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A STUDY OF METHODS FOR LOWERING AERIAL ENVIRONMENTAL SURVEY COST

ENVIRONMENTAL APPLICATIONS OFFICE

OF THE

GEORGE C. MARSHALL SPACE FLIGHT CENTER

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SCI SYSTEMS, INC.

HUNTSVILLE DIVISION

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JANUARY, 1973

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ABSTRACT

This document presents the results of a study of methods for lowering the cost of environmental aerial surveys. A wide range of low cost techniques were investigated for possible application to current pressing urban and rural problems.

The objective of the study is to establish a definition of the technical problems associated with conducting aerial surveys using various low cost techniques, to conduct a survey of equipment which may be used in low cost systems, and to establish preliminary estimates of cost. A set of candidate systems are selected and described for the environmental survey tasks as described herein.

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1.0 INTRODUCTION AND SUMMARY

The National Aeronatics and Space Administration is engaged in applying the results of space program developed remote sensing techniques and analysis methods to studies of the earth. In particular the Environmental Applications Office of the MSFC Science and Engineering Directorate has applied areal environment survey methods to pinpoint the effect of agricultural pests on economic crops. It is evident that such techniques may find wide application to many problems involving other rural environmental problems, as well as possible applications to urban and suburban problems.

The application of conventional aerial survey methods to problems of a more restricted nature leads to a relatively high cost per unit data obtained. Conventional techniques, with aircraft suited for conventional aerial survey or mapping, are limited in maneuverability in a limited geographical area, and crew and operating cost tend to be expensive. The objective of this study is to explore the feasibility of practical lower cost approaches to perform aerial surveys in both rural and surburban environments.

The major task involved is the performance of this study was in defining the technical problems associated with various low cost systems. This included definition of the problem, establishing typical applications, flight patterns, and defining typical sensor requirements. The problems and approaches that could be used in control and navigation were investigated. Take off and recovery problems and techniques were investigated, and a survey made of legal and safety aspects. Details of these investigations are found in Section 2.0.

A survey of equipment is presented in Section 3.0. This included a wide spectrum of possible candidate craft, engines, controls and support equipment.

The acquisition and operating cost of the various systems were then estimated. A possible operational procedure is suggested for the candidate systems, and is used in estimating the cost of performing the survey task postulated.

The candidates for the low cost aerial survey system range from small radio controlled models to high performance military drones. Included as a candidate is a small manned aircraft and radio controlled lighter-than-air craft.

The primary selection of vehicles is performed in Section 4.0. The selected systems are presented in Table 2-1, along with their approximate cost of acquisition and operation, and their most suitable applications and utilizations.

TABLE 2-1, CHARACTERISTICS OF SELECTED SYSTEMS

SELECTED SYSTEM	COST OF AQUISITION	OPERATING COST*	APPLICATION	UTILIZATION
A Model/Drone	Moderate $15,000 - $25,000	Low $2 to $3/hr.	Small Agricultural - Mining Operations	Moderate 20 to 100 days per yr.
B Light Aircraft	Moderate $12,000	Moderate $6 to 8 /hr.	Small to Large Areas	High - 100 days per yr. or greater
C R. C. Blimp	High $40,000 to $60,000	Low $3 to $4/hr.	Urban	High - Joint Use By City Departments
D Rental Aircraft	None	High $35 per hr.	Large Areas	Low - 1 to 20 Days/yr.

* Does not include cost of crew.

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The candidates selected for the low cost system included a model/drone (a large model type craft in the 60 to 80 pound class), a light manned aircraft, and the Radio Controlled (RC) blimp. These candidates were selected for slightly different applications. The model/drone is most suitable for extremely small, isolated agricultural problems, while the manned light aircraft is more suitable for larger areas, or where a large volume of data is to be collected from a general area. The RC blimp is best suited for urban and suburban applications. The RC blimp acquisition cost is almost out of the category of low cost systems, but the high use factors which it may find in large urban areas, the low operational cost and inherently safe operation make the system very appealing.

The study has identified the problems associated with a wide range of possible candidate systems. An emphasis was placed on unmanned systems, since the lower payload required would tend to allow smaller and presumably lower cost craft to be used. The conclusions of the study show that

- Military drones or Remotely Piloted Vehicles (RPV) are not well suited for the intended applications.

- A small model/drone is suitable for only small survey areas due to the limited range possible with visible control and tracking techniques.

- The use of a remote controlled blimp is the best choice for urban areas due to its inherently safe operations and ability remain on station for long periods of time.

- The small model/drone shows more potential as a highly cost-effective technique pending solving certain technical problems.

The technical problems which should be addressed so that the model/drone could lead to a more effective system are:

- The development of a compact, light-weight camera

- The development of a low cost tracking and stability augmentation (auto-pilot) system

It is believed that the development of the above items is fairly straightforward; development cost has not been determined, but it is estimated to range from $25,000 to $75,000 for the tracking system, and possibly $5,000 to $10,000 for the camera. Several possible approaches to the problem of tracking and control are discussed in Section 2.0. A more detailed discussion regarding the conclusions and recommendations is found in Section 5.0.

2.0 DEFINITION OF PROBLEM

This section of the report is devoted to defining the problems associated with a low cost aerial survey system. Typical missions and requirements are postulated to serve as a basis for candidate systems to be compared. Three general categories of applications are identified; the urban, the agricultural/rural, and the natural disaster.

A discussion of sensor equipment is presented; a multicolor camera is the most likely sensor equipment to be used. Typical flight patterns and altitudes are selected in Section 2.3 to establish the time required to perform various missions.

The problems associated with control, stabilization and navigation are discussed in Section 2.4. Take-off and recovery problems are discussed in Section 2.5, and a summary of the legal and safety aspects are presented in Section 2.6.

2.1 TYPICAL APPLICATIONS AND OPERATIONAL REQUIREMENTS

Both the urban and suburban environments offer substantial opportunities for application of remote sensing methods to assist in the solution of current pressing problems. The broad problem of urban transportation can be assisted by providing indications of traffic density and flow, and local peculiarities. Such methods can be more complete than approaches based on sampling techniques. Assistance can also be given to local governments and industries for optimum plant siting with minimum ecological interference. In the hands of a local government a low cost aerial system could provide an assessment of situations requiring a prompt reaction if proper sensing instruments were provided. This includes an assessment of major accidents on freeways, civil disorders, and an aid to the evaluation and enforcement of pollution control measures.

A low cost aerial survey system might find wide application to many rural and agricultural problems such as fertilizer and pesticide efficiencies, yield forecast, soil moisture status and reserves, soil temperatures and a definition of optimum action schedules.

Other applications include the evaluation of mining operations—the impact on surrounding environment, and the evaluation of damage due to natural disasters such as floods, hurricanes, and earthquakes.

A low cost aerial survey system may be suitable for a broad range of problems. However, for purposes of this study the problems are restricted to several more specific applications so that the operational requirements may be better defined, and the study may proceed to evaluate candidate systems.

The applications to be studies are grouped under three major categories. They are:

I. Urban Applications
II. Agricultural/Rural
III. Natural Disasters

Under group I. above, a typical application is the study of traffic flow, or in estimating number and locations of people during civil disorder, etc. Air sampling over urban and suburban area is another possible application. For purposes of this study it is assumed that only moderate altitude and mobility is required, but ability to remain on station and endurance is of prime importance. Major constraints to operating in urban areas is the liability incurred in the event of an accident, and the fact that there are usually local ordinances governing flights over the city and ordinance prohibiting noisy operations.

The second category of applications are those found in rural or agricultural regions. These are further classified as given below:

1. "Spot" Problems—Where wide areas of forest or crops are dying or debilitated. This could be due to infestation, pollution, or long term changes in weather patterns. It is possible such conditions are present or incipient without the local population being aware of it. Large areas of land should be surveyed in this case. The data can be examined at a later time, to "spot" the problem and diagnose it. As a model, an area 100 miles by 35 miles is chosen, at an altitude of up to 12,000 feet.

2. Local Agricultural Infestation—It is reasoned that often assistance could be rendered to farmers in regard to problems with particular crops, or where there is reason to believe that a particular pest is involved. In this case a low cost method is often desirable to examine several small areas. As a model it is assumed that several areas of about 5 miles^2 are to be examined from an altitude of 3000 feet, each within the same general area.

3. Survey of Mining Operations—It may be desirable to observe the effect of mining operations on a relatively small watershed. The ideal time for such observation may be during or just after rainstorms, such that water flow and subsequent soil transportation by water may be observed. A typical operation may involve one linear flight along a 1 mile path at 1500 to 3000 feet altitudes.

The third category, natural disasters, would involve general surveys of an area after hurricanes or flooding. The use envisioned would be to estimate damage, or to assist in a long term study. An area of 10 miles^2 at an altitude of 3000 feet is established as the model in this case.

A summary of the requirements for all the problems defined is given in Table 2-2.

In Section 2.3 the areas postulated will be used in establishing a possible flight pattern and survey time. Eventually, the candidate systems will be evaluated on the basis of the cost of performing these tasks, among other considerations.

2.2 CHARACTERISTICS OF SENSOR EQUIPMENT AND CONTROL

The primary sensor used in the gathering of data for the analysis of agricultural and forest problems is the multicolor camera. The camera that is in use currently takes four pictures simultaneously, each of which may be filtered individually. The four photographs of a scene may be studied individually or in a composite form, such that a skilled investigator may quickly determine stress in foliage. The resolution required for the invisaged application is not severely stringent. It has been estimated that a 35 mm camera, using a 50 mm lens at an altitude of 3000 to 5000 feet would be adequate. Film resolution of 100 lines/mm (corresponding to Kodak Plus-X types) are adequate. The greater resolution afforded by special purpose aerial reconnaisance type films are not necessary and could probably not be utilized due to engine vibration and movement of the aircraft (roll and pitching)*. Film speed and camera speed reflect a

---

*Using tables derived for aerial photography use (Figure 14, Hycon Corporation Reference Book) and MIL-STD-150A Resolving Test gives the following resolution for a 50% contrast ratio:

For an Angular Rate of 100 millradians/sec. (aircraft movement). Shutter speed 1/500 sec. Focal length 1.9 inches (50 mm). The angular resolution is .4 milliradians. Lens/film resolution is 60 lines/mm.
For an altitude of 3000 feet this is approximately a 1.2 foot resolution.

TABLE 2-2 PARAMETERS IN TYPICAL APPLICATIONS

	Application	Altitude	Min. Req. Endurance	Area Covered	Approx. Range of Air Speed	Ability to Remain on Station	Sensors	Problems
I.	Urban	2K to 5K ft.	4 to 6 hrs.	10 $miles^2$	30 to 60 mph	Yes	Photog. -Time Lapse -Movie Real Time -Direct -TV -Low Light Level	-Noise -City Ordinances -Hazard to Aircraft
II. 1	"Spot"	12K ft.	30 to 60 minutes	3500 $Miles^2$ (100 x 35 mi)	100-200 mph	No	Photog. -Multi Colors -Infrared	-Navigation -Control -Endurance
II. 2	Local Ag.	3K ft.	30 minutes	5 $miles^2$ (2.5 x 2)	60 - 80	No	Same	
II. 3	Mining	3K ft.	15 minutes	1 $mile^2$ (1 mile pass)	60 - 80	No	Same	-Navigation and Control in Bad Weather
III.	Disasters	3K-10K ft.	15 minutes	10 $miles^2$ (5 x 2)	60-80	No	Same	-Navigation - Control

compromise. The vibration and aircraft movement indicate the need for fast shutter speeds, while the use of filters, the need for resolution and latitude indicate a slower film and shutter speed. Since most of the agricultural investigations would be made on clear days and during hours of good sunlight, a compromise can be established. For unfiltered lens, using ASA speed 100, a tentative compromise would be 1/500 seconds at f8.

Actually, four colors are not essential to the analysis; three or even two colors may give sufficient information.

The general requirements for the camera are:

1. Two, three or four photographs must be taken simultaneously with individually filtered lens.
2. A motor driven film advancement mechanism must be provided.
3. A high capacity film magazine is needed. This must hold 60 to 200 exposures.
4. Manually adjustable speed from 1/60 to 1/1000 should be provided.
5. Automatic aperature control is desirable but not essential.
6. No focusing mechanism is necessary.
7. The camera should not weigh more than 10 lbs.
8. Film should be commercially available 35 mm.
9. Lens should be interchangeable so that 35 mm, 50 mm, 90 mm and 135 mm could be used.

A survey of cameras revealed that there is no camera available meeting all the above requirements. The most promising prospect is the modification of the Leica M3 or the Nikon 35 mm cameras. It appears that a development effort is necessary to obtain a suitable camera, meeting the requirements stated above.

The study has proceeded on the assumption that such a camera can be obtained, albeit a development effort is required.

The sensor most appropriate for urban problem analysis is a time lapse camera or TV cameras. TV cameras are preferred because of the real time presentation of data; giving a operator the ability to adjust the presentation, location and/or other qualities of the data. The use of TV cameras introduces the need for a wideband transmitter, a large source of electrical power, and consequently greater payload ability of the aerial platform. With the advent of low-light level TV and TV systems with high dynamic range, the use of TV as the primary sensor for the urban application is especially attractive. An advantage of the TV system is also in the recording of the data on magnetic tape for later analysis; unwanted data being erased and the tape used again. In the long run, it appears that the TV systems are probably more cost-effective in the urban system than film-photography systems, providing the airborne platform has sufficient payload capability.

Secondary sensing systems may include devices for sensing the presence, degree of, and constituents of air pollutants such that locating the source is possible. Self-contained, packaged units capable of this type of measurement are being developed by various sources; the "integrating nepholometer, Model 550" from Meteorology Research, Inc., for example.

Air and ground temperatures (temperature inversions are of particular interest to the study of air pollution) are within the realm of measurements which may be supported by the low-cost aerial platform.

2.3 FLIGHT PATTERNS, ALTITUDES, NUMBER OF PHOTOGRAPHS

In this section the factors which must be considered in selecting the flight pattern, altitude, and number of photographs are identified. The above are important since they affect the time and ultimately the cost of performing a given task. In the following paragraphs the factors are discussed in a general sense, and are directed more toward the surveying of large agricultural type areas than toward the more restricted urban application. In this section it is assumed that the sensor is a camera.

- Resolution—This factor has been identified previously in the discussion of sensor equipment. Resolution is affected by the camera/film parameters, aircraft vibration and motion, and altitude. Tables and charts are available showing the resolution as a function of angular motion, shutter speed, focal length, and lens/film resolution. Forward motion of a light drone or model has a negligible affect upon resolution, but for high-speed systems the forward motion must be compensated for.

- Area Covered by Photo—This is determined by the focal length of the camera and altitude.

- Aircraft Stability—The angular motion of the aircraft may affect the area covered by the photograph if taken at an altitude other than straight and level. Stabilized camera platforms are not under consideration because their size, weight and cost are not consistent with the idea of the low-cost system.

- Tracking and Control—Errors in tracking introduce an unknown into determining the position of the aircraft, and control problems may prevent the operator in positioning the aircraft to the desired location.

- Endurance—Aircraft and/or camera endurance will have a definite affect upon flight patterns and time to perform a task.

- Speed/Rate of Climb/Altitude Limitations—These characteristics may prove to be a definite limiting factor to some of the smaller systems.

- Terrain Factors—Irregularity of the terrain or the plan of the area to be surveyed would affect flight patterns and time. This factor could vary to a large degree, but to facilitate further study it will be assumed henceforth that all surveys will be conducted over rectangular areas. A highly irregular shape does place emphasis on maneuverability of the aircraft, and possibly a more stringent requirement on the tracking and control function.

- Ability to Position Ground Equipment—Ideally, the ground control/support equipment should be located centrally within the area to be surveyed, and in forthcoming analysis this will be assumed. However it is clear that this will be unlikely in real cases, where terrain and unimproved roads will hamper the positioning of the ground equipment.

- Craft Maneuverability—A characteristic of high speed drones and aircraft is that a wide area is needed to turn them around without causing excessive G-loads. Therefore, this factor could be very important in the surveying of relatively small or irregular areas.

As the factors given above become better defined, a typical mission will be given for the applications postulated in Section 2.1.

2.3.1 Stability

The stability of aircraft is concerned with the degree to which it deviates from its straight and level attitude when perturbed by external forces, and how it responds to such perturbations. For high speed aircraft, with high wing loadings and small moments of inertia, this is a very complex subject. This not only involves an aerodynamic treatment but must involve the response of all elements of the control system. Fortunately the emphasis is in low airspeed systems, which are inherently more stable.

By observing the flight of properly trimmed light aircraft and models, it appears that the most severe disruption to straight and level flight is due to the aircraft flying into vertical columns of moving air resulting from the rising of warm air (thermals) due to uneven ground heating. The wings will usually encounter an unequal upward flow of air such that a roll will be introduced. Depending upon the design of the aircraft, amount of dihedral angle, etc. the craft will return to normal flight accompanied by a slight turn, and a slight pitching movement due to the precession of the engine.

If the aircraft encounters a strong thermal head on there is usually a sudden increase in altitude without an accompanying pitch, roll or yaw. When strong thermal activity is present, as is usually the case in most southern or midwestern states in the summer, it is generally possible to reach an altitude above which the air is calm. However, at these altitudes one must contend with the ground being obscured by the clouds formed when the thermal columns reach a point where condensation occurs.

Generally gusty weather, that is usually associated with frontal activity or large movement of air, is a more severe problem but is one that is readily apparent to operators on the ground. The low altitude low performance system would not be a good candidate for operation in such weather.

The stability affects the usability of photographs taken with the result that some redundancy is required in photographic coverage. It is useful to identify some of the parameters associated with this problem, although a thorough analysis is not intended. Assuming that a light drone or model, with no camera stabilization is being flown above flat terrain at moderate altitudes as is shown in Figure 2-1. The craft is at an altitude h, with a camera whose angular coverage is α . In an ideal case a photograph need be taken only at intervals of x. It is assumed that the film speed and shutter speed are such that the forward motion of the craft are not significant.

The aircraft instability will introduce the factors shown in Figure 2-2. Where $\emptyset$ is the aircraft roll angle, β is the aircraft pitch angle, and θ is the aircraft yaw angle. The result is that the actual projection of the camera angle on the ground is a series of trapazoids, and that to insure that the area to be surveyed is covered adequately the interval between photos must be decreased.

During a perturbation of level flight by a thermal, it is noticed that the resulting aircraft stability parameters identified occur in a correlated manner, but that the peak roll, pitch and yaw do not occur simultaneously.

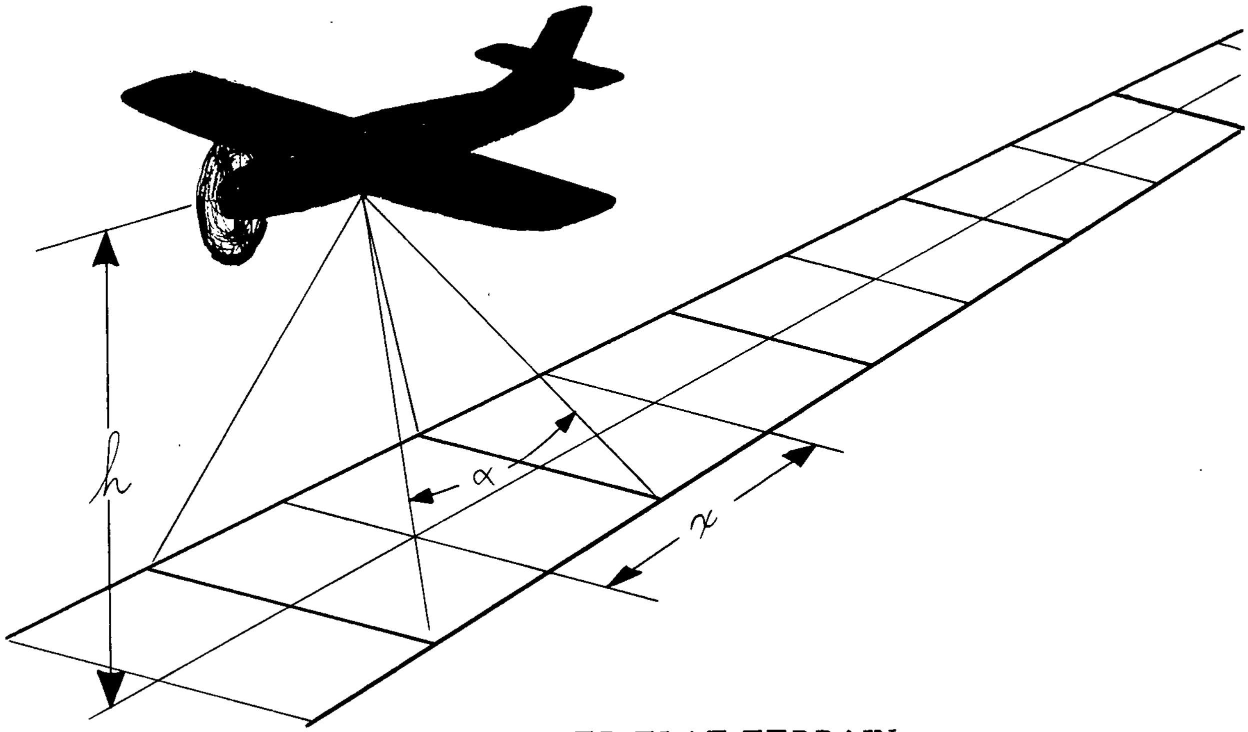

FIGURE 2-1, LEVEL FLIGHT OVER FLAT TERRAIN

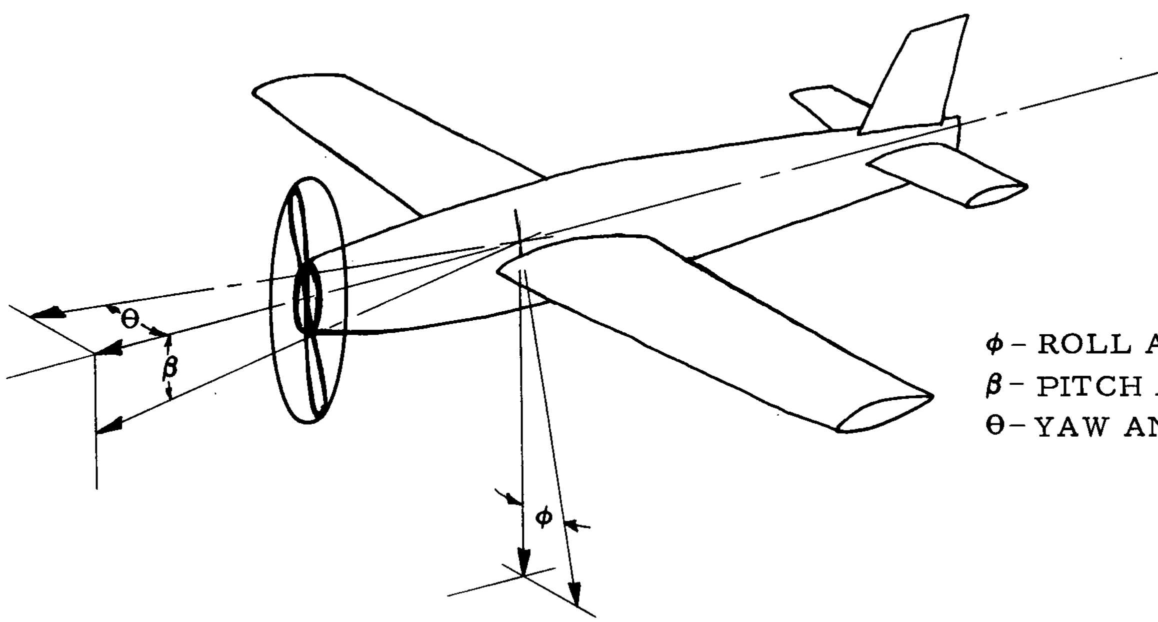

FIGURE 2-2, ANGLES OF PERTURBATION OF LEVEL FLIGHT

The maximum angular deviation and angular rates depend upon the size and design of the craft and upon the degree of the disturbing air currents, but some typical values are postulated to observe the effect upon the photography problem.

Assume that a lightweight drone or model is being used with the following parameters:

$v = 100$ mph (assume ground speed = air speed)

$h = 3000$ feet

$\alpha = 40.8^{\circ} \times 27^{\circ}$ for a 35 mm camera with 50 mm lens.

The area covered by the photograph is 2230 feet x 1445 feet and a photograph is required every 1445 feet or 9.85 seconds.

Now assume a roll of peak amplitude of 10° is encountered. A photograph taken at this time covers

$$h \tan(\alpha/2 + \emptyset) = 3000 \tan(20.4^{\circ} + 10^{\circ}) = 1520'$$

on one side, and

$$h \tan(\alpha/2 - \emptyset) = 540' \text{ on the other.}$$

Compared to the original coverage this is short on one side by 575 feet. This alone would cause a loss of 52% of the coverage if the roll were to be opposite on two adjacent photographs. The aircraft would then turn giving an angle which deviates from the original axis of flight by perhaps 5° and might pitch up or down by 5°. A projection on the ground if a photograph were taken at this time would appear as shown in Figure 2-3. The figure indicates that the interval between photos should be shortened by 636' in the direction of flight, which is 44%.

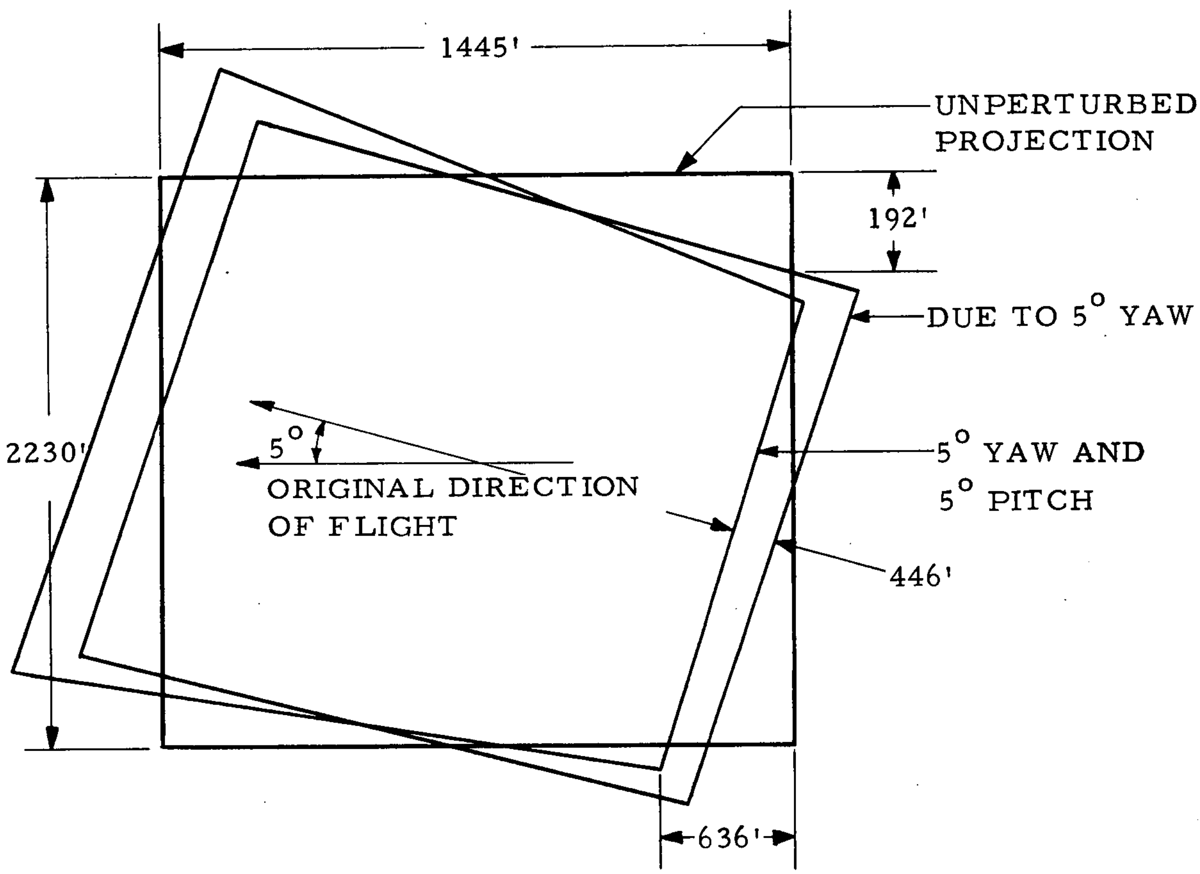

FIGURE 2-3, PROJECTION ON GROUND DUE TO PITCH AND YAW

Thus the number of photographs required for straight and level flight should be increased by a factor of about 2 to cover a given area in the turbulent conditions outlined.

This, of course, assumes almost continual perturbation of the craft, and that no loss of photographic coverage can be tolerated. Neither of the assumptions are quite correct. In the first case it is possible that an operator on the ground can observe (with binoculars) the frequency and degree to which the craft is being affected and can adjust the number of photographs per second accordingly. Also a knowledge of the desired per cent coverage required can be taken into account.

The foregoing discussion has brought to light the effect of stability on aerial photography. It may be well to consider alternatives to merely increasing the number of photographs, which is to provide more stability.

An inherent stability is obtained in aircraft by providing dihedral angle in the wings, providing a low center of gravity, generous surface in the vertical and horizontal fin, and by aligning the thrust through the pitch axis. Often such techniques compromise performance by increasing drag, such that only fairly low performance systems are inherently stable.

Conventionally, the operator augments the stability of model aircraft as well as light manned aircraft. This technique is not generally suitable for ranges beyond about one mile for small models because attitude and motion is misinterpreted.

Active stabilization by auto-pilots involves a significant jump in cost and complexity of the system, but is necessary for extending the range. Since it may be possible to integrate the stabilization with control and tracking functions, this will be discussed in more detail in following paragraphs.

Attitude control in out-of-sight flights have not been discussed in this regard because it is a slightly different problem. Inertial reference is essential in this case because the craft can go into a coordinated maneuver with no abnormal G-loadings, and unless corrected will eventually end in a crash. This is true even for a manned aircraft operating under "blind" conditions. But this type of attitude control, at least for low performance craft, does not require the fast response of a camera stabilization system, and may be performed in part by ground controllers if the essential information is fed back. The essential information consists of rate-of-turn, airspeed/engine speed, and altitude. Supplementary information consists of rate of climb/dive, angle-of-bank, and heading. Some alternate approaches in the attitude control problem are discussed in Section 2.4.

Flight Patterns

By making some simplifying assumptions typical mission times can be established for some of the problems postulated in Section 2.2. This section will provide a first-cut approximation which can be modified by the more detailed investigation in later chapters.

The assumptions used in this section are that:

(1) Resolution is adequate using a 35 mm camera at 3000 feet, with a 50 mm focal plane.

(2) Stability is such that no redundancy is necessary to insure adequate coverage of the surveyed area.

(3) Tracking and control errors are assumed negligible.

(4) Terrain factors are considered negligible.

(5) Wind conditions are negligible.

A small aircraft (model type or small drone) is assumed with the following characteristics:

Cruising Speed	60 mph	Tracking - Visual
Rate of Climb	400 fpm	Altitude Limit - 5000 feet
Total Weight	50 lbs.	
Payload	10 lbs.	
Endurance	30 min.	

Applying this system to local agricultural problem, which is postulated as an area 2.5 by 2 miles gives the following.

Assuming that the controller, launch and recovery system can be located in a central position, as shown in Figure 2-4, it is noticed that the maximum horizontal distance to the craft is only 1.6 miles (a slant range of 1.7 miles).

The camera has a projection of 2230 x 1445 feet at 3000 foot altitude. This requires that about 10 photographs be taken on each E-W track and a total of 5 tracks are necessary. A total distance of 14.5 miles are necessary to cover the area, and about 3.2 miles are necessary in positioning the craft, climbing and returning. At the stated speed about 25 to 30 minutes flying time would be required. A total of 50 photographs are required. This is, of course, multiplied by the number of separate color photographs required per photograph.

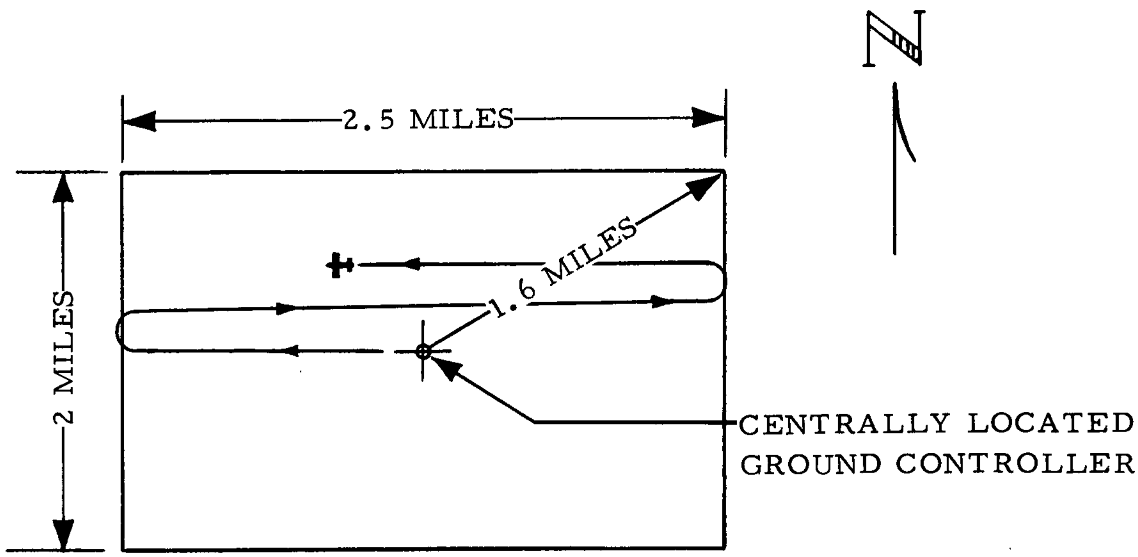

FIGURE 2-4, FLIGHT PATTERN OF SMALL CRAFT
- LOCAL AGRICULTURAL PROBLEM

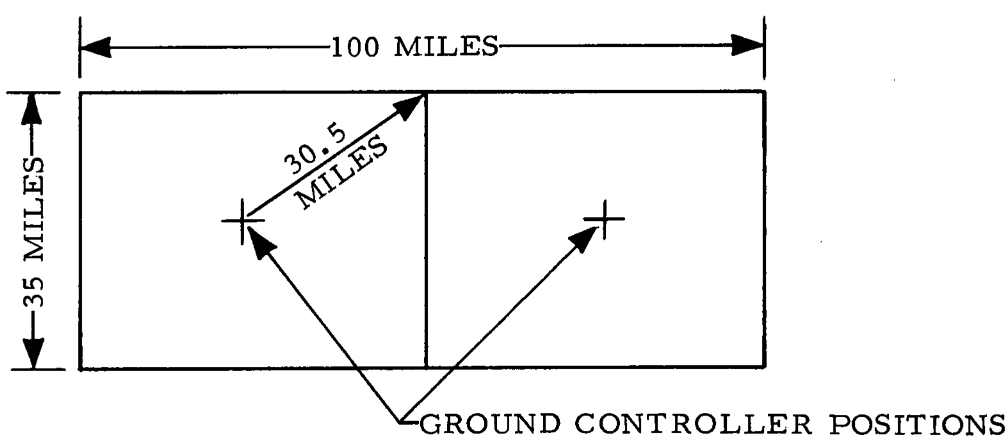

FIGURE 2-5, LARGE AREA PROBLEM, DRONEAIRCRAFT

In the ideal case presented it appears that the characteristics of the small aircraft given are probably adequate. It appears that an inordinately large number of photographs are needed, such that a need for more altitude, and/or a wider lens angle is indicated. The latter is preferred since the performance of small aircraft decreases rapidly at increasing altitudes. It is also obvious that if any of the simplifying conditions assumed are not met, the system is not very attractive; i.e. if the weather was slightly gusty or the controller could not position himself ideally.

Similarly, the situations postulated for the mining operation evaluation (II-3 of Table 2-2) and natural disasters (III of Table 2-2) require respectively about 6 to 8 minutes and about 50 minutes. The latter case, however, is probably out of range of a visually tracked and guided system.

The large area (II-1 Table 2-2) problem would require frequent moving from one ground location to the other for the small drone. For instance, if the system described above could be put into position twice a day, it would take 350 days to survey the area postulated. Clearly, a higher performing system is necessary in this application. A drone having the following characteristics is postulated:

Cruising Speed	200 mph	Tracking - Beyond Sight
Rate of Climb	400 to 600 fpm	Altitude Limit - 15K ft.
Total Weight	300 to 400 lbs.	
Payload	50 lbs.	
Endurance	45 to 60 minutes	

Assuming that the ground system could be set up within the area as shown in Figure 2-5, and that two locations are necessary, it is seen that a horizontal range of 30.5 miles is required.

Assuming an altitude of 12K feet, gives a projected area of 8920 x 5880 feet from the same camera as used before. Each half of the area would require 5.25 hours flying time, or about 6 flights. Two or three flights could possibly be conducted per day. By allowing two days to travel by ground to the second location, the entire area could be surveyed in 5 to 6 days. About 1890 photographs are required for the total area.

2.4 METHODS OF TRACKING AND CONTROL

In this section a survey of alternative methods of tracking and control are presented. Where possible some of the problems are identified, and system trade-offs discussed. Although the tracking function is somewhat separate from the control function, the two functions and the required equipment can often be integrated. The control function is meant to include not only directing the airborne equipment properly, but includes maintaining a stable attitude and altitude. A thorough discussion of automatic stabilization or autopilot techniques is beyond the scope of this study.

Generally, as the speed, range and accuracy requirements of a particular mission increase, the tracking and control system becomes more elaborate. The cost of the system increases, as does the size and weight of both the airborne and ground support equipment. An increase in system size and weight also tends to reduce the ground mobility of the system. A simple alternative to increasing the tracking accuracy is merely to provide redundancy in the collection of sensor data; i.e. to increase the number of photographs per given area. This approach of course requires more film to be carried aloft, thus reducing endurance. More importantly, it increases the time and effort required to analyze the data, and is limited to fairly short range systems.

In general the true value of employing a more elaborate tracking and control system is to extend the range, and thus the area which may be surveyed. Extension of the range of the craft requires additional payload and endurance capability, and the addition of stability augmentation (an autopilot) if beyond visible sighting.

In the following paragraphs some of the problems associated with the tracking and control problem are identified, and some alternative methods for providing this function is suggested.

Locating Reference Position

Locating the reference point, or the position of ground control equipment is not a severe problem because of the availability of topographical maps of most areas within the United States. The 7.5' quadrangle maps are of sufficient detail and accuracy to locate and plan the surveys envisaged in this study.

Direct Observation with No Navigational Aids

It is difficult to estimate the accuracy both in position and attitude which may be obtained by direct observation of the craft by observers on the ground. Experience and skill will no doubt be large factors, but the nature of the terrain could also affect the operator's judgment. Individuals have reported being able to control model aircraft at distances up to about a mile and at altitudes of from 300 to 500 feet. No information has been found regarding the navigational accuracy which can be obtained in this manner. The limitation to direct visible control over models, apparently, is the fact that the motion or direction of the craft is misinterpreted by the controller, even when the craft is clearly visible. Typical models have wing spans of about 50 inches and wing surfaces of 250 to 300 in^2. Larger craft, with larger surfaces and painted to afford maximum visibility, could undoubtedly be controlled at greater ranges. Intuitively, one would reason that the range would be proportional to the linear dimensions, at least on very clear days. Thus if one mile is the range of small models with approximately 4 feet of wingspan an 8-foot wingspan craft could be controlled at 2 miles if all other factors were increased proportionally. However, the larger model would probably not fly at twice the speed, and would be at least as stable, if not more so, such that the actual maximum range would be greater.

<u>Altitude Sensor</u>

The addition of a small barometric altitude sensor and a suitable down link transmitter would aid altitude estimates and allow a much more accurate flight pattern to be maintained. A lightweight rate of climb device is available for model gliders which weighs only 1.5 oz. and draws 35 ma. An altitude sensor and transmitter could be fabricated with only a little more weight.

<u>Triangulation from Two Points</u>

By letting two operators record elevation and azimuth from two separate locations the position of the craft can be fixed. The problem is that the data must be read and the calculations performed quickly to be useful. Also, at least one of the operators may be involved with controlling the craft, thus dividing his attention. A system which would automatically measure the angle information as the operator manually sites the craft, and compute position and altitude could be constructed. The system would consist of two transit type siting instruments with angular shaft encoders. One local and one remote siting (connected through a cable of 100 feet or more) would feed information to a small minicomputer, which would in turn compute the position and altitude and display it to the operator.

The accuracy which could be obtained with a low cost set of equipment using this technique may not be sufficient. For example, letting the two operators be separated by 100 feet, and using 12 bit angular transducers (accuracy $\pm$ 5.27 minutes) gives an error of 1250' when the craft is one mile away. A 14 bit transducer (1.318 minutes) reduces this to about 800 feet. Figure 2-6 shows the zone of uncertainty in navigation using the triangulation method. The craft is located at C in the figure and the two ground operators are located at B and C. The shaded area represents the area of uncertainty in positions due to angular errors ϵ_{α} and ϵ_B. The error can be reduced by increasing the baseline, 1, but this leads to cumbersome equipment setups. The accuracy of the transducer could also be increased. However, it is noted that shaft encoders become fairly expensive in the 14 bit to 16 bit range. Sixteen bit mini-computors are common. Further it is difficult and tedious to hold the devices on the target, and it is still limited to short ranges, such that this technique does not appear to be a satisfactory method of tracking.

With Transponder On Board

At greater ranges, where the craft leaves the range of visible siting, a transponder could be placed on board the craft. Time delay from the interrogation to the received transponder signal gives range information. Angular information can be obtained by interferometer techniques, or by using angular information from a high gain antenna. The latter is dependent upon the use of fairly high frequencies, e.g. x-band, for obtaining high antenna gain with a small antenna. A transponder on the aircraft could operate with a low duty cycle, such that total power consumption can be low. Tracking systems of this nature are in use, and a survey will be made to determine their suitability in the low cost system.

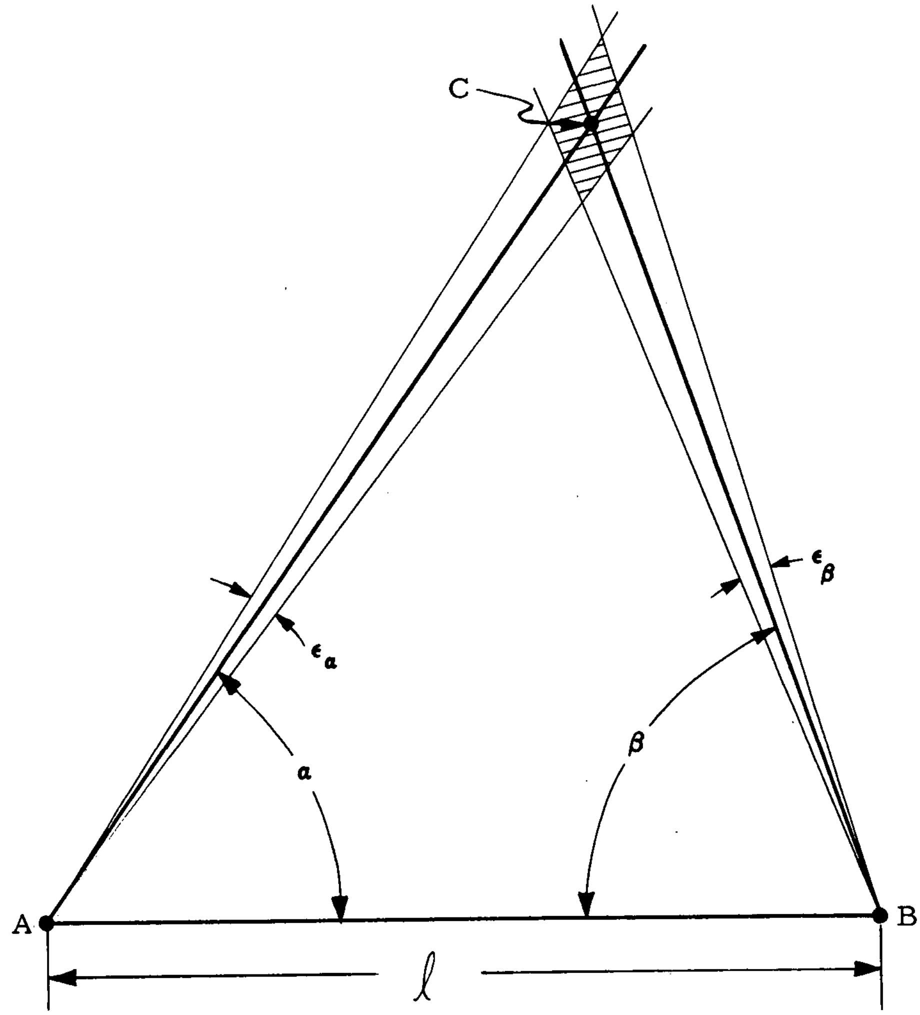

FIGURE 2-6 TRIANGULATION FROM GROUND OBSERVERS

Radar

Ordinary skin reflection radar does not seem very suitable for this application because of the poor radar target afforded by the small remote aircraft. At the low altitudes which may be flown in some applications, a severe ground clutter problem would be encountered.

Use of Laser Rangefinder

Low power, infra-red lasers have been used for determining distance with a very high degree of accuracy. The principle involved is the same as that used in radar; time measurement of a reflected pulse. The use of infra-red or optical frequencies however allows a very small beamwidth to be used, and does not require much transmitted power. A laser rangefinder could be coupled to angular transducers, with the information used to automatically compute position and altitude. Such a system would entail considerable development and does not appear attractive at this time.

A survey of existing tracking system in use (or which have been used in the past) at various missile ranges reveals that they are too complex for use in the low cost aerial survey system. In fact, most of the systems are not mobile at all. The systems in use at the various missile ranges are of course capable of determining trajectory and position to within much greater degree of accuracy than is necessary for the low-cost aerial survey system.

A survey of tracking systems used for various military drones was also conducted. The Vega system, manufactured by Vega Precision Laboratories, fulfills most of the requirements that are essential for a low cost, portable system. It is a modular system, which would allow tailoring to specific needs. The entire ground system can be transported in a small van.

Essentially, the portable Vega system employs a high frequency (C-band) high gain antenna to obtain bearing information, an on-board transponder for range, and usually an on-board barometric altitude sensor to determine altitude. Additional channels may be used for transmitting back other data over the transponder data link. A list of various equipment which may be used in the low cost system are given in Appendix A , along with the specifications of Vega Model 626C portable tracking system.

The airborne tracking equipment is comprised of a transponder, data encoder, and a barometric sensor. Total weight, not including batteries is about 7 lbs. Figure 2-7 is a block diagram of the Vega Model 626C tracking system.

Figures 2-8 and 2-9 show two ways in which a command/control link may be incorporated into the system. Figure 2-8 is a fairly conventional configuration where attitude, heading and altitude are maintained by an autopilot. In Figure 2-9 airborne weight is saved by relegating the autopilot functions to a ground computer. In the case of fairly stable drones, it may be possible to incorporate only a single gyro system in the aircraft, and compute the aircraft attitude from the gyro information and airspeed/engine information. In addition to reducing airborne weight, this concept is attractive from a cost standpoint since the cost of minicomputers is decreasing while the cost of gyroscopic equipment is not.

It is interesting to note that some military drones are fitted with control systems for either in-sight use or out-of-sigt use. The MQM-33A (OQ-19) for instance has an out-of-sight capability, using a G-force limited autopilot. The MQM-33B, however, is fitted for in-sight operations and the aircraft may be controlled to any degree by the ground operators. The in-sight version also uses gyro-stabilization, however, and the cost reduction may not be significant.

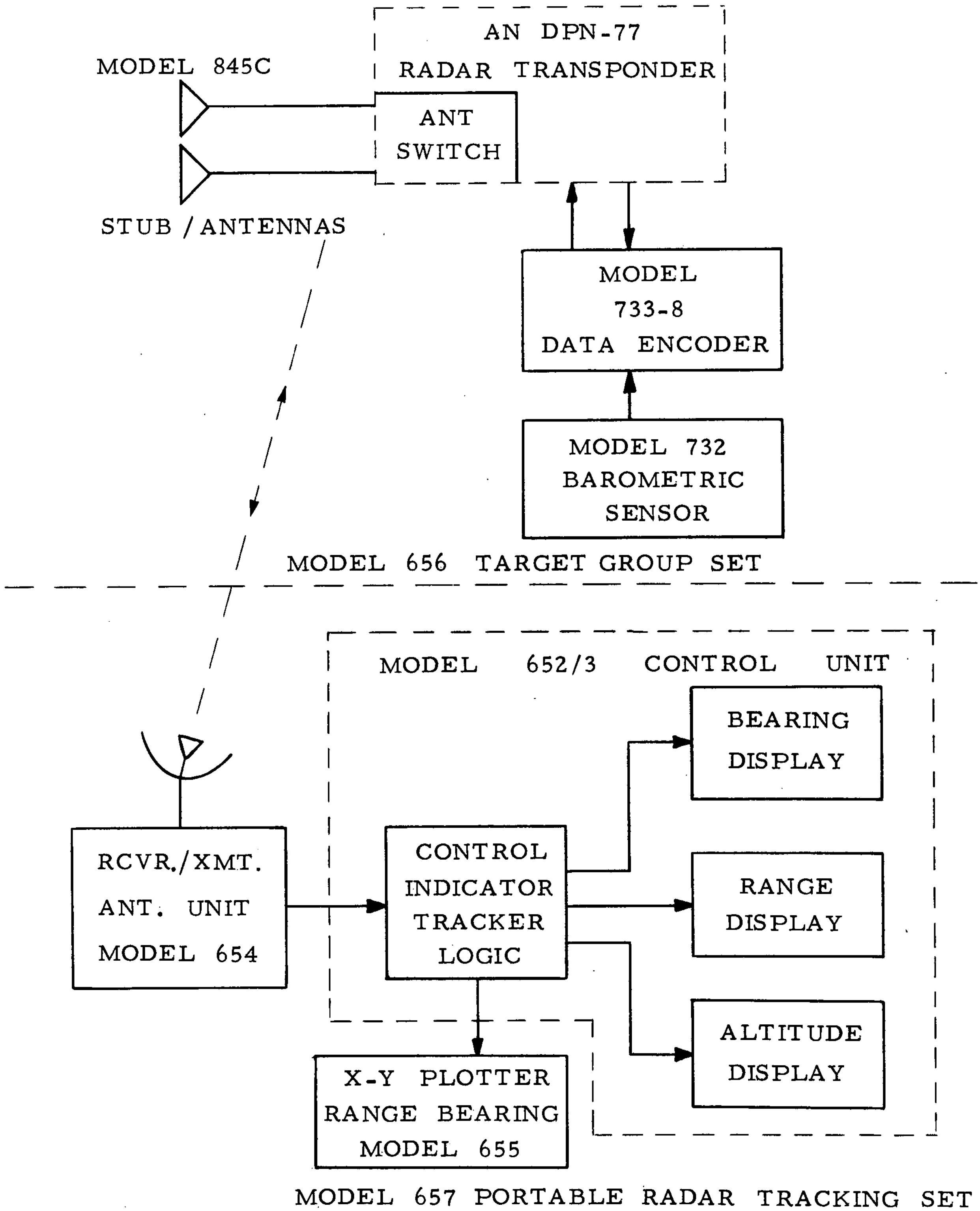

FIGURE 2-7 VEGA MODEL 626C PORTABLE RADAR TRACKING SYSTEM, BLOCK DIAGRAM

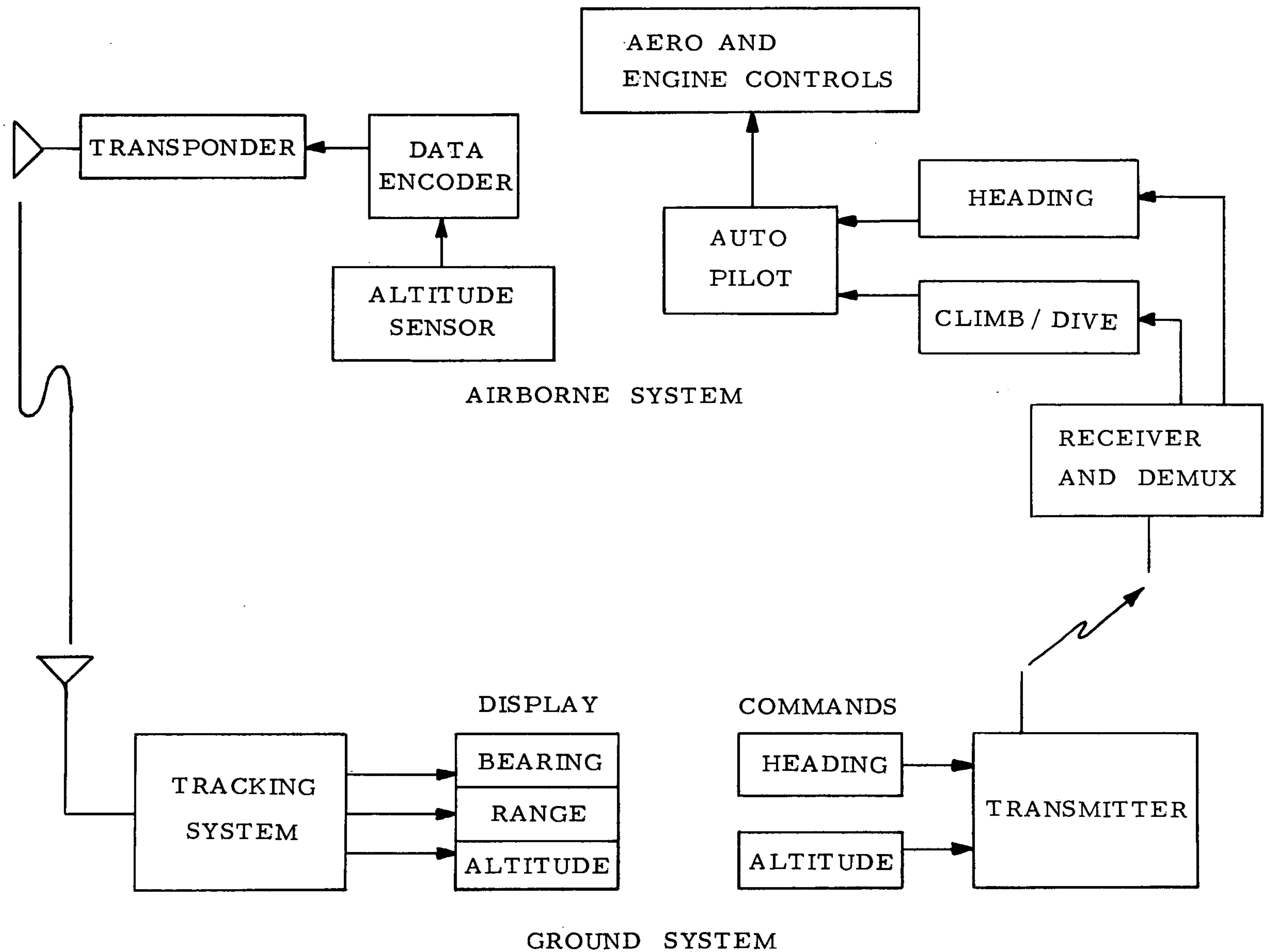

FIGURE 2-8 TRACKING AND CONTROL, BLOCK DIAGRAM

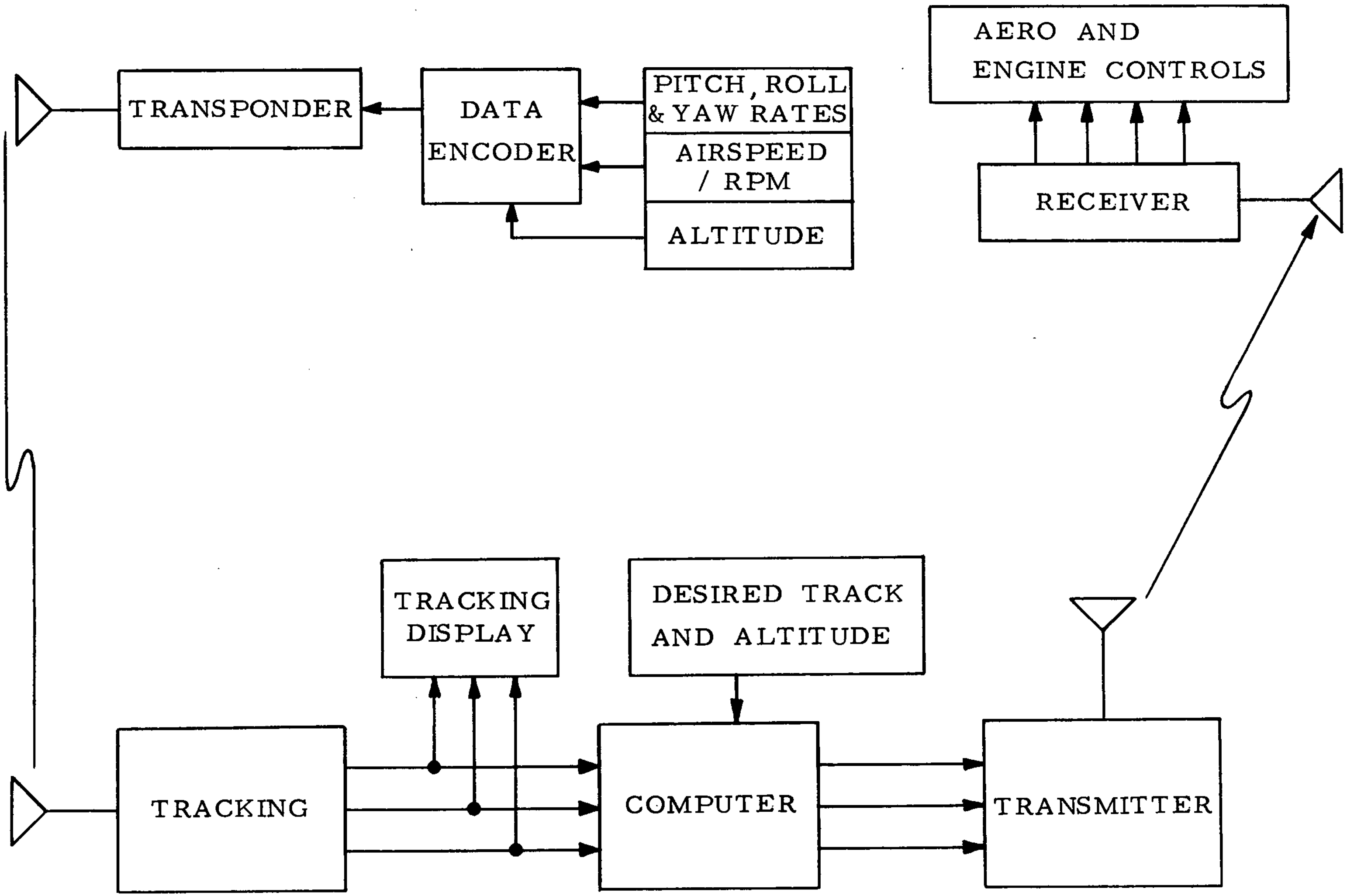

FIGURE 2-9 INTEGRATED TRACKING AND CONTROL, BLOCK DIAGRAM

The Electrostatic Autopilot

A technique has been employed recently in the control of model aircraft which shows great promise for the low cost aerial survey system. This technique involves the use of the electrostatic fields directed radially away from the earth as a means of obtaining attitude information. An interesting paper describing the theory and mechanics involved in this method*, states that sufficient flights have been made to demonstrate the validity of the concept. Essentially, the technique depends upon the gradient of the electrostatic field, which is very large up to about 15,000 ft.. Below 2000 ft. the E field is large but there may be anomalies in the gradient due to suspended particles (as near a smokestack). Roll can be sensed, and subsequently controlled, by sensing the difference in E field intensity at the wing tips. At present the sensor consists of a radioactive source (ideally an alpha emitter) and a high input impedance device such as an FET transistor. Two axis stabilization, roll and pitch, was achieved using only three sensors and two differential amplifiers. The system was reported to cost less than $100. Test flights, according to the paper cited, have shown that the system is unaffected by winds, thermals, drizzle and cloud cover. As may be expected, operation is affected near large thunderstorm cells.

Investigations are presently being conducted, some of which are apparently being funded by the Advanced Research Projects Agency (ARPA).

Control of yaw or heading cannot be done with the electrostatic auto pilot, of course, but ailerons can be coupled with rudder. In any event yaw isn't as severe a problem as roll or pitch.

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*"Introducing the Electrostatic Autopilot", Mr. J. Hill, Astronautics and Aeronautics, November 1972.

Conclusions

Tracking and control equipment for drone aircraft extend the capabilities of the craft for aerial surveying but the cost of such operation is large. Approximate cost of the Vega ground system is $100,000.

A minimal control system may be fitted into a small drone/model but the range and tracking accuracy of such a system is not known. Further investigation and a development effort would appear necessary for the minimal system.

2.5 TAKE-OFF AND RECOVERY PROBLEMS

The take-off and recovery of any aircraft are the most critical events occurring during a mission. The problem is more severe for higher performance aircraft because these aircraft have high stalling speeds and become less stable as the airspeed decreases. Typically, small model aircraft take off and land using a runway much the same as full size aircraft. But while full size aircraft may have a cruising to stall speed ratio of 2 to 1 (without flaps), there is much less latitude for smaller craft. The above results in the necessity of what appears to be unproportionally long runways (200 feet for 50' wingspan models) and a high incidence of crashes during landing. A large number of mishaps during landing are observed for skilled operators, such that for unskilled operators the number of mishaps may be unacceptably high.

For high performance drone aircraft (military target vehicle) conventional landing is out of the question since the control problems are so severe. The method used in this case is to deploy a parachute at altitude.

Take-off operations of military drones are not well suited for the low-cost system. Most military drones achieve flying speed through the assistance of expendable rockets (JATO). Such operations are not only expensive, costing anywhere from $100 to $1000 a launch, but are extremely hazardous.

Take-off and landing operations typical of military target drones have the advantage that landing gear are not necessary, skilled operators are not necessary, and large landing/take-off areas are not necessary. A storage compartment for the parachute must be provided, however.

For extremely low performance, small aircraft the use of a folding take-off/landing deck with arresting gears may be feasible. Other than the problems mentioned previously, there would be a large cost involved in fabricating the folding deck, a time factor involved in deploying it, and a problem in transporting it.

An alternate method of launching a moderate sized drone, in the 50 to 200 lbs. class, is by a catapult arrangement. This method would allow launch into the wind at a favorable angle of attack, would be considerably more compact than the folding deck concept, and could be deployed quickly. A design cost would be incurred, however. Energy storage for the launch system could be provided by compressed air, an elastic mechanism, or chemically.

Rotary launchers are used by some military drones. This entails the use of a tether attached to the wing tip and to a swivel mounted in the center of a circular take-off area. The speed of the drone is allowed to build up in this manner until a controllable flying speed is reached. This technique requires considerable space for take-off, and is not recommended for the low-cost application.

2.6 LEGAL AND SAFETY ASPECTS

The legal and safety aspects relevant to the use of unmanned vehicles appears to pose a considerable operational constraint. This is particularly true for the urban and suburban application. An investigation was undertaken to determine what regulations might govern the operation of such vehicles.

A review of the Federal Air Regaultions disclosed that outside of controlled airspace (area under control of FAA - generally near airports, airways, climb corridors, etc.) the use of models or drones are not covered. There are rather strict rules governing the use of moored and free balloons, and rockets in Part 101 of Volume IV of the FAR. Parachuting is covered in Part 105.

A review of city ordinances was conducted next. The City Code of Ordinances of Huntsville, Alabama was found to be more restrictive. Section 3-12 of the code states that use of model aircraft is forbidden except when permitted by and in areas designated by the Director of City Parks. In addition, Section 3-3 states that a minimum altitude of 1500 feet must be maintained by aircraft over city limits. There are also ordinances on noise (Section 3-9) and the granting of special permits (Section 3-11) in regard to aircraft operation.

Questionnaires were prepared and mailed to several south-eastern cities (Memphis, New Orleans, Birmingham and Atlanta), a sample of which is given in Appendix B . The response to the questionnaire was not overwhelming, but it is suspected that ordinances would be enacted where none exist now, and as noted in one response, complaints would arise upon the advent of low-flying models.

The results of this investigation, though only superficial, seem to indicate that an emphasis must be placed on a quite and inherently safe vehicle for urban operations. It is also believed that if local governments had a direct part in the participation of the flights, or could be shown an immediate benefit of the studies little opposition would be incurred.

In conversation with personnel at the U. S. Army (MICOM) Drone Project Office, it was concluded that considerable difficulty may be encountered with the use of drone aircraft. Both a safety plan and a frequency plan must be submitted to the Army and approved before army drones can be operated. Most flights of military drones originate at a few test ranges provided for that specific purpose. Some military drones are approved for and operated by contractor personnel, while others can only be operated by military personnel.

In view of the safety and legal requirements which must be met, and because of the inherently hazardous operation of drones, it is believed that their use must prove highly efficient or low cost to offset these major disadvantages.

3.0 SURVEY OF EQUIPMENT

The purpose of this section is twofold: (1) to present a summary of candidate equipment that is available, and (2) to present typical characteristics of a variety of techniques.

In the first, it is of interest to know what equipment may be readily purchased, is in the military inventory, or may be obtained conveniently by some other means. For the second purpose, a wide variety of candidates are included, even though many of them are no longer in production or were only experimental. The candidate systems include:

- Fixed Wing Aircraft
  - Drones
  - Manned Aircraft
  - Models
- Rotary Wing Aircraft
  - Helicopters
  - Tethered Helicopters
  - Model Helicopters
  - Autogyros
- Lighter-than-Air Craft

Some other possible candidates were mentioned in the study proposal; flexible wing aircraft, STOL and platforms. The STOL type of aircraft are actually fixed wing aircraft, with the addition of design features to improve their take-off and landing performance, and are discussed under fixed wing aircraft. Flexible wing aircraft also operate much the same as fixed wing aircraft, the only major difference being their parachute-like wing construction. This construction allows the wing to be stored easily, such that some steerable parachute/recovery vehicles using this concept have been proposed. However, as a low cost aerial survey candidate there appears to be no outstanding advantage. Similarly, the various flying platforms which have been constructed for experiments were not investigated because their instability and control problems do not seem compatible with a low cost aerial survey system.

This section also includes a survey of engines and control and data links.

3.1 CHARACTERISTICS OF CANDIDATE SUBSYSTEMS

<u>Drone Aircraft</u>

The primary use of drone aircraft is by the military for use as target vehicles. Since the range of weapons varies considerably, so does the performance of the various drones. However, even the lowest performance drone is capable of considerable speed; its value as a weapons training aid would be little otherwise. Some of the military drones have been used for remote surveillance, but here again the emphasis is on speed. Not all of the drone aircraft in the military inventory is reported since the high performance types are definitely not suitable for the low cost aerial survey system. Table 3-1 is a summary of the drones considered in this study.

TABLE 3-1, DRONE CHARACTERISTICS

1.	Name	MQM-33 (OQ-19) MQM-36 (O2R-5) (Navy)
	Launch	Ground-launched by JATO, rotary launcher or catapult.
	Power Plant	One McCulloch, four cylinder, two cycle aircooled engine, 72 hp at 4150 rpm, 84 hp at 5000 rpm.
	Fuel Cap.	11.3 gal.

Guidance	Autopilot and command guidance.	
Recovery	Parachute	
Dimensions	Span (with pods on wingtip) (without pods)	13' 2.5" 11' 6"
	Length	12' 3"
Weight	(Launch Weight)	326.8 lbs.
Performance	Max Speed S/L Stall Speed S/L Rate of Climb S/L Service Ceiling Endurance (S/L) Endurance at 15K Ft.	222 mph 70 mph 3060 fpm 23,000 ft. 1 hour 71 min.
Cost Data	$3000 to $5000 (estimated) if in production	
Manufacturer	Northrop Corp.	
Current Status	Operational	

2.

Name	MQM-61A Cardinal	
Launch	One M-58A2 JATO	
Power Plant	McCullouch TC-6150-J1, 6 Cylinder 2 Cycle, Turbocharged 125 h.p.	
Guidance	Command-Autopilot	
Recovery	48 ft. Parachute	
Dimensions	Span (with tip tanks) Length Height	12'11" 15'12" 3'4"
Weight	Launching	620 lbs.
Performance	Max Speed Service Ceiling Endurance (25K ft.) Rate of Climb Stall Speed (S/L)	Over 350 mph 43,000 ft. Over 1 Hour 7.9 m to 25K ft. 78 mph
Cost	$12,000 to $15,000	
Manufacturer	Beechcraft	
Current Status	Operational and In Production	

3.	Name	MQM-58A	
	Launch	Zero length using two JATO rockets.	
	Recovery	2-stage parachute, 67' diameter.	
	Power Plant	One 225 h.p. Lycoming, four-cylinder, four-stroke.	
	Guidance	Radio Command, On-Board Programmer	
	Dimensions	Span	13' 4"
		Length	16' 1"
		Height	3' 7"
	Weight	Empty	922 lbs.
		Payload	233 lbs.
	Performance	Max. Speed (S/L)	345 mph
		Service Ceiling	20K Ft.
		Endurance	45 Minutes
	Cost	————	
	Manufacturer	Aerojet-General	
	Current Status	Not in Production	

4.	Name	Bikini	
	Launch	Pneumatic rail/6 ft. in length	
	Recovery	16' parachute	
	Power	2.7 h.p., 2 cylinder, 2 stroke	
	Guidance	Radio-command.	
	Dimensions	Span	8' 0"
		Length	6' 4"
	Weight		40 lbs.
	Performance	Cruise Speed	60 mph
		Rate of Climb	Several Hundred fpm
		Endurance	Reconnaisance of several miles.
	Manufacturer	Republic Aviation	
	Status	Experimental - Built about 1963	
		Service Ceiling	5000 feet
	Remarks	Uses off-the-shelf model airplane parts.	

5.	Name	MQM-74	
	Launch	Zero length - two JATO bottles.	
	Recovery	Parachute	
	Power Plant	Turbo-Jet	
	Guidance	Command-Autopilot	
	Dimensions	Span Length Height	5.5' 11.7' 2.3'
	Weight	Launch Max. Flight Zero Fuel Weight	358 lbs. 322 253
	Performance	Max. Speed (S/L) Ceiling Rate of Climb (S/L) Endurance	460 mph 35K Ft. Over 4000 fpm 1 hour at 20K ft. and 320 mph
	Manufacturer	Northrup	

6.	Name	MQM-34D Firebee	
	Launch	One 2.2 KS - 11,000 JATO	
	Power	Turbojet-Continental J69-T-29 (1700 lb. thrust)	
	Guidance	AN/DRW-29 Radio or Digital	
	Recovery	6' Drag and 81.6' Main Parachute	
	Dimensions	Span Length	12.9' 22.9'
	Weight	Maximum	2,060 lbs.
	Payload		300 lbs.
	Performance	Speed Ceiling Endurance	600 mph 55K ft. 90 min. at Optimum Alt.
	Manufacturer	Ryan Aeronautical Co.	
	Cost	$65,000	
	Status	Operational	

Light Aircraft - Manned

Manned aircraft is included in the list of candidate systems. The present method of gathering data, especially in the local agricultural problems, is through the use of manned aircraft. The aircraft currently in use is in the Cessna 206 to 210 class. Operating cost, including the pilot, is from $35 to $45 per hour on a rental basis. In a later section alternate means of operation with a manned aircraft which could possibly reduce operating cost is discussed. The alternate operation entails operation with a less costly aircraft, and one which is more suited to operation out of smaller rural airports. A wide range of such aircraft are currently being manufactured, including the Piper PA-18, the Champion Citaberia, and the Maule M-4.

Table 3-2 gives data concerning the Piper PA-18 just cited. Several other aircraft are available with similar characteristics and cost.

TABLE 3-2, LIGHT MANNED AIRCRAFT

Name	PA-18 Super Cub	
Power	One Lycoming 0-320, four cylinder, 150 h.p.	
Dimensions	Span	35' 2.5"
	Length	22' 7"
Weight	Empty	930 lbs.
	Max. T.O.	1,750 lbs.
Performance	Max. Speed (S/L)	130 mph
	Cruise (75% power)	115 mph
	Stall (flaps down)	43 mph
	Rate of Climb (S/L)	830 fpm
	Service Ceiling	19,000 ft.
	T.O. Run	200 ft.
	Range with Max. Fuel & Payload	460 miles
Cost	$8,000 - $12,000	
Manufacturer	Piper Aircraft Co.	
Status	In Production	

STOL

Short Take-Off and Land (STOL) aircraft are differentiated from light aircraft in that they usually have been designed with the STOL as the foremost consideration. In most cases special flaps or other devices have been incorporated. There are a number of aircraft available in the light, utility class capable of STOL operations such as the Helio H-250 and H-295 (also in USAF inventory as the U-10), and the Fairchild Porter and Porter/ Pilatus. Wren Aircraft Corporation has marketed kits which convert many of the standard Cessna light aircraft into the STOL category. STOL aircraft are not considered further candidates for the low cost aerial survey application, however, as the cost is as high, if not higher, than the current method of acquiring data.

Manned Helicopters

Manned helicopters are capable of performing several of the tasks outlined in Section 2.0. They have some obvious advantages over conventional aircraft, and allow the real time analysis of the object terrain not afforded by many unmanned vehicles. The major objection to helicopter operation is cost; both acquisition and operation. A rather high maintenance cost is incurred in helicopter operation due to constant engine loading and in most cases a very complex hub/damper assembly. In an effort to find a low cost vehicle the Hughes helicopter is presented in Table 3-3. The Hughes helicopter, one of the smallest in production, may not provide adequate payload. A helicopter representing a slightly larger class is the Bell model also given in Table 3-3.

TABLE 3-3 , MANNED HELICOPTERS

1.	Name	Hughes Model 300, U. S. Army TH-55A	
	Power Plant	Lycoming H10-360-A1A, 180 h. p.	
	Accommodations	2 place side by side 100 lb. baggage capacity	
	Dimensions	Main Rotor Diameter	25' 3.5"
		Tail Rotor Diameter	3' 10"
		Length	25' 10"
	Weight	Empty (Model 300)	958 lbs.
		(TH-55A)	100 lbs.
		Max T-O	1,670 lbs.
	Performance	Max. S/L Speed at Max. T-O Weight	86 mph
		Econ Cruise	66 mph
		Rate of Climb (S/L)	1140 fpm
		Hovering (with ground effect)	
		(300)	7700 ft.
		(TH-55A)	5500 ft.
		Hovering (no ground effect)	
		(300)	5800 ft.
		(TH-55A)	3750 ft.
		Service Ceiling (300)	13,000 ft.
		Endurance With Max. Fuel	
		(300)	3.5 hr.
		(TH-55A)	2 hr., 35 min.

2.	Name	Bell Model 206A Jet Ranger, U.S. Army OH-58A	
	Power Plant	Allison T63-A-700 Turboshaft, 317 shp	
	Accommodation	Pilot/Copilot side by side two passengers or 40 ft^3 of cargo area	
	Dimensions	Main Rotor Diameter	35' 4"
		Length	40' 11"
	Weights	Empty	1583 lbs.
		Max. T-O	3000 lbs.
		Max. Zero Fuel	2525 lbs.
	Performance	Max. Speed (S/L) with 2760 lbs. gross wt.	150 mph
		Cruise for Max. Range	117 mph
		Cruise for Max. Endurance	56 mph
		Max. R of C (S/L)	1780 fpm
		Service Ceiling	19,000 ft.
		Hover (in GA)	13,750 ft.
		Hover (no GA)	9,000 ft.
		Endurance (S/L)	3 hrs. 30 min.

Droned Helicopters

Droned helicopters represent rather formidable problems in control. A large drone helicopter system was developed for the Navy DASH system. The ground based control system and winched down landing system of the cited system proved to be very complex, as well as the drone helicopter itself. Cost data is not known. Two helicopters were developed for the system; the QH-50A and the QH-50C. The characteristics of the QH-50A (the smaller of the two) are given in Table 3-4 on the following page.

TABLE 3-4, DRONED HELICOPTERS

1.	Description	Contra-Rotating Blade Droned Helicopters	
	Dimensions	Rotor Diameter	20'
		Height	8' 3"
		Length	8' 70"
	Weight	Empty	578 lbs.
		T.O. Weight	885 lbs.
	Performance	Max. Speed (SL)	78 mph
		Rate of Climb (SL)	956 fpm
		Absolute Hovering Ceiling	3200 ft.
		Combat Radius	33 miles
	Manufacturer	Gyrodyne	
	Status	Unknown	
2.	Type	Drone Helicopter	
	Name	DH-2C	
	Power	AiResearch Gas Turbine GTP 30-91, 85 shp	
	Dimensions	Length	18' 8"
		Rotor Diameter	16'
		Height	7'
	Weight	Max. T.O.	560 lbs.
		Empty	476 lbs.
	Performance	Speed	85 mph
		Ceiling	13,000 ft.
		Range	90 miles
	Manufacturer	Del Mar Engineering Laboratories	
	Status	Unknown	

Model Helicopters

Model helicopters have recently become available.* Control problems, and virtually zero payload capabilities prevent them from being candidates for the aerial survey system.

Tethered Helicopter

The concept of a tethered helicopter as a means of providing a low cost surveillance platform has been put forth.** Although any tethered concept is necessarily restricted in maneuverability, a high endurance and low operating cost can be obtained. This is achieved by the use of prime power being transmitted via the tether cable. A rotor driven by propulsion units located on the rotor leads to a fairly simple teetering hub assembly.

Autogyro Drone

An autogyro uses the aerodynamic lift of a rotating wing rather than a fixed wing. The rotating wing allows the entire speed envelope of an equivalent fixed wing aircraft to be lowered. Consequently a shorter take-off or landing run is required. The NV-101 drone autogyro, described in table 3-5 appears to be a modified OQ-19 fixed wing drone. A rotor spin-up system, powered by compressed air from the ground, allows the drone to take off almost vertically.

*DU-BRO Whirly Bird 505, a kit manufactured by DU-BRO Products, Inc., Wauconda, Illinois.

**"Preliminary Concept Exploration of Sensor Platform as Tether", SCI Report P671, June 1972.

TABLE 3-5 , AUTOGYRO DRONE

Type	Autogyro Drone	
Name	NV-101	
Power	McCulloch 0-100-1, 2 cycle, 4 cylinder, 72 hp.	
Dimensions	Length	12' 4"
	Rotor Diameter	24'
Launch	Zero Length - Rotor Spun Up by Compressed Air	
Recovery	Landing	
Performance	Speed	20 - 160 mph
	Rate of Climb	1700 fpm
	Service Ceiling	14K ft.
	Endurance - Full Power	1 hour
	- Reduced Power	3 hours
Manufacturer	Northrup Corp.	
Status	Unknown	
Comment	Appears to be a modified OQ-19.	

Model Aircraft

A survey of current model aircraft available did not produce any aircraft suitable for the aerial survey task. This is because none of the models available afford any significant payload or range. The one exception is a small model aircraft used in making 8 mm movies*. This model was a modified DU-BRO Sportsman powered by an Enya .60 engine. Total aircraft weight is 8-3/4 lbs., including the payload—a Kodak Instamatic Super 8 movie camera. The wingspan of this model is estimated to be about 55 inches, and speed is about 40 mph. The camera is mounted in the nose, and the engine mounted in a pylon above the wings in an effort to solve the problem of engine effusents coating the camera.

Model-Drone

The designation model-drone is given to an aircraft that is too big to be considered a model and too small to be considered a drone. The Bikini aircraft (40 lb. weight) could fall in this class. A more recent and likely candidate was recently reported.** The aircraft was developed for Philco-Ford, apparently for a military application, by Sachert and Riggs Aviation Consultants. Specifications are given in Table 3-6.

Photographs of this craft appearing in the referenced magazine article reveal several noteworthy features. First, it is of a conventional monoplane design with high wing and nose mounted engine. Second, an exhaust system is seen to carry away and muffle the engine effusents. Third, conventional model aircraft controls and components are used.

*"Aerial Movie Making", R.G. Southerland, R. C. Modeler Magazine, June 1971, pp. 72-75.

** "Something Other Than Sunday Flying", Dick Tichenor, R. C. Modeler Magazine, Dec. 1972.

TABLE 3-6, MODEL-DRONE

Configuration	High Wing Monoplane	
Size	Unknown, Wing Area	20 ft^2
Weight	Gross	75-83 lbs.
	Payload	40 lbs.
	Speed	50 to 70 mph
	Service Ceiling	6000 ft.
Launch/Recovery	Fixed Landing Gears	
Power	5 h.p., 2 cylinder, 2 stroke of special design.	
Endurance	Classified	

The rather surprising 40 lb. payload would be sufficient to allow not only the sensor equipment but additional control and tracking equipment. It is not known whether the 40 lb. payload included the weight of the fuel.

Lighter-than-Air

For many reasons lighter-than-air craft appear attractive for the low-cost aerial survey system applied to the urban application. These vehicles are classified as either rigid (dirigibles) or nonrigid (blimps) and may further be classified as either manned or unmanned. The use of manned blimps or dirigibles have many advantages as a stable, long endurance platform for scientific experiments. The enormous cost of procuring and operating manned blimps eliminates them as candidates for the applications described in this report. Procurement cost may well run into several million dollars. Several vehicles and a crew of from 15 to 20 men are required, as is the case with the four operational blimps in this country at the present time.

Because of the high cost of manned blimps, it is natural to consider smaller unmanned blimps as a lower cost alternative. The characteristics that are afforded, and which are well suited to the urban application are:

- Ability to remain on station for extended periods of time.
- High endurance.
- High stability with little vibration.
- A wide operating speed range.
- Noncritical control problems.
- Inherently safe operation.

A disadvantage is the high cost of inflation. Helium, one of our more scarce resources, costs about \$75 per 1000 ft^3. In large cities, however, the utilization of a small blimp may be so high that deflation is not necessary. This is especially true if the system could be shared between various factions of the municipality. One can easily visualize applications by the fire and police departments in emergencies, as well as studying traffic flow, air pollution study, or general land survey use.

Preliminary design and development of a complete lighter-than-air system has reportedly been done by Developmental Science Corp.* One model is capable of a 180 lb. payload, while a smaller model is capable of a 60 lb. payload. The smaller model is about 11 feet in diameter, can cruise from 35 to 90 mph, and has a maximum endurance of about 8 hours. The pro-

*Developmental Science Corp.
15747-49 Valley Blvd.
City of Industry, California

jected production cost of the smaller model should be in the range of from \$30K to \$40K. The cited company has reportedly developed a launch and recovery system which is more efficient and quicker than techniques used in the past.

Safety is a foremost consideration in the urban applications. A blimp, upon failure of its engine or depletion of fuel, would fall at a fairly slow rate.

The sensor most suitable for the droned blimp is the TV camera. The use of this sensor gives rise to an added advantage; the sensor itself can be used in the navigation of the blimp since most often it will be operated over fairly familiar urban areas with prominent landmarks.

3.2 Survey of Engines

There is a large gap in the range of sizes of engines designed specifically for aircraft use. The small engines surveyed are those designed for use in model aircraft, while the larger engines are designed for drone and full size aircraft. The maximum size for the models is about 4 h.p., while the minimum size for drones is 48 h.p. The area in between these two extremes can be characterized by a number of engines designed for chain saws, go-carts and small motorcycles.

Actual availability of the low power drone types is questionable—the only source is probably the surplus market. At present the smallest known piston type drone engine in production is the McCullough of about 72 h.p. Typically, all the smaller engines are 2-cycle which have a high power to weight ratio but extremely poor specific fuel consumptions. The middle range, represented by the nonaircraft types could incur a significant cost in adapting them to aircraft use. The high power to weight ratio go-cart engines are particularly high in vibration and noise, but use a carburetor that is not attitude sensitive. The motocycle type engines, especially the two-cylinder types are very smooth, quiet and are much more efficient. Many types are available from 8 h.p. to 35 h.p. Some modification would be necessary to lighten them for aircraft use since most have integrally cast gear-box and clutch housings. However, because of high volume production and consequently lower cost, they are probably the best candidates for the horsepower range indicated. A summary of engines within the range of interest are given in Table 3-7. All except the last are 2 cycle engines. The power and fuel consumptions of cart engines are not given by the manufacturer because they are subject to intake and exhaust manifold tuning methods which may be employed by the user. It is believed that they fall in the range of 8 to 20 h.p., and that SFC is very high (.4 to .6 g/h.p.-hr).

Other than the high SFC, small model A/C engines present other problems. Unburned fuel and lubricant is generated profusely and has a tendency to coat most of the aircraft surface aft of the engine. This problem has caused one aerial photographer/modeler to devise an aircraft with the camera mounted in the nose and the engine mounted above the wings*. This configuration is probably not acceptable, however, in view of the requirement for inherent aircraft stability presented elsewhere in this report. A better solution is to provide exhaust stack/muffler system that would direct the effusent away from the camera system.

Another problem is vibration. However, multicylinder engine configurations allow the nonreciprocating masses to be balanced out, such that fairly smooth operation results.

*"Aerial Movie Making", R. G. Southard, R. C. Modeler, June 1971, pp 72-75.

TABLE 3-7 SURVEY OF ENGINES

Type	Manufacturer	Power h.p.	Cyl.	Displacement in^3	Weight	S.F.C. gal./h.p.-hr.	F.C. gal./hr.
Model Aircraft	Ross	1	1	.6	8 oz.	.56	.56
"	Northfield Ross	.35	1	.3	7 oz.	.56	.196
"	"	.7	2	.6	15 oz.	.56	.39
"	"	2.5	4	1.2	26 oz.	.56	1.4
"	"	4.0	6	1.8	40 oz.	.56	2.4
Cart	McCulloch MC49E	—	1	4.9	12 lbs.	—	—
"	MC91B	—	1	6.05	11.5 lbs.	—	—
"	MC101	—	1	7.5	12.3 lbs.	—	—
Motor Cycle	Yam. 125	15 (max)	2	7.5	—	.11(4000-8000 rpm)	.77 at 5000 (7 h.p.)
	Yam. 250	28 (max)	2	15.0	—	.11	1.65 at 5000 rpm (15h.p.)
Drone	Nelson	48(max) 45(cont)	4	63	68 lbs.	.13	6.3
"	McCulloch	72	4	—	—	.157	11.3
Light Aircraft	Cont.	65	4	—	150 lbs. (est.)	.065	4.2

A third problem associated with relatively small engines is that the useful power band is quite limited. This is the result of relatively simple carburation-ignition configurations and radical port timing. The latter being necessary to obtain an acceptable power to weight ratio. The result is that erratic operation occurs at anything less than full throttle. According to vendor brochure, however, the speed range on the larger multicylinder engines for models (number 3, 4 and 5 of Table 3-7) is from 2500 to 15,000 RPM.

In summary, if the most appropriate size for the low cost platform is found to fall within the range of from 4 to 48 h.p., further investigations are necessary to determine how the best power plant should be obtained. This task is not believed to be particularly difficult.

3.3 CONTROLS AND DATA LINK

A number of radio-command guidance systems have been developed under the auspices of the military for use on the various drone systems tabulated. Since they have been in operation a number of years and can be obtained along with the drone, further investigation is merely superfluous. What is more interesting and relevant to this study are the newer light-weight control systems available commercially. Such systems are beginning to take advantage of such recent innovations as integrated circuits, and further any reasonably astute electronics company could modify these controls to suit special needs. As an example the specifications for a popular model aircraft control system are given as follows:

- TRANSMITTER

GDA-405-S and GDS-405-D Specifications-Transmitter—RF carrier frequency: Crystal controlled on 27 MHz, 53 MHz, and 72 MHz. Frequency stability: Within ± .005% on 27 MHz band. Within ± .002% on 53 and 72 MHz bands. Temperature range: 0 to 160 degrees F. RF output citcuit: Pi network. RF input power: 500 mw. Min. modulation: On-off carrier keying. Approx. current drain: 100 ma on all bands. Controls: Eight channels, four with trim. On-Off switch. Frequency selector switch. Trainer push button. Power Supply: Internal 9.6V 500 mah nickel-cadmium battery. Rechargeable simultaneously with receiver battery at 35 to 40 ma from 120 volt power line. Dimensions: 7" H x 7" W x 2" D. Net weight: w/battery, 2-3/4 lbs.

- RECEIVER

GDA-405-2 Specifications - Receiver—Local oscillator operating frequency: Crystal controlled on 27 MHz, 53 MHz and 72 MHz. Frequency stability: .003% on 53 and 72 MHz bands. Temperature range: 0 to +160 degrees F. Sensitivity: 5 uV or better. Selectivity: 6 dB down at ± 8 KHz; 30 db down at ± 9 KHz. Current Drain: 10 ma. Intermediate frequency: 453 KHz. Power Supply: 4.8V Battery Pack GDA-405-3. Controls: ON-OFF switch. Frequency selector switch. Dimensions: 1-5/32" H x 1-3/16" W x 2-17/64" D. Net weight: 2.5 oz.

- BATTERY

GDA-405-3 Specifications - Receiver Battery—Type: Nickel-cadmium. Rechargeable simultaneous with the transmitter batteries at 35 to 40 ma from 120V power line. Voltage: +2.4V and +4.8V outputs. Current rating: 500 ma hours. Dimensions: 1-1/4" H x 1-1/4" W x 2-1/16" D. Net weight: 3.8 oz.

- MINIATURE SERVO MOTOR

  GDA-405-4 Specifications—Input Signal: Pulse 1-2 msec wide, 4 V P-P. Thrust: 3 lbs. at rack; 24 in./oz. at rotor. Travel time: 0.6 sec. Linear output travel: 1/2" end to end. Rotary output travel: 90° rotation. Temperature range: 0° - 160°F. Power Requirements: Battery—4.8 VDC. Idle current—15 ma. Stall current—450 ma. Gear train backlash: Less than .002". Mechanical output: 1 rotary arm: 1 rotary wheel; 2 linear racks. Position accuracy: 1.0%. Dimensions: 1-5/2" H x 7/8" W x 2-17/32" L (length includes mounting ears; height includes outputs). Net weight: 1.75 oz.

- SUB-MINIATURE SERVO MOTOR

  GDA-505-4 Specifications - Input Signal: Pulse, 1-2 msec wide; 4V P-P. Thrust: 3 lbs. at rotor. Rotary Output Travel: 90° rotation. Temperature Range: 0° - 160°F. Power Requirements: Battery, 4.8V CT; idle current, 15 ma maximum; stall current, 450 ma nominal. Gear train backlash: Less than .002". Mechanical output: 1 large rotary arm, 1 small rotary arm, 1 offset rotary arm, 1 rotary wheel. Position accuracy: 1.0%. Dimensions: 1-17/32" H x 23/32" W x 1-7/8" L (length includes mounting ears, height includes the outputs). Net Weight: 1.25 oz.

- Frequency Combinations Available—Adjacent channels: 27 MHz: 29.995/27.045, 27.095/27.145, 27.145/27.195. 53 MHz. 53.1/53.2, 53.3/53.4, 53.4/53.5. 72 MHz: 72.08/72.24, 72.16/72.32, 72.40/72,96. Available only as single channel: 75.640.

It is recommended that model aircraft controls be used if possible because of their low cost. For heavier model aircraft, in the region above 80 lbs., the torque available from the model type servo-motors is probably not adequate. Model type controls would not suffice in military target drones where a very severe environment is encountered (high altitudes, cold temperatures, etc.).

Data Link

An air to ground data link for candidates for the agricultural problem does not appear necessary, except for those necessary for attitude control or tracking. This data can be transmitted back through the transponder. As discussed previously in Section2.4 encoders are available from Vega Precision Laboratories for this with either eight channels (Model 733-8) or sixteen channel (Model 733-16) capacity. Demultiplexing and conversion equipment for the above models are also available.

A data link for transmitting wide bandwidth signals, such as TV video from the urban application platform, presents more of a problem. A typical air to ground link is postulated having the following characteristics:

Receiver Bandwidth, B	6 MHz
Receiver Noise Figure, F	10 dB
Required S/N at Receiver	20 dB
Path Length	10 miles
Frequency of Carrier	5 GHz
Path Loss	131 dB
System Losses (Cable, Couplers, etc.)	5 dB
Transmitter Antenna Gain	0 dB
Receiving Antenna Gain	0 dB
Receiver Sensitivity = 10 log (KTB) + F	-96.2 dBm
Required Transmitter Power	29.8 dBw

The transmitter power is clearly unreasonable, but the use of a parabolic antenna of only 4.75 ft. diameter, with a gain of 35 dB reduces the required transmitter power to only 24.8 dBm (300 mw). The use of the high gain antenna would require some means of keeping it directed toward the airborne transmitter. A high gain antenna mounted on the airborne platform would be unduly complex.

Amplifiers and transmitters for video signals must provide good distortion and linearity characteristics, and therefore contribute significantly to the cost of the system.

In the TV system some additional equipment for aiming the TV camera, and other controls associated with the camera may be necessary. A system composed of the following items is envisaged, with their estimated cost:

	Cost
• TV Camera	$ 3,000
• TV Camera Pan & Tilt Mechanism	2,000
• TV Camera Controls	2,000
• C-Band or S-Band Transmitter	5,000
• Parabolic Antenna, Manually Pointed	1,500
• Receiver/Demodulator	1,000
• TV Display	500
	$15,000

Home type video recorders are available for about $2,000, but for high quality video a professional type recorder may be required.

3.4 ACQUISITION AND OPERATING COST

Some of the elements required of various candidate systems have been identified. In this section the acquisition and operating cost of the candidate systems are estimated. However, in order to proceed with this task, two additional items must be established, which are: (1) the identification of additional support equipment and an estimation of its cost, and (2) the establishment of operational methods for the various candidate systems. The latter has a very important bearing on the operational cost of any of the candidate systems. It is concerned with how much time the system may spend in the field, how much data is to be gathered, and cost of supporting personnel. True cost is difficult to estimate in many cases because direct procurement from vendors may not be necessary for some systems. For instance, in the case of drone systems, the equipment may be transferred from the military to NASA. Other systems, while appearing inexpensive, entail an initial design or development effort which would increase true cost.

3.4.1 Operational Methods

Present Method

One reason that the investigation of low cost techniques for aerial survey was instigated was the high cost of obtaining data using present techniques. Presently data are obtained through the use of manned aircraft, requiring at least one pilot and one photographer. In this section the cost of obtaining data in this manner is discussed, and some alternate procedures in manned aircraft operation are suggested which would tend to reduce cost. The application is restricted to the local or "spot" agricultural problems in this section, although certain parts of the rationale developed in this section could be applied to other problems (urban, disasters).

The current practice is, having identified a potential problem area, an aircraft is flown to the area in question to obtain photographs. The flying time to and from the area to be surveyed frequently exceeds the time spent surveying the area. Although the weather data is obtained from ESSA beforehand, often conditions are not well-suited for photography upon arrival. The cost of a round trip is often incurred without obtaining data. The aircraft used thus far has been fitted for aerial mapping. Typically, these aircraft are in the Cessna 206 - 210 class, and operating cost on a rental basis ranges from $35 to $45 per hour with pilot. Procurement of an aircraft and employment of full time pilot would lead to a reduction in the operating cost if a high utilization could be maintained.

<u>Unmanned Aerial Survey System</u>

The method of operation envisaged using a low cost unmanned aerial system is described; a mobile ground system, carrying the unmanned craft and necessary support equipment and crew is dispatched to an area to collect data. Upon collecting data over one particular area, the system then moves to the next survey site. Thus, the crew may be in the field for several days or weeks, collecting data from a large number of different survey sites before returning to home base.

The advantage of this technique over the present manned aircraft system is that only one long round trip between home base and the general area to be surveyed is required. If unsuitable weather is encountered the crew could wait at the survey site until the weather is suitable, providing the bad weather does not last too long. Further, bad flying weather should not hamper the transport of the ground support equipment between sites.

The unmanned craft, support equipment, spare parts and personal equipment would be transported to the survey site. It is also practical to provide equipment for overnight stays, such as might be required in remote areas. This would include storage of food, water, cooking and sleeping facilities, etc. However, this would not normally be required. Food and lodging is assumed available at reasonable distances to the survey site.

The method of operation in the case of the urban application is of course much different. A much longer amount of time is spent at the survey site. It is reasonable to believe that in the larger cities or suburban areas an unmanned aerial survey system could be utilized to such an extent that ground mobility is of no importance. Because the nature of the urban application is very different from the other applications, the most likely candidate system for the urban application cannot be compared easily with the other candidate low-cost systems.

Alternate Method Manned Aircraft

One could readily visualize a manned aircraft operating in much the same manner as the unmanned system just described. The aircraft would be dispatched to a general area, where several days would be spent moving from one survey site to another before returning to home base. The problem encountered by both the airborne and ground party are similar; that is, the obtaining of lodging, food, local transportation, extra compensation pay to personnel, etc.

A survey of the Alabama-Georgia area disclosed that small airports are numerous. The average distance between adjacent airports is on the order of 30 miles, and the most remote point is within 50 miles of a small airport. Most of the small airports lack accommodations such as rental

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cars, restaurants, etc. but almost all of them have fuel, telephones, and rudimentary maintenance available. Thus, a sweep through an area to be surveyed, operating from one small airport after another could lead to the collection of data much more economically than does the present practice. Such an operation requires an aircraft of moderate performance, an ability to operate from the smaller airports, and with sufficient capabity to transport two men, equipment and personal equipment. An aircraft such as the Piper PA-18 or Champion Citaberia are possible candidates.

The major advantage of the manned aircraft approach is the speed with which a series of surveys could be completed. The disadvantage, as opposed to the ground supported low cost system, is that not as much personal equipment could be carried. A ground vehicular system could carry cooking and sleeping facilities, for instance. Bad weather would prevent the collection of data in either case, but in the small manned aircraft it could also prevent movement between sites. Fairly astute operators will be required in either case, but the use of a pilot in one case could increase cost. An advantage to the manned approach is that a real time evaluation of the terrain, and more selective photography lead to a saving in film, survey time, and time of evaluating the collected data.

3.4.2 Required Support Equipment

Unmanned System

Support equipment required for a small model/drone would include a truck with all maintenance, tracking and control equipment, spares, and personnel equipment, and a trailor which would transport the planes and the launcher. If the system is extremely simple, a crew of two men may suffice.

Support equipment for a drone includes that given above plus a separate van to house the tracking equipment. A crew of three or possibly four may be necessary.

The support equipment for an RC blimp could be quite involved. Equipment for inflation or deflation is necessary and some means of mooring the vehicle. A crew of three or four and several vehicles may be necessary. It is possible that a city may find a fairly constant use of such a system, such that the inflation/deflation and transportation are unnecessary. A permanent crew of two men is probably necessary.

Manned Aircraft

The light aircraft system would require the acquisition of the aircraft, and possibly some minor modification. The use of a detachable pod to carry personal equipment and supplies could be carried underneath the craft. During actual survey missions the pod could be left at local airfields. A major cost of aircraft ownership is hanger rental or tie down fees. Maintenance cost is included with the operating cost.

Estimated Equipment Cost

A preliminary estimation of the candidate system cost is given in Table 3-8 System A of the table is a light manned aircraft system.

System B is a drone system such as those in use by the military. The drone system is capable of out-of-sight operation which reflects a rather high procurement cost of the ground support equipment.

System C is a much simpler model/drone system which is not capable of out-of-sight operation.

TABLE 3-8

CANDIDATE SYSTEM AND SUPPORT EQUIPMENT COST

Candidate System	Initial Cost of AB Equipment	Operating Cost/Hr.	Ground Support Equipment	Storage Cost	Crew*
A Light-Manned Aircraft	$10,000	$6-8	None	$30/ month**	2
B Drone	$ 5,000	$4.00 $100/launch ***	$100,000	None	3
C Model/ Drone	$ 1,000	$2.00	$15,000- $25,000	None	2
D Blimp	$40,000	$4.00	$15,000- $25,000	$30/ Month**	2
E Present Rental Aircraft	None	$45.00 (Includes Pilot)	None	None	1

*Crew - Assume $50/day plus $15/day if in field overnight.

**Typical cost of hanger rent at large city private airports.

***Cost of small JATO bottles.

System D is a blimp system with an on-board TV camera and down-link, and System E is the manned aircraft used in the present mode of operation. These costs are of course only approximate and are given to aid in further comparison of the systems.

3.4.3 Cost and Time of Performing Survey

Some insight into the feasibility of the various systems may be gained by estimating the time and cost involved in performing a typical survey by the various candidate systems. It is difficult to determine what a real mission may consist of, but two cases are postulated; one in which only a few small areas are to be surveyed, and another in which a great deal of area is to be surveyed. The first case consists of the several local agricultural tasks as defined in Section 2.1, and the latter case is the spot or wide area problem also described in Section 2.1. In both cases a distance to the survey site from home base is selected arbitrarily as 150 miles. In the first case, it is assumed that there are five survey sites located at intervals of ten miles. This mission will be identified as Mission I. The second case, Mission II, is assumed to consist of continuous area of say 100 miles long and 35 miles wide.

By calculating the time for each of the candidate systems to travel to the site, set up equipment, survey each site, and return to home base, the cost and time of a survey may be established on a per square mile basis. Using the two extreme cases presented may provide a basis for establishing the cost for other missions, providing some method of amortizing the procurement cost can be established.

An estimation of survey time for each candidate system was done assuming no delays due to unsuitable flying or photographing weather. This assumption is probably too simplifying for the large area missions. Further comment is made at the end of this section regarding delays due to weather.

Further assumptions are that the small 35 mm camera with 50 mm focal plane is used in Candidate Systems A, B, and C. The present system (E) uses a 9" x 9" film with a 6" focal plane, which gives more coverage and better resolution than the 35 mm camera. The larger camera would allow a higher altitude, (and consequently greater coverage) than the other systems, but in order to simplify the calculations the altitudes of all candidate systems are the same. The results for Mission I are as follows:

Candidate A, the light-aircraft would require about two days total time which includes two round trips and a total of about 10 hours flying time.

Candidate B, the drone system, would require about three days total, two of which are devoted to travel to and from home base. About 3 or 4 hours flying time, five launches and recoveries, and two overnight stays for three people are necessary. Candidate C, the model-drone, would require about four days total, with three overnight stays for two people.

Candidate E, the present method using manned aircraft would require one day, and a total of about 8 hours flying time.

In the larger task, Mission II, we have seen previously in Section 2.0, Flight Patterns, that the small model-drone would require an extremely long time (350 days for the area and model-drone performance given in Section 2.0) such that it is concluded that for large area surveys, it is not a likely candidate.

A larger, higher performance drone system (Candidate B) was seen to require about 10 hours flying time, to require about 8 days (to which two days travel from home base is added) and would require about 8 flights.

The light-aircraft system (Candidate A) at an airspeed of 100 mph would require 60 hours to perform the survey. Flights from home base, local airports and return may add another 20 hours, so that total flying time is about 80 hours. About 12 days are required to perform the task.

The existing method, Candidate E, flying at 150 mph and at 12K feet would only require 40 hours flying time to survey the area. Allowing 15 days to survey the area requires 30 more hours flying to and from home base for a total of 70 hours flying time.

Based on the estimates given above for the two missions described, the operating cost of the various candidates are presented in Table 3-9. The table does not include any procurement cost or cost of film and processing.

Conclusions

Although the cost estimates presented are necessarily sketchy and subject to a great deal of modifications, some conclusions may be drawn. First, the drone systems are the most expensive methods for obtaining a relatively small amount of data as typified by the local agricultural example.

For a larger task the military drone and the present method appear more attractive, but still cost more than the light-aircraft approach, while the small model/drone is not feasible.

TABLE 3-9 COST AND TIME OF PERFORMING SURVEY

MISSION I

150 Mile Trip
5 Small Sites Located 10 Miles Apart
Altitude = 300 Ft.

Candidate System	Total Time (Days)	Flying or Operating Time (Hrs)	Operating Cost	Crew Cost*	Per Diem**	Total
A Light Aircraft	2	10	80	200	0	280
B Drone	3	4 5 launches	516	450	90	1056
C Model/ Drone	4	4	8	400	90	506
E Present	1	8	360 ,	50	0	410
			MISSION II	400 Mile Trip One Large Site 100 x 35 Miles		
A	12	80	640.00	1200	300	2140
B	10	10 launches	840	1500	450	2790
C	—	——	——	——	——	——
E	15	70	3150	750	——	3900

*Crew Cost 50/day.

**Overnight paid 15/day.

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Since the military drone approach appears expensive in both cases, it is recommended that it be dropped from further consideration as a candidate. When the procurement cost of the drone system is considered, it is also seen to be very expensive.

One could reason that for even larger areas to be surveyed a drone system is attractive, and could possibly lead to less costly collection of data on a per unit data basis. However, for even larger areas than thos described other existing methods of collecting data, while not low cost in nature, are low cost in a per unit data sense. These systems are the high speed aircraft systems, or satellite systems currently in use.

Since three candidate systems for the small problem (Mission I) are so close in cost, it is believed that other factors rather than cost could be the overriding factor in determining their suitability for the application. The factor of weather, and operator safety for instance would tend to favor the ground based system.

A review of data presented by cognizant government personnel has shown the degree to which weather can affect the results of the time of performing these surveys. In a case similar to Mission II, using the present technique (Candidate E) it was found that some 115 hours flying time were required to cover a similar area, over a total time of from 3 to 4 months. This comes about because weather suitable for color photography is actually somewhat rare. In the northern Alabama area, for instance, only about 3 days per month are suitable during the worst months, and 13 days per month during the best month (October). In addition the hours suitable vary from about 2 hours a day to 7 or 8 hours a day depending upon the time of the year.

Therefore, the actual time of performing the surveys should be increased over what is shown in Table 3-9 due to the weather and sun angle factors.

4.0 PRIMARY SELECTION OF VEHICLES

Three candidate systems are selected as being the most suitable for the low-cost aerial survey systems. They are: the model-drone, the light-manned aircraft, and the RC blimp. The model-drone system is selected because of its versatility and low cost in collecting small quantities of data such as in the local agricultural task, the evaluation of mining operations, possibly in natural disasters, and other problems involving a low quality and quantity of data. The light-manned aircraft is selected for agricultural or rural situations because it is much more cost-effective as the quantity or quality of the data is increased slightly, or if a high use of the system is expected. The model-drone system is attractive if the collection of data is on a sporadic basis. This is because less expense is involved in storing the system, and because the crew could possibly be used only on a part-time basis. Therefore, much of the remaining paragraphs of this section will be devoted to sizing the model-drone candidate, and in establishing the required support equipment.

The radio-controlled blimp is selected for the collection of data over urban areas. This system was selected because of the prime importance of safety and endurance. The only other possible candidate is the manned helicopter, which of course requires a highly skilled operator, is noisy, and involves a high operating cost.

4.1 SIZING

Drone-Model

The task of sizing the model-drone is initiated by considering the size and weight of the payload. The weight of the payload has been previously stated as about 10 lbs. While this is a worthwhile goal, it is probably not very realistic. Further, since some fundamental tracking or downlink equipment is desirable, and may be added at a later time the payload should be increased. The most suitable approach for launch and recovery has been identified as launching from a zero length pneumatic launcher with parachute recovery, such that a bin for the parachute must be provided.

The payload is tentatively chosen as 40 pounds, and a gross weight of 80 lbs. is probably achievable for a craft of moderate airspeed.

The airspeed is next selected. In this case a relatively slow airspeed is desired so that stability is easily achieved, the craft is easy to fly and track visibly, and to keep fuel and power requirements down. The economics of collecting data require that a reasonable speed be maintained, however, so that a choice of 60 mph is made.

A review of some of the model aircraft show that wing loadings of 2 lb/ft^2 are typical, while the Bikini of Table 3-1 has a wing loading of about 5 lbs/ft^2. Wing loading on light aircraft is as high as 10 lbs/ft^2. Choosing a wing loading of 5 lbs/ft^2 for the model-drone gives a required area of 16 ft^2. A wing plan of 8' x 2' is appropriate.

A wing is required with a coefficient of lift C_L given by:

$$C_L = \frac{W}{\rho V^2 A}$$

where

ρ = density of air (.00238 slugs/ft^3 at sea level and 59°F)

V = Velocity (88 ft/sec)

A = Area of wing (16 ft^2)

W = Weight of craft

which gives

$$C_L = .271$$

Using data for a Clark-Y airfoil, the angle of attack is found to be about -1.2^{o}.* This angle of attack corresponds to a coefficient of drag C_d of .0139. The wing profile drag is

$$D = C_d \rho \frac{V^2}{2} A = 20.5 \text{ lbs.}$$

The total drag (profile drag of wing and body and induced drag) is probably half again that given above, so that the total power to maintain level flight at 60 mph is

$$P \approx \frac{30(88)}{550} = 4.7 \text{ h.p.}$$

In order to obtain reasonable rate of climb an engine of 6 to 8 h.p. maximum would be required.

The specific fuel consumption (S.F.C.) of small two-stroke engines was seen to be about .56 g/hp-hr (Table 3-7) so that the cruising fuel consumption is 2.73 gal/hr. At climb it would be about 4 gal/hr. For a 30 minute duration about 1.5 gallon of fuel is required, or 9 pounds. This reduces the usable payload to 31 lbs. A parachute and the mechanism to deploy it is allotted 10 pounds, so that the weight available to the sensor, down link transmitter, and any extra control equipment is 21 lbs.

"Elementary Fluid Mechanics", Veunard, Wiley and Sons, 1958. The Clark-Y Data is for a 48' x 8' rectangular airfoil tested at $N_r \approx 6 \times 10^6$.

The performance of such a craft is difficult to estimate. Because the cost of constructing a craft of the size and weight outlined above is not excessive it is reasonable to suggest that the design and construction of such a craft be commissioned. The craft could then serve to generate performance tables which could be used further in obtaining a more accurate analysis of performing the aerial survey task. The data necessary in such an analysis would include:

- Cruising speed as a function of altitude and payload.
- Rate of climb as a function of altitude and payload.
- Endurance at various speeds and altitudes.
- Service ceiling.
- Useful range and altitude with visible tracking and command.
- Quality of data obtained.

A prototype model-drone could also be used to observe the flying characteristics, i.e. the stability, maneuverability, etc., to determine what changes are required in the final model.

Components of the model-drone should be off-the-shelf model airplane types wherever possible. A simple design, high wing monoplane, with a conventional mounted engine in the nose is recommended. Exhaust stacks to direct the engine exhaust away from the sensor are necessary, and if too much power loss is not incurred, the engine should be muffled.

The engine power is slightly larger than what is available for model aircraft, such that a small motorcycle engine might have to be modified for airborne use.

Radio-Contr olled Blimp

The sizing of the RC blimp is based on a payload of about 40 lbs., which includes a TV camera and controls, batteries, a wide band transmitter, and a receiver and demodulator forcontrolling the blimp and camera. Added to this is 120 pounds for the engine, fuel and small alternator. The structure of the blimp and skin would probably weigh 60 lbs., so that a total weight of 220 pounds ($\approx$ 100 Kg) must be carried aloft.

The lifting power of Helium at standard temperature and pressure is about 1.114 gm/liter, such that the volume of Helium required is

$$V = \frac{100 \text{ Kgm}}{1.114 \text{ gm/l}} = 87\text{K liters}$$

$$= 3070 \text{ ft}^3$$

Assuming a blimp whose shape is that of a prolate spheroid whose minor diameter, b, is 1/3 of its major diameter, a, has a volume

$$V = 1/3\ \pi a b^2$$

$$= 1/3\ \pi a(\frac{a^2}{9})$$

Solving for a

$$a^3 = \frac{3070 \text{ ft}^3}{.466} = 6580 \text{ ft}^3$$

$$a = 18.7 \text{ ft.}$$

$$b = 6.3 \text{ ft.}$$

Further calculations show that, assuming a C_d of .3, at 30 mph only 3.6 hp is required. At 60 mph the power required is 28.8 h.p., and at 90 mph about 100 h.p. However, at speeds beyond about 40 mph, the structure would probably have to be re-inforced, increasing weight, volume of helium, and power.

An approach to the RC blimp that may be used is to rely more on aerodynamic lift and less on the buoyancy of the helium. This would probably lead to a higher performing system at less cost, but would require some minimum airspeed.

4.2 SUPPORT EQUIPMENT

Some of the support equipment necessary for the various candidate systems have been identified previously in order to estimate cost. In this section more of the technical details of the selected candidate systems will be discussed.

Model/Drone

The most important ground support item for the model-drone is probably the launch mechanism. The most appropriate technique for launch was selected as being a catapult mechanism, powered by compressed air. This technique has been used for light drones in the past (reference Table 3-1, Bikini, by Republic Aircraft), but engineering data for such mechanisms could not be obtained. The catapult should be designed as a trailor so that two men could easily position the catapult for a clear launch into the wind.

A launch for such an application might be 16 feet long extended, telescoping to eight feet for travel. Assuming that a velocity of 40 mph must be reached by the model to get above stalling speed, the model would be subjected to about 4.5 g acceleration on take-off. Assuming that a supply pressure of 200 psi is available, a piston of 2.15 inch diameter is necessary to supply the necessary thrust for launching the 80 lb. craft. While such an arrangement is probably feasible, a design effort is necessary to provide a compact, lightweight design.

Other support equipment include the control equipment, and a vehicle suitable for carrying personnel, equipment, spare parts, personal equipment, and at least two model - drones. A large van, the type classified as a "slide-door" by Chevrolet, would probably be adequate. The roof of such a van could be fitted with a collapsible guard rail and used as an observation deck by the operators of the craft.

A "cherry-picker" mechanism as used by telephone repairmen would probably not be worth the expense. It is probable that the added height obtained (30 feet) would extend the operator's horizon, but as pointed out in earlier chapters, controllability of the craft will define the maximum usable range. The use of the "cherry-picker" would also require a heavier, more costly, and more cumbersome vehicle.

Figure 4-1 depicts the model-drone system.

RC Blimp

The RC blimp is the prime candidate for urban or surburban aerial survey tasks. The support equipment includes the ground based portion of the data link. The requirement for this equipment was discussed in Section 3.4. It included a high gain parabolic disk antenna, mounted so that it could be manually pointed at the blimp, a C band receiver, demodulator, TV display, and recorder. The need to have this equipment portable or mounted in a van could possibly be dispensed if a suitable location were found atop some high building.

Support equipment will be necessary for launch and recovery operations. Equipment will be necessary forinitial inflation, for moving the vehicles, and possibly for deflation and transport to a different site. A system where the craft is recovered, and moored to a mast mounted on a truck, could

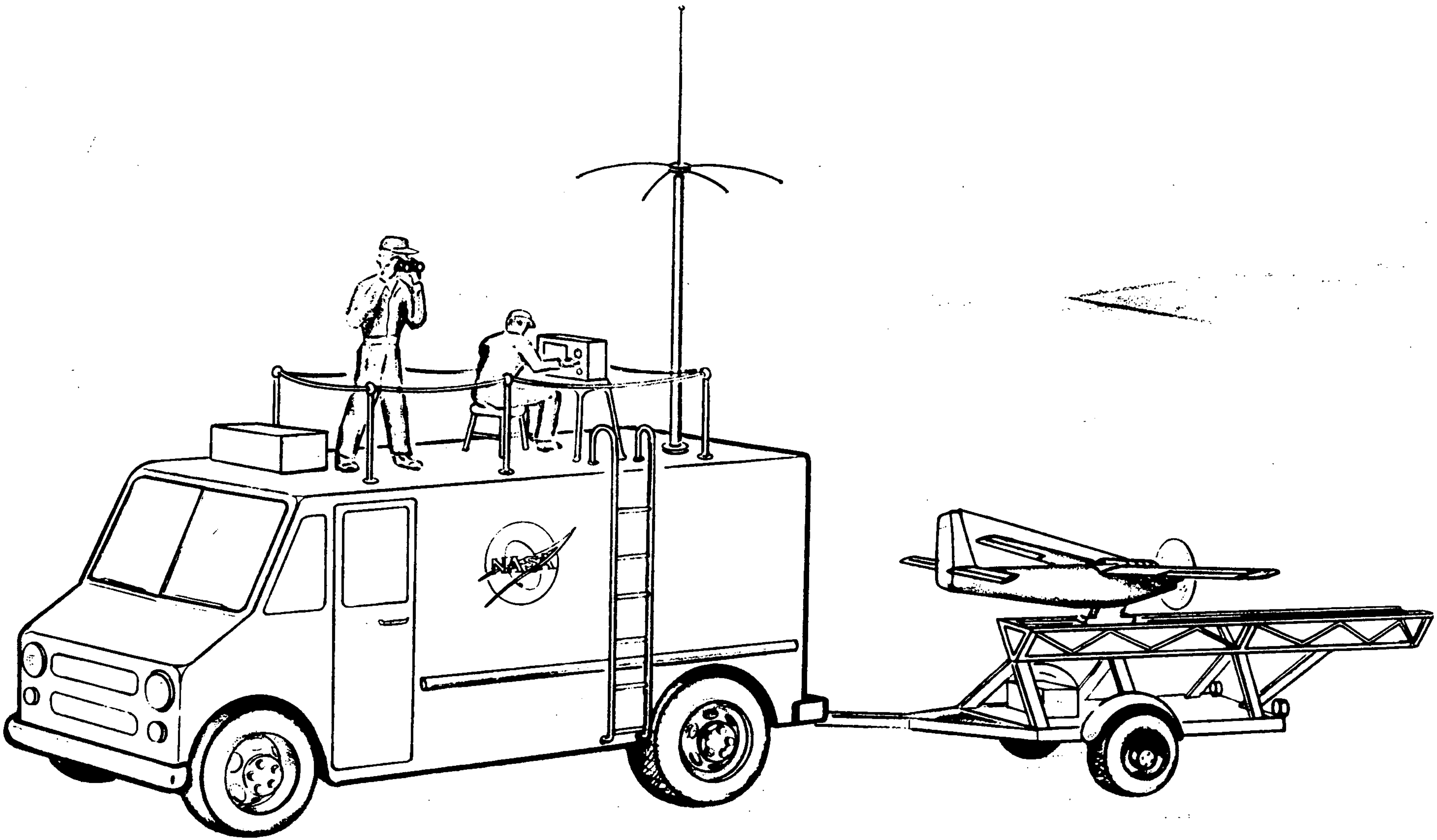

FIGURE 4-1, THE MODEL-DRONE AERIAL SURVEY SYSTEM then be towed into a hanger for storage or maintenance. The operations required for launch and recovery are not clear, but reportedly some proprietary work has been done along these lines.* Presumably, the cost of support equipment has been established.

One problem is that primary control of the vehicle may be done at a location remote from the launch/recovery area. A local controller could possibly take over at launch/recovery location, transferring control to the primary controller after the craft is well airborne. Thus, another requirement is established; a local control set and a communication link (possibly telephone) between a primary and secondary controller.

*Developmental Science Corp., referenced previously.

4.3 TRAINING

A certain degree of skill and training is required on the part of operators of model aircraft. Even experienced pilots of full size aircraft have reported that controlling model aircraft is "tricky", such that some considerations should be given to the training aspects of model/drone operation.

It is advised that an inexpensive model craft and controls be acquired so that the operators could become acquainted with the fundamental control characteristics of RC model flight. The next step would be flight with a larger, perhaps the development model or prototype, model-drone. This training craft would of course not be fitted with sensors, so that less loss is incurred upon the event of a crash. A lightened payload would also give more margin for operator error, as well as decrease the momentum of the craft upon impact with the ground. Finally, fully loaded flights should be attempted and practiced to allow the operator to become thoroughly familiar with the flight characteristics.

The most critical part of craft operation, take-off and landing, has been eliminated through the use of the pneumatic launcher and parachute recovery system.

The nature of operation with an RC blimp cannot be visualized quite so readily, but clearly a similar training and familiarization routine is warranted. It would seem that operation of a blimp would be somewhat easier than with the model/drone.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The study has identified some of the problems associated with a low cost aerial survey system. An emphasis was placed on unmanned systems, since the lower payload required would tend to allow a small and lower cost airborne system to be used. However, it was found that the low cost unmanned systems, such as characterized by the model/drone, are cost-effective only when used with relatively small survey areas. This is precisely the nature of some of the applications for which the system may be intended.

When the amount of data to be collected, or the size of the survey area is increased, the light-manned aircraft technique appears more cost effective. The use factor, that is, how much time per year or how often the system will be used, also has an important bearing on the economics of any of the candidates. If only occasional acquisition of data is intended, then the method used at present is probably superior to any of the low cost approaches because no initial acquisition of equipment is necessary.

The use of high performance drones, such as in use by the military, appear to be unsuitable for any of the tasks outlined because of the high acquisition cost of ground support equipment and the inherent danger of launch operations.

The use of either drones or smaller model/drones over urban-suburban areas must be ruled out, such that the only suitable candidate is the RC blimp. The procurement cost of the RC blimp system is higher than the lightest manned helicopter available, but is more suitable for analysis or study missions. Since it may also be used for emergency applications, its use could probably be justified in some of the larger urban areas.

It is recommended that the use of the model/drone be explored further. Specifically, the design and fabrication of a craft should be undertaken and test flights flown. This is recommended because it is believed that a modest cost would be involved, and the craft could be used to obtain performance data which would lead to a more accurate analysis of this method of obtaining data. Particularly important is knowledge pertaining to its maximum useable range, the quality of data obtained, endurance, and problems of control.

Another promising series of investigations which should be conducted is that of low cost methods of control and tracking the model at extended ranges, i.e., out of sight. While present tracking systems are very expensive, the use of phased array techniques and low cost mini-computers have advanced in recent years - this is a technology that is not in use in the present drone tracking systems. A serious investigation along these lines was beyond the scope of this study, but it is believed that incorporation of advanced techniques could increase measurably the use of the low cost model/drone system. This is another reason that the model/drone should be of sufficient size to accommodate any electronics that may be carried aloft in future investigations.

It is also recommended that the electrostatic autopilot be investigated, and tested in the model/drone. The use of a low cost autopilot and tracking system would extend the range of the system, creating a highly effective, low cost method of gathering data. Even the autopilot without an accompanying tracking system could possibly greatly extend the range over what is currently possible using visual control.

The use of an autopilot and tracking system also has the effect of increasing the accuracy of the photographs taken with a resulting saving in the number of photographs which must be taken.

A third benefit of an autopilot is that the greater stability and controllability will probably result in fewer mishaps, and lead to some overall cost savings.

It is recommended that the prototype craft use fixed landing gear to eliminate initial design of the launcher. The launcher/parachute system can be designed after feasibility of the airborne system is proven.

The use of the R C blimp is not yet clear, possibly because the intended use or the nature of urban investigations, or a knowledge of the urgency of such studies is not as well known. It would appear that further supporting data pertinent to the design, cost, and use of such craft is necessary before recommendations of procurement.

Finally, it is recommended that a low weight camera be designed with the characteristics described in Section 2.2.

APPENDIX A

SPECIFICATIONS AND CHARACTERISTICS OF

VEGA PRECISION LABORATORIES

PORTABLE TRACKING SYSTEM

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VEGA MODEL 626C PORTABLE RADAR TRACKING SYSTEM

Vega's Model 626 C Portable Radar Tracking System is used to track manned or unmanned target vehicles in range, azimuth and altitude.

The Model 626C Portable Tracking System is comprised of the Model 657 Portable Radar Tracking Set (ground station) and the Model 656 Target Group Set (airborne package). The Model 657 Portable Radar Tracking Set provides indications of instantaneous target slant range from zero to 100,000 yards, azimuth over 360 degrees continuously, and plots a permanent recording, in rectangular coordinates, of slant range vs azimuth. Altitude data, sensed and telemetered by the air-borne Target Group Set, is indicated up to 30,000 feet by the ground based Portable Radar Tracking Set. The Portable Radar Tracking Set can be shipborne, ground stationary or mobile, and is capable of tracking the airborne Target Group Set from below the horizon to zenith.

The entire Model 626C Portable Tracking System is completely portable and self-contained so that tracking may be performed anywhere in the world without dependence on availability of support services from other systems. No other system is presently available that can offer this important advantage.

The Model 657 Portable Radar Tracking Set consists of four major units:

1. Antenna Group, Model 654
2. Radar Set Control, Model 652/3
3. Target Position Display, Model 655
4. Single Axis Antenna Stand, Model 662

This equipment is designed to operate from an input voltage source of 115 volts, single phase, 60 Hertz. The power requirement is 250 watts nominal, 400 watts maximum. As an option, the system can be designed to be compatible with other power sources.

The Model 656 Target Group Set consists of the following:

1. Radar Transponder, AN/DPN-77 (Modified)
2. Data Encoder, Model 733-8
3. Barometric Sensor, Model 732
4. Antenna Group
5. Miscellaneous Installation Accessories

The Model 656 Target Group Set is delivered as a kit to permit simple installation in the MQM-74A target with no modification to the drone. Other kits in various forms are available to adapt to a desired vehicle.

The system has been adapted to various manned and unmanned target vehicles, and successful flight demonstrations have been performed with the manned UH-1E Helicopter, the QH-50D Drone Helicopter, the high performance MQM-74A Target Drone, the MQM-33 Drone, various manned aircraft, and a drone boat.

With the use of Vega's Model 642 Pulse Position Coded Command System, the Model 626 C Radar Tracking System is capable of command control of the vehicle as well as tracking the vehicle.

Various options are available with the Model 626C Portable Radar Tracking System such as extended range and high accuracy plotting.

Model 626C Specifications

The system is designed to function within its specified accuracy when installed on shipboard. It is also capable of operation when installed on a mobile land vehicle without deterioration of performance.

SYSTEM PERFORMANCE

Slant Range	0 to 100,000 yards
Slant Range Resolution	10 yards
Slant Range Accuracy	$\pm$ 20 yards
Altitude	0 to 30,000 feet
Altitude Resolution	100 feet
Altitude Accuracy	$\pm$ 200 feet (below 20,000 feet with Model 732 pressure transducer)
Elevation Coverage	Cosecant Squared Pattern Minus 10° to 90°
Azimuth Angular Coverage	360° continuous
Azimuth Angular Accuracy	$\pm 1^\circ$
Azimuth Tracking Rate	20° /sec maximum
Azimuth Acceleration	10° /sec^2 maximum
Azimuth Slew Rate	32° /sec maximum
Elevation Tracking Rate	Unlimited, Cosecant Antenna
Data Output	1 to 8 channels
Data Accuracy	$\pm$ 0.5 percent of full scale
Data Format	0-5 volt
Acquisition	Automatic full azimuth sector scan $\pm 16^\circ$

System Performance (Continued)

Re-Acquisition	Range Modified Sector Scan 0-16 N.M.: $\pm 8^{o}$ 16-32 N.M.: $\pm 4^{o}$ 32-50 N.M.: $\pm 2^{o}$
Readout-Display	Range, Bearing, Altitude
Readout-Plotter	Range, Bearing on 10" x 15" X-Y Plotting Paper
Plotter - Range Scales	4 Range Scales, 1K yds, 2K yds, 4K yds, 8K yds per inch
Range Gate	Automatic Sweep for Acquisition and Tracking
Frequency Range	5.4 to 5.9 GH_z (tunable)
Address Code	2 Pulse Code
AGC	Meter Display for Signal Strength

OPERATOR'S CONTROLS:

Transmitter ON-OFF

Antenna Slew

Antenna Lockout

Range Select

Altitude Calibration for Barometric Pressure

Transmitter Code Setting

Transponder Fixed Delay Setting

GENERAL (Ground Tracker Package)

Control Unit (Model 652/3):

Size:	17" x 14.5" x 15.4"
Weight:	60 pounds
Power:	115 volts 60 Hz

GENERAL (Ground Tracker Package) (Continued)

Antenna Unit (Model 654):

Size:	30" diameter x 41.5"
Weight:	100 pounds
Power:	115 volts 60 Hz

Display Unit (Model 655):

Size:	20.1" x 16.8" x 9.4"
Weight:	60 pounds
Power:	115 volts 60 Hz

SINGLE AXIS MOUNTING STAND:

Size:	5 feet long by 2 feet wide by 2 feet high (folds for shipping)
Weight:	25 pounds

GENERAL (Airborne Package)

Transponder:	AN/DPN-77
Size:	6" x 7" x 3"
Weight:	5-1/2 pounds maximum
Power:	28 VDC at 1.4 amps maximum

Data Encoder (8 channels), Model 733-8:

Size:	3.4" x 2.0" x 2.4"
Weight:	18 ounces
Power:	28 VDC at 0.4 amps

Barometric Sensor, Model 732:

Size:	2-1/2" diameter x 2-1/2" long excluding protrusions
Weight:	8 ounces

COMPONENT LIST

FOR

MODEL 626C PORTABLE RADAR TRACKING SYSTEM

A. TARGET GROUP SET (INSTALLATION KIT) MODEL 656

1.	AN/DPN-77 Radar Transponder (Modified)	(1 each)
2.	Vega Model 733-8 Encoder with Video Cables and Fittings	(1 each)
3.	Vega Model 732 Barometric Sensor	(1 each)
4.	Vega Model 845C Stub Antenna	(2 each)
5.	Plastic Tubing with Fittings	(1 each)
6.	Antenna Cable with RF Connectors	(2 each)
7.	Power Cable with Connector	(1 each)
8.	Open End Wrench to Fit RF Connectors	(1 each)
9.	Complete Installation Instructions	(1 set)

B. PORTABLE RADAR TRACKING SET, MODEL 657

1.	Vega Model 652/3 Radar Set Control	(1 each)
2.	Vega Model 654 Antenna Group	(1 each)
3.	Vega Model 655 Target Position Display	(1 each)
4.	Interconnecting Cables with Connectors	
	a. Control Unit to Antenna Unit	
	25 feet long	(1 each)
	150 feet long	(1 each)
	b. Control Unit to Display Unit	
	8 feet long	(1 each)
5.	Power Cable and Connector (8 feet long)	(1 each)
6.	Single Axis Antenna Assembly Mounting Stand, Model 662	(1 each)
7.	Items 1 through 6 Housed in a Reusable Shipping Container	

ENVIRONMENTAL (Portable Radar Tracking Set, Model 657)

Designed to meet general equipment requirements of MIL-E-16400, class 2.

*Temperature (ambient)	
Operating	-28°C to +65°C
Nonoperating	-62°C to +75°C
Vibration	MIL-STD-167 Type I
Shock	MIL-S-901 Grade B, Class I, Type A
Salt Spray	MIL-STD-202 Method 101, Cond. B
Humidity	MIL-E-16400 95 percent at 60°C
EMI	MIL-STD-461
*Target Position Display unit:	0°C to +40°C (operating) -10°C to +60°C (nonoperating)

ENVIRONMENTAL (Target Group Set, Model 656)

Designed to meet general equipment requirements of MIL-E-5400, class 1A.

Temperature	
Operating	-40°C to +55°C (+71°C intermittent)
Nonoperating	-62°C to +85°C
Vibration	MIL-STD-810 Method 514 20-2000 cycles, 10G (Peak)
Shock	MIL-STD-810 Method 516 30G (Peak) 11 milliseconds
Humidity	MIL-STD-810 Method 507

Environmental (Target Group Set, Model 656) (Continued)

Leakage (immersion)	MIL-STD-810 Method 512
EMI	MIL-STD-461

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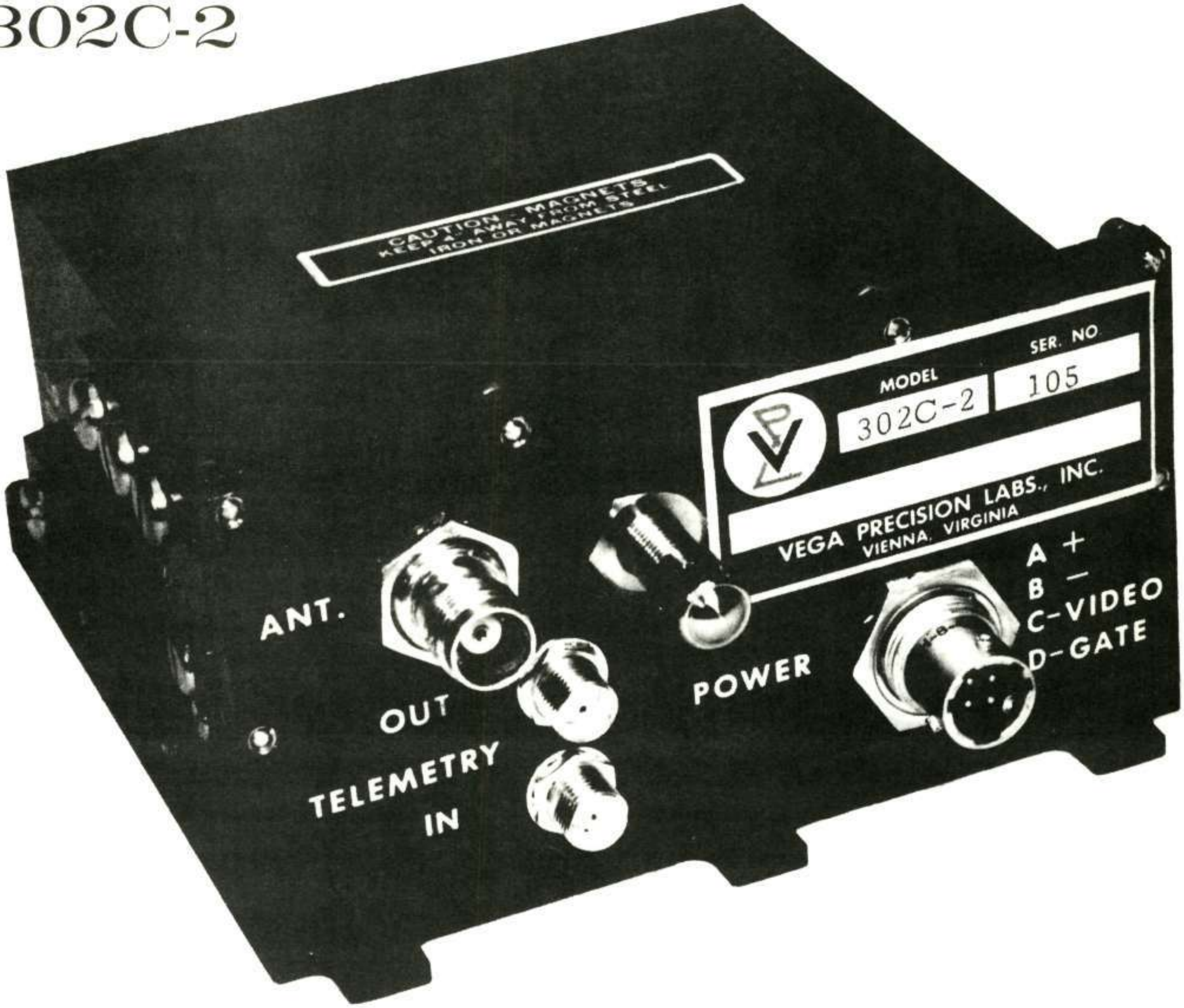
VEGA MODEL 626C PORTABLE RADAR TRACKING SYSTEM, TYPICAL VAN SETUP

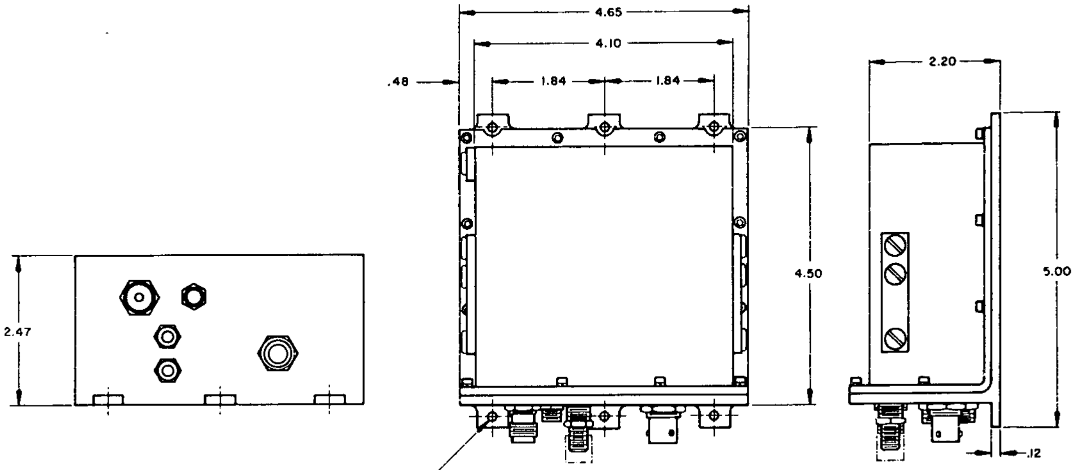
C-BAND RADAR TRANSPONDER

MODEL 302C-2



This equipment is used in missile, satellite, drone, rocket, and target applications as an enhancement device for a C-band tracking radar. It is also capable of performing with the Vega Model 603C Telesponder Telemetry and Command Control Systems. The significant feature of this unit is its extremely light weight (43 ounces) while still maintaining the electrical and environmental characteristics of superheterodyne transponders.

C-BAND RADAR TRANSPONDER



FRONT VIEW TOP VIEW SIDE VIEW

GENERAL:

TRANSMITTER-RECEIVER FREQUENCY SEPARATION: At least 50 MHz
OUTPUT IMPEDANCE: 50 ohms; nominal
INPUT IMPEDANCE: 50 ohms; nominal
DUPLEXER: Foŭr Port Ferrite Circulator
LINE VOLTAGE: 22 to 32 VDC. Power line not grounded within transponder
TRANSIENTS: Per MIL-E-26144
POWER CONSUMPTION: 28 V DC input, 1.1 amp at 1000 pps, D.P. Mode
ANTENNA CONNECTOR: TNC Female
INTERNAL TEST POINTS: Provided to allow rapid isolation of malfunction to a particular module
EXTERNAL TEST POINTS: A pulse signal equivalent to the decoder input. A pulse signal indicative of the coincidence gate pulse.
REVERSE POLARITY PROTECTION: Provided to prevent permanent damage upon application of reverse polarity DC input voltage up to maximum 50 volts and Zener Diode Transient Protection

PHYSICAL:

SIZE: 4.69 x 4.65 x 2.47 inches, excluding mounting feet & connectors. 43 cubic inches (displacement volume)
WEIGHT: 43 ounces nominal

ENVIRONMENTAL CONDITIONS:

VIBRATION: SINE: 5 to 25 cps, 0.4 inch double amplitude 25 to 2500 cps, 15g
VIBRATION: RANDOM: 0.009 G2rms/cps up to 150 cps. Increase to 0.2 G2rms/cps, from 600 to 800 cps decrease to 0.02 G2rms/cps, at 2000cps.
TEMPERATURE OPERATING: -67°F (-54°C) to +167°F (+75°C) ambient temperature
NON-OPERATING: -80°F (-62.2°C) for 3 davs + 167°F (+75°C) for 3 davs
SHOCK: 125g (6 milliseconds) in any direction
ALTITUDE: 760 mm of mercury to 0.04 mm of mercury (230,000 feet altitude)
HUMIDITY: Any, up to 100% including condensation due to temperature changes
ACCELERATION: 125g applied along any axis for 3 minutes
RFI: Per MIL-1-26600

C-BAND RADAR TRANSPONDER

MODEL 302C-2

RECEIVER:

TYPE OF RECEIVER: Superheterodyne
FREQUENCY RANGE: 5400 to 5900 MHz
FREQUENCY ADJUSTMENT: Single Control L.O. Tuning. Accessible from exterior.
(L.O. & Preselector) Preselector tuning accessible from exterior
FREQUENCY STABILITY: ±2 MHz after 3 minute warmup
RECEIVER TRIGGER SENSITIVITY: –70 dbm (single pulse and double pulse with optimum spacing)
DYNAMIC RANGE: +20 to -70 dbm
IMAGE REJECTION: 60 db minimum
RECEIVER BANDWIDTH: 11 ±3 MHz
RECEIVED PULSE WIDTH:
Single Pulse: 0.25 μsec to 5.0 μsecs
Double Pulse: 0.25 μsec to 1.0 μsec
RECEIVED PULSE RISE TIME, SINGLE AND DOUBLE PULSE: 0.1 μsec or less
PULSE CODE OPERATION: Single Pulse & Double Pulse
DOUBLE PULSE CHARACTERISTICS: 3.0 to 12.0 μs spacing; continuously adjustable
Will Accept: ±0.15 μsec
Will Reject: ±0.3 μsec
TRANSPONDER RECOVERY TIME: Transponder will reply to each of three interrogations (single or double pulse) when the spacing between any two successive interrogations is 50 μsecs or more. Peak power output will be within 1 db of limits specified
FREQUENCY OF OPERATION FOR SINGLE & DOUBLE PULSE OPERATION: Within ±2 MHz of the frequency to which the receiver is tuned.

TRANSMITTER:

FREQUENCY RANGE: 5400 to 5900 MHz
TRANSMITTER TUNING: Single control, accessible externally
FREQUENCY STABILITY: ±3 MHz for all operating conditions except temperature. During changes in ambient temperature frequency drift will not exceed 50 KC/°C (27.8 KC/°F)
PEAK POWER OUTPUT: 400 watts minimum
PULSE WIDTH: 0.5 ±0.1 μsec
TRANSMITTER PRF: 10 to 2600 pps
PULSE RISE TIME (10% to 90%): 0.1 μsec maximum
PULSE FALL TIME (90% to 10%): 0.2 μsec maximum
DELAY JITTER: Will not exceed 0.02 μsec peak-to-peak for input signal levels of 0 dbm to –55dbm. Will not exceed 0.05 μsec peak-to-peak for input signal levels of –55 dbm to –65 dbm.
PULSE WIDTH JITTER: 0.01 μsec maximum
TRANSMITTER SPECTRUM: R-F B.W. will not exceed 3.0/pulse width in μsec measured at 1/4 power **(R-F Bandwidth in MHz)**
LOCKOUT PROTECTION: Provides for no response during 50 μsec recovery time of transponder
RESPONSE TO VALID INTERROGATIONS (% of time): 99% of interrogation signals at all input signal levels of 0 to -70 dbm
SYSTEM DELAY VARIATION: Maximum Variation will not exceed 0.05 μsec for signal levels of 0 to -65 dbm
SHORT OR OPEN AT ANTENNA TERMINAL: Transmitter will meet all requirements after application and removal of either a short or an open circuit at the antenna terminal
RANDOM TRIGGERING: Will not exceed 10 pps under any operating conditions
TRANSMITTER DUTY CYCLE: The transmitter will meet requirements specified at any duty cycle up to 0.002.
INTERNAL DELAY: Adjustable 2.5 to 6.0 μsecs

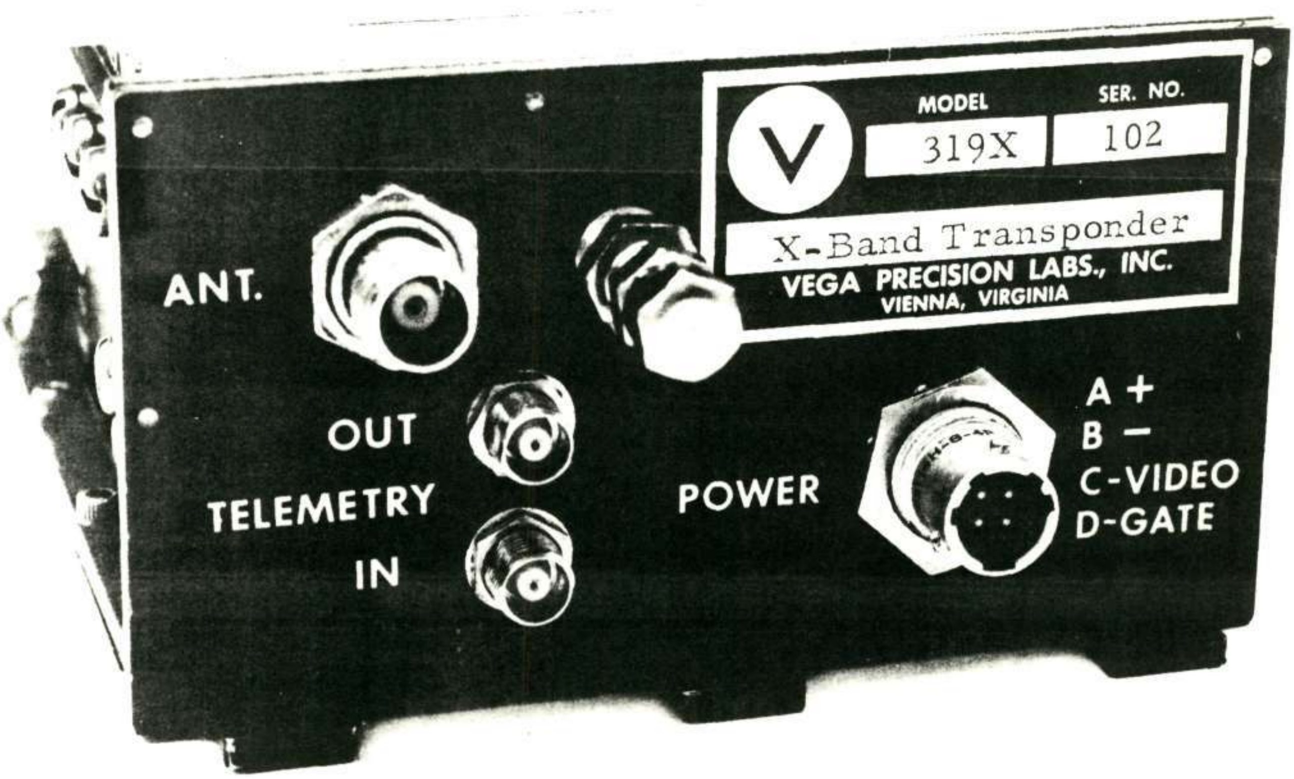
CONNECTORS:

ANTENNA: TNC female
TELEMETRY: TM female
POWER: MS 3114H-8-4P (mates with PTO6 E-8-4S)

239 MAPLE AVENUE VIENNA, VIRGINIA 22180 (703) 938-6300

X-BAND RADAR TRANSPONDER

MODEL 319X



This equipment is used in missile, satellite, drone, rocket, and target applications as an enhancement device for an X-band tracking radar. The significant feature of this unit is its extremely light weight (43 ounces) while still maintaining the electrical and environmental characteristics of superheterodyne transponders.

Model 319X

X-BAND RADAR TRANSPONDER

GENERAL:

TRANSMITTER-RECEIVER FREQUENCY SEPARATION: At least 50 MHz
OUTPUT IMPEDANCE: 50 ohms, nominal
INPUT IMPEDANCE: 50 ohms, nominal
DUPLEXER: Four Port Ferrite Circulator
LINE VOLTAGE: 22 to 32 VDC. Power line not grounded within transponder
TRANSIENTS: Per MIL-E-26144
POWER CONSUMPTION: 45 watts at maximum duty cycle and 28 VDC input
ANTENNA CONNECTOR: TNC Female
INTERNAL TEST POINTS: Provided to allow rapid isolation of malfunction to a particular module
EXTERNAL TEST POINTS: A pulse signal equivalent to the decoder input. A pulse signal indicative of the coincidence gate pulse.
REVERSE POLARITY PROTECTION: Provided to prevent permanent damage upon application of reverse polarity DC input voltage up to maximum 50 volts and Zener Diode Transient Protection

PHYSICAL:

SIZE: 4.69 x 4.65 x 2.47 inches, excluding mounting feet & connectors. 43 cubic inches (displacement volume)
WEIGHT: 43 ounces nominal

ENVIRONMENTAL CONDITIONS:

VIBRATION: SINE: 5 to 25 cps, 0.4 inch double amplitude 25 to 2500 cps, 15g
VIBRATION: RANDOM: 0.009 G^2rms/cps up to 150 cps. Increase to 0.2 G^2rms/cps, from 600 to 800 cps decrease to 0.02 G^2rms/cps, at 2000 cps.
TEMPERATURE OPERATING: −35°F (−37°C) after 3 days with power off, case temperature up to +167°F (+75°C)
NON-OPERATING: −80°F (−62.2°C) for 3 days +167°F (+75°C) for 3 days
SHOCK: 125g in any direction 3 shocks in opposite directions along each axis for 6 m sec. each
ALTITUDE: 760 mm of mercury to 0.04 mm of mercury (230,000 feet altitude)
HUMIDITY: Any, up to 100% including condensation due to temperature changes
ACCELERATION: 125g applied along any axis for 3 minutes
RFI: Per MIL-I-26600

239 MAPLE AVENUE VIENNA, VIRGINIA 22180 (703) 938-6300

X-BAND RADAR TRANSPONDER

MODEL 319X

RECEIVER:

TYPE OF RECEIVER: Superheterodyne

FREQUENCY RANGE: 9100 to 9600 MHz

FREQUENCY ADJUSTMENT (L.O. & Preselector): Single Control L.O. Tuning. Accessible from exterior. Preselector tuning accessible from exterior.

FREQUENCY STABILITY: ± 2 MHz after 3 minute warmup

RECEIVER TRIGGER SENSITIVITY: -65 dbm (single pulse and double pulse with optimum spacing)

DYNAMIC RANGE: +20 to -65 dbm

IMAGE REJECTION: 60 db minimum

RECEIVER BANDWIDTH: 11 ±3 MHz

RECEIVED PULSE WIDTH:
- **Single Pulse**: 0.25 μsec to 5.0 μsecs
- **Double Pulse**: 0.25 μsec to 1.0 μsec

RECEIVED PULSE RISE TIME, SINGLE AND DOUBLE PULSE: 0.1 μsec or less

PULSE CODE OPERATION: Single Pulse & Double Pulse

DOUBLE PULSE CHARACTERISTICS: 3.0 to 12.0 μsec spacing continuously adjustable
Will Accept: ±0.15 μsec
Will Reject: ±0.3 μsec

TRANSPONDER RECOVERY TIME: Transponder will reply to each of three interrogations (single or double pulse) when the spacing between any two successive interrogations is 50 μsecs or more. Peak power output will be within 1 db of limits specified

TRANSMITTER:

FREQUENCY OF OPERATION FOR SINGLE & DOUBLE PULSE OPERATION: Within ±2 MHz of the frequency to which the receiver is tuned.

FREQUENCY RANGE: 9200 to 9500 MHz

TRANSMITTER TUNING: Single control, accessible externally

FREQUENCY STABILITY: ±3 MHz for all operating conditions except temperature. During changes in ambient temperature frequency drift will not exceed 50 KC/°C (27.8 KC/°F)

PEAK POWER OUTPUT: 400 watts minimum

PULSE WIDTH: 0.5 ± 0.1 μsec

TRANSMITTER PRF: 10 to 2600 pps

PULSE RISE TIME (10% to 90%): 0.1 μsec maximum

PULSE FALL TIME (90% to 10%): 0.2 μsec maximum

DELAY JITTER: Will not exceed 0.02 μsec peak-to-peak for input signal levels of 0 dbm to -55 dbm. Will not exceed 0.05 μsec peak-to-peak for input signal levels of -55 dbm to -65 dbm.

PULSE WIDTH JITTER: 0.01 μsec maximum

TRANSMITTER SPECTRUM (R-F Bandwidth in MHz): R-F B.W. will not exceed 3.0/pulse width in μsec measured at 1/4 power

LOCKOUT PROTECTION: Provides for no response during 50 μsec recovery time of transponder

RESPONSE TO VALID INTERROGATIONS (% of time): 99% of interrogation signals at all input signal levels of 0 to -65 dbm.

SYSTEM DELAY VARIATION: Maximum Variation will not exceed 0.05 μsec for signal levels of 0 to -65 dbm

SHORT OR OPEN AT ANTENNA TERMINAL: Transmitter will meet all requirements after application and removal of either a short or an open circuit at the antenna terminal

RANDOM TRIGGERING: Will not exceed 10 pps under any operating conditions

TRANSMITTER DUTY CYCLE: The transmitter will meet requirements specified at any duty cycle up to 0.002

INTERNAL DELAY: Adjustable 2.5 to 6.0 μsecs

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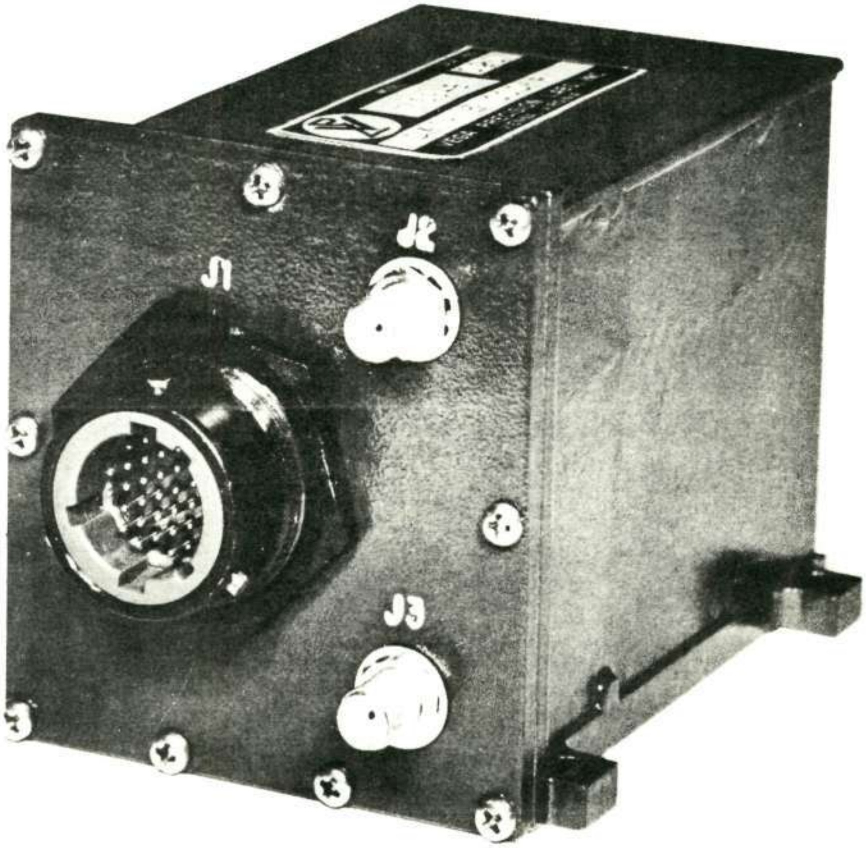
MODEL 733-8



The Model 733-8 Eight Channel Data Encoder is designed for use with Vega transponders in a complete PPM telemetry system. The ground components of the system are the Vega Model 728 Demodulator and the Vega Model 725 D/A Converter, or the Vega Model 657 Portable Radar Tracking Set. The Model 733-8 generates a two-pulse per cycle PPM code after each interrogation from the transponder. The first pulse is the range pulse from the transponder and the next two pulses in the chain are generated by the Model 733-8 Data Encoder. The second pulse is sync index pulse. Its time position with respect to the range pulse encodes the channel number being encoded during the present cycle. The third pulse encodes the actual telemetry data to be transmitted. The data pulse is transmitted with ±0.3 percent accuracy of full scale.

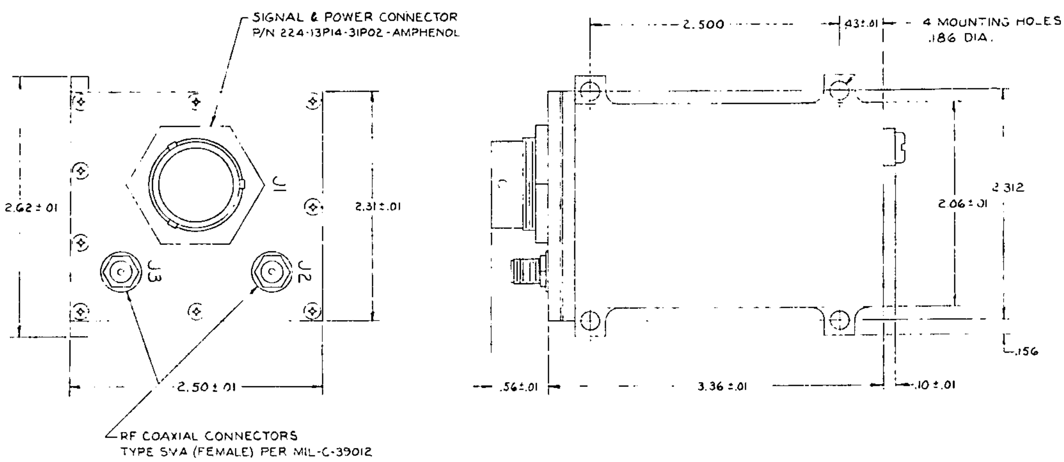
The Model 733-8 Data Encoder, when operating with a Vega Transponder, has a fail-safe feature which allows the transponder to continue to transmit a tracking pulse upon interrogation in case of an encoder failure. This permits the transponder to be used for range safety tracking.

The Model 733-8 Data Encoder has positive (OV to +5V) analog data input and a positive (4.6V to 8.1V) sensor voltage output, externally adjustable.

Super-commutation can be implemented by wiring common data inputs to several channels to improve the data rate.

Sub-commutation is available as an option.

Eight Channel Data Encoder



ELECTRICAL

Telemetry Input Impedance:	100,000 Ω (all channels)
Telemetry Input Voltage Range:	0V to +5V, positive
Sample Rate Per Channel:	One eighth of the radar PRF
Interrogation:	From Vega Transponder
Encoder Output:	To Vega Transponder
Accuracy of Voltage to Time Conversion:	±0.3 percent of full scale maximum
Max. Interrogation Rate:	4 KHz (limited only by telemetry time frame of 250 μsec.)

MECHANICAL

Size (Excluding Mounting Flange and Connectors):	2.22 inches high x 3.350 inches long x 2.500 inches wide
Volume (Excluding Mounting Flange and Connectors):	18.6 cu. in.
Weight:	12.4 oz.

ENVIRONMENTAL

Temperature:	–40 degrees C to +70 degrees C
Altitude:	Unlimited
Shock:	100 "g" for 11 milliseconds in all axes
Vibration:	15 "g" peak sinusoidal, from 20 to 2000 cps; 24 "g" rms from 200 to 700 cps; for all axes
Static Acceleration:	100 "g" in all planes
Power Consumption:	22 to 31 VDC at 0.5 amps maximum

CONNECTORS

Type:	Amphenol 224-13P14-31P02 Amphenol 224-16N14-31S02 (mates with above)	1 each used
	Omni-Spectra OSM-212 Omni-Spectra Mate-Any OSM	2 each used

VIENNA, VIRGINIA 22180 (703) 938-6300 TELEX NO. 89-2521

APPENDIX B

QUESTIONNAIRE AND RESPONSE

RELATING TO LEGALITY OF DRONE

OPERATION OVER CITIES

105

B

SCI SYSTEMS, INC.
P. O. Box 4208 - Huntsville, Alabama - 35802
Telephone 205-881-1611

17 November 1972
2160-051

Office of City Attorney
City Hall
710 N. 20th Street
Birmingham, Alabama

Dear Sir:

We at SCI Systems, Inc. are currently conducting a study for the National Aeronatics and Space Administration's Environmental Applications Office One part of this study entails the feasibility of operating small, unmanned aircraft or lighter-than-air craft over urban areas for such purposes as vehicular traffic study or pollution control.

A knowledge of local ordinances of some of the larger municipalities would be helpful in this study. Therefore, we are submitting this questionnaire in the hope that we may guide the study in realistic and fruitful directions.

Your help in completing the questionnaire or in adding any pertinent comment would be greatly appreciated.

Sincerely,

SCI SYSTEMS, INC.

James R. Stansberry

James R. Stansberry

JRS:cp

Enclosure: As stated above.

1. Are there any ordinances governing the use of model aircraft or unmanned vehicles over the city?

Only experimental and test flying.

2. Is the flight of such vehicles prohibited?

Permitted upon approval of executive director of airport and controller on duty in tower.

3. Can the flight of such vehicles be authorized, and if so by whom?

see above

4. Are there any minimum altitudes for flight over the city?

Not less than 1,000 above any obstruction and at horizontal distance less than 2,000 feet.

5. Are there any ordinances covering noise level of aircraft?

No

6. Have the permissible noise levels been established? No

If so, has a particular method of measurement been specified?

7. In the advent that a safe technique were designed, and occasional flights were made over the city, in your opinion, what would be the public reaction?

Unable to give opinion at this time.

Person Completing Questionnaire D. Osradker

314 City Hall

Title Research Atty

1. Are there any ordinances governing the use of model aircraft or unmanned vehicles over the city?

No.

2. Is the flight of such vehicles prohibited?

No - covered under FAA Regulations.

3. Can the flight of such vehicles be authorized, and if so by whom?

Subject not covered in present City Code.

4. Are there any minimum altitudes for flight over the city?

2,000 feet for fixed wing; 1,000 feet for rotorcraft.

5. Are there any ordinances covering noise level of aircraft?

No.

6. Have the permissible noise levels been established? No.

If so, has a particular method of measurement been specified?

Answered.

7. In the advent that a safe technique were designed, and occasional flights were made over the city, in your opinion, what would be the public reaction?

In the absence of an adequate public relations program, I feel the public reaction would be quite adverse. I would anticipate innumerable public inquiries and complaints.

Person Completing Questionnaire [signature]

Title Director of Aviation