filled with air. The lifting gas is allowed to expand inward, collapsing the ballonets as altitude (or temperature) is increased. Just enough air pressure is supplied to the ballonets to maintain the external shape of the blimp.

In order to operate at an altitude of 5,000 or 6,000 feet without valving helium, an airship can be inflated at sea level to only about 90 percent of its gas capacity, leaving a 10 percent slack space in the gas cells of a dirigible or, in a blimp, a ballonet volume of 10 percent of the total volume.

For the purposes of this study, the impurity factor and the expansion factor have been combined into a single-volume factor, Kv, which has been assigned the constant value of 85 percent as representative of typical practice.

e. Lifting volume geometry. The choice of geometry for a lifting volume is a compromise between minimizing surface area and weight and maximizing the favorable external aerodynamic characteristics one wishes to exploit. Minimum surface area and weight to contain any given volume of gas is minimized, obviously, by the use of a spherical container. Free balloons approximate spherical shapes.

f. Nonlifting shapes. In the case of true LTA vehicles (dirigibles and blimps) the departure from a sphere is made in the direction of tear drop, or cigar shape, to reduce the frontal area and drag in the forward flight direction. These are the classical shapes of LTAs that attain all or most of their lift statically. Note that the frontal area can be reduced very much, but one pays for this with considerably more surface area and structure to contain the gas volume. On the other hand, one also generates platform area which can act as a wing to provide dynamic lift.

g. Lifting shapes. The shapes defined are representative of pure LTAs but do not provide as effective dynamic lift surfaces as those which have a greater span, as is typical of airplane wings. It is still desirable from a structure and weight viewpoint to depart as little from a sphere as possible, while aerodynamically it is best to have a long wing. Intuitively

one might expect an optimum vehicle shape somewhat like a hemisphere. For the same volume as a sphere, the hemisphere would have 1.26 times the diameter and 1.59 times the wing area. Even the hemisphere is not a good airfoil shape; its frontal area/volume relationship is poor, being identical to that of the full sphere.

With regard to weight one would expect a long and thin wing to require more structure than a short, stubby one. Likewise, a spherical structure should be stronger and lighter than a stretched-cigar shape, like a dirigible of the same volume.

h. Fuselage weight. While the "wing" size and weight of the hybrid aircraft may vary over a considerable range, the basic mission requirement does not vary significantly. We can thus consider the wing as a provider of Net Lift = (Total Lift - Wing Weight). One may thus consider all the remaining structure as that which is both associated with mission accomplishment and governed by the mission. This remaining structure we shall call the fuselage with the understanding that it includes the propulsion system, control system (tail, etc.), landing gear, and standard aircraft instrumentation. The net lift equals this fuselage weight plus crew, fuel, and special police equipment.

Using these definitions, one can estimate the useful load (UL) limits of a LTA craft to be as much as equal to the empty weight of the craft and as little as one half the empty weight of the craft.

4. Performance. While the heavier-than-air types are subject to the cube-square law*, the static lift of an LTA type increases as the cube of its size right along with its empty weight, so that the efficiency of a giant machine should be no less than that of a small machine. Indeed, a plot of the limited data available (Figure A-1, confirmed the linear (cube-cube) relationship to such a remarkable degree that it suggests more confidence in the

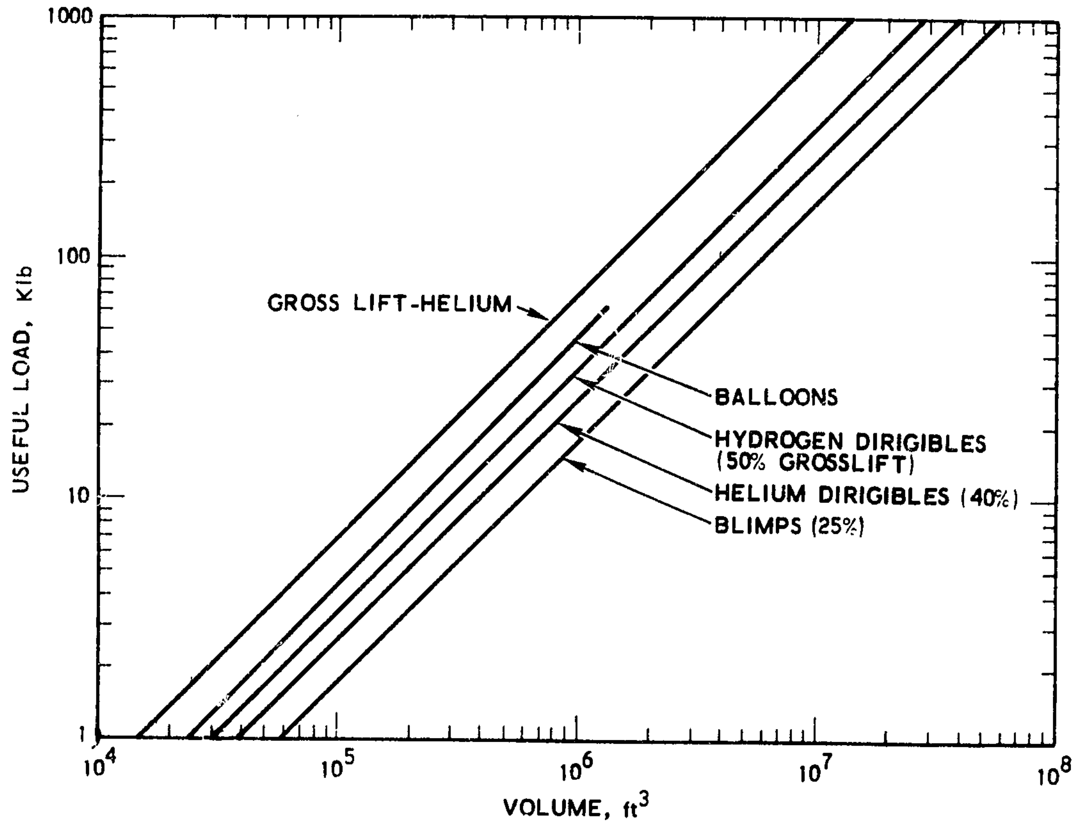

Figure A-1. Useful Load Capabilities of LTA Craft

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*The structural weight increases as the cube of the size, but dynamic lifting ability increases only as the square of the size, so that larger airplanes will have lower useful load ratios than smaller ones.

ability to develop a weight rationale than was originally expected. The scatter of data points was so little for each discrete type of LTA as to provide certain insights regarding LTA potential on the basis of these observations:

- The useful load ratio of rigid types of LTAs (dirigibles) is considerably higher than for the nonrigid types (blimps). Useful-to-gross weight ratios of 40 to 50 percent are typical for dirigibles, while blimps seldom exhibit ratios of better than 25 percent.
- The higher (50 percent) useful weight fraction for dirigibles is associated with the hydrogen-filled types, while the 40 percent value is associated with the helium-filled types. The difference cannot all be accounted for by the 7-percent increased lifting ability of hydrogen. A small remainder is probably due to a somewhat more conservative design practice on the later American (helium-filled) models versus the earlier European (hydrogen-filled) models. (Although the heavier American designs proved weaker than the lighter German ones.)
- Nonvehicular-type LTAs (weather balloons, logging balloons, tethered Aerostats, etc.), manufactured with more modern materials and engineering than found in present blimps, attain useful load fractions of approximately 70 percent. To obtain a fair comparison with

dirigibles and blimps, of course, it would be necessary to add a propulsion system, fuel, and a "car" which would reduce the useful load values below those of dirigibles but probably above existing blimps.

- Inflated structures are not as efficient for construction of LTAs as are rigid structures; neither are they cheaper. It is difficult to justify why the blimp type attained a toe hold at all, except that their major role as antisubmarine warfare (ASW) patrol aircraft during World War II was assigned soon after the Hindenburg disaster, at the height of criticism of the dirigible types. Furthermore, the shortage of airplanes and materials at the beginning of World War II probably resulted in giving airplanes the highest priorities for metals, since the LTA types could be built of rubberized cloth.

For the purposes of this study it was necessary to obtain representative weights of LTA elements. Furthermore, the LTA elements are not like conventional shapes for dirigibles or blimps but are of shapes closer to that of airplane wings. While structural shapes of almost any configuration can be attained with inflated structures, nothing has been discovered during this study that would indicate their superiority in weight, performance, or cost. The weights and costs derived herein have been based upon the assumption of rigid structure techniques and quality characteristics of light airplanes in keeping with the speeds and applications assumed in police operations for

these LTA and hybrid aerial vehicles. On the other hand, no specific structural system is specified. Should these types become desirable and the manufacturers thereof decide to use inflated rather than rigid structures, such structures should then be evaluated on their own merits.

B. Autogiros

Helicopters and autogiros display many family resemblances, but they also exhibit some major dissimilarities in characteristics because of the fundamentally different manner in which they are operated. The autogiro rotor is not powered but dragged through the air like an airplane wing. The air flows upward through the autogiro rotor and turns it like a windmill. The turning rotor acts in almost all respects like an airplane wing, and the training for an autogiro pilot is essentially the same as that for a fixed wing aircraft pilot.

On the other hand, the helicopter rotor is powered. It is not dragged through the air but drags the rest of the aircraft through the air. To do this it must be tilted forward, directing the airflows downward through the rotor. In this respect it differs most from the autogiro rotor, because of its effect on the blade-angle distribution: At high forward speeds the retreating blade of the autogiro rotor starts to stall from the hub rather innocuously, whereas the retreating-blade stall of the helicopter starts at the tip producing major effects on drag, power, roughness, and control. The powered helicopter rotor results in a torque-reaction problem, hence the need for a tail rotor.

In case of a power failure the helicopter must pass through a transition phase from where the air flows downward through the rotor to where it flows upward and establishes the autorotational process. At certain speeds and altitudes this transition period can become a dangerous condition. Such conditions define the "dead man's curve" for the helicopter, a hazard that does not exist in the autogiro because it is always in autorotation and there are no such transitional flight modes. However, the helicopter can hover. This capability has been such a major factor in making it the dominant aircraft choice that to date it has been produced in a quantity two orders of magnitude greater than that of the autogiro, even though it was developed a score of years later.

1. Analytical factors. The rotor on an autogiro serves precisely the same purpose as the wing of an airplane. It is driven by air flowing upward through the rotor as it translates horizontally. As shown in Figure A-2, the rotor is tilted back to provide an angle of attack, just as if it were a wing.

A separate propulsion system (e.g. propeller) is required to drag it through the air. The autogiro rotor is essentially a wing of low wing loading, and this is why it can fly so slowly. Also, the blades of the turning rotor are traveling at a higher airspeed than is the aircraft as a whole, so they can provide lift when the forward velocity would be too low to provide lift from a fixed wing. The most successful autogiros have disk loadings of between 1 and 3-lb/ft^2 as compared with light airplane wing loadings of 10 to 15; modern light helicopters have disk loadings of 3 to 5, and some large helicopters have values as high as 14 or 15. Needless to say, they do not

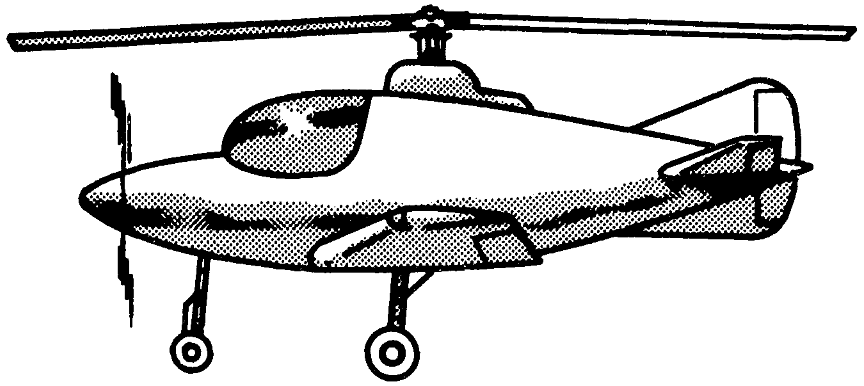

Figure A-2. Autogiro Rotor

autorotate as gently as the old autogiros. For emergency landings, the more highly loaded helicopters depend upon the fact that they have multiple engines and seldom have to autorotate with a total power failure.

The autogiro cannot hover, of course; however, "jump takeoff" characteristics (if useful for mission accomplishment) can be attained (at a price in dollars and complexity) by providing a rotor run-up mechanism. Jump takeoff is the autogiro's answer to jet-assisted takeoff (JATO) in a fixed-wing aircraft. Kinetic energy stored in the rotor can be employed to provide the instantaneous power for a helicopter-like takeoff; but, in addition to a rapid, short takeoff similar to a JATO equipped airplane, the gentle autorotation capability of the autogiro allows a flared, zero-speed landing in event of an engine failure.

In the case of the airplane wing, maintaining lift at low speeds requires an increasing angle of attack and operation near stall angles where the drag is high. These large angles are postponed in the autogiro rotor by having the airfoils go around fast, even though the forward speed is low, thus allowing the use of lower pitch angles nearer the airfoil's best lift-to-drag ratios L/Ds. The maximum overall L/D of an autogiro rotor is 10-11 as compared to 20 or so for a fixed wing. As in the case of wings, the rotor loses efficiency as forward speed is decreased, but with less increase in angle of attack than the wing. The angle of attack margin of the rotor allows it to maintain rotor r.p.m. and nonstalled conditions long after the fixed-wing has stalled. The basic characteristics do not change, however.

For the same forward velocity, the helicopter employs higher tip speeds (typically 700 ft/sec) than the autogiro. Assuming an autogiro designed with best L/D at 100 mph (146 ft/sec), its tip speed would be 420 ft/sec. A wing, in dropping from 100 mph to 20 mph would suffer a dynamic pressure loss ratio of $\left(\frac{100}{20}\right)^2 = 25:1$, whereas the tips of the autogiro rotor suffer a dynamic pressure loss ratio of $\left(\frac{420}{360}\right)^2$ or only 1.34:1.

Since at low speeds the rotor blades suffer less decrease in dynamic pressure, they require less increase in blade pitch and they can remain flying long after the airplane's wing has stalled. This is not the power picture however. The autogiro rotor is extracting a lot of energy out of the airstream to keep turning, and this shows up in an L/D ratio as poor as that of a wing (if the wing were prevented from stalling by some means). As far as level flight is concerned, the autogiro rotor acts, for all practical purposes, like an "equivalent wing" with an aspect ratio of $\frac{4}{\pi}\left(= 1.27\right)$ and a wing loading equal to that of the rotor disk loading.

Basically an autogiro rotor acts like a round wing but one which lets some air leak through from the bottom surface to the top surface. The significance of this is that some of the energy can be removed from this air to drive the rotor as a windmill (air turbine). Whereas a wing can only deflect air, the autogiro rotor can decrease the absolute velocity by extracting energy from the air. Using this energy to drive the blades at a speed higher than the forward velocity it, therefore, allows them to produce the same lift at lower pitch angles than in a fixed wing. Therefore, the autogiro rotor is essentially an antistall device.

2. Summary

While extensive data could be analyzed, evaluated and discussed, the end result would undoubtedly show that, in terms of pure utility, the helicopter is the present leader, with the autogiro, very closely matching its capability. The combination of the two in a compound represent the ultimate. As for performance, based upon the same power and gross weight, the fixed-wing aircraft provides better capabilities in the area of speed, payload, range, and rate of climb. Of course, performance depends upon wing (or disk) and power loadings, which can be varied greatly, causing considerable variations in these performance elements. Whether it be considerations of utility and its accompanying factor, performance, the vehicle chosen must fulfill the objectives of safety and utility at an acceptable cost. This has been the primary complaint against the helicopter. Its utility is outstanding but its costs, both initial and operational, have been considered by many to be excessive.

It is not difficult to understand why such costs are higher for the helicopter. The additional dynamic components -- principally required for hovering -- are costly by definition. They must be made of costly alloys, for lighter weight, and machined to closer tolerances. The sum total equals a more expensive machine.

The autogiro has somewhat fewer dynamic components; consequently, its initial cost is lower. However, it is not as low as some believe. The real cost saving for the autogiro is in the area of operational costs. Operational cost differentials between the autogiro and the helicopter are more pronounced than their initial cost differential. Operational costs of the autogiro are estimated to be about half that of the helicopter, or approximately the same as for other STOLs. The lower costs result from a lower power setting to achieve the same cruise speed (less fuel and oil), fewer inspections (labor service costs), and higher overhaul time on the engine (e. g., overhaul time for the Lycoming 0-360, 180-horsepower engine is 750 hours for helicopters versus 2,000 hours for both the autogiro and the fixed wing.

In the indirect-cost area there is again a savings due principally to the fewer number of limited-life components in the autogiro and consequently, less unscheduled maintenance and lower hull-insurance rates (the autogiro's approaching those of the fixed wing). All of these factors reduce the autogiro's total operational costs.

In summarizing the cost picture, the final relative results would accord the least initial cost to the fixed wing, the next higher to the autogiro, and the highest to the helicopter. Operational costs would be in the same order. However, data presently available show that the operational costs of the autogiro are comparable to those of the fixed wing. In other words, the autogiro will be almost as expensive as the helicopter to buy, and almost as cheap as the fixed wing to maintain. It appears to offer potential for police work and should be given as much consideration as helicopters and fixed-wing STOLs in future evaluations. While no autogiros have been developed specifically for police work, and none are in production, operational models of certified designs are extant and available for demonstration.

C. Remotely Piloted Vehicles

With personnel representing such a large portion of the cost of an aerial operation, it is possible that the optimum course is towards more sophisticated (and expensive) hardware to reduce personnel requirements rather than towards a lower cost vehicle requiring more personnel. The evaluation of Remotely Piloted Vehicles (RPVs) with regard to their effectiveness and safety would appear justified.

1. Safety factors. The purpose of this safety analysis study was to investigate the level of hazard that might be imposed on the general public by a system of unmanned surveillance aircraft (RPVs) that would be airborne on an around-the-clock basis in a metropolitan environment. The analysis was done for a specific area, since the situation can vary with demographic features. Because of the availability of data, the Los Angeles area was selected for the study.

In the analysis, two separate hazard sources were considered:

(1) Those resulting from RPV aircraft malfunctions which would cause it to crash in populated areas.

(2) Those resulting from a mid-air collision of the RPV with other aircraft. In this case, "non-participants" in other aircraft would be endangered as well as people on the ground.

In (1) above, the approach used was first to investigate the accident statistics for current manned aircraft configurations that might be presentative of the RPV configuration. The current aircraft considered re fixed-wing aircraft and helicopters. By examining a range of possible t was felt that the hazard levels, as they would exist for likely RPV figurations, could be bounded. The general effects on the accident rate might result from the removal of the "on-board" pilot were then con- red. Other studies have shown significant contributions of the pilot, ative to aircraft losses, in malfunction situations and in the selection of he best available impact location for crash situations.

The analysis of the collision problem is based on a simple random collision model in which the reduced capability of the RPV, from the standpoint of collision avoidance as compared to a manned aircraft, is considered.

The analysis for hazard source (1), while done for Los Angeles environment is considered representative for most large metropolitan areas. The analysis for (2) is more directly tied to the Los Angeles situation, which is characterized by a large high-density metropolitan area surrounding one of the most heavily used air traffic hubs in the country. Therefore, its applicability to other cities is considered much more limited.

Additional discussions related to RPV and other types of air- aircraft crash hazards are included in Appendix B.

APPENDIX B: AIRCRAFT CRASH HAZARDS AND COLLISION MODEL

A. Hazards Associated with Aircraft Crashes

Detailed hazard evaluations for vehicle (or debris) impact are usually performed for space vehicle and ballistic vehicle launches from test ranges. These analyses are based on detailed knowledge of vehicle characteristics including configurational details, failure modes, and their effects. Details of this type are not available for the previously discussed RPV. The objective of this analysis is, therefore, limited to defining the "rough-order-of-magnitude" hazards that might be characteristic of this vehicle.

As previously stated, it was assumed that the basic RPV would be similar either to current fixed-wing aircraft or to helicopters. The approach was to first investigate accident statistics that might be characteristic of these manned vehicles in the environment being considered. Because of the limited time available, the undefined configuration of the RVP, etc., it was decided to use historical accident data for these aircraft categories as the basis for a hazard assessment. Historical data were shown previously for general aviation and commercial aviation for the years 1968 through 1971. The data show relatively constant accident rates for general aviation and a downward trend for commercial aviation.

The 1968 data, utilized in this analysis because of its availability and better definition of accident statistics by aircraft type, are considered representative of the current and near-future situations.

The number of accidents occuring off airport per year which can be expected from flight operations were calculated. The results of this calculation show that for every 100, 000 hours, 4. 01 accidents can be expected in fixed wing operations and 10. 22 accidents can be expected in helicopter operations.

It is known that a substantial portion of the accidents that occur involve the pilot (errors or related factors). However, it is also apparent that the onboard pilot can contribute in many ways to avoidance of potentially hazardous situations through his experience, sensory perception, etc., which cannot be duplicated by any mechanicsl system. No basis could be established for quantitatively evaluating the difference in this respect that might exist for a manned vs an unmanned system and it was assumed, for this analysis, that there would be no significant difference.

Other studies have indicated the pilot's effectiveness in avoiding losses of aircraft after a hazardous situation develops. Reference 1-36 indi-ates that the pilot's effectiveness in this respect varies from about 30 percent more than 90 percent. This effectiveness will certainly vary with the ot's capability and training. In this context, effectiveness is defined as:

$$\text{Effectiveness} = \frac{\text{No. of potentially hazardous situations - No. of crashes}}{\text{No. of potentially hazardous situations}}$$

pilot with an effectiveness of 0. 90 could be expected to avoid loss of t 9 times out of 10 when a hazardous situation develops.

In addition, an "on board" pilot of an aircraft can select, to varying degress, the final touchdown point if an off-airport landing or impact is imminent. On the other hand, it seems reasonable to assume that a remotely located pilot would have a greatly reduced capability for coping with this situation. Therefore, it was assumed that for an unmanned system, any situation that would be classed as a potentially serious incident for a manned aircraft would result in a crash of the aircraft if it were unmanned. Implicit in the assumption, relative to the capability of the unmanned vehicle, is that the crash point for the vehicle would be located at random within the area of interest (i. e. Los Angeles Metropolitan Area).

If we use the data previously indicated as a measure of the pilot's effectiveness in preventing potentially serious situations from becoming aircraft losses with the above assumptions, the number of serious incidents which would result in the crash of an unmanned aircraft can be obtained. Thus between 5. 73 and 40. 10 accidents could be expected for unmanned fixed-wing aircraft in every 100, 000 flight hours; and between 14. 59 and 102. 20 accidents could be expected for unmanned helicopters in every 100, 000 flight hours.

The hazard in terms of the expected casualties can then be evaluated assuming that each of the accidents resulted in a crash with a random impact location. The casualty expectation is the average number of people who would be a casualty as a result of the crash. It is a function of the population characteristics, i.e. population density in the area of interest, and the vehicle characteristics. One of the vehicle characteristics of interest is its physical size, since this is related to the land area directly affected by the impact of the vehicle (or its debris). This area is called the casualty area and a value of 1,000 sq ft was estimated for the RPV and small aircraft.

If it is assumed that the aircraft (casualty area : 1,000 sq ft) impacts at random in the area of interest with its average population density of 2,340 persons per square nautical mile, the casualty expectation would be 0.063. The casualty expectation associated with keeping one vehicle airborne on an around-the-clock basis for one year is between 0.032 and 0.222 for a fixed-wing aircraft and between 0.081 and 0.566 for a helicopter. If accident statistics for commercial aviation rather than general aviation were used in the calculations, the lower bound for casualty expectations would approach 0.001 casualty per year for fixed wing operations.

The upper bound would be defined by the accident statistics for helicopters (general aviation) under the assumption that the remote pilot would have a very low capability to avoid a crash for most serious accident situations that occur and that he would have essentially no capability to affect the crash point from the standpoint of reducing the hazard. The corresponding value is 0.57 persons for a system in which a vehicle is airborne on an around-the-clock basis.

It should be noted that the aforementioned values are based on the flight [illegible] associated with having one aircraft airborne at all times. If the system

requires multiairborne vehicles, the above values would be increased by the number of airborne aircraft. For instance, if an average of 10 aircraft were to be airborne at all times, the above data indicates that the casualty expectation per year would range from 0.01 persons to 5.7 persons.

B. Aircraft Collision Model

A collision model based on previously discussed hazard values was the second area investigated. A simple model was developed first to express the mathematical relationship between the traffic density and the number of midair "conflicts" that might be expected within the airspace of interest. A random traffic model, in which the relative position of potential conflict pairs is random within the airspace of interest, was assumed. The airspace of interest, in this case, was the Los Angeles Basin Area, which has an assumed size of 60 to 120 sq. nmi. The number of aircraft in the area was based on 1980 data from Reference 1-37:

	Number of Aircraft	
	1980	1990
Mixed Airspace (4,000 to 10,000 ft Altitude)		
IFR	80	240
VFR	450	1350
TOTAL	530	1590
Uncontrolled Airspace (0 to 4,000 ft Altitude)	450	1350

The airspace from 0 to 4,000 ft altitude was assumed to the operating area for the RPV. The above data indicates an aircraft density of 0.0625 aircraft/sq nmi in the Los Angeles Basin.

If there are N regular aircraft that are in random flight within the airspace of interest and M surveillance aircraft that are random in position with respect to members of the N group, there are N × M possible independent pairs of aircraft. If we designate the probability of conflict between any pair as Q, the probability of conflict between two aircraft of the N + M total aircraft of concern is:

$$P = 1 - (1 - Q)^{N \times M}$$

The total probability can be approximated in this case by the equation

$$P = N \times M \times Q$$

If the density of traffic is uniform in the altitude layer of interest (in this case 0 to 4,000 ft), then a conflict is defined as occurring if the aircraft come within x ft vertically and y feet horizontally. The dimensions x d y will depend upon the aircraft configurations. For purposes of this lysis, x was assumed to be 10 feet and y to be 50 feet. The area reprerated by these dimensions is called the aircraft hazard area.

The factor Q, under the assumption of the random relative location he two aircraft, can be evaluated from the following equation:

$$Q = \frac{V_{AHA}}{V_{AS}}$$

where V_{AHA} is the volume swept out in unit of time by the aircraft hazard area and V_{AS} is the volume of the airspace of concern. V_{AHA} will depend upon the relative speed, V_r, between the potential conflict pairs. For purposes of this type of analysis, 120 knots is considered representative. Thus, for our situation the Q per day for the Los Angeles Metropolitan Area is:

$$Q = \frac{(V_r)(24)(x \cdot y)}{V_{AS}}$$

$$= 150.2 \times 10^{-6} \text{ (per day)}$$

Using an aircraft density of 0.0625 planes per square mile, as defined by the Los Angeles Basin data, and assuming that the controlled airspace is a small part of the total area of concern, we obtain an average number of aircraft of 25 in the Los Angeles Metropolitan Area.

For a surveillance system of one aircraft airborne at all times (M = 1), the probability of a conflict per day based on a total of 25 aircraft and one RPV in the airspace of interest would be:

$$P_{conflict} = (1)(25)(150.2 \times 10^{-6})$$

$$= 3755 \times 10^{-6} \text{ (per day)}$$

The above value indicates that for a system of one airborne RPV aircraft at all times, it would be expected that there would be approximately one conflict a year under the random location assumption. Obviously, not all the "conflicts" would result in a collision when one or both of the vehicles are manned.

For manned aircraft, statistics are available as to the frequency of critical situations that have occurred, the number of actual collisions that have occurred, and the number of hazardous incidents that have been reported on a yearly basis. Reference 1-38 indicates that 28 percent of the 1,128 hazardous incidents reported in 1968 were classified as critical near misses. During the same year there were 38 midair collisions. Thus, the collisions were 3.4 percent of the hazardous incidents reported, and it was assumed for this analysis that, for piloted aircraft, 3.4 percent of the hazardous situations would likely result in loss of the aircraft. In reality, this value may be somewhat high, since all near misses were probably not reported. For piloted aircraft operating in the traffic density assumed for the Los Angeles Basin, the total probability per day of collisions between N(=25) regular aircraft and M(=1) surveillance aircraft would be:

$$P_{collision} = (0.034)\ (3755 \times 10^{-6}$$

$$= 127 \times 10^{-6} \text{ (per day)}$$

These data are based on manned aircraft. The question then arises as to what this value would be for the case where one of the vehicles, i.e., the surveillance aircraft, does not have an on-board pilot. Many factors such as vehicle speed, visibility (day and night), collision-avoidance aids used, etc., would have to be considered to provide a realistic evaluation. However, a brief study of the collision problem, considering the field of view of the pilot, aircraft position, speed, etc., indicated that a relatively minor degradation

occurs if one of the aircraft is assumed to be "blind" and cannot react to the situation. For representative vehicle speeds, this degradation was determined to be approximately 20 percent. You would expect approximately 20 percent more collisions to occur where one aircraft is "blind" as compared to both having a capability of seeing and reacting to the situation. Therefore, it was estimated that the total probability of collision for an RPV with other aircraft would be 152×10^{-6} (per day).

To determine the casualty expectation, a collision was assumed to result in the crash of the RPV vehicle and the likely crash of the conflicting manned aircraft. Thus, a hazardous situation is created to people in the aircraft and to people on the ground. The casualty expectation based on one person in the aircraft would be

$$E = 5.55 \times 10^{-2} \text{ (per year)}$$

The hazard to people on the ground from the impacting aircraft was based on an average unprotected population density of 2,340 persons/sq mi in the Los Angeles Metropolitan Area. The conditional casualty expectation in event of a crash of both the RPV and the aircraft would be 0.126 persons and the casualty expectation per day considering the probability of collision between the RPV and other aircraft would be

$$E = (152 \times 10^{-6})\ (0.126) = 19.1 \times 10^{-6} \text{ (per day)}$$

On a yearly basis, the casualty expectation per airborne RPV would be 0.70×10^{-2}. It should be noted that the above value is for a single airborne RPV (on an around the clock basis). If the average number of RPVs airborne is 10, the above value would be 0.07 persons per year.

Therefore, for a system comprised of M RPVs, the total hazard due to collision with other aircraft would be

	Casualty Expectation/yr	
	M = 1	M = 10
People on the Ground	0.007	0.07
People in the Aircraft	>0.06	>0.60
Total	>0.06	>0.67

C. Summary and Hazard Comparison

1. Hazard summary. In sections A and B, the following casualty expectation values were calculated per year for an RPV system consisting of M vehicles airborne at all times:

Hazard Source	Casualty Expectation/yr	
	M = 1	M = 10
RPV crashes	0.001 - 0.57	0.01 - 5.66
RPV collisions with other aircraft	>0.06	>0.67

The above data indicate that, based on a system of 10 RPVs, it can be expected that from approximately one person per year to greater than

6 persons per year would be a casualty as a result of the airborne operations, depending upon the vehicle characteristics. These are expected values and, if an accident occurs, the actual number of casualties would vary from zero to a relatively large number. For example, in the crash of a transport aircraft in Kenner, Louisiana, 24 "non-participant" casualties occurred. A crash of a transport aircraft in a residential area in Tonrane, Vietnam killed 107 persons on the ground; the number injured could not be established. In 1967, the crash of a small plane in El Segundo killed 2 persons and injured 1 on the ground. In the recent crash of a TU 144 in Goussainville, France, 35 persons were casualties.

As previously indicated, the missile ranges have required hazard evaluations for many of the launches from those sites. The hazard is evaluated using the same general approaches used in this analysis, but more sophisticated analyses are possible because better defined input data are available. These analyses are used to establish if the hazards to non-participants are acceptable. While no criteria have been published as to what they consider acceptable, calculated hazard levels for past flights can be used to obtain an understanding of their attitude on this subject. It should be kept in mind that their basic criteria involve a "need vs risk" approach and many of the high hazard launches can be assumed to be for programs with a high national priority.

2. Hazard comparison. In the previous section, the annual casualty expectation associated with the operation of a fleet of 10 RPVs in the Los

Angeles metropolitan area was indicated to exceed one person per year. This number of casualties is insignificant compared to the Los Angeles accident statistics from other causes. For instance, in 1971 there were 439 motor vehicle deaths in Los Angeles and an estimated 1,510 deaths from all accident sources. The accidental injury rate is approximately 100 times the accidental death rate, which indicates that in excess of 150,000 people were injured in Los Angeles. Therefore, the incremental hazard associated with RPV operation is indeed insignificant compared to other accident sources for the general public.

The hazards to which people are exposed can generally be classed as resulting from "participation" acts and "imposed" acts. The former involves some degree of participation by the person affected and includes industrial accidents, recreational accidents, etc. Most of the accidental injuries and deaths discussed fall into this category. Hazards from imposed acts are those which are placed upon a person without his participation. The hazard to the general public created by a missile launch is an example of a hazard created by an imposed situation. Obviously, public acceptance of hazards associated with "participation" acts is significantly different than those from "imposed" acts. The hazard associated with two situations are provided below. Additional information on a variety of hazard sources are provided in Reference 1-40.

3. Space vehicle launches. The national ranges are responsible assuring that every reasonable precaution is observed in planning and executing all operations which result in the launch of missiles and satellites in order to prevent injury to nonparticipants and damage to property. The casualty expectation is the hazard parameter generally used to evaluate the risk. While "acceptable" hazard levels have not been published by Range Safety, the casualty expectation values for flights that have been permitted to be launched can be used as an indication. The maximum known predicted casualty expectation for a launch was approximately 1×10^{-4}, but characteristically the hazard has been 10^{-5} or less, and an average value would probably be about 10^{-6}. The maximum number of space launches per year, 74, occurred in 1966. Discussions with Range Safety personnel at our launch sites have indicated that it is very unlikely that they would accept more than a few launches per year with a predicted hazard level of as high as 1×10^{-4}. However, based on 74 flights and a 10^{-4} hazard for each, the annual predicted casualty expectation is 74×10^{-4}. This value is an order of magnitude lower than the predicted annual casualty expectation associated with an RPV system consisting of one airborne vehicle. A more likely practical limit on the acceptable annual hazard at our launch ranges (for instance, the average value of 1×10^{-6} indicated above) would increase the difference between this accepted hazard and the projected hazards for the RPV system.

4. Commercial aircraft operations around large airports. Reference 1-39 indicates that there is a significant hazard to people around major airports. For instance, the document indicates that the casualty expectation may be as high as 0.6×10^{-4} for a single commercial jet landing at Los Angeles International Airport, based on an estimated one million people within the possible impact zone in case of an accident. Based on the commercial traffic into LAX, the predicted annual value of E as shown in Ref. 1-39

could be as high as 12 persons. The above data were developed for another purpose, and did not consider the protection factors provided by buildings, etc. and assumed a random impact of the aircraft. If these factors were included, the annual casualty expectation would probably approach a value of one person, which would be similar to the hazard projected for an airborne fleet of 10 RPVs.

It should be kept in mind in this case, that the public acceptance of a hazard associated with a manned system such as a commercial airliner is considerably different than it is for an unmanned system. It should also be noted that in studies of other "nuisances", such as noise around airports, that acceptance of an annoying situation by a person is generally related to the degree of his association or identification with that situation. Therefore, since a majority of the public can identify itself with commercial aviation, a different acceptance level probably may exist for this situation than it does, for example, for our unmanned space flights or an RPV system. It should also be noted that the present hazard to people around the airport is a result f a gradual buildup of both airplane traffic and population density around the port.

5. Conclusions. This analysis shows that the hazards for fixed-ng and helicopter RPV operations are significantly greater than have en accepted at our space and ballistic launch sites. It also shows that they be about the same order of magnitude as the hazard created by air fic at Los Angeles International Airport (LAX). No effort was made with is study to establish the "acceptability" of the prediced hazard levels.

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However, if it is assumed that a direct relationship exists between the apparent benefits from a technological advance or activity and the acceptability of risks associated with it, as has been advanced by other writers, then it would appear that the benefits from the RPV system would have to approach the benefits from the air traffic at LAX to be considered "acceptable".

The use of lighter-than-air or hybrid vehicles would reduce the hazard to persons on the ground significantly and would also have a beneficial effect on reducing midair contacts due to their high visibility. If serious consideration is given to operating RPVs over congested areas, however, these aircraft types should be included as candidates.

APPENDIX C: COMPARISON OF STOL/HELICOPTER EFFECTIVENESS

The Dade County report (Ref. 1-2a) may be described as a technical and cost diary of a single STOL airplane introduced into a system that has previously employed helicopters. In conjunction with the CAL report (Ref. 1-2b), this report probably represents the first comprehensive and objective comparison made between aircraft types in a police operation. Without the LEAA grant, it is doubtful that such data could have been collected during the exigencies of routine police operations. This is evidenced by the fact that several combined fixed-wing/helicopter operations have existed in the past without comparitive data of this type having been generated. Tables 7-1 through 7-10 are extracted from Ref. 1-2b. Unfortunately, an accident reduced the total test time available and the evaluation did not provide conclusive results. Nevertheless, these tables are included in the appendix to introduce the non-Law Enforcement reader (aircraft manufacturers, etc.) to some of the typical patterns and characteristics of police aerial activities without his needing to refer to other documents.

Table C-1. STOL Effectiveness and Off-Airport Landing Data*

Total number of missions	
which helicopter could handle as effectively:	41
which helicopter could not handle as effectively:	12
which could be handled effectively only by the helicopter:	2
which could be handled effectively only by the STOL:	9
in which it would have been advantageous to land at the scene:	7
in which it would not have been advantageous to land at the scene:	45
in which helicopter could have landed:	42
in which helicopter could not have landed:	7
in which STOL could land:	17
in which STOL could not land:	32
in which STOL made an off-airport landing:	0
where it was advantageous to land; the helicopter could land, but the STOL could not:	2
where it was advantageous to land and neither the helicopter nor the STOL could land:	1
where the effectiveness was compromised by having the STOL:	4
where the effectiveness was not compromised by having the STOL:	45
Total number of missions flown	53

Table C-2. Helicopter Effectiveness and Off-Airport Landing Data*

Total number of missions	
which STOL could handle as effectively:	21
which STOL could not handle as effectively:	18
which could be handled effectively only by the helicopter:	15
which could be handled effectively only by the STOL:	0
where it would have been advantageous to land at the scene:	24
where it would not have been advantageous to land at the scene:	15
where helicopter could have landed:	36
where helicopter could not have landed:	3
where helicopter did land:	23
where helicopter did not land:	16
where STOL could land:	1
where STOL could not land:	38
where helicopter landed and STOL could have landed:	1
where helicopter landed and STOL could not have landed:	22
where it was advantageous to land but neither helicopter not STOL could have landed:	0
Total number of mission flown	39

*Ref. 1-2(b)

Table C-3. STOL Effectiveness by Mission Type*

Mission Type	Approximate No. of Hours Flown by the STOL by Mission Type	Percentage of Hours Where Helicopter Would Have Been as Effective as the STOL	Percentage of Hours Flown Where Helicopter Would Not Have Been as Effective as the STOL	Percentage of Hours Flown Where Mission Could Only Have Been Handled by the Helicopter	Percentage of Hours Flown Where Mission Could Only Have Been Handled by the STOL
Unscheduled Missions:					
Armed Robbery	0.5	100	0	0	0
Civil Disturbance	13.5	75	25	0	25
Scheduled Missions:					
Fire Detection	2.0	100	0	0	0
General Surveillance	25.0	80	20	4	12
Illogical Dumping	4.0	100	0	0	0
Lighted Patrol	13.0	38	62	0	46
Recreational Area	5.0	80	20	40	20
Rooftop Surveillance	5.0	20	80	0	40
Rural and Vacant Area	4.0	50	50	0	0
Search and Stolen Vehicles	7.0	100	0	0	0
Traffic Patrol	9.0	100	0	0	0
Water Patrol	8.0	81	19	0	19
Water Pollution	2.0	100	0	0	0

*Ref. 1-2(b)

Table C-4. Helicopter Effectiveness by Mission Type*

Mission Type	Approximate No. of Hours Flown by the Helicopter by Mission Type	Percentage of Hours Flown Where STOL Would Have Been as Effective as the Helicopter	Percentage of Hours From Where STOL Would Not Have Been as Effective as the Helicopter	Percentage of Hours Flown Where Mission Could Only Have Been Handled by the Helicopter	Percentage of Hours Flown Where Mission Could Only Have Been Handled by the STOL
Unscheduled Missions:					
Civil Disturbance	13.583	74	27	27	0
Drowning	0.583	0	100	0	0
Photographic	2.917	37	63	63	0
Scheduled Missions:					
Fire Detection	3.000	33	67	67	0
General Surveillance	15.000	47	53	40	
Illegal Dumping	2.000	0	100	100	
Lighted Patrol	3.000	100	0	0	
Narcotics	2.000	0	100	100	
Recreational Area	4.000	50	50	50	
Rooftop Surveillance	5.000	100	0	0	
Rural and Vacant Area	2.000	0	100	100	
Search for Stolen Vehicles	2.000	50	50	0	
Traffic Patrol	9.000	67	33	22	
Water Patrol	5.000	60	40	40	
Water Pollution	2.000	100	0	0	

Table C-5. Helicopter Landings by Mission Type*

	Approximate No. of Hours Flown by the Helicopter by Mission Type	Number of Incidents Where the Helicopter Landed	Total No. of Off-Airport Landings Made While Handling Incidents
Unscheduled Missions			
Civil Disturbance	13 Hr, 35 Min	4	4
Drowning	35 Min	1	2
Photographic	3 Hr, 55 Min	1	1
Scheduled Missions			
Fire Detection	3 Hr	2	2
General Surveillance	15	6	7
Illegal Dumping	2	2	3
Lighted Patrol	3	-	-
Narcotics	2	3	3
Recreational Area	4	3	3
Rooftop Surveillance	5	-	-
Rural and Vacant Area	2	2	2
Search for Stolen Vehicles	2	2	3
Traffic Patrol	9	2	2
Water Patrol	5	3	3
Water Pollution	2	1	1

*Ref. 1-2(b)

Table C-6. Helicopter Landings by Type of Incidents*

Type Incident	Number of Incidents for Which the Helicopter Landed
Aircraft Accident	1
Arrests:	
One male arrested for public intoxication (Sniffing lacquer thinner) Four males arrested for shooting at houses from boat	
Car Stripping Investigation	1
Checks of persons in remote areas	3
Civil Disturbance	4
Landed at command post for fuel, information, and tear gas replenishment	
Demonstration of Helicopter	1
Drownings	2
Information	1
Narcotics Investigations	5
Photography at Crime Scene	1
Recovery of Stolen and/or Abandoned Vehicles	8
Warnings:	3
One incident of illegal dumping Two incidents of people discharging firearms	

Table C-7. Airspeeds Used by the Helicopter and STOL while Performing Missions

Airspeed, MPH	Percent of Helicopter Missions in Which This Speed was Used	Percent of STOL Missions in Which This Speed was Used
0-10	7.9	*
11-20	7.9	*
21-30	18.4	*
31-40	21.1	0.0†
41-50	26.3	19.2
51-60	44.7	46.2
61-70	76.3	92.3
71-80	7.9	55.8
81-90	*	36.5
91-100	*	38.5
101-110	*	36.5
111-120	*	38.5
121-130	*	7.7
131-140	*	1.9

*Ref 1-2(b)
†Not within the performance capability of the aircraft in present configuration.

Table C-8. Helicopters and STOL Flight† Duration Distributions*

Flight Duration	Helicopter			STOL		
	Number of Flights	Percent of Total Flights	Cumulative Percentage	Number of Flights	Percent of Total Flights	Cumulative Percentage
0 - .50 Hrs	4	7.5	7.5	3	4.8	4.8
.51 - 1.00 Hrs	13	24.5	32.0	3	4.8	9.6
1.01 - 1.50 Hrs	11	20.8	52.8	6	9.5	19.1
1.51 - 2.00 Hrs	24	45.3	98.1	26	41.3	60.4
2.01 - 2.50 Hrs	1	1.9	100.0	16	25.4	85.8
2.51 - 3.00 Hrs	-	-	100.0	4	6.3	92.1
3.01 - 3.50 Hrs	-	-	100.0	3	4.8	96.9
3.51 - 4.00 Hrs	-	-	100.0	2††	3.2	100.0

*Ref. 1-2(b
†On missions H-70-222 and 235, the helicopter refueled a total of three times while away from its base. These two missions are treated as 5 flights for purposes of this tabulation.
††The longest STOL flight was 3 Hrs, 50 Min as compared with 2 Hrs, 10 Min for the helicopter.

Table C-9. Helicopter Data, Equipment Used*

Number of missions where special equipment was used:	25
Lights:	9
Lighted patrol only	2
Lighted patrol and illumination by request	7
Illumination by request only	0
Number of incidents where illumination was used to assist ground units	11
Public Address	10
Siren	3
Tear gas cannisters	2
Still camera	5
Movie camera	1
Floats	1
Litter	1
Number of missions where no special equipment was used:	25
Number of missions in which additional specialized equipment could have been used:	9
Improved hi-intensity lights	6
Liquid tear gas for dispenser	1
Movie camera	1
Live T.V.	1

*Ref. 1-2(b)

Table C-10. STOL Data, Equipment Used*

Number of missions where special equipment was used	22
Lights:	15
Lighted patrol only	6
Lighted patrol and illumination by request	7
Illumination by request only	2
Number of incidents where illumination was used to assist ground units	10 or more
Public address	7
Siren	2
Still camera	1
Number of missions where no special equipment was used:	31
Number of missions in which additional specialized equipment could have been used:**	16
Permanent police radio installation	4
Stabilized prism monoculars	4
Binoculars†	3
Additional VHF navigation-communication radio	2
Floats	2
Air and water sampling equipment	1
Weather radar	1

Ref. 1-2(b)

In addition, on 5 missions, the pilot or observer stated that an FAA waiver permitting flight below 1,000 feet over densely populated areas would have been helpful.

A portable hand held radio transceiver (Dumont HH-300) was used with a permanent antenna mounted on the aircraft routed on the aircraft pending delivery of a permanent police radio installation.

† Three types of binoculars were subsequently evaluated and found to be unsatisfactory.

CHAPTER VIII. GLOSSARY

ACE	Aerial Crime Enforcement
ADF	Automatic Direction Finder
AFFDL	Air Force Flight Dynamics Laboratory
AHS	American Helicopter Society
AR	aspect radio
ASME	American Society of Mechanical Engineers
ASW	antisubmarine warfare
ATC	Air Traffic Control
CAL	Cornell Aeronautical Laboratory
c_p	specific heat
CTOL	conventional takeoff and landing
DELAG	Pre-WWI German airline using dirigibles
DOT	Department of Transportation
ECLB	emergency crash locator beacon
EW	empty weight
FAA	Federal Aviation Agency
FAR	Federal Aviation Regulation
FM	frequency modulated
GCA	ground-controlled approach
GW	gross weight
HP	horsepower
H.T.M.	Helicopter Technik, Munchen (Munich)
IAA	Interagency Agreement

IFR	instrument flight rule
IR	infrared
JATO	jet assisted take-off
Kv	single volume factor, combined impurity and expansion factors
LAPD	Los Angeles Police Department
LAX	Los Angeles International Airport
L/D	lift-to-drag ratio
LEAA	Law Enforcement Assistance Administration
LTA	lighter than air
NASA	National Aviation and Space Administration
NAV/COM	Navigation and Communications Satellite
NILECJ	National Institute of Law Enforcement and Criminal Justice
nmi	nautical mile
NTSB	National Transportation Safety Board
ONR	Office of Naval Reserve
PA	public address (system)
PL	payload
[illegible]	probability of conflict
R&D	research and development
RPB	remotely piloted blimp
r.p.m.	revolutions per minute
RPMB	remotely piloted mini-blimp
RPV	remotely piloted vehicle

SAS	stability augmentation system
SEC	secondary electron conduction
SLS	sea level standard
STOL	short take-off and landing
SVFR	special visual flight rule
TBO	time between overhauls
TOR	technical operations report
TV	television
UL	useful load
UNICOM	Private aviation frequencies for unofficial (non-FAA) communications
V_{AHA}	volume swept out in unit of time by the aircraft hazard area
V_{AS}	volume of airspace
V_C	minimum speed at which adequate control is available
V_{cp}	cruise speed
VFR	visual flight rule
VFW	Now VFW Fokker, European Aircraft Manufacturing Company
VHF	very high frequency
V_L	loiter speed
V_m	minimum speed
V_{max}	maximum speed
V_{NE}	never-exceed speed
V_r	relative speed
VRC	Vehicle Research Corporation
VTOL	vertical take-off and landing
WPAFB	Wright Patterson Air Force Base

CHAPTER IX. REFERENCES AND BIBLIOGRAPHY

The reference list is divided into 3 Sections. The first section entitled Operational References includes all documents pertinent to law enforcement operations. These include all past reports, regardless of subject, if directed primarily at police operations or if study was carried out with the support or direction of a law enforcement agency.

The next section, entitled Technical References, includes purely technical works pertinent to the aerial vehicle or its equipment.

The final section, entitled Cost References, includes all aspects of cost whether involved in the vehicle itself or the operation in which it was involved. In light of the comments in the first paragraph above, cost data obtained from existing police operations would most probably be found in Operational References while cost data obtained from non-police sources would be found in this section.

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D. INDUSTRY

Many Corporations, organizations and individuals were contacted for data for this study and the overwhelming majority were not only cooperative but generous in providing information. A portion of this information was proprietary and provided to The Aerospace Corporation with the assurance of such treatment.

Some of this information contributed directly to the results developed or stated and therefore should be referenced with due credit to the originating organizations. Obviously, this would require the very exposure which would destroy, at least in part, the proprietary nature of the material.

As a compromise, it was decided to acknowledge receipt of data from contributors in this section without stating in detail the nature of the material received.

In support documentation, a collection of pertinent data has been assembled and will be made available to government or other organizations which are in a position to properly control the disclosure of the material. At the same time, the report material prepared on the basis of any organizations' data will be submitted to that organization for review and comment. If enough organizations approve the disclosure of their information, a non-confidential appendix may be issued in later printings of the report.

At this time the receipt of material is acknowledged with thanks from the following organizations and individuals.

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Nagler Aircraft Corp., Phoenix, Arizona

Piasecki Aircraft Corp., Philadelphia, Pa.

Rotorway Inc., Tempe, Arizona

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2 Autogiro Manufacturers

Aero Resources Inc., Gardena, Calif. (Successor to McCulloch's J-2 Autogiro Interests)

Bensen Aircraft Corp., Raleigh, N.C.

Farrington Aircraft Corp., Paducah, Kentucky

McCulloch Aircraft Corp., Lake Havasu City, Ariz.

Saalfeld Aircraft Co., San Diego, Calif.

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Individuals who provided helpful information on autogiros:

T. F. Hanson, Rotary Wing Consultant, Newhall, Calif.

Mr. B. Lindenbaum, Deputy for Studies and Analyses, AFFDL WPAFB, Dayton, Ohio

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