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Report

TASK FINAL REPORT

on

APPLICATIONS OF A HIGH-ALTITUDE POWERED PLATFORM (HAPP)
(Report No. BCL-OA-TFR-77-5)

by

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FOREWORD

The study reported herein was carried out by Battelle's Columbus Laboratories for the NASA Office of Applications, as a task under Contract No. NASw-2800. The study leader was Mr. Mark B. Kuhner, and the work was done under the general supervision of Dr. A. C. Robinson, Battelle's manager for the contract. Task monitor in the Office of Applications was Mr. Samuel W. Fordyce, Code ECF.

EXECUTIVE SUMMARY

The High-Altitude Powered Platform (HAPP) is a conceptual unmanned vehicle which can be either an airship (balloon) or airplane. It would keep station above a fixed point on the ground by means of an electric motor-driven propeller with sufficient thrust to overcome the force of the wind. Its nominal altitude would be 21 km (70,000 ft). Power would be provided by a microwave beam from the ground. The airship HAPP, somewhat similar to a blimp, would point into the wind and require only enough power to remain stationary. The airplane HAPP would fly in a small circle above the ground installation that supplies its microwave power. Either version could serve as a platform for remote sensing devices or communications relay equipment.

Two studies of the HAPP concept were carried out simultaneously. Stanford Research Institute examined the technical feasibility and cost of the platform itself, and this study, by Battelle, examined potential remote sensing and communications applications of the HAPP with the aim of determining how well the HAPP could compete with other platforms that might be used for the same purposes.

The objectives of the Battelle study were to compile a list of potential uses for the HAPP and do conceptual system designs for a small subset of the most promising applications. The method used was to postulate a scenario for each application specifying a user, a set of system requirements and the most likely competitor among conventional aircraft and satellite systems. For each scenario, a HAPP system was designed to meet the requirements, and the cost of the resulting HAPP system was compared with the cost of the conventional system. For remote sensing applications, the competitors are aircraft based systems because of requirements for high resolution and/or high frequency coverage. For communications, the competing systems use satellite, or ground-based transmitters.

As part of the study of remote sensing applications, a parametric cost comparison was done between aircraft and HAPPs. Based on the operating costs of the two systems and the area which can be covered by each, it was shown that, for most remote sensing applications, aircraft can supply the same data as HAPPs at substantially lower cost. The critical parameters in determining the relative costs of the two systems are the sensor field of view and the required frequency of the observations being made. Because the HAPP is stationary it can cover a large area only if wide angle sensors can be used. Whether or not such sensors are appropriate depends on the particular application. Another implication of the HAPP's stationary nature is that very frequent observations cost no more with a HAPP than infrequent observations. With an airplane, cost goes up in direct proportion to the frequency of observation. The parametric analysis shows that the HAPP is only competitive with an airplane when sensors having a very wide field of view are appropriate and when the phenomenon being observed must be viewed at least once per day. This eliminates the majority of remote sensing applications from any further consideration.

Based on this analysis three remote sensing applications were selected for more detailed analysis:

- Forest fire detection
- Ice mapping on the Great Lakes
- Enforcement in the 200-mile fisheries zone.

Continuous observation is desirable for forest fire detection since a fire, once started in dry weather, can spread very rapidly. The sooner a fire is spotted, the more likely it is that it can be extinguished before it gets out of control. Since it is not practical to supply continuous coverage with an aircraft, a direct cost comparison between aircraft and HAPPs cannot be made. Therefore, a simple cost benefit analysis was done, assuming a value for timber which represents an average for the United States. The amount of timber which could be saved from destruction by continuous observation is difficult to determine, and the analysis resulted in a range of benefit/cost ratios from 0.5 to 3.0, depending on the assumptions made. This indicates that widespread use of HAPPs for fire detection may not be cost effective. However, if it is assumed that HAPPs would only be used in areas such as the forests of the Northwest, where extremely valuable timber is grown, then benefit/cost ratios between 2 and 12 are derived. Thus, the HAPP appears to be a promising platform for protection of particularly valuable timberland.

The Great Lakes ice mapping application is based on project ICEWARN run by NASA and the Coast Guard during the winters of 1974-75 and 1975-76. ICEWARN was part of the Great Lakes-St. Lawrence Seaway Navigation Season Extension Demonstration Program. It showed that maps of winter ice conditions derived from airborne imaging radar are of considerable utility for winter navigation. Ice conditions have traditionally closed the Great Lakes to navigation during the winter, and the economic benefit to be gained from keeping them open is very large. Maps showing ice conditions on the lakes enable ship captains to select the best routes to avoid becoming stuck or seriously slowed by the ice. These maps are a key part of a larger program which can keep the Lakes open year round. It is shown in this report that three HAPPs equipped with scanning imaging radars could supply the necessary images for about the same cost as an aircraft system which would cover the lakes four times per day. The HAPP system would be superior because its coverage would be continuous and because it could also be used as the basis of a marine traffic monitoring, and a search and rescue system. This would be accomplished by the use, on each ship, of a radio beacon which would broadcast the ship's identification every time a radar pulse is received. The HAPP system would use these identification signals together with the locations determined by the radar to keep track of the movements of all ships on the Lakes.

The third remote sensing application examined here is enforcement of the 200-mile fisheries zone. This new Coast Guard duty presents a complex problem, and no remote sensing system can provide a complete solution. However, the need to determine the locations of all fishing vessels in the zone is basic to any enforcement system, and remote sensing can provide this information. Data on vessel location, courses and speeds have a variety of other uses for the Coast Guard including enforcement of regulations on oil tankers, traffic control for collision avoidance, and search and rescue. It is shown in this report that a number of HAPPs deployed along the coast and equipped with radars could supply this information at a cost which would be quite competitive with aircraft. Since it would supply continuous coverage, the HAPP system would be superior to an aircraft system for collision avoidance, and for search and rescue.

Satellites do not appear to be competitive with HAPPs for the remote sensing scenarios postulated in this report. The requirement for coverage several times per day for the Great Lakes and fisheries scenarios means that several satellites would be needed in either case. Even with fairly low estimates for the cost of each satellite, the overall system cost is considerably higher than for the HAPP alternatives. For the forest fire scenario, a geosynchronous satellite would be required to give continuous coverage. Resolution requirements lead to a satellite which would weigh at least 11,000 kg (25,000 lb). Placing such a heavy satellite in geosynchronous orbit is well beyond the capability of any currently planned Shuttle upper stage.

The selection of the communications applications examined in this study was based on current national needs in communications and the capabilites of the HAPP. They do not represent all possible communications applications of the HAPP, but rather a sampling which could be analyzed within the time and money constraints of the present study. The applications chosen for examination were:

- Continuation of the Rocky Mountain States Education Experiment
- Communications experiment platform
- UHF television broadcast
- Nationwide television distribution.

In the Rocky Mountain states scenario, the possibility of using HAPPs to continue the ATS-6 Health Education Telecommunications (HET) experiment in the Rockies was examined. In this experiment the ATS-6 was used to relay educational television programs from a central site in Denver to 56 junior high schools and 12 public broadcast stations in the eight states of the Federation of Rocky Mountain States. The scenario analyzed here assumes that a number of HAPPs would be used to relay programs to the existing ground terminals installed for use with ATS-6. It so happens that, in this case, an alternative system is cheaper. This alternative system includes a leased transponder on a domsat and new C-band ground terminals at all receiving sites. This system would cost about $940,000 per year. The most optimistic possible estimate for the HAPPs is $1 million per year for the HAPPs alone without any payloads.

The communications experiment scenario is based on the observation that a HAPP can relay signals over long distances (520 km radius) but costs substantially less than a satellite and is more flexible than a satellite in the sense that experimental payloads can be retrieved for repair, modification or replacement. For similar reasons, space science instruments are often tested on balloons before a commitment is made to a satellite program. A HAPP would not be limited to hardware experiments. Numerous aspects of utility, user acceptance and market potential depend more on the type of service provided than on the method of implementation. With its long range, the HAPP could be used to test a variety of communications services which might ultimately be provided by a satellite.

In order to estimate the range of costs of HAPPs used for communications payloads without specifying any particular experiments, two HAPP payloads have been defined in terms of the weight required to duplicate the capabilities of existing experimental satellites. One is the Japanese Broadcast Satellite and the other is ATS-6. A payload with weight equal to the Japanese Broadcast Satellite would represent a comparatively modest set of experiments while an ATS-6 size payload would represent a very sophisticated set of experiments. For each case the cost of the HAPP itself, exclusive of experimental payloads, is compared with the cost of an equivalent satellite platform. The satellite system cost is composed of the launch cost plus the cost of a satellite bus. The HAPP cost consists of the cost of the HAPP itself plus the cost of a bus to supply basic services to the payload. For the small payload, the annual cost of the satellite system, assuming a ten-year life, is $1.4 million to $2.3 million, while the HAPP system annual cost would be $0.62 million to $0.67 million--less than half as much. For the large payload, the equivalent figures are: satellite system, $4.2 million to $6.5 million per year; HAPP system, $0.9 million to $1.0 million per year. So, for the large payload, the HAPP costs less than one-quarter of the satellite system cost. A 10-year lifetime was assumed because this should be possible for communications satellites in the near future; however, the useful work of an experimental satellite is likely to be completed well before its components begin to fail. If a 2-year useful life is assumed for the satellites, then the small and large satellites have an annual cost which is, respectively, 11 and 20 times higher than the HAPP system costs.

The third communications scenario examined in this study involves the use of a HAPP for UHF television broadcast. The characteristics of a typical UHF television broadcast station are compared with the station characteristics that would result if a HAPP-borne transmitter and antenna were used instead of a conventional tower-mounted antenna. The conventional station used for comparison, WOSU-TV, located in Columbus, Ohio, has a 335 m (1100 ft) high tower and its range, for grade B service, is 97 km (60 miles). Grade B service denotes a signal strength which requires a roof-mounted, high-gain receiving antenna to produce a good picture. The annual operating costs for the system elements which could be replaced by a HAPP-based system are $200,000. These costs include the cost of ownership of the tower, antenna and transmitter, the payroll for the technical staff to maintain and operate the transmitter and the cost of electric power.

A HAPP located above this TV station could receive signals from the ground and rebroadcast them over a very large area using a fairly small transmitter. A 6-kw transmitter would provide grade B service at a range of 520 km (322 miles), far enough to cover a multistate area. The yearly cost of this system would be $1.3 million including the HAPP, HAPP payload, uplink from the ground, operating staff payroll and electric power.

The conventional station, with its 97-km range, reaches about 2 million potential viewers, so its $200,000 per year operating cost is about 10 cents per year per viewer. The HAPP system would reach 50 million people, and its annual cost per viewer would be about 2.6 cents, or one-quarter the cost of the conventional system. These figures indicate that the HAPP has considerable potential as a platform for low-cost broadcasting to a large region.

Because of these favorable results, the use of HAPPs for national network TV broadcasting was also examined. A scenario was set up postulating that some group wishes to establish a new national TV network. The cost of implementing this network with HAPPs was compared with the cost of a system using a satellite to distribute program material to local stations, which subsequently rebroadcast it. The satellite distribution network currently being set up by PBS was used as a model for this system.

The HAPP system uses 13 HAPPs to cover the entire continental United States. A satellite is used to relay programming material from a central control station to the individual HAPPs. Each HAPP broadcasts to a multistate region with enough power so that normal TV receivers can be used. Such a network is fundamentally different from any current network in that there are no location stations; rather, there are 13 regional stations. This is both a strength and a potential weakness. The weakness is that many desirable features of local programming are not available. The strength lies in the fact that elimination of a large number of local stations reduces the overall network cost substantially.

A network like PBS, with 165 local stations, has an estimated annual operating cost of $214 million. Such a network can reach 60 to 70 percent of the population. A HAPP network with 13 regional stations which cover the entire continental United States would cost only $25 million per year, an order of magnitude less than the conventional network. This would be a single-channel network; i.e., each HAPP would broadcast on only one channel. For about $66 million per year the network could be structured so that each HAPP would broadcast on eight channels simultaneously. This is still only about a third of the cost of the conventional network in which each station broadcasts on only one channel, so the HAPPs would deliver a substantially superior service at a lower cost.

A similar application which was briefly examined in this study is subscription television. The cable TV industry has yearly revenues of about $1 billion and has financed about $1 billion in plant and equipment. It brings up to 12 channels of programming to over 7700 communities in the United States. The eight-channel HAPP network mentioned above would require only about a third of the capital currently invested in cable systems and would provide nationwide coverage. A brief investment analysis was carried out to determine the annual revenue per subscriber required to support an eight-channel HAPP network on the basis of subscription fees only, exclusive of advertising and other revenues. The results, assuming about 11 million subscribers, are $1.15 per month per subscriber. This compares very favorably with the $7.00 or so typically charged for cable service.

It was concluded that, for most remote sensing applications, HAPPs are competitive with aircraft only when nearly continuous, uninterupted observation is required. For those applications where horizon-to-horizon sensing is practical, the HAPP is competitive with aircraft when observations must be made at least one to four times per day. For the remote sensing applications studies here, the ranking from most to least potential value appears to be: (1) forest fire detection; (2) coastal traffic surveillance; (3) Great Lakes ice mapping. Additionally, it was determined that HAPPs have great potential as platforms for communications relay. Of the communications applications studied here, direct broadcast to home TVs has by far the most potential value. HAPPs also have considerable potential as communications experiment platforms. They are considerably less costly than satellites. For applications like the Rocky Mountain States Education Experiment where small numbers of ground stations are involved, satellite systems are likely to be less expensive than HAPPs.

On the basis of the results obtained during this study, the following recommendations are made:

- The best applications in both communications and remote sensing deserve more detailed study including cost/benefit analyses, but priority should be placed on communications. Direct broadcast to home TVs deserves highest priority.

- The cost of HAPP payloads is currently uncertain but has significant impact on overall system cost. Further study is needed.

- Forest fire detection appears to have a potentially high benefits/cost ratio, but the economic value of continuous surveillance is difficult to determine. Further study is needed to make an accurate assessment of the true benefit/cost ratio.

- The favorable results for direct TV broadcast suggest that other applications involving large numbers of low-cost receivers should also be investigated. Examples are land mobile communications and personal mobile telephones (i.e., battery-powered radio telephones small enough to carry on the person).

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SECTION 1. INTRODUCTION

1.1 HAPP Description

HAPP is an unmanned vehicle which keeps station above a fixed point on the ground by means of an electric motor-driven propeller with sufficient thrust to overcome the force of the wind. The nominal altitude is 21 km (70,000 ft) which, in the continental United States, is the altitude at which wind velocities are usually minimum. As the concept has evolved since its original proposal, the vehicle can be either a balloon (called an aerostat since it is stationary) or an airplane which flies in a small circle above a fixed station. In either case, power is beamed to the HAPP by a high-powered microwave transmitter on the ground. A rectenna aboard the HAPP receives and rectifies the microwave energy, producing direct-current electricity to drive the propeller and to power the payload. Auxiliary power may be derived from solar cells or batteries but the main source is the microwave beam. The requirement that the HAPP remain within the beam results in it being a stationary rather than a mobile platform.

1.2 Study Divisions

The current NASA study of the HAPP concept is divided into two parts. The Stanford Research Institute (SRI) is studying the technical feasibility of the HAPP concept and estimating the likely costs of a variety of HAPP configurations. Battelle's Columbus Laboratories (BCL) has investigated potential applications of the HAPP platform, determining appropriate payloads for a number of applications and comparing the costs of HAPP systems for each application with the cost of competing systems.

This report describes the Battelle applications study. Further technical details about the HAPP platform itself can be found in the companion SRI report.(1)*

1.3 Study Objectives And Methodology

The applications considered in the Battelle study fall into two categories: remote sensing and communications. The objectives in both areas were basically the same but the methodology was different. The objective was to find a small number of applications that appeared to be well suited to HAPP capabilities and analyze them to determine how well a HAPP system could perform in each application and how its cost would compare with the costs of other systems which would serve the same purpose.

In communications, the types of applications for which the HAPP is well suited were fairly obvious at the beginning of the study. A number of applications were suggested to Battelle by the NASA Task Monitor and, after some study and discussion, a subset of these was selected for inclusion in the Battelle investigation.

In remote sensing, the best applications were not obvious. Because the HAPP is stationary over a fixed point, it lacks the flexibility of aircraft and, because the HAPP is at a comparatively low altitude, it lacks the broad area coverage of satellites. To find those applications for which the HAPP is in the strongest competitive position vis-a-vis these other platforms it was decided that the longest possible list of potential applications should be assembled and that these should go through a preliminary screening process to eliminate all but those with the best potential. The screening technique devised for this purpose was a parametric cost comparison with aircraft based on the widest practical field of view of sensors appropriate for a given application and the required frequency of coverage (number of observations per day or year). This

* References, denoted by superscript numbers, are at the end of the text.

comparison made it very clear that, for many applications, aircraft can supply the same data as HAPPs at substantially lower cost. Three applications which this screening suggested were best for HAPPs were selected for further study.

For each application studied, a scenario was structured to define the requirements for a remote sensing or communications system. Based on these requirements a payload was conceptually designed and the weight and cost of the payload were estimated. From the payload weight the HAPP platform cost was estimated. (The HAPP platform costs, supplied by SRI, include capital cost, variable cost such as electric power and maintenance and the cost of operating personnel.) The cost of operating the payload was added to the platform and payload fixed costs to form an estimate of overall cost. Similar costs were generated for competing systems and compared with those of the HAPP system. Cost elements which would be the same for either system were not included. For example, in the remote sensing scenarios, costs of data interpretation and dissemination are not included. In a scenario involving a television broadcasting station, the costs of programming, advertising, administration, etc., are not included; only the costs of equipment and personnnel required to put a signal on the air are considered.

SECTION 2. REMOTE SENSING APPLICATIONS

Balloon platforms, both tethered and free flying, have been used for many remote sensing applications since their earliest days when manned balloons were used as military observation platforms.[2-5] Their use, however, has been limited by various operational factors. Tethered balloons are limited to relatively low altitudes (typically 5 km or less) by practical limitations on the length of the tether. Because of the low altitude, the ground area that can be observed is small. Free-flying balloons can attain much higher altitudes (up to 50 km), but float with the wind. Because they move freely, it is difficult to control the area of coverage. As a result, free-flying balloons have not found many applications for Earth observations.

The HAPP combines the best qualities of both kinds of balloons. Like the tethered balloon, it stays over a fixed point and can stay aloft for a long period of time. Like the free-flying balloon, it operates at a very high altitude (21 km, or 70,000 ft). For these reasons, the HAPP appears to have a place among the remote sensing user's arsenal of different platforms. The following analysis shows what this place is in relation to the two most prominent existing platforms: satellites and aircraft.

2.1 Important Parameters of a Remote Sensing System

There are many important parameters which must be considered when a remote sensing system is being designed for a particular application, but when a comparison of platforms alone (as opposed to complete systems) is being done, and when that comparison is for a wide variety of applications rather than a single use, there are five parameters which are of primary importance:

- Frequency of coverage
- Ground resolution
- Size of area covered
- Instrument payload capacity
- Cost.

2.1.1 Frequency of Coverage

The required frequency of coverage (number of observations per day or year) varies widely for different applications. For mineral exploration, it may suffice to make a single observation never to be repeated. At the other end of the spectrum are applications like forest fire detection where continuous observation is desirable. A potential strong point of HAPPs is that their cost is independent of the frequency of coverage required. The cost of an aircraft is directly proportional to coverage rate, so for applications requiring very frequent observations, aircraft cost is often prohibitive.

The issue of coverage rate is more complicated for satellites since it depends on orbit characteristics. A geosynchronous satellite can give continuous coverage of approximately one-third of the Earth, but because of the great altitude, the satellite designer must choose between very low resolution from moderate sized sensors or very large sensors and, therefore, very great cost. For satellites in low Earth orbit, coverage rate depends on the orbital elements chosen. In theory, orbits can be designed to see the same point on the Earth as often as once per day or even more; however, very frequent coverage of some points is only bought at the expense of never seeing other points*. An orbit that repeats itself in a short period--resulting in frequent coverage--necessarily traces out a path with widely separated ground tracks. An orbit with closely spaced ground tracks must take a long time to repeat itself, resulting in infrequent coverage. As an example of satellite coverage rates, consider Landsat. It sees every point on the Earth once every 18 days. To get a higher coverage rate designers would have needed to use sensors with wider fields of view, resulting in more geometric and radiometric distortion and higher data rates. In short, then, HAPPs can have a decided advantage over either aircraft or satellites for applications requiring very frequent coverage.

2.1.2 Ground Resolution

The 21-km altitude of a HAPP means that, for any given sensor, ground resolution would be about the same as for a U-2 aircraft. Typical values are shown in Table 2-1. The inherent resolution for any given

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* Unless sensors with very wide fields of view are used, this is undesirable for most applications.

TABLE 2-1. GROUND RESOLUTION FROM 21 KM (70,000 FT) FOR VARIOUS SENSOR TYPES

Sensor Type	Ground Resolution (meters)
Photographic Camera	0.3 - 1.5
Multispectral Scanner	1.5 - 60
Infrared Scanner	1.5 - 60
Microwave Radiometer	Depends on frequency and antenna size
Radar	Depends on frequency and antenna size

sensor is angular rather than linear; i.e., a particular sensor can resolve points which are so many milliradians apart. The ground resolution in meters is, therefore, proportional to range. Thus, an airplane flying at low altitudes could achieve higher resolution than a HAPP using the same sensor. However, most remote sensing applications do not require higher resolution than is obtainable from a HAPP.

Resolution from satellites is, of course, generally much coarser than from aricraft. Military reconnaissance satellites achieve high resolutions by using very large instruments and low altitudes with resulting short lifetimes. This approach is too costly for civil applications. For satellites at moderate altitudes using moderate sized instruments, resolutions in the range of 30 to 300 meters are typical for visible and IR scanners. Higher resolutions are possible with photographic cameras, but return of the film to Earth is a problem. At geosynchronous altitudes, resolutions around 2 km are typical. In short, it can be said that ground resolution from a HAPP platform would be as good as from an airplane and much better than from a satellite.

It should be noted that while scanners are mentioned here, these scanners would necessarily be different from those normally used aboard NASA aircraft and satellites. The typical NASA scanner uses a rotating mirror or prism to scan across the flight path of the platform, and the forward motion of the platform is used to scan along track. Since the HAPP is stationary this system cannot be used. However, scanners can be built which do not require platform motion. A second rotating mirror or prism moving at right angles to the first can be used, or, as in the case for many military forward looking infrared (FLIR) scanners, a linear array of sensing elements can be used to create along-track resolution.

2.1.3 Size of Area Covered

The size of the area which can be seen from a HAPP at 21 km depends, of course, on the angular field of view (FOV) of the sensor being used. For an FOV of θ degrees (i.e., −θ/2 to +θ/2 measured from the vertical) the diameter of the area in view can be approximated by:

$$d = 2h \tan \theta/2 \quad , \qquad (2\text{-}1)$$

where

d = diameter

h = altitude (21 km)

θ = FOV.

This equation is an approximation based on a flat Earth assumption. It is accurate for all but very large FOV's. The exact expression for a curved Earth is:

$$d = R[\sin^{-1}(\frac{R+h}{R} \sin \theta) - \theta] \quad , \qquad (2\text{-}2)$$

where R is the radius of the Earth and θ is expressed in radians. Figure 2-1 is a graph of this relation. The maximum possible FOV corresponds to horizon-to-horizon coverage and is approximately 171 deg. This gives a coverage diameter of 1040 km (646 statute miles).

For most remote sensing applications, however, this figure is nearly meaningless. At large look angles, the line of sight is nearly tangent to the Earth's surface, resulting in severe perspective distortion. A much more serious problem is that the atmospheric transmission path is very long, causing radiometric distortion and a general obscuring of the Earth's surface. Furthermore, unless the terrain is fairly flat, large parts of it may be hidden at very wide look angles. These facts are

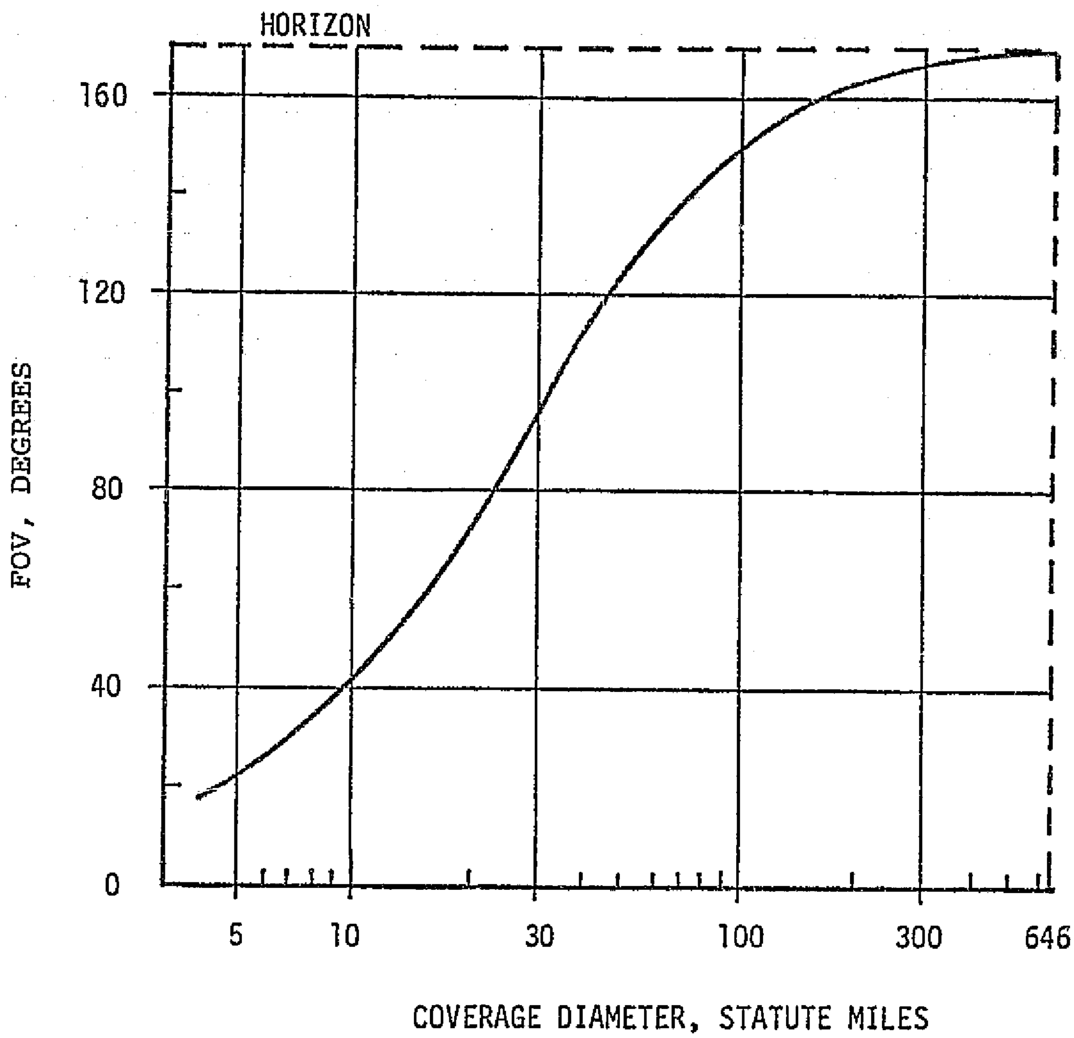


FIGURE 2-1. DIAMETER OF AREA SEEN FROM A HAPP VS SENSOR ANGULAR FIELD OF VIEW (FOR 70,000-FT ALTITUDE)

reflected in the specifications of available sensors. Commercially available photographic cameras and multispectral scanners have maximum FOVs of around 100 to 107 deg. Commercial airborne infrared scanners typically scan 120 deg, with a few going out to 140 deg. With an FOV of 140 deg, a HAPP-borne sensor can see a circle 117 km (73 miles) in diameter. For 100 deg, the diameter is only 51 km (32 miles).

Of course, panoramic sensors that see from horizon-to-horizon are available, but their usefulness is limited to a few specialized applications such as military reconnaissance where targets are manmade objects that extend above the ground.

Microwave sensors are an exception to the above discussion. Side-looking radar, for example, may gather useful data on ice cover at sea or on lakes at very large look angles. In Project ICEWARN(6,7), for example, maps of Great Lakes ice cover were made from images produced by a side-looking radar. The radar was flown at an altitude of 3.4 km (11,000 ft) and mapped a swath 100 km wide. This corresponds to an angular FOV of approximately 172 deg. The imagery near the edges of the swath was not nearly as good as that near the center, but was considered adequate for the application.

2.1.4 Instrument Payload Capacity

The payload capacity of the HAPP is not clearly defined. There is not any theoretical limit, but there are practical limits which are discussed in the SRI feasibility study. The types of designs investigated for the airplane concept appear to set a practical limit of around 900 kg. For the airship concept, the size of the gas bag increases rapidly with payload weight and the problem of launching the vehicle becomes more and more difficult. A reasonable estimate of maximum payload capacity, at least in the near term, seems to be about 6000 kg. This is much more than adequate for most remote sensing applications.

For comparison, the payload capacities of some typical remote sensing aircraft are listed in Table 2-2. It can be seen that a HAPP could match or exceed the payloads of all but the largest remote sensing aircraft.

TABLE 2-2. INSTRUMENT PAYLOADS OF SOME TYPICAL REMOTE SENSING AIRCRAFT

Aircraft	Payload (kg)
Cessna 180	180
U-2	640
Learjet 24	1000
WB57F	1900
P3	2300
Convair 990	6400
NC-130B	9230

Since light weight and high reliability are important characteristics of potential HAPP payloads, they will probably resemble satellite payloads more then airborne payloads. Thus, it is worthwhile to look at the weights of some typical remote sensing satellite payloads. Table 2-3 shows this data. The total payload weight for a HAPP system would be more than the weight of the instruments alone because supporting hardware such as command and telemetry, thermal control and data linking equipment would also be required. However, such spacecraft-peculiar hardware as solar panels would not be required since the HAPP payloads can receive power from the microwave system used to drive the HAPP propeller. (The payloads will generally only require a small fraction of the power used by the platform itself.) So the total HAPP payload weight would probably be somewhat less than the weight of an equivalent satellite. Table 2-3 indicates, then, that 2000 kg should be adequate to support most remote sensing applications for a HAPP.

2.1.5 Costs

The SRI study addresses costs in some detail. The results will be summarized here. SRI recommends that both the airplane and airship vehicles should be developed, and estimates that the development costs

TABLE 2-3. PAYLOADS AND WEIGHTS OF SOME REMOTE SENSING SPACECRAFT

Satellite/Instruments Carried	Instrument Weight (kg)	Total Spacecraft Weight (kg)
Nimbus D		
IR interferometer spectrometer		
Filter wedge spectrometer		
Satellite IR spectrometer		
Backscatter UV spectrometer		
Temp./humidity IR radiometer		
Selective chopper radiometer		
Cloud-top altitude radiometer		
UV solar monitor		
Image-dissector camera	135	570
Landsat A		
Return beam vidicon camera		
Multispectral scanner	149	815
SMS		
Visible and IR spin-scan camera system		
Space environment monitoring system		
Data collection system	75	225
Seasat		
Altimeter		
Scatterometer		
Imaging radar		
Microwave radiometer		
Visible and IR radiometer	300[a]	2200[a]

(a) Seasat weights are approximate.

for a dual program would be between $8.5 million and $18 million. For an airship program alone the development cost would be $6.5 million to $13 million. For the airplane only the development cost would be $4.5 million to $10 million.

The yearly operating costs are also given in the SRI report. These costs include capital cost of the vehicle and microwave system (ammortized @ 10 years), launch and recovery cost, operations cost, replacement and repair cost and cost of microwave power. The costs for a number of payload weights have been estimated. They can be summarized by the graph of yearly cost vs payload weight shown in Figure 2-2.

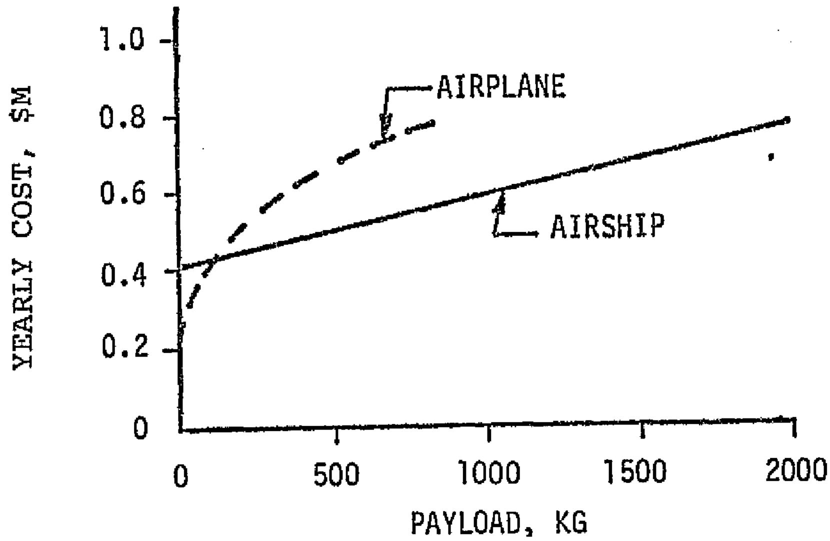


FIGURE 2-2. SRI ESTIMATES OF YEARLY HAPP OPERATING COST VS PAYLOAD

2.2 Comparison of HAPP Costs With Aircraft Costs

Table 2-4 shows a general comparison of HAPPs, aircraft and satellites based on four of the five parameters considered in the forgoing discussion. The fifth parameter is cost. Table 2-4 shows a set of generalizations to which there are exceptions for specific cases. If the generalizations are accepted as being basically--if not precisely--true then the conclusion is that, as a remote sensing platform, a HAPP is more like an airplane than a satellite. This is not surprising in view of the basic similarities between HAPP and aircraft technical implementation and altitude.

TABLE 2-4. COMPARISON OF HAPP, AIRCRAFT AND SATELLITES

	Satellites			
	Low to Medium Altitude	Geosynchronous	HAPP	Aircraft
Area Covered	Broad	Broad	Limited	Limited
Resolution	Low	Very low	High	High
Frequency of Coverage	Infrequent	Often as desired	Often as desired	Often as desired
Payload Capacity	Low to medium	Low to medium	High	High

Since HAPPs and aircraft are so similar in the kind of results they would deliver, cost becomes the primary factor in making a choice between the two for any particular application. A parametric cost comparison between HAPPs and aircraft has been done as part of this study. It shows that for applications requiring low frequency of coverage (less than about once per day) HAPPs are not competitive with aircraft. This permits a great many applications to be eliminated from any further consideration in this study.

The comparison made is between the cost of the HAPP or aircraft platform alone on the basis of cost per year per unit area covered. It is assumed that the costs of sensors, data processing and data dissemination are approximately the same for a given application regardless of the platform chosen. This assumption may not be entirely accurate but it is reasonable for purposes of preliminary screening of candidate applications.

The cost for the HAPP is easy to compute if the weight of the payload can be estimated. The yearly operating cost, Y, is read from Figure 2-2. For a sensor FOV of θ and an altitude, h, the HAPP observes a circle of radius $h \tan(\theta/2)$ so the cost per unit area is:

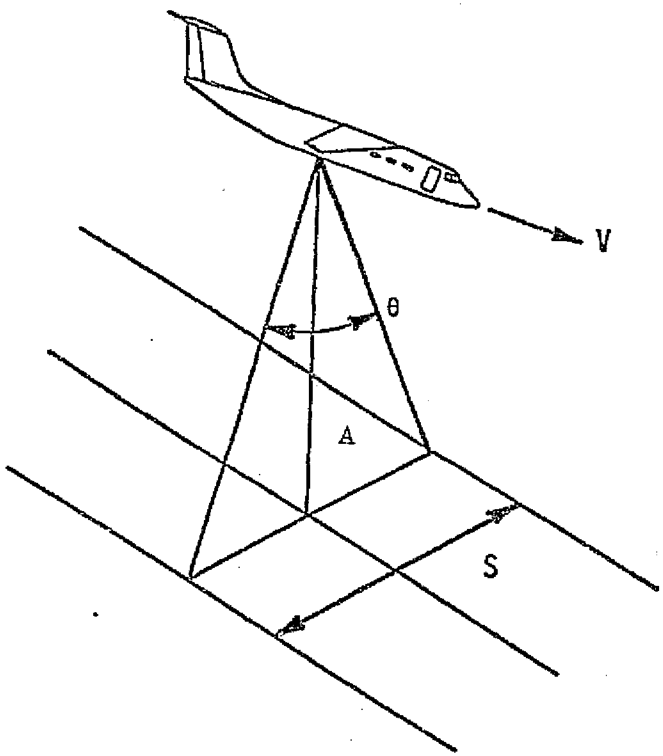
$$C_H = \frac{Y}{\pi(h \cdot \tan(\theta/2))^2} \quad (2\text{-}3)$$

The aircraft cost is somewhat more complicated. Figure 2-3 shows the parameters involved. The area covered per unit time is the velocity times the swath width, or 2 AV tan (θ/2). For a single flight the cost per unit area covered is the aircraft operating cost per hour, C, divided by the area covered per hour. If the resulting cost per flight is multiplied by the total number of flights per year, the result is the aircraft cost per unit area covered per year, C_A. This is given by:

$$C_A = \frac{365\ NC}{2FAV\ \tan\ (\theta/2)} \quad , \quad (2\text{-}4)$$

where N is the number of flights per day. Note that the aircraft operating efficiency, F, has been inserted in the denominator. F is the ratio of total hours flown to hours during which data are being gathered. Since F is always less than one, its inclusion increases the cost calculated from Equation (2-4). Factors affecting F are time to climb to altitude and time to descend, time to transit to and from the site, time lost over the site due to swath overlap and turns, and time taken for instrument calibration. NASA Ames' experience with the U-2 is that F = 0.4 is average.(8) For the Learjet 24 the best possible value (considering only time to climb and descend as lost) is about 0.7. For our parametric analysis, a value of 0.5 has been chosen.

Values of the other parameters needed to evaluate Equation (2-4) are shown in Table 2-5. With the exception of the Cessna 180 figure, the operating costs in this table come from discussions with NASA personnel at either Ames Research Center(8) or Johnson Space Center(9). The Cessna 180 figure was taken from a 1975 FAA study(10) and inflated to 1977 dollars. These costs reflect all aspects of operation, including capital cost of aircraft and ground facilities, maintainance, ground and flight personnel and so on. The altitudes shown are not ceilings but rather the highest altitude at which the aircraft routinely operate. The speeds are the cruising speeds normally used for remote sensing.



θ = SENSOR FOV

A = AIRCRAFT ALTITUDE

V = AIRCRAFT VELOCITY

S = SWATH WIDTH = 2H tan(θ/2)

N = NUMBER OF TIMES PER DAY AREA IS COVERED

F = OPERATING EFFICIENCY = (TOTAL FLIGHT HOURS)/(HOURS OF DATA GATHERING)

C = AIRCRAFT HOURLY OPERATING COST

FIGURE 2-3. PARAMETERS AFFECTING AIRCRAFT OPERATING COST

TABLE 2-5. AIRCRAFT OPERATING PARAMETERS

	Altitude, km	Speed, km/m	Operating Cost Per Hour, $	Cost Per Unit Area Covered*, (C/2AV), $/km^2
Cessna 180	2.0	260	50	0.10
C-130	9.1	460	1250	0.30
Convair 990	12.2	890	3800	0.34
Learjet 24	12.2	810	700	0.06
WB-57F	15.2	740	1290	0.12
U-2	19.8	740	3750	0.26

* Assumes θ = 90 deg, and F = 0.5

The costs per unit area covered shown in the last column of Table 2-5 assume a sensor FOV of 90 deg and an operational efficiency of 0.5. They are not intended to refer to any specific application, but they are useful for general comparison of aircraft costs to one another. In looking at the high costs for the C-130 and Convair 990, it must be remembered that these aircraft have very large payloads (see Table 2-2). One might also ask why a user would ever choose a U-2 since it has a relatively high cost and yet a small payload. The answer lies partly in the fact that the $3750/hr shown in the table is the total operating cost to NASA , covering ground facilities, maintainance personnel and so on. Outside users are charged a marginal cost to cover fuel and other variable costs connected with a specific flight. This marginal cost is $1260/hr which gives a cost per unit area of $0.09/km^2. One might still ask why the outside user does not choose the Learjet 24, since it costs only $0.06/km^2. The answer is that he will probably not find one available since NASA's only Learjet is used primarily for infrared astronomy and is not generally available for other applications.

In comparing HAPP and aircraft costs it should be pointed out that since the HAPP is not a mobile platform it will probably be used in applications requiring a dedicated platform. That is, the platform is purchased to be used continuously for one application (or combination of applications). It must be presumed that a user who purchases a platform and has the freedom to chose between a HAPP and an airplane also has the freedom to purchase the aircraft of his choice. In this analysis it is assumed that he purchases the aircraft which is least expensive to use, namely, the Learjet 24.

If the values for the Learjet are substituted in Equation (2-4), together with F = 0.5, the result is:

$$C_A = \frac{25.6\ N}{\tan\ (\theta/2)}\ (\$/\text{km}^2) \quad . \qquad (2\text{-}5)$$

For the HAPP, it is reasonable to assume that the total payload weight (including instruments, data link, power conditioning, thermal control, etc.) will usually be in the range of 200 to 1000 kg. So, from Figure 2-2, the yearly operating cost is between \$400,000 and \$600,000 per year. Choosing \$500,000 as representative and putting it into Equation (2-3) for HAPP cost per year per unit area, along with h = 21 km gives:

$$C_H = \frac{350}{[\tan\ (\theta/2)]^2}\ (\$/\text{km}^2) \quad . \qquad (2\text{-}6)$$

For the HAPP to cost less than an aircraft, then, requires that Equation (2-6) be less than Equation (2-5):

$$\frac{350}{[\tan\ (\theta/2)]^2} < \frac{25.6\ N}{\tan\ (\theta/2)} \quad . \qquad (2\text{-}7)$$

(Note the assumption that the aircraft and HAPP sensors have the same field of view, θ.) This inequality becomes:

$$N \tan\ (\theta/2) > 13.6 \quad . \qquad (2\text{-}8)$$

Remembering that N is the number of observations per day, it can be seen that the HAPP is only competitive with aircraft if very high frequency of coverage is required or if very wide field-of-view sensors are applicable. For example, if a moderately wide angle sensor (θ = 100 deg) is required, HAPP is not competitive unless coverage is required 11 times per day or about once every two hours. This obviously rules out applications such as crop disease detection, snow mapping, mineral exploration, and a host of others. On the other hand, if a panoramic sensor with an FOV of, say, 170 deg can be used, a frequency of coverage requirement of once per day is enough to make the HAPP comparable in cost to an airplane. For twice per day coverage the HAPP would be superior.

The analysis leading to Inequality (2-8) contains many assumptions and approximations, but the results are useful because they definitely elimi ate from further consideration applications requiring infrequent coverage and because they point to panoramic sensor applications as being promising candidates for HAPP.

2.3 Choice of Applications For Further Study

The method used for finding those applications to which HAPP's are best suited was to compile the most comprehensive list possible of economically significant applications for remote sensing and to eliminate as many as possible by a preliminary screening. Of those remaining, three which appeared to have the highest potential ratios of benefits to costs were selected for further study. These are ice mapping to aid navigation, forest fire detection and marine traffic surveillance.

The approach to compiling a list of remote sensing applications was three-pronged. First, Battelle personnel drew on their own experience with remote sensing; second, the literature was consulted; and third, discussions were held with various people at NASA centers.

In the literature, the most comprehensive sources of applications are the proceedings of the symposia on remote sensing of the environment held annually in Ann Arbor, Michigan. These symposia draw papers from an international cross section of workers in all phases of remote sensing. Also valuable were the Manual of Remote Sensing(2) and a report titled "Earth Resources Applications of the Synchronous Earth Observatory Satellite (SEOS)"(11) prepared for NASA by the Environmental Research Institute of Michigan. This latter is valuable because it addresses itself particularly to applications requiring a high frequency of coverage.

Visits to NASA Wallops Station and the Earth Resrouces Program Office at Johnson Spaceflight Center were also of great value. At Wallops, discussion centered on applications in the coastal zone, and land applications were primarily discussed at Johnson.

Table 2-6 presents the list of applications compiled during this study. The results of preliminary screening are given for each application.

TABLE 2-6. APPLICATIONS OF REMOTE SENSING

Application	HAPP Candidate?	Reason
<u>Water Resources</u>		
Water Quality/Pollution Monitoring	Possible	Some Cases Require High Frequency of Coverage
Snow Mapping	No	Low Frequency Coverage
Flood Mapping	No	Mobile Platform Required
<u>Marine Resources, Environment</u>		
Sea Temperature Mapping	No	Very Low Resolution Required; Satellite Superior
Ice Detection/Mapping	Yes	Wide FOV Sensor Applicable
Mapping Shoal Areas	No	Low Frequency of Coverage Required
Pollution Detection/Mapping	Possible	Some Cases Require High Frequency of Coverage
Chlorophyll Detection	No	Low Frequency of Coverage Required
Fish Location	No	Mobile Platform Required
Red Tide Detection	No	Low Frequency of Coverage Required
Coastal Current Mapping	No	Low Frequency of Coverage Required
Coast Guard Law Enforcement	Yes	Wide FOV Sensors & High Frequency Coverage
Marine Traffic Control	Yes	Wide FOV Sensors & High Frequency Coverage
<u>Weather and Climate</u>		
Temperature/Pressure/Wind Measurement	No	Limited Area of Measurement Does Not Justify Cost
Rain Detection	No	Limited Area of Measurement Does Not Justify Cost
Air Pollution Detection	No	Limited Area of Measurement Does Not Justify Cost
<u>Disaster Prediction/Monitoring</u>		
Earthquake Prediction	No	Limited Area of Measurement Does Not Juftify Cost
Tornado Detection	No	Suitable Technology Not Available
Hurricane Tracking	No	Mobile Platform or Satellite Superior

TABLE 2-6. (Continued)

Application	HAPP Canadidate?	Reason
Terrain And Minerals		
Terrain Mapping	No	Low Frequency of Coverage Required
Mineral Exploration	↓	↓
Fossil Fuel Location	↓	↓
Surface Mining & Reclamation	No	Low Frequency of Coverage Required
Forest Lands		
Fire Detection And Mapping	Yes	High Frequency of Coverage Desirable
Inventories	No	Low Frequency of Coverage Required
Desease Detection	↓	↓
Insect Damage Detection	↓	↓
Air Pollution Damage Detection	↓	↓
Storm Damage Mapping	↓	↓
Timber Harvest Planning	↓	↓
Harvest Monitoring	↓	↓
Recreation Resource Inventory	↓	↓
Recreation Resource Monitoring	↓	↓
Range Lands	↓	↓
Inventories	↓	↓
Range Resource Monitoring	↓	↓
Wild And Domestic Animal Inventory	No	Low Frequency of Coverage Required

TABLE 2-6. (Continued)

Application	HAPP Candidate?	Reason
<u>Crops And Soils</u>		
Soil Mapping	No	Low Frequency of Coverage Required
Soil Moisture	↓	↓
Crop Identification/Forecasting	↓	↓
Insect And Disease Detection	No	Low Frequency of Coverage Required
<u>Urban Environment</u>		
Land Use Planning	No	Low Frequency of Coverage Required
Traffic Control	?	Cloud Cover & HAPP Cost Are Problems
Urban Change Detection	No	Low Frequency of Coverage Required
<u>Civil Engineering</u>		
Construction Material Surveys	No	Low Frequency of Coverage Required
Terrain Analysis/Soil Survey	↓	↓
Drainage Networks	↓	↓
Slope Stability Analysis	↓	↓
Highway Route Location	No	Low Frequency of Coverage Required
<u>Law Enforcement</u>		
Border Surveillance	Possible	High Frequency of Coverage Required

The screening is based primarily on the frequency of coverage and field-of-view requirements for each application since these have been shown to be the critical parameters in the cost competitiveness of HAPPs. It can be seen from the table that the most common reason for ruling out an application is that it does not require a high frequency of coverage. Other reasons given are fairly obvious in most cases. For example, flood mapping requires a platform that can quickly be moved to and from the flooded area. Fish location requires a platform that can be moved away from the coast. The applications under weather and climate usually involve in situ detection rather than true remote sensors; i.e., the detectors measure phenomena in their immediate vicinity. A stationary HAPP equipped with such detectors would monitor a small volume of space, and so its high cost is not likely to be justified. Remote sensing of smoke plumes is an exception to this, but does not appear to justify further study since visual observations from the ground seem adequate for detection, and a platform that can fly through the plumes is generally required to determine their composition.

The earthquake prediction application is based on the concept of placing rows of corner reflectors along each edge of a fault and using a laser to measure their relative motion. This application has frequently been suggested for satellites and it would appear that satellites are better suited to it, since a great many HAPPs would be required to cover a large enough area to be significant. Furthermore, frequency-of-coverage requirements are very low.

Urban traffic control has been suggested as an application for HAPPs. Using high resolution sensors aboard a HAPP above a city, traffic flow could be monitored for the purpose of control by the phasing of traffic lights and dispatching of police to trouble spots. However, the sensors would have to be optical to provide the required resolution, and cloud cover would be a serious problem in most cities. Furthermore, it would probably be difficult to justify the high cost of a HAPP system for this application.

Water quality monitoring and pollution detection and mapping are listed as possible applications. The study of the movement of pollutants often requires that very frequent observations be made. This is especially true in bays and estuaries where the interaction of tides, winds and currents makes for complex flow patterns which change rapidly with time. However, the fields of view of the required sensors are narrow enough so that these applications are borderline insofar as HAPP competitiveness with aircraft is concerned. Furthermore, any given bay or estuary would only need to be observed for a short period (a few weeks to a few months) to obtain enough data to enable prediction of future flows. Since the HAPP, as envisioned in the SRI study, requires a large, complex ground facility, it is not well suited to temporary installation.

HAPPs might be used for border surveillance to detect illegal crossings. A high frequency of coverage would certainly be desirable. However, it would take a great many HAPPs to cover, say, the entire U.S.-Mexican border. Also, the high resolution required to spot individual humans would be difficult to achieve from 21 km. Light aircraft flying at low altitude would probably be superior to HAPPs in this application. In this study, border surveillance has not been ruled out but further analysis has been concentrated on applications which appear more promising.

The applications marked "yes" in Table 2-6 are Coast Guard law enforcement, marine traffic control, ice detection and mapping, and forest fire detection and mapping. The first three can all be done with radars which scan from horizon to horizon (or nearly so) and they all require coverage more than once per day. Thus, the parametric comparison with aircraft suggests that they are good HAPP candidates. Forest fire detection and mapping cannot be done effectively with panoramic sensors but a fairly wide FOV is permissible and there are important benefits to be gained from continuous coverage, which is difficult if not impossible with other platforms.

The applications marked "yes" have all been given further study. Coast Guard law enforcement and marine traffic control are treated as a single application, so three separate "scenarios" are considered. Due to the short length of the current study and the fact that a total of seven application areas (three in remote sensing and four in communications) have been examined, no single application could be studied in great depth. The purpose of the analyses of individual applications is to suggest which ones can most profitably be examined in greater depth in future studies.

2.4 Forest Fire Detection

Forest fire detection was chosen as a candidate application for HAPPs because it is an application where the economic benefit increases in proportion to frequency of coverage and because relatively wide angle sensors can be used, resulting in a relatively low HAPP system cost per unit of area covered. Furthermore, the U.S. Forest Service is currently using aircraft remote sensing for fire detection in certain areas, and infrared sensors similar in capability to those being used on the aircraft could easily be carried onboard a HAPP.

Since fires, once started, can sometimes spread very rapidly, the earliest possible detection is highly desirable. The sooner a fire is detected, the quicker firefighters can be mobilized to contain and extinguish it. Therefore, the ability of a HAPP to provide continuous coverage of an area makes it an attractive platform for fire detection. To provide continuous coverage with aircraft is prohibitively expensive.

For most applications of remote sensing some particular frequency of observation can be specified as adequate to meet a user's needs. If the user requires coverage once per day for some purpose, then twice-a-day coverage has no additional benefit. Under these circumstances it is easy to compare the cost of a HAPP with an aircraft. The yearly cost of providing once-a-day coverage with the aircraft is compared to the annual cost of operating the HAPP. But, for forest fire detection, no such definitive comparison can readily be made. Any increase in frequency of coverage should decrease the loss from fire and so have an increased economic benefit. Continuous observation is desirable and HAPPs can provide this while aircraft cannot, so no direct comparison can be made. Therefore, in this report, an estimate will be made of the cost/benefit ratio for a HAPP system.

The analysis starts with an overview of U.S. forest acreage, annual losses and expenditures for fire fighting. The reduction in potential losses attributable to current protection techniques is given and the additional savings which a HAPP system could yield is estimated. The cost of an appropriate HAPP system is estimated and the resulting cost benefit ratio is computed.

2.4.1 Forest Fire Protection Expenditures

U.S. forest land is categorized by type of timber and ownership in Table 2-7. The general character of timber holdings is undergoing

TABLE 2-7. FOREST LAND AREA IN 1970(12)

Forest Land Categories	Area (Thousands)	
	Km^2	Acres
All forest land (including pulpwood)	3,049	753,549
All commercial timberland	2,022	499,670
Federally owned/managed	433	107,109
State/county/municipal	117	29,012
Private		
Tree farms	526	131,135
Forest industry	272	67,341
Other (e.g., woodlots)	668	165,101

a gradual change. U.S. Government holdings are growing slightly, while private holdings are concentrating slowly in two disparate directions. Large holdings of western softwoods are being farmed more efficiently with replacement supertrees. Eastern holdings of hardwoods are growing, but these holdings tend to be of the relatively small woodlot type. Overall holdings of forest lands (including pulpwood) are slowly increasing, while holdings of softwood saw timber are being slowly drawn down.

Expenditures for forest fire protection are categorized in Table 2-8. Federal expenditures are shown to represent only 13 percent ($20 million) of the estimated expenditures for detection and combatting of all forest fires. These expenditures do not reflect the value of volunteers or the fact that everyone in a forest area is a part-time fire spotter. Professional fire spotting is also a seasonal activity and the effort devoted to fire spotting depends on the condition of the forest. The usual fire season also varies with the climate and geography and may be as short as 2 months or as long as 8 months. Forest fire protection practices and expenditure levels are related to these factors, particularly the low level of private sector expenditures. The U.S. Forest Service estimates(13) that only 2 percent of its employees represent full-time equivalent fire spotters, or 750 people of 36,674 total employment (19,735

TABLE 2-8. FOREST FIRE PROTECTION EXPENDITURES[12]

Category	Dollars	Percent of Total
Federal (1974)	20,079,000	13.3
State/County (1974)	130,286,000	86.6
Private (1973)	847,000	0.05
Total Recent Annual Expenditures	$151,212,000	

permanent) in April 1977. Industry Code 241--Logging Camps and Logging Contractors, used as a proxy for a private sector forest service, also has highly seasonal employment ranging from 61,500 to 91,700 people (1970-1975). If one percent of these were full-time equivalent fire spotters, this would also be equivalent to 750 people to cover a much larger timberland area. As shown in Tables 2-9 and 2-10, current protection methods are

TABLE 2-9. ANNUAL FIRE LOSSES[12]

Forest Stock	1974 Forest Area (Thousands)		Average Annual Fraction
	Km^2	Acres	Burned (70-74)
Federal (Protected)*	2745	678,253	0.00145
State and Private (Protected)*	3124	708,129	0.00209
Unprotected	258	63,835	0.00729

* Includes protected non-forest watershed areas.

relatively effective considering the nature of the fires and the level of expenditures in relation to the value of the product. For the expenditures and acreage shown in Tables 2-7 and 2-8, the annual expenditures for both detection and fire fighting are $47/km^2/year ($0.20/acre/year).

To hold down the costs of fire detection and improve efficiency, the U.S. Government, as well as state and private owners, are shifting to aerial spotting. In the case of state governments in the East, the shift is not as rapid as might otherwise occur since there are both tangible (theft prevention) and intangible social and political benefits to having a forest ranger present in parks and forests. Table 2-9 shows the average percentage of fire losses for 1970-1974 together with the forest area for 1974. Table 2-10 assigns the causes for these fires.

TABLE 2-10. CAUSES OF FIRES IN 1972-1975[12]

Fire Cause	Average Percentage
Lightning	10%
Smoking	10%
Campfires	5%
Equipment Use	5%
Railroads	5%
Caused by Children	10%
Miscellaneous	10%
Arson	25%
Burning Debris	20%

The range of values of the timber lost due to fires is shown in Table 2-11, and covers two methods of valuation. Because of the wide variation in values, no one general value is appropriate. The problem in assessing values is that much of the loss is contingent upon events after the fire as well as the nature of the fire itself. There is also growing belief that certain types of fires in certain types of forests may be beneficial in clearing undergrowth or permitting growth of commercially valuable species. Some examples of the way damage due to fires is contingent are illustrated by both the lowest and highest valuations of Table 2-11. If the sagebrush/grass/watershed gets reasonable (but not too much) rain during the following season, there is no silting in streams, which is the source of damage. In this case, there is no economic loss other than \$2700-\$4900 per km^2 (\$10-\$20 per acre) for fire fighting. In the case of high-value western softwoods, many fires kill trees but do not destroy timber values and can make access easier. If the timber is salvaged before insects devalue the wood (6 months to 2 years), no value is lost. If the mills are fully committed to other work or no salvage is attempted because of the remoteness from current operations, the loss can run to \$3.7 million per km^2 (\$15,000 per acre).[14] The value of typical loss due to a forest fire selected for this study is the average of the old growth and second growth classes, \$310,000 per km^2 (\$1,250 per acre).

TABLE 2-11. VALUES FOR FIRE DAMAGE

Type of Timber/Land	Valuation Method Used	Value per Km^2	Value per Acre
Sagebrush/Grassland	Handbook[16]	\$62,000	\$250
Arizona Pine Stumpage	2,500 bf/acre @12¢/bf	\$74,000	\$300
Second Growth Class	Handbook[16]	\$250,000	\$1,000
Old Growth Class	Handbook[16]	\$370,000	\$1,500
Oregon Softwood Stumpage	40,000 bf/acre @25¢/bf	\$2,500,000	\$10,000
Idaho Softwood Stumpage	60,000 bf/acre @25¢/bf	\$3,700,000	\$15,000

2.4.2 Aircraft Remote IR Sensing of Forest Fires

Because the HAPP would be adopting technology currently in use in aircraft, the Boise (Idaho) Interagency Fire Control Center was contacted to determine the currrent status of this capability. The goal of the Boise Center is to be able to catch fires at their earliest stage and put them out with a small crew. They fly three light aircraft (Queen Air, King Air, Merlin 3 turboprop) 300 to 500 hours each per year and can spot consistently 0.05 m^2 (0.5 ft^2) fires.[15,16] Their costs per hour of flying are \$225 to \$443 including the capital and labor cost for the infrared scanner.[17] They fly from 2400 to 5800 m (800 to 19,000 ft) above the terrain with a total field of view of 120 deg. Most of their operational effect is concentrated in the fire season of approximately 4 months, with a range of 2 to 6 months. The computed costs for detection are $0.12 to $0.23 per square kilometer per day ($0.30 to $0.60 per square mile per day) or $36 to $72 per square mile per fire season for one look per day at 480 km/hr (300 mph). Areas at high risk can be viewed more often and the aircraft are also used in fire mapping to assist in fire fighting operations planning. The major advantage of this method of detection is that small fires, started during the night such as those caused by lightning, cigarettes or improperly extinguished campfires, can be detected while they are still smouldering in the early morning before the sun warms and drys out the forest debris and allows a major fire.

2.4.3 HAPP System Description

The U.S. Forest Service currently detects fires from aircraft equipped with infrared scanners having a 120-deg field of view. The HAPP could not use such scanners but could use military forward-looking infrared devices (FLIR). Specifications of individual FLIRs are classified, but in general they have weights, power requirements and performance equivalent to scanners. Control from the ground station would steer the FLIR on a HAPP, and zoom optics would allow close examination of areas of interest. A TV link to the ground would provide real-time viewing. The HAPP would need to operate only during the fire season, typically 4 months. It is assumed that the HAPP would be stored on the ground for the rest of the year and operating personnel would be assigned to other duties.

Appendix A describes the approach used in this report to estimate HAPP payload weights and costs. The weights of payload items are assumed to be the same as those of similar items on a satellite. The costs are also based on satellite hardware costs but are assumed to be less for reasons of less stringent reliability reuqirements and the absence of the severe g-loading and vibration associated with a launch.

Table 2-12 shows a weight statement for the HAPP payload. As mentioned previously, the specifications of individual FLIR sensors are classified, but 40 kg is representative of the weight of a FLIR appropriate for forest fire detection. The weights of the other items are typical of spacecraft hardware required to support such a sensor.

TABLE 2-12. PAYLOAD WEIGHT STATEMENT FOR FOREST FIRE DETECTION

Component	Weight (kg)
FLIR Sensor	40
TV Link	30
Telemetry and Command	10
Power Conditioning	10
Wiring Harness	10
Thermal Control	15
Structure	30
	145

The payload cost is estimated to be in the range of $2 million to $7 million depending on the number procured, procurement schedule and the number of similar and analogous components adaptable from other military and NASA programs. This cost includes not only the HAPP-borne equipment but also the ground equipment necessary for controlling the HAPP payload and receiving and displaying the real time imagery.

The yearly operating costs for the HAPP are based on the assumption that it is deployed only during the 4-month fire season. SRI's operating cost figure for a HAPP of the required size is $440,000. For a 4-month operation, two-thirds of SRI's estimated annual cost of electric power and operating personnel can be subtracted. So for a 4-month year the cost would be $440,000 minus two-thirds of $92,000, or a total of $380,000.

The cost of operating and maintaining the payload is based on the assumption of a two-man ground crew. To cover vacations and absences, five shifts are required. The cost for a full man-year, including overhead, is assumed to be $40,000. For a 4-month fire season, the total cost of the five two-man shifts is then $130,000. During the rest of the year these personnel could be assigned to other duties.

The total yearly system cost (assuming a 10-year life for the payload) is then:

Item	Cost ($, thousands)
HAPP	380
Payload	200 to 700
Operation	130
Total	710 to 1,210

2.4.4 HAPP Benefit and Cost Assessment for Forest Fires

As is evident from the fire loss statistics of Table 2-9, detection with current methods cuts potential fire losses by a factor of about four. The benefits of continuous surveillance of all parts of a large forest area are very hard to estimate and so a range is used here. It is assumed that somewhere between a quarter and three quarters of current losses could be saved; one quarter is conservatively low and three quarters is probably very optimistic.

With a 120-deg field view for the infrared sensor, a HAPP at a nominal altitude of 21,300 m (70,000 ft) can monitor 4304 km^2 (1662 mi^2) or 1.07 million acres. The current annual average expected fire loss in this size area is $2.4 million as determined from the average fraction burned in protected areas (0.0018) and a nominal average value of timber of $1,250 per acre from Tables 2-9 and 2-11. The calculation is: (0.0018 x 1.07 x 10^6 acres x $1,250 per acre) = $2.4 million. The range of expected losses based on the values of Table 2-11 is $72,000 to $29 million.

Thus, a nominal value of the loss without a HAPP is $2.4 million, of which 25 to 75 percent could be saved by continuous surveillance during the fire season, resulting in a potential saving of $600,000 to $1,800,000. The HAPP annual cost is expected to be in the range of $710,000 to $1,200,000 per fire year. Therefore, the ratio of benefits to costs is somewhere in the range of 0.5 to 2.5. While this result is inconclusive, it suggests that HAPPs have enough potential in this area to warrant a more detailed study.

It should also be noted that the brief analysis presented here assumes an average loss of $1,250 per acre but, as shown in Table 2-11, the actual value varies widely from $250 to $15,000 per acre. If HAPPs were used only in areas of high-value timber rather than on a nationwide basis, a very different benefit/cost ratio would result. Assuming an area where typical fire damage is $1.2 million per km^2 ($5000 per acre), the expected annual loss in a HAPP size area would be $9.6 million. So the savings attributable to continuous surveillance would be in the range of $2.4 million to $7.2 million. The resulting ratio of benefits to costs would lie between 2 and 10 .

In conclusion, then, it can be said that the utility of a nationwide system of HAPPs for forest fire detection cannot be determined without more detailed study, but for use in areas of particularly valuable timber, the HAPP appears to have considerable promise.

2.5 Great Lakes Ice Reconnaissance

Traditionally, navigation on the Great Lakes has been suspended from mid-December until early April because of weather and ice conditions. A program permitting year-round navigation would be highly desirable since the large industrial centers aroung the Great Lakes rely heavily on them for economical commercial transportation. Seventeen percent of U.S. waterborne commerce moves through Great Lakes ports. For Canada, 31 percent of such traffic travels on the Lakes(7). Because of the yearly interrruption of Lake traffic, many users of iron ore, coal, limestone, gypsum and other products must either stockpile large amounts of these materials for winter use or rely on more expensive modes of transportation. Radar-equipped HAPPs could serve as key elements in a system for permitting year-round navigation on the Great Lakes. The radars would map the extent and characteristics of ice on the Lakes, and the resulting information would assist ship captains in selecting routes across the Lakes. Some historical background makes it clear how the HAPPs would fit into an overall system.

In 1969, a preliminary investigation of the technical and economic feasibility of extending the Great Lakes navigation season into the winter was carried out by the U.S. Army Corps of Engineers. This study concluded that such an extension was physically possible and recommended that a demonstration program be carried out. In 1970, such a program was authorized by the Congress. A group of federal, state and private organizations collabroated on a Great Lakes-St. Lawrence Seaway Navigation Season Demonstration Program.(18,19)

During the program a number of ships continued to navigate the Lakes despite the winter ice. A key element of the deomonstration consisted of disseminating information about ice conditions to ships on the Lakes. Various dissemination programs culminated in project ICEWARN during the 1974-1975 and 1975-1976 winter navigation seasons.

A U.S. Coast Guard C130B aircraft equipped with a Motorola AN/APS-94C side-looking airborne radar (SLAR) operating at X-band was flown over selected regions of the Great Lakes on a regular basis to gather images of the ice. The SLAR data were transmitted to the U.S. Coast Guard Ice Navigation Center in Cleveland, Ohio. Two separate communications links were used. The primary link was from the aircraft up to the NOAA-GOES satellite, then down to a ground station at Wallops Island, Virginia, and from there to the Cleveland Ice Center by land line. A backup link consisted of tape payback from the aircraft to selected ground stations and then on to the Cleveland Ice Center by land line. At the Cleveland Ice Center, the raw data were used to generate high quality SLAR images. These images together with hand-drawn interpretive ice charts were transmitted via facsimile scanner to ships operating on the Lakes.

The C130-B was flown at an altitude of 11,000 ft, and the resulting image swath was from 5 to 50 km on either side of the aircraft. The AN/APS-94C radar's 0.5-deg beamwidth resulted in azimuth resolution of 45 meters at the near range and 450 meters at maximum range. Range resolution was 80 meters.

Because SLAR cannot measure ice thickness an additional short-pulse downward-looking radar was flown aboard a C47 aircraft to measure this important parameter. Since ice thickness changes very slowly, these flights could be made at comparatively long intervals. During the entire 1974-1975 season only nine ice thickness flights were made. On the other hand, the SLAR flights were made on an average of once every other day, with daily coverage during periods of rapid ice movement.

2.5.1 HAPP System Description

A system composed of three radar-equipped HAPPs and a single ground control station to monitor and control the radars could provide the same information as project ICEWARN. Such a system will be described here, and the cost will be estimated. This cost will then be compared with the cost of an aircraft system which would supply the same information.

Figure 2-4 shows the areas that were covered in project ICEWARN. Each rectangle represents a single radar swath with a width of 100 km or less. The scenario postulated in this study would use three HAPPs to cover these same areas. The advantage of the HAPP system over an aircraft system is that more frequent coverage could be supplied. Ship captains who participated in project ICEWARN indicated that when the ice is moving they have very little confidence in 12 to 24-hour-old information.[6] Therefore, in this scenario it is postulated that coverage four times per day would be desirable in an operational system.

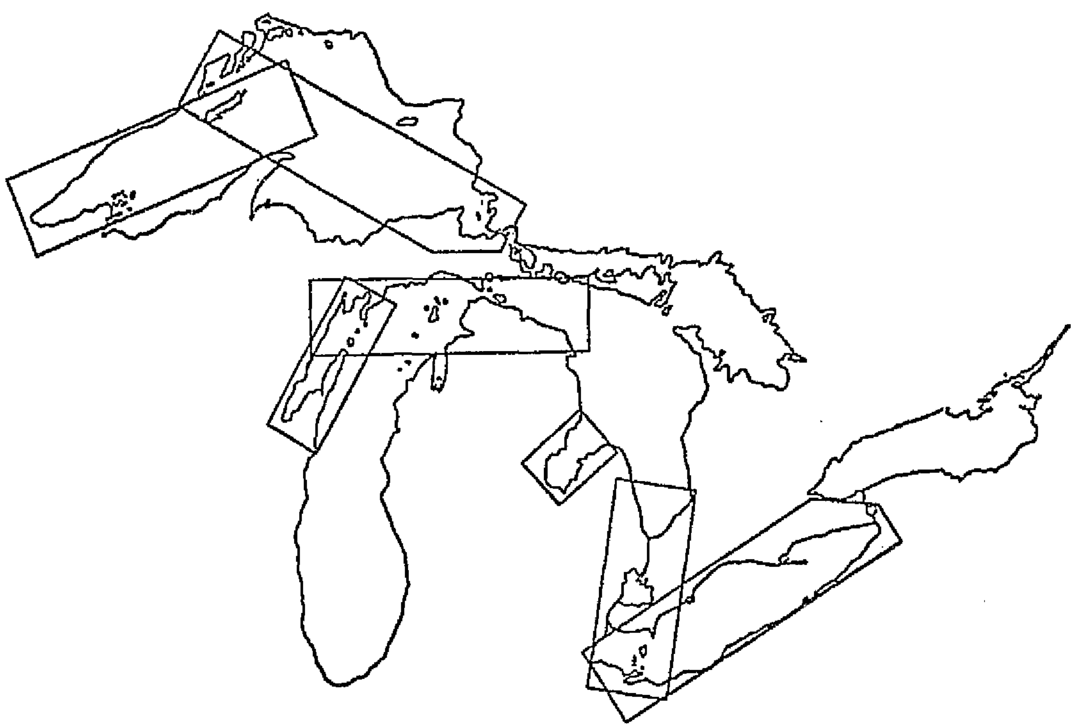


FIGURE 2-4. PROJECT ICEWARN COVERAGE

Figure 2-5 shows the locations and coverage patterns of three HAPPs required to give the same coverage as project ICEWARN. Since the HAPP is stationary, SLAR cannot be used for ice imaging, but a forward-looking scanning radar such as is used for aircraft navigation and weather detection could be used. With a sufficiently large antenna the resolution of the SLAR used in ICEWARN could be matched or exceeded. The maximum and minimum ranges shown in Figure 2-5 are based on the use of this type of radar. The maximum range is the range at which the angle of incidence of radar energy on the ice is the same as the angle of incidence at maximum range in ICEWARN. This angle of incidence is a primary determinant of the appearance of the radar image. The minimum range is the range at which range resolution begins to become substantially degraded due to the fact that the radar pulse travels into the ice rather than along it. The choice of this range is somewhat arbitrary.

The radar proposed here can serve other purposes besides ice reconnaissance. Since it can also detect ships, it could be used for traffic control and search and rescue. It would be especially useful

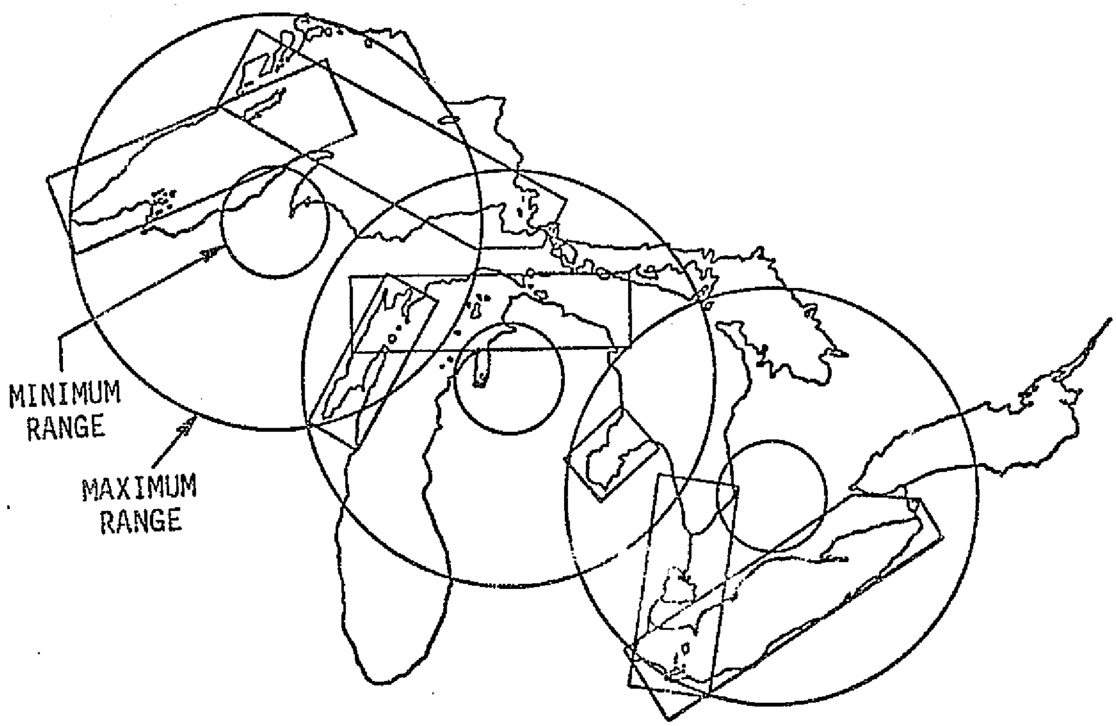


FIGURE 2-5. COVERAGE OF HAPPS TO DUPLICATE PROJECT ICEWARN

in conjunction with beacons aboard individual ships; the required technology is already in use and well understood. When a shipboard beacon receives a train of pulses from the HAPP radar it transmits a code word which identifies the ship. This information can be used in the HAPP control center to display the locations of all beacon-equipped craft on the lakes. In an emergency, a distress signal can be appended to the identification code. Thus, the nature of the emergency and the name and location of the ship are all immediately known to the Coast Guard. A technical description of the radar proposed for this application is contained in Appendix B. The same radar is also suitable for the Coast Guard law enforcement and traffic surveillance scenario discussed later.

The method of estimating HAPP payload weights and costs is described in Appendix A. Table 2-13 shows a weight statement for the payload postulated for ice reconnaissance.

TABLE 2-13. ICE RECONNAISSANCE HAPP PAYLOAD WEIGHT STATEMENT

	Weight kg
Radar Transmitter/Receiver	10
Antennas	1400
Telemetry and Command	10
Radar Down Link	30
Power Conditioning	10
Thermal Control	10
Wiring Harness	10
Structure	400
	1880

The weight of the radar transmitter/receiver is derived from the Bendix RDR-1400 Multi-Mode Radar, a radar having very similar characteristics to the one described here. The Bendix unit weighs 7 kg.

The antenna weight comes from a classified DoD airborne phased-array antenna upon which the antenna described here is modeled. The DoD antenna is considerably smaller and the weight has been scaled up in direct proportion to aperture size. Two antennas, each weighing 700 kg, are required since each HAPP must view about 180 deg in azimuth, but current phased-array tehcnology only allows electronic beam steering over about half this arc. Weights of the other components come from comparison with satellite component weights.

Based on the considerations described in Appendix A, the capital cost for each of the three HAPP payloads is estimated to be $5 million. The only satellite payload similar to the radar is the SEASAT synthetic aperture radar, which will cost about $5 million. An appropriate satellite bus would cost around $7 million to $9 million. Thus, the total for a satellite would be $12 million to $14 million. Assuming that the HAPP payload costs a little more than a third of this, a figure of $5 million is arrived at. Assuming a 10-year life, this is $500,000 per year. The yearly operating cost for the HAPP platform is $530,000 (see Figure 2-2). A control station will also be required to operate the radars and monitor the data returned. It is assumed that a single central control station can control all three HAPPs. The personnel requirement is five two-man shifts at $40,000 per man per year, but, since operation is only for 4 months per year, personnel cost is $130,000 per year. It is assumed that these personnel could be assigned to other duties during the remainder of the year. Cost of the control station itself is assumed to be $2.5 million; spread over 10 years, this is $250,000 per year. So the total system cost is:

	Cost Per Year ($, millions)
3 HAPPs	1.6
3 Payloads	1.5
Control Station	0.25
Personnel	0.13
	3.48

The cost of data interpretation and dissemination is assumed to be the same for the HAPP system as for a competitive aircraft system and so is not included. Once per week flights are required to obtain ice thickness information not obtainable by the HAPP radar, but these flights are also required in the aircraft-based system and so they are also a common element of cost and are not included.

2.5.2 Comparison With Aircraft System Cost

The starting point in estimating the aircraft system cost is to use the coverage pattern shown in Figure 2-4 to calculate the total flight distance needed for a single radar pass over all the areas being mapped. This distance is 2150 km (1160 nmi). Assuming that an aircraft similar to the Learjet 24 is used and taking the values of Learjet 24 operating parameters from Table 2-5, the total yearly aircraft operation cost is:

$$2150 \, \frac{\text{km}}{\text{flight}} \cdot \frac{1}{815 \, \frac{\text{km}}{\text{hr}}} \cdot 700 \, \frac{\$}{\text{hr}} \cdot 4 \, \frac{\text{flights}}{\text{day}} \cdot 120 \, \frac{\text{days}}{\text{year}} \cdot \frac{1}{0.5} = \$1.8\text{M} \quad .$$

In the preceding equation, 0.5 is the operational efficiency factor. The cost of owning and operating the aircraft sensors is difficult to estimate accurately but standard NASA charges to outside users can be used as a guide. In addition to a flat charge of so many dollars per hour of flight time, NASA also charges an additional hourly fee, for every hour during which data are actually being generated. This covers the cost of owning and operating the sensors and the cost of preliminary processing to generate raw data products. For the U-2, Ames charges \$1981 per hour for sensor operation regardless of the sensor being used. For the WB57-F, Johnson Space Center charges between \$1050 and \$1200 per hour depending on sensor type. For this study it will be assumed that \$1500 per hour is required to own and operate the aircraft sensors. Then the total yearly sensor cost is:

$$2150 \, \frac{\text{km}}{\text{flight}} \cdot \frac{1}{815 \, \frac{\text{km}}{\text{hr}}} \cdot 1500 \, \frac{\$}{\text{hr}} \cdot 4 \, \frac{\text{flights}}{\text{day}} \cdot 120 \, \frac{\text{days}}{\text{year}} = \$1.9\text{M} \quad .$$

Therefore, the total yearly cost for aircraft plus sensors is $3.7 million, compared with $3.5 million for the HAPP system.

2.5.3 Conclusions

While the costs of the aircraft and HAPP systems are esentially equal, the HAPP system has certain important advantages over the aircraft system. First, the HAPP system provides continuous observation of the ice rather than four times per day coverage. During times of unusually rapid ice movement this would be valuable. But more importantly, ships would be easily detected with the HAPP radar, allowing the Coast Guard to keep track of the locations of all major craft on the Lakes. If each ship is equipped with a beacon which broadcasts a coded identification signal each time it is interrogated by a radar pulse, then the system could display the locations and names of all suitably equipped craft on the Great Lakes. Also, a ship experiencing an emergency could add a distress code to its identification signal. This would form the nucleus of a search and rescue system.

It can be seen then that while the HAPP and aircraft ice reconnaissance systems have about the same cost, the HAPP system, because it provides continuous surveillance, can perform other valuable functions not available from the aircraft system. Therefore, it would appear that Great Lakes ice reconnaissance is a good candidate application for HAPPs.

2.6 Coast Guard Law Enforcement and Maine Traffic Surveillance

With its new duty to enforce laws associated with the 200-mile fisheries zone, the U.S. Coast Guard must now patrol over 2 million square miles of ocean. This task will require the aquisition of many new ships and aircraft. While the HAPP is not likely to become a mature system soon enough to help the Coast Guard with near-term problems, it could find a future place among an array of patrol and surveillance platforms. In the scenario presented here, the HAPP is shown to be a cost-effective alternative to aircraft for one of the patrol functions that is likely to be required in a future Coast Guard enforcement system.

Enforcement of the 200-mile fishing limit is a complex job involving many things beyond prohibiting certain ships from certain areas. There are regulations involving the total allowable catch for each country, time and area allocations for each vessel, season and area restrictions, prohibition of fishing for certain species, specification of allowable equipment, minimum net mesh size, and other legal restrictions. Clearly, remote sensing systems cannot supply all the information necessary to enforce these regulations, but they can supply at least the most fundamental data required; namely, what ships are in the 200-mile zone and what their positions and courses are.

Basic information on ship locations and courses has a number of applications, and a recent study of the 200-mile zone problem by the Office of Technology Assessment (OTA) suggests that perhaps this information should be fed to a data correlation and display center for coverage of the complete fisheries zone.[20] The study says that such a center " would be costly, but it could also provide information on oil tankers, commercial cargo carriers, surveillance for search and rescue missions and other similar activities". The OTA study suggests that airborne radar combined with shipboard beacon transmitters provide a means for gathering this kind of information.

It will be shown here that the HAPP is also a suitable candidate platform for a radar surveillance system. Analysis indicates that the HAPP is quite competitive with aircraft both in terms of the quality of the data produced and the system cost.

2.6.1 HAPP System Description

The scenario presented here for purposes of comparison between HAPPs and aircraft assumes that the coast of the continental United States must be patrolled four times per day to a distance of 200 nautical miles from shore. Four times per day is adequate for determining vessel locations for enforcement purposes. For other applications such as search and rescue and collision avoidance, the continuous vessel speed and course information available from a HAPP platform would be very valuable.

Appendix B gives a technical description of a radar which would be suitable for this application and also for the ice mapping application previously discussed. For ice mapping, its maximum practical range is about 260 km (140 nmi), but for ship monitoring, it could be effectively used all the way to the radar horizon which, for a platform at 21 km (70,000 ft) altitude, is 602 km (325 nmi). Its resolution is 0.1 deg in azimuth (1044 m at maximum range) and 150 m in range, which would be adequate for enforcement purposes. Figure 2-6 shows the 200-mile zone and the locations of six HAPPs, which could cover the entire zone. The minimum range shown in the figure is 160 km (50 nmi), which is determined by signal-to-clutter ratio considerations.

Ships operating within the 200-mile zone would carry beacons such as those described in the ice mapping scenario. These would allow the identification and location of each ship in the zone to be plotted and continuously updated. The tracking of beacon-equipped ships does not require the large, expensive radar described in Appendix B, but since the system is being used for enforcement it is necessary to be able to

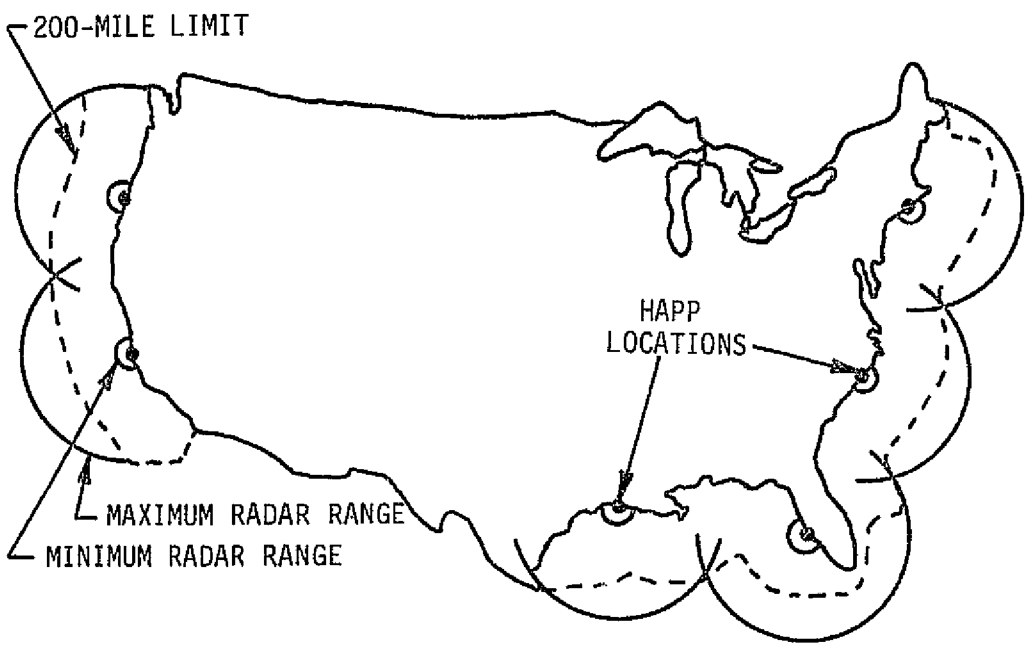


FIGURE 2-6. LOCATIONS OF SIX HAPPS REQUIRED TO COVER 200-MILE ZONE

locate ships not equipped with beacons or ships whose beacons have "accidentally" become inoperative. It is this capability which requires a high-resolution radar.

2.6.2 Comparison with Aircraft System Cost

The HAPP payload description and weight would be the same as for the ice mapping application. Yearly opearating cost of the HAPPs would be higher--$800,000 per year each-- since they are operated for 12 months rather than 4 months. The payload cost would be the same, $500,000 per year each. The cost of operating the payload is based on the assumption of five two-man shifts for each HAPP at $40,000 per man per year including overhead. So the operating cost is $400,000 per year. The total yearly cost for each HAPP is then $1.7 million and the total for all six is $10.2 million per year.

The cost of carrying out four times per day surveillance with aircraft can be computed in the same way it was for the ice mapping task. The total distance which must be covered with the radar is 6930 km (3740 nmi). Using an operating cost of $700 per hour, a speed of 815 km/hr (440 knots) and an operating efficiency of 0.5, the yearly cost for four flights per day is $17.3 million. If the costs of the payload, its operation and personnel and facilities for data interpretation are the same as for the ice mapping task--$1500 per flight hour--then this adds $18.5 million per year. So the total cost for the aircraft system is $35.8 million per year.

The HAPP system, then, costs only about a third of the cost of a comparable aircraft system, and it supplies continuous data rather than 4 times daily data. These data can be used not only for enforcement but for traffic control and search and rescue. So the HAPP is a very competitive platform for this application.

2.7 Satellite Alternatives to HAPP Systems for Coast Guard Law Enforcement, Great Lakes Ice Mapping and Forest Fire Detection

Because of the requirements for unusually high frequencies of coverage combined with high resolutions in the applications examined in this report, satellite systems have not been considered as competitors to HAPPs. While the reasons for this have been discussed in general terms, it is worthwhile to briefly discuss the likely costs and capabilities of satellite alternatives for these applications.

Consider first the Coast Guard law enforcement scenario. To achieve a high frequency of coverage, a geopynchronous satellite would be desirable, but the resolution requirement for this application places such a satellite well beyond the current state of the art. A synthetic aperture radar could not be used since the satellite is effectively stationary. A real aperture radar would need an immense antenna. At X-band, for example, 1-km ground resolution would require an antenna 1.3 km in diameter. Such a structure would obviously be very expensive. Determination of how well it might compete with a HAPP system would require an analysis beyond the scope of this report.

Acceptable resolutions could be obtained by low altitude satellites but the number of spacecraft required to give four times per day coverage would be very large. The OTA report cited previously[20] states that SEASAT project personnel have determined that eight SEASATs would be required to give twice per day coverage of the entire 200-mile coastal zone. SEASAT-A will cost in the neighborhood of $70 million. Assuming that in an operational system the satellites would be about $20 million each, including a Shuttle launch, eight satellites would cost $160 million. Assuming they last 5 to 10 years, this comes to $16 million to $32 million per year for coverage twice per day. This does not compare favorably with the HAPP system, which costs $10.2 million and provides continuous coverage.

A similar argument applies to the Great Lakes ice mapping scenario. A SEASAT-like satellite would be appropriate for mapping Great Lakes ice. A Battelle-developed orbit planning computer program called IGOS cannot handle more than two satellites at a time but it shows that two satellites can just barely supply once per day coverage of the entire Great Lakes. Again using $20 million for the cost of each satellite and 5 to 10-year lifetime, this is $4 million to $8 million per year. The HAPP system costs $3.5 million per year and provides continuous surveillance of the ice along with search and rescue and traffic monitoring functions, which could not be done with once per day coverage.

While a geosynchronous satellite for ice or traffic surveillance would need to be extremely large, a satellite for forest fire detection would have more manageable dimensions since infrared sensors can use apertures 3 to 4 orders of magnitude smaller than microwave sensors with the same resolution. Nevertheless, such a satellite would still be extremely large. A study by the Aerospace Corporation on advanced space system concepts(21) proposes a geosynchronous forest fire detection satellite which would be 5 by 18 m (15 by 60 ft) in size and weigh 11,300 kg (25,000 lb). Their estimate for the cost of this satellite, including launch, is $230 million. However, this cost presupposes the existence of a very large space tug not in NASA's current plans. The development cost of the tug is not included in the $230 million. Besides being expensive this concept has rather low capability. The minimum size detectable fire would be 3 by 3 m (10 by 10 ft). By the time a fire has grown to this size it may be spreading rapidly, if so, it will soon be out of control. Current airborne sensors used by the U.S. Forest Service can detect fires as small as 0.2 by 0.2 m (0.7 by 0.7 ft). At this point, a fire started by a cigarette or lightning strike is still smoldering and a fire fighting crew can usually be dispatched while it is still easy to extinguish. A HAPP could carry a sensor which would duplicate the current airborne capability, and so be considerably more valuable than a satellite sensor.

In summary, then, satellite systems buildable with current or near-term technology would be more expensive than HAPP systems for the applications considered here, would offer less capability, or both.

SECTION 3. COMMUNICATIONS APPLICATIONS

The virtues of high altitude antennas are well known to everyone who is even slightly familiar with communications. At almost all frequencies, higher altitude antennas result in both longer range and better reception. At VHF and higher frequencies radio wave propagation is essentially line of sight; atmospheric reflection and refraction do not play a significant role. Therefore, a high antenna is especially important at high frequencies. The higher the antenna, the further it can "see" around the curvature of the Earth. UHF and VHF broadcast or repeater stations are often placed on mountain tops to take advantage of this principle, and television broadcasts have been made from aircraft to obtain even greater ranges.

In Korea, Iran, and Nigeria tethered balloon systems supplied by the TCOM Corporation, a subsidiary of Westinghouse Electric Corporation, are being used for national television broadcasts. Because of the considerable technical problems arising in the design and operation of a very long tether, the balloons are limited to altitudes around 3000 to 4600 m (10,000 to 15,000 ft). Each balloon carries a 1-kw transmitter with a line of sight range of 200 km (125 statute miles). For comparison, a television station with a tower 305 m (1000 ft) high has a line of sight range of about 90 km (55 miles). Figure 3-1 shows how balloons at five locations are used to cover nearly all of Nigeria.

Because of its great altitude, a HAPP would make an ideal antenna platform. With its nominal altitude of 21,000 m (70,000 ft), the line of sight (LOS) range would be 520 km (322 statute miles). Figure 3-2 shows the relative sizes of the LOS coverage areas for antennas mounted on a 300-m (1000 ft) tower, a 3000-m (10,000 ft) tethered balloon and a 21,000-m (70,000 ft) HARP. This simple picture clearly shows the great potential of the HAPP as a platform for communications. The HAPP can cover seven times as much area as the tethered balloon and 33 times as much area as the tower. An even better appreciation for the broad area coverage of the HAPP can be gained from Figure 3-3 which shows that, assuming horizon-to-horizon coverage, only 13 HAPPs would be required to cover virtually the entire continental United States. In mountainous

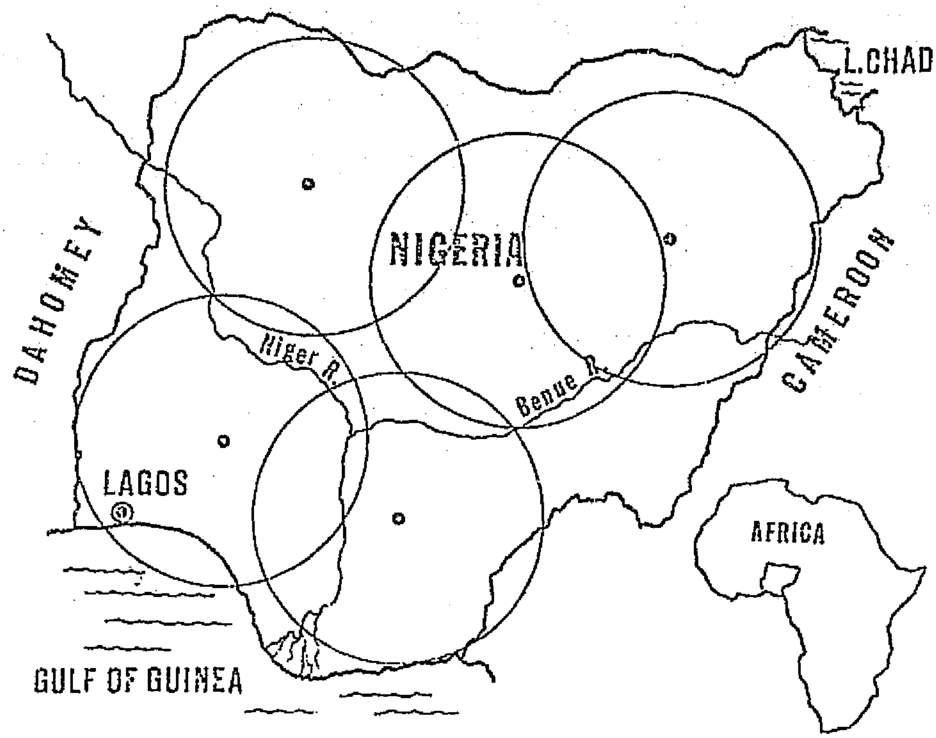


FIGURE 3-1. TETHERED BALLOON TELEVISION BROADCAST NETWORK IN NIGERIA

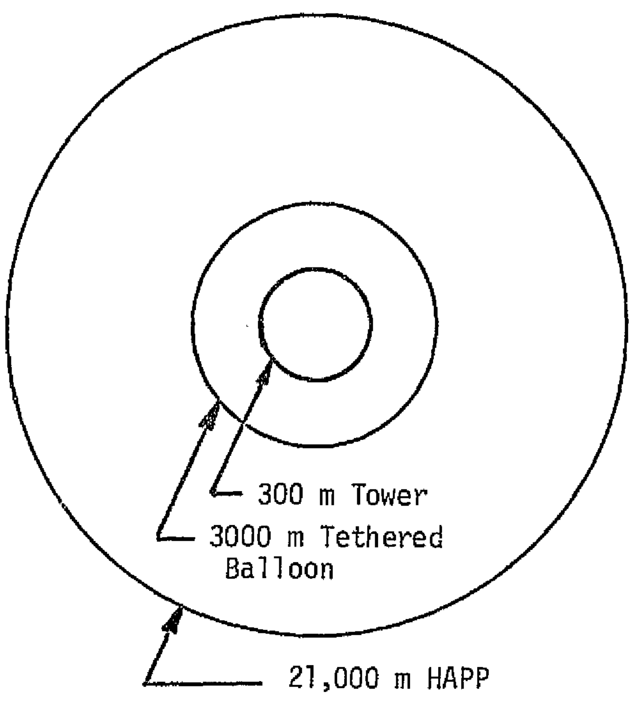


FIGURE 3-2. RELATIVE SIZES OF COVERAGE AREAS FOR THREE ANTENNA PLATFORMS: 300 METER TOWER, 3000 METER TETHERED BALLOON AND 21,000 METER HAPP

regions some areas would not be able to communicate with this HAPP network because of intervening terrain. However, a very large fraction of the U.S. would be covered.

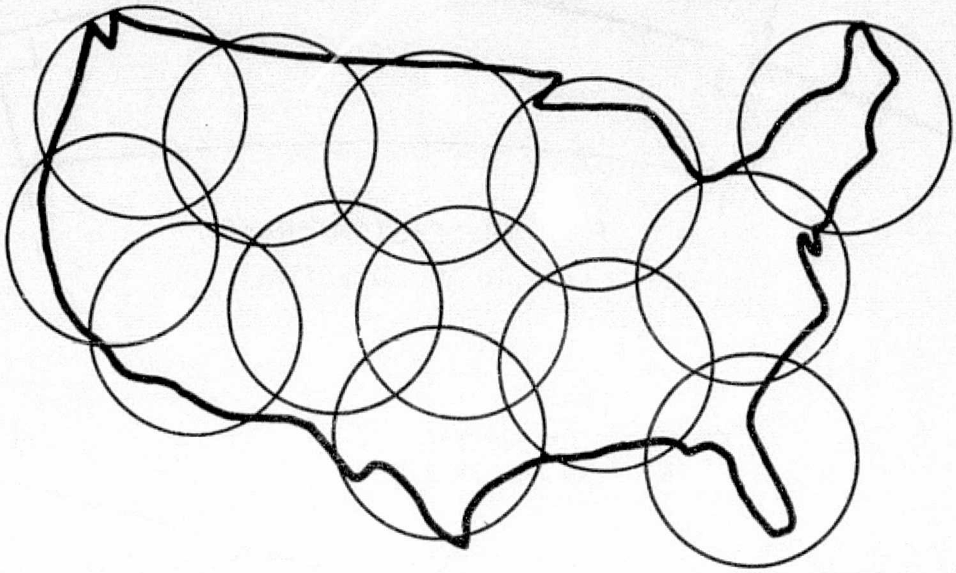


FIGURE 3-3. 13 HAPP'S COVERING CONTINENTAL UNITED STATES

3.1 HAPP Range and Payload Capabilities for Communications Relay

The 520-km LOS Range given here for the HAPP is based on the assumption of a smooth Earth; i.e., there are no hills or mountains. In rough terrain the line of sight range is, of course, shortened. One way of expressing the amount of shortening deals with the case of a high-gain receiving antenna. The range reduction is given as a function of the minimum antenna elevation angle which will clear surrounding terrain. Figure 3-4 shows the geometry of this situation. In the top illustration flat terrain allows transmission from the HAPP to extend to the horizon. The middle illustration shows an intervening mountain. In the bottom illustration the receiving antenna is pointed upward a few degrees to

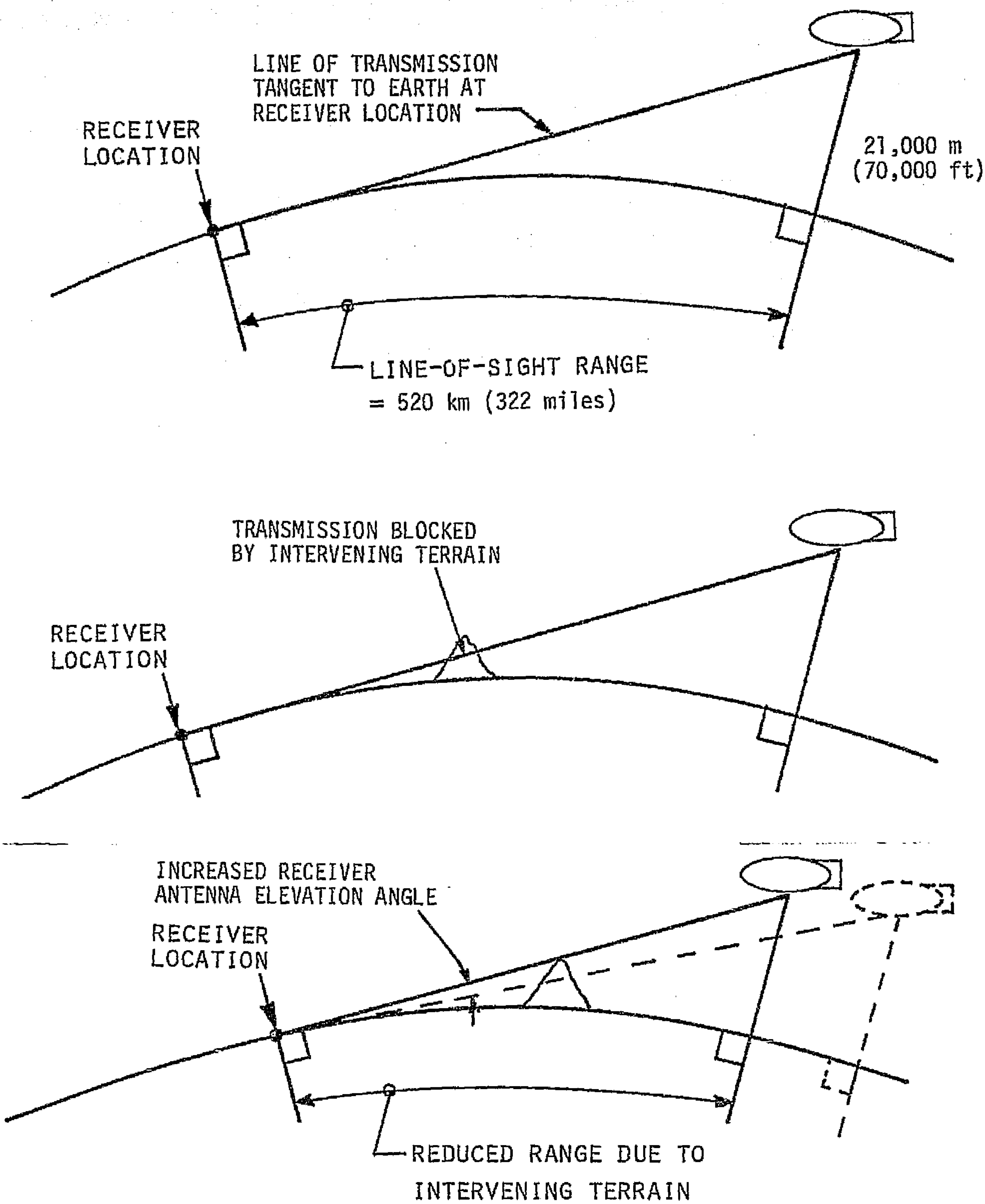


FIGURE 3-4. RANGE REDUCTION DUE TO ROUGH TERRAIN

clear the mountain. The HAPP must be moved closer to be on the line of sight to the antenna. Note that points between the antenna location and the mountain are in a "shadow" area and cannot receive transmission from the HAPP. They have higher minimum antenna pointing angles than the receiver location shown and so the HAPP is out of range relative to them. The range as a function of minimum antenna elevation angle is:

$$S = \frac{R}{R+h} \sin\left(\alpha+\frac{\pi}{2}\right) \cdot \left\{[(R+h)^2-R^2\cos^2(\alpha)]^{1/2}-R \sin\alpha\right\}, \quad (3\text{-}1)$$

where

S = range measured on surface of Earth

R = radius of Earth

h = HAPP altitude

α = receiving antenna elevation angle.

Figure 3-5 is a graph of this relationship; it shows that LOS range falls off very rapidly as the required elevation angle increases. However, in all but very rough terrain, required angles are usually not more than 2 deg or so. In selecting locations for satellite system ground terminals. NASA often searches for locations in a natural bowl of surrounding high terrain to shield the antenna side lobes from interference. Experience in this selection process suggests that terrain requiring elevation angles above 5 deg is extremely rare. As the graph shows, 5 deg corresponds to a range of about 200 km (125 miles). So LOS range in areas such as the Rockies could be considerably less than the nominal 520 km, but it is still much longer than the range available from a conventional broadcast tower.

For some applications it may be desirable to relay signals from one HAPP to another and the question arises, what is the maximum range over which such a relay can be made? The maximum range will be determined by intervening terrain. Figure 3-6 shows the geometry of the worst case of intervening terrain. A high mountain is located midway between the two HAPPs. For a mountain whose height above sea level is m and HAPPs at altitude h, the maximum range D is:

$$D = 2[(r+h)^2 - (r+m)^2]^{1/2} \quad . \quad (3\text{-}2)$$

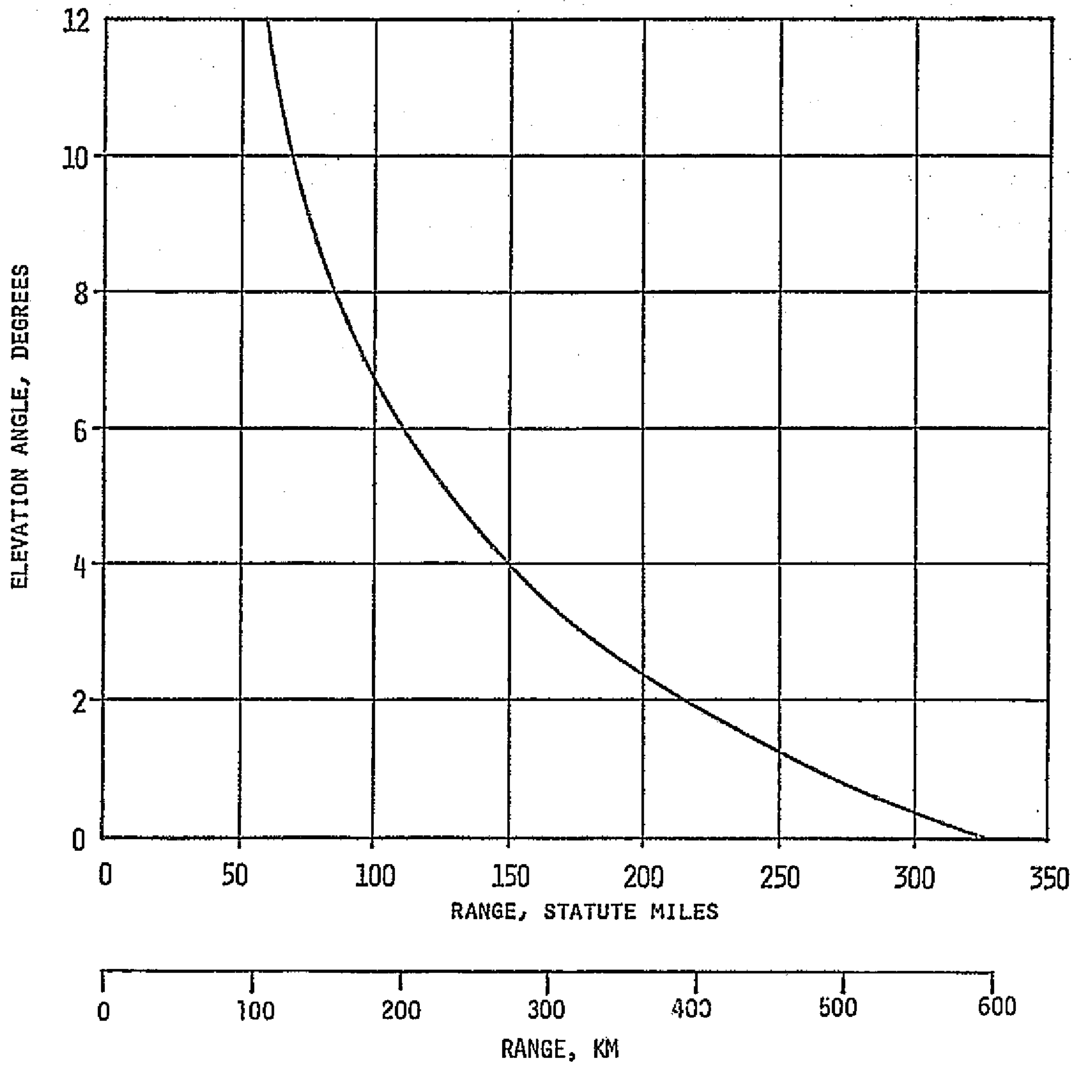


FIGURE 3-5. LOS RANGE AS A FUNCTION OF GROUND ANTENNA ELEVATION ANGLE

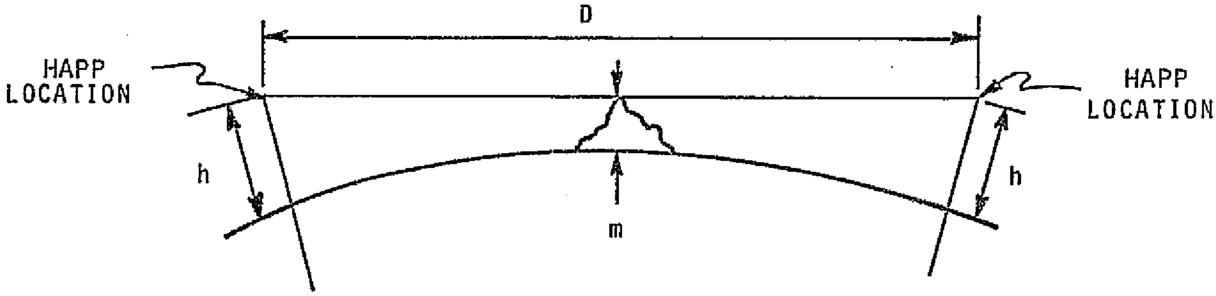


FIGURE 3-6. GEOMETRY OF HAPP TO HAPP RELAY

The highest mountain in the continental United States is Mount Whitney, 4415 m (14,486 ft). Using this value for m and 21,000 (70,000 ft) for h, the result is D = 930 km (578 statute miles). This is the minimum value of the maximum range for HAPP-to-HAPP relay. The maximum value is just twice the distance from a HAPP to its horizon or 1040 km. So HAPP-to-HAPP relay range is not strongly affected by the terrain below.

The payload capacity of the HAPP is another important consideration. SRI's study indicates that a 6000-kg payload is feasible. This is adequate for almost any foreseeable communications application. For comparison, ATS-6 weighs 1350 kg (including some hardware not used for communications) and Intelsat V will weigh 834 kg. So the HAPP could carry very complex and powerful communications payloads.

3.2 Applications Chosen for Analysis

For remote sensing, Battelle chose applications for further study by generating a very long list of candidates and screening them to find those best suited to the HAPP. In the case of communications, the kinds of uses to which the HAPP is best suited were much easier to identify than for remote sensing. NASA Headquarters personnel in the Special Communications Applications Section of the Office of Applications drew up a short list of candidate applications. This list included:

- Two-way video communications to small platforms
- Educational TV broadcast to continue ATS-6 based system for Rocky Mountain States Education Experiment
- Land mobile communications
- Communications experiments platform
- Personal communications ("Dick Tracy" wrist radios)
- Direct broadcast to unmodified home TV sets.

Within the limits of time and funds available for this study, it was not possible to analyze all of these. Three were chosen for further consideration, namely, educational TV, communications experiment platform and direct broadcast to home TV sets. If more time had been available, personal communications would have been added since this appears to be an application for which the HAPP has a considerable advantage over a satellite. This advantage derives from the much shorter range with the HAPP, which should permit a more compact personal radio. However, very complex switching would be required to accommodate a large number of users. An adequate analysis of the very elaborate system required for this application is beyond the scope of the present study.

The three applications chosen for analysis are reprerentative of a broad range of applications in terms of the costs of the platform and payloads. They clearly show the major advantages and disadvantages of the HAPP as compared to satellite communications systems.

3.3 Rocky Mountain States Education Experiment

One of the major experiments conducted with the ATS-6 satellite was the Health/Education Telecommunications (HET) Experiment. This program had six components: Appalachian Regional Commission Experiment, Veterans Administrations Experiment, Rocky Mountain States Experiment, Regional Medical School Experiment, Alaskan Health Experiment and Alaskan Education Experiment. A common set of hardware items was used for all of these.

The Rocky Mountain States Experiment has been selected as an appropriate scenario for assessing the value of HAPPs for educational TV distribution in a mountainous area. It highlights some key issues in the comparison of satellites with HAPPs for communications.

In the Rocky Mountain States Education Experiment (RMSEE) educational television material was relayed to 56 junior high schools and 12 public broadcast stations in the eight states of the Federation of Rocky Mountain States. Program material orginated at a network control center in downtown Denver and was relayed to a nearby uplink terminal for transmission to the ATS-6. Aboard the satellite a spot-beam antenna which radiated to and received energy from a 9.15-meter reflector was used to transmit to the ground receiving terminals. By using two offset antenna feeds a footprint consisting of a pair of overlapping 0.85-deg spots was produced on the ground. Two separate pointings of this antenna system were required to cover the entire eight-state area. Figure 3-7 shows the coverage pattern and the locations of the ground stations.

3.3.1 HAPP Network to Duplicate ATS-6 Coverage

The number of HAPPs required to duplicate the coverage shown in Figure 3-7 is not easy to determine. As indicated previously, the maximum possible range from any given ground terminal to a HAPP relay depends on the nature of the surrounding terrain. In flat areas the maximum range is 520 km, but as the maximum allowable receiving antenna elevation angle increases, the range goes down rapidly. Within the scope of the present study it was impossible to examine the detailed topography at all of the ground stations shown in Figure 3-7. Therefore, optimistic and pessimistic assumptions were made about the average terrain characteristics and the true situation is assumed to lie somewhere between the two.

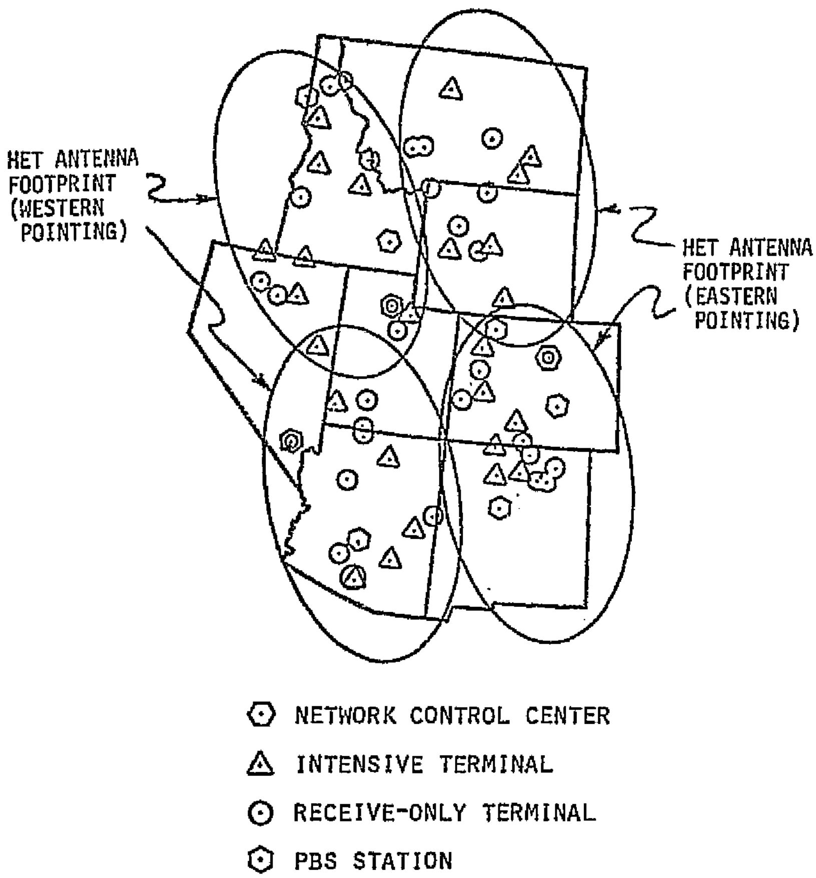


FIGURE 3-7. ROCKY MOUNTAIN STATES EDUCATION EXPERIMENT - COVERAGE IN ORIGINAL EXPERIMENT

Under the optimistic assumption nearly all of the receiving stations near the edges of the reception area shown in Figure 3-7 are in fairly flat areas or are on high ground. Therefore, the antennas at these sites can be pointed nearly horizontally and the maximum 520-km HAPP range can be used. Figure 3-8 shows the result of this assumption. All but perhaps three or four of the ground terminals can be served by two HAPPs. The southern HAPP would relay signals from the Network Control Center to the northern HAPP.

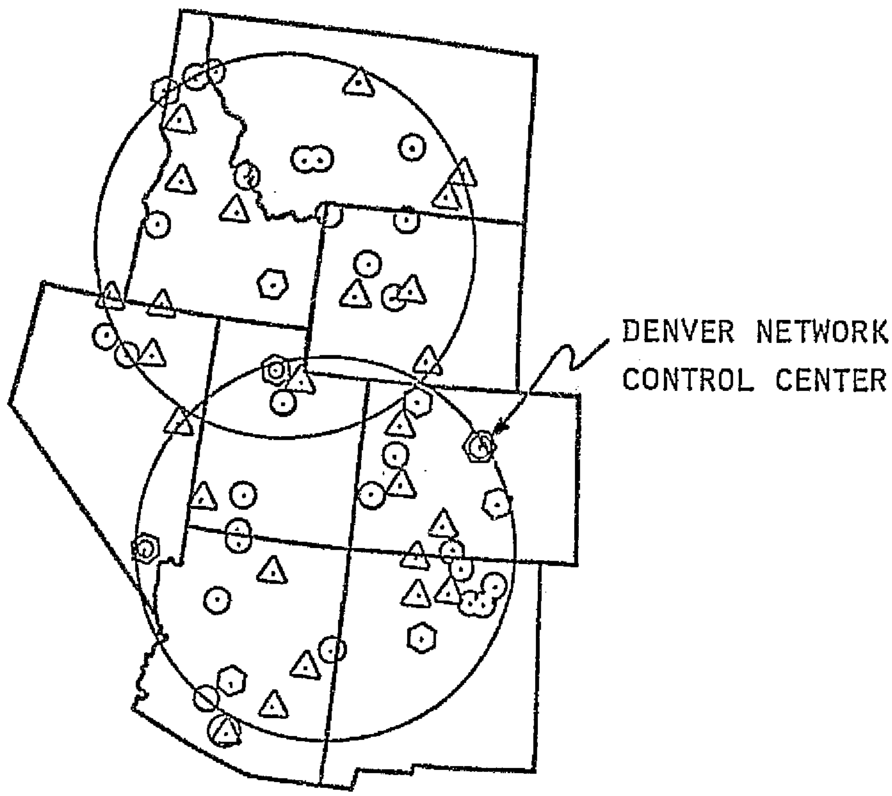


FIGURE 3-8. OPTIMISTIC ESTIMATE OF THE REQUIRED NUMBER OF HAPPS

The pessimistic assumption is that most of the receiving stations are in quite rough terrain or are located in valleys, with the result that any antenna elevation angle less than 5 deg will result in blocked transmission. As shown in Figure 3-5, this reduces the line-of-sight range to 206 km (128 miles). Figure 3-9 shows the result of this assumption; fifteen HAPPs are required.

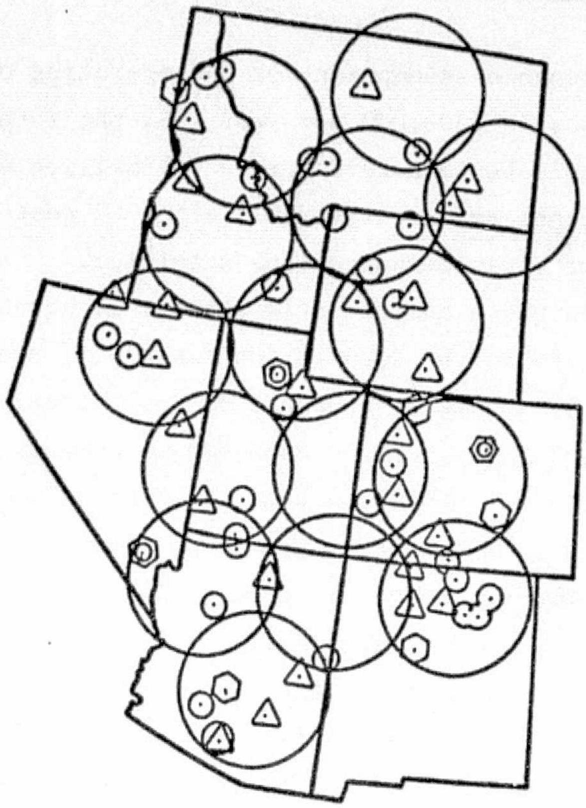


FIGURE 3-9. PESSIMISTIC ESTIMATE OF THE REQUIRED NUMBER OF HAPPS

At this point a clarifying note is in order. It was previously stated that thirteen HAPPs could cover the entire continental United States. It was pointed out, however, that some locations would be blocked from receiving HAPP transmissions by intervening terrain. The areas which would be blocked would be in mountainous terrain. Since the population density in these areas is low the percentage of people not able to receive HAPP transmissions would be small.

The current scenario is based on different assumptions. In this scenario reception must be guaranteed at each of 56 separate sites all located in the mountain states. This calls for a much more conservative design philosophy. Furthermore, the estimated requirement for 15 HAPPs represents an upper bound and the actual number required is very likely to be considerably fewer than this.

3.3.2 Cost Comparison

A reasonable assumption for the operating cost of the HAPPs (without payloads) is $500,000 per year. So the total cost for two to fifteen HAPPs would be somewhere between $1 million and $7 million per year. This does not compare favorably with the cost of leasing a transponder on a commercial communications satellite.

Western Union has recently entered an agreement to lease three Westar transponders to the Corporation for Public Broadcasting for $800,000 per year each. This rate is guaranteed for 5 years. For single-year leases RCA is currently charging around $650,000 per transponder.[22] Since the HET system operated at S-band, new Earth stations would have to be acquired for compatibility with C-band transmission from a domestic satellite. Receive-only C-band ground stations suitable for use at individual schools are currently being sold in quantities of 1 to 10 for around $30,000 each.[22] In large quantities, the price would probably be $10,000 each.[22] If it is assumed that 56 ground stations necessary for the 56 junior high schools being served can be acquired for $25,000 each which is depreciated over 10 years and that a transponder channel costs $800,000 per year, then the total cost for a C-band domestic satellite system is $940,000 per year. This is less than the $1 million which represents the most optimistic estimate for the HAPP platforms alone excluding payloads. So for this application, the HAPP is not competitive with a commercial domsat.

However, this does not mean that the HAPP would not be competitive for other educational television applications. Consider an alternative scenario where the same size area must be covered but the terrain is relatively flat so that two HAPPs suffice. Suppose also that 12 TV channels are required. The Westar satellite mentioned above carries 12 transponders (one channel per transponder) and weighs 574 kg. A HAPP could easily carry a payload similar to the Westar. Such a HAPP would cost about $500,000 per year. Assuming that a satellite such as a Westar costs $15 million to $20 million and that an equivalent HAPP payload costs one-third as much, the total yearly cost for a HAPP plus payload (assuming 10-year amortization for the payload) would be $1.0 to $1.2 million per year. For the two HAPPs necessary to cover the whole area, the cost is then $2.0 to $2.4 million per year. But 12 channels would be provided, so the cost per channel would be $170,000 to $200,000 per year. This compares very favorably with the $650,000 to $800,000 figure for domestic satellite channels. Actually, the overall system costs should compare even better than this since ground stations to work with HAPPs would be less expensive than those used with a satellite.

The general conclusion to be drawn is that in cases where a small number of channels are required and/or a large number of HAPPs are needed, a domestic satellite system is less expensive than a HAPP system. However, since HAPP cost is fairly insensitive to payload size, a HAPP system may be able to provide a large number of channels to a limited area at a lower per-channel cost than a satellite.

3.4 HAPP For Communciations Experiments

In astronomy and other space sciences, high-altitude balloon programs have often been precursors of satellite programs. New instruments can be tested inexpensively on balloons before a commitment is made to a satellite system. The low cost of a balloon program derives partly from the low cost of the balloon itself -- typically $30,000 including launch, tracking, and recovery -- but also from the comparatively low cost of the instruments themselves. A 1976 report of the National Research Council[23] states that a balloon payload generally costs one-third to one-tenth as much as a comparable satellite payload. The report states that "this difference is partly attributable to the more severe environment of a satellite launch and partly to requirements for high reliability and quality assurance dictated by the one-shot, throwaway nature of satellite instruments. Balloon instruments are regularly recovered, refurbished if necessary, and flown again."

Another advantage of balloon platforms is the flexibility they allow in experimenting with new kinds of hardware. The National Research Council report comments that "balloons, because of their low cost and their much milder environments, have permitted the development and use of innovative instruments that could be tried on one flight, modified, and reflown a few months later. Indeed there has been a justifiable bias in selecting satellite experiments against innovations and toward conservative, proven designs".

For most experiments in applications such as remote sensing and communications, conventional high-altitude balloons suffer from a serious drawback. They drift with the wind. Since they drift rapidly, most experiments are limited to a few hours or days so that the balloon can be recovered before it drifts over the ocean or across a national border. But the HAPP does not suffer from this problem. Able to keep station for a year or more, a HAPP could be used for many communications experiments now carried out using satellites.

SRI's estimate of HAPP development cost is $4.5 million to $18 million. Compared with satellite costs this is modest. The launch and recovery costs are estimated to be $5,000 for the airplane HAPP and $30,000 to $50,000 (depending on size) for the airship HAPP. These low costs would permit payloads to be changed or modified frequently during an experimental program.

A HAPP would not be limited to testing new hardware per se. Many experiments carried out by ATS-6 tested human aspects of long distance video communications. Many aspects of utility, user acceptance, market potential and other questions depend more on the type of service provided than on the method of implementation. With its 520-km line-of-sight range, a HAPP could be used to test a variety of communications services which might ultimately be provided by a satellite.

3.4.1 HAPP System

In order to estimate the range of costs of HAPPs used for communications experiments without specifiying any particular experiments, two HAPP payloads have been defined in terms of the weight required to duplicate the capabilities of existing experimental satellites. One is a rather small payload and the other is quite large.

The small payload is equivalent in size to the Japanese Broadcast Satellite or the Japanese Communications Satellite, both of which are designed to experiment with various technical and institutional aspects of communications. A Delta 2914 launch vehicle is required to place either one into geosynchronous orbit.

The large payload is equivalent in size to the ATS-6, and thus represents a very sophisticated payload capable of carrying out a wide variety of experiments. A Titan III-C launch vehicle is required to place such a payload into geosynchronous orbit.

Table 3-1 shows weight statements for both payloads. Both the weights for the satellite and the weights for the HAPP payloads are given. The HAPP payload is lighter for a number of reasons. First, no propulsion or altitude control is required for the HAPP. The HAPP electric power system can be quite simple since abundant power is available from the microwave receiving system used to power the HAPP stationkeeping motor. Thermal control is less elaborate due to less severe environmental conditions. Structure accounts for the same percentage of the total weight in either the satellite or HAPP payload.

TABLE 3-1. COMMUNICATIONS EXPERIMENT PAYLOAD WEIGHT STATEMENTS

	Small Payload		Large Payload	
	Satellite Payload Weights (kg)	Equivalent HAPP Payload Weights (kg)	Satellite Payload Weights (kg)	Equivalent HAPP Payload Weights (kg)
Propulsion & Attitude Control	75	--	186	--
Telemetry & Command	11	11	43	43
Experiment Payload	83	83	451	451
Electric Power [(a)]	73	5	261	17
Thermal Control	22	10	64	25
Structure & Harness	77	21	352	184
	341	130	1357	720

(a) Electric power weight includes solar array for satellite; includes only simple power conditioning for HAPP.

3.4.2 Cost Comparisons

First consider the likely costs of the satellite platforms. The major elements of cost are the launch and the satellite bus (i.e., satellite without payloads). For the small payload, the NASA cost of a Delta 2914 launch would be about \$14 million and the cost of the bus would be around \$7 million to \$9 million. Assuming a 10-year life (rather optimistic) leads to a yearly cost of $2.1 million to $2.3 million. For a Shuttle launch, including a SSUS-D upper stage, the cost would be about $7 million. So the yearly cost would be reduced to $1.4 million to $1.6 million. The HAPP to do the same job would cost about $440,000 per year. Some sort of bus would be required in this system also to provide telemetry and command, power conditioning, thermal control and structural and electrical attach points for the payload. This bus should be considerably cheaper than the satellite bus for the reasons previously discussed for other HAPP payloads and also because no attitude control, propulsion or power source are required. Assuming that the HAPP bus costs one-quarter of the $7 million to $9 million for the satellite bus, and assuming a 10-year life, the yearly bus cost is $0.18 million to $0.23 million, so the total HAPP system cost is $0.62 million to $0.67 million per year or less than half the least cost of a satellite alternative.

For the large payload, the Titan III-C launch cost would be $45 million and the satellite bus would cost $15 to $20 million; thus, the total yearly cost would be $6 million to $6.5 million. A Shuttle launch including a two-stage IUS would be $27 million so the total yearly cost for the Shuttle era would be $4.2 million to $4.7 million. A HAPP to support the large payload would cost $540,000 to operate, and again assuming a HAPP bus costs one-quarter of a satellite bus, then the yearly cost for the overall HAPP system -- platform plus bus -- would be $0.92 million to $1.0 million or about one-quarter of the cost of the equivalent satellite platform.

A summary of all these figures is given in Table 3-2.

TABLE 3-2. COSTS OF EXPERIMENT PLATFORMS

	Yearly Cost ($, millions)	
	Small Payload	Large Payload
ELV Launched Satellite	2.1 - 2.3	6 - 6.5
Shuttle Launched Satellite	1.4 - 1.6	4.2 - 4.7
HAPP	0.62 - 0.67	0.92 - 1.0

It can be seen that the yearly cost of the HAPP is considerably less than the cost of an equivalent satellite platform. In addition, the HAPP offers considerably more flexibility than the satellite in the sense that payloads can frequently be modified or replaced. It should also be noted that the assumption of a 10-year life is extremely generous for an experimental satellite. Even if it lasted 10 years, the useful work of such a satellite would likely be finished much sooner, making the effective cost per year proportionally higher. If the useful lifetime of the satellite is assumed to be two years, then the satellite for the small payload has a yearly cost more than eleven times higher than the HAPP. The large satellite would have an annual cost more than 20 times higher than the HAPP.

3.5 HAPP System for UHF Television Broadcast

As previously discussed, television broadcasting depends largely on line-of-sight transmission and so the range of a television station depends directly on the height of its broadcasting antenna. The higher the antenna, the further it can "see" around the curvature of the Earth. To get an idea of the cost-effectiveness of using a HAPP-borne transmitter for television broadcast, the characteristics of a typical UHF television station can be compared with the station characteristics which would result if a HAPP transmitter were used instead of a conventional tower-mounted antenna.

3.5.1 Conventional System

WOSU-TV, located in Columbus, Ohio, is owned and operated by The Ohio State University and broadcasts on Channel 34 (590-596 MHz). Its range, for grade B service, is 97 km (60 statute miles). The range of a broadcast station is not easy to define since it depends not only on the characteristics of the transmitting hardware but also on the type of receiving equipment used by the home viewer -- the antenna height and gain and the receiver sensitivity -- as well as the picture quality which the viewer will tolerate. Therefore, the broadcast industry usually does not use the kind of link budget calculations typically done for satellite communications. Rather than compute the receiver signal-to-noise ratio (S/N) and use a desired S/N to specify transmitter power requirements, the broadcast standard is in terms of field strength at the receiving antenna. Grade B service is defined as 1500 μv/m at a receiving antenna 9 m (30 ft) above the ground. A roof or tower-mounted high-gain (approximately 9 dB) receiving antenna is required to receive a good picture with grade B service, and so the distance at which this service is provided can be taken as the maximum range of the station.

Figure 3-10 shows the broadcast coverage area for WOSU compared with the coverage which would result if a HAPP-borne transmitter were used. Because of the very large area covered, the system cost per viewer can be reduced by using a HAPP instead of the conventional system. This will be demonstrated below.

If a HAPP were used instead of the conventional equipment used at WOSU-TV the components replaced by the HAPP system would be: tower and strobe lights; antenna; transmitter; coaxial cable from transmitter to antenna; technical personnel to maintain and operate transmitting equipment. The HAPP system would consist of: HAPP; HAPP payload including transmitter, receiver for up-link from station, and support equipment; technical personnel to operate HAPP and HAPP payload; transmitter for up-link from station to HAPP. All other elements of the station would be the same for either system including program production staff, advertising sales staff, management, studio facilities, buildings and so on.

The costs of the WOSU-TV hardware elements which would be replaced by the HAPP system are*:

1100-ft tower and strobe lights	$323,000
Antenna	150,000
1100-ft coaxial cable	110,000
60-kw transmitter	450,000
Total	$1,033,000

To estimate yearly operating costs, it is assumed that the transmitter is amortized at 10 years and the other items at 20 years, giving a yearly hardware capital cost of $74,000. The payroll for technical staff to operate the transmitting equipment is estimated from FCC statistics[11].

* Costs related to Battelle by WOSU-TV's chief engineer were incurred in 1973 and have been inflated to 1977 dollars.

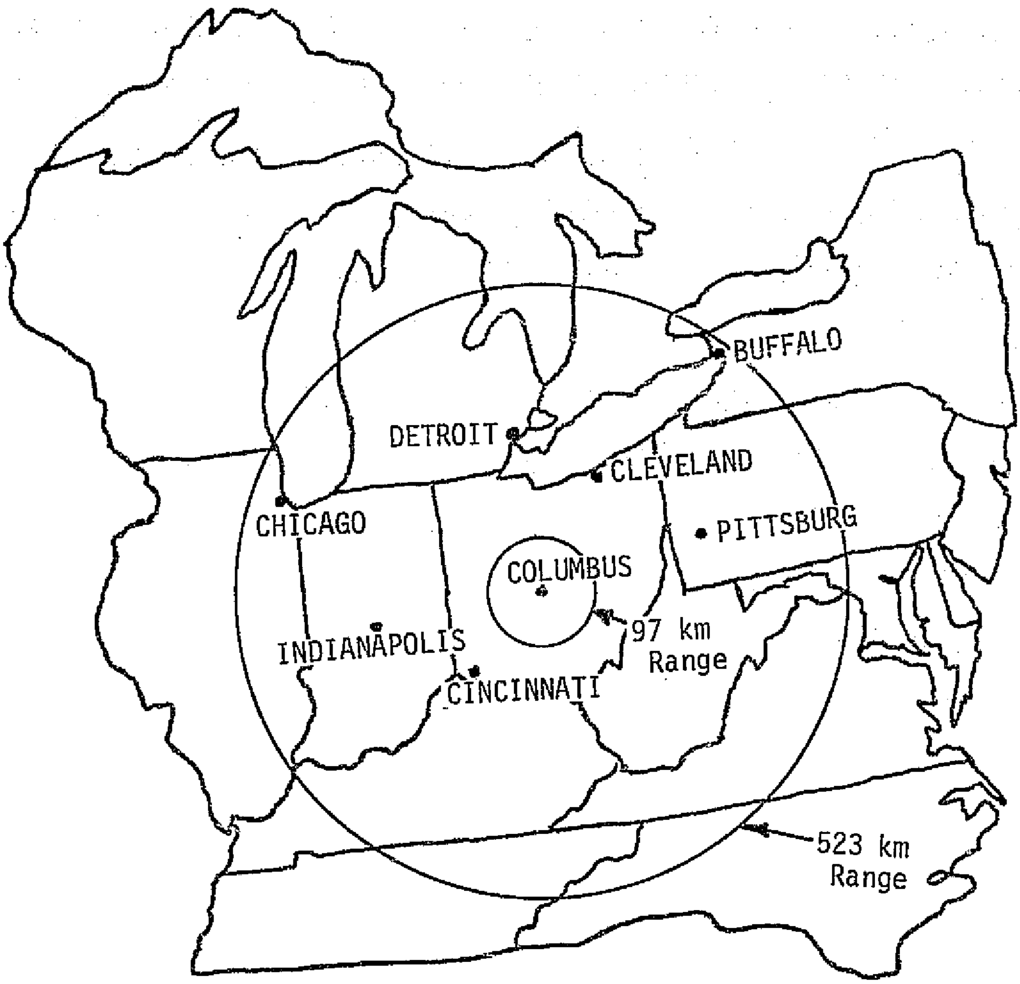


FIGURE 3-10. BROADCAST COVERAGE AREAS FOR A CONVENTIONAL UHF TELEVISION STATION WITH 97 KM RANGE AND A HAPP STATION WITH A 523 KM RANGE

The average technical payroll for all U.S. television stations in 1973 was \$146,000. Inflated to 1977, this is approximately \$186,000. Assuming that about half of the technical staff time is devoted to maintaining and operating the transmitter, this comes to about \$93,000 per year for personnel replaced by the HAPP system.

The cost of electric power to operate the 60-kw transmitter is estimated by assuming a transmitter efficiency of 60 percent, an energy cost of 5 cents per kw-hr, and operation 18 hours per day, 365 days per year. The result is \$33,000 per year.

The total yearly cost of items replaced is then:

Hardware	\$ 74,000
Technical staff payroll	93,000
Electric power	33,000
Total	\$200,000

3.5.2 HAPP System

The cost of the HAPP system depends on the HAPP payload weight which in turn depends on the transmitter power required. The appropriate equation for calculating the transmitter power is:

$$F = \frac{7\sqrt{P_t G_t}}{R} \quad , \qquad (3\text{-}3)$$

where F is the field strength at the receiving antenna in volts per meter, P_t is the transmitter power in watts, G_t is the transmitting antenna gain and R is the range in meters. Using 1500 μv/m (grade B service), a range of 520 km (322 miles) and an antenna gain of 2 (3 dB), this equation can be solved for P_t. The result is 6.3 kw. The TCOM system used in Iran and Nigeria uses a 1-kw transmitter which weighs 82 kg. Transmitter weights scale approximately as the square root of power output. So a 6.3-kw transmitter using the TCOM technology would weigh about 200 kg. A dually redundant transmitter would weigh 400 kg. Starting from this figure, an overall weight statement for the HAPP payload can be built up, as shown in Table 3-3.

Figure 2-2, presented earlier, shows that the yearly operating cost for a HAPP with an 820-kg payload is approximately \$550,000. The cost

TABLE 3-3. TOTAL UHF BROADCAST HAPP PAYLOAD WEIGHT STATEMENT

Component	Weight (kg)
Transmitter *	400
Diplexer *	15
Up Link *	30
Transmitting Antenna	140
Telemetry and Command *	15
Power Conditioning	10
Wiring Harness	10
Thermal Control	50
Structure	150
Total	820

* These items are dual-redundant.

of the payload itself is very hard to estimate. Using the reasoning outlined in Appendix A, it is assumed that a comparable satellite payload would cost $20 million and that the HAPP payload would cost a third of this, or $6.7 million. If this is amortized over 10 years, the result is $670,000 per year. The cost of the ground side hardware for the up-link is small and can be assumed to be included in the payload cost. To estimate the cost of personnel to operate the HAPP payload, it seems reasonable to assume that about the same number of people are needed as are needed to operate the conventional ground-based system, so the technical staff costs are put at $93,000 per year. The electric power required for the transmitters is one-tenth that required for the conventional system. However, there is a large loss in the microwave uplink which will attenuate the power by a factor of about 5. So the yearly cost of electric power for the transmitters is about half that for the conventional system, or $15,000. The total yearly cost for the HAPP system can then be summarized as follows:

Item	Yearly Cost
HAPP	$ 550,000
Payload	670,000
Payload Operating Staff	93,000
Electric Power for Transmitter	15,000
Total	$1,328,000

3.5.3 Cost Comparison

To compare the costs per viewer of the HAPP and conventional systems, the populations of the two coverage circles shown in Figure 3-10 have been determined. From census figures for individual county populations in Ohio, the number of people in the 60-mile circle is 2 million. The number of people living within the HAPP broadcast zone is about 50 million. So the yearly cost per viewer of the conventional system is:

$$\frac{\$200,000}{2\ \text{million}} = \$0.10/\text{person}/\text{year} \quad .$$

The cost for the HAPP system is:

$$\frac{1.3\ \text{million}}{50\ \text{million}} = \$0.026/\text{person}/\text{year} \quad .$$

It can be seen that the HAPP system costs approximately one-fourth as much as the conventional system. It must be remembered, though, that this savings is a result of the HAPP system's broad area of coverage. If broadcast range must be limited to avoid interference with other stations, the savings will disappear. The success of HAPP-based broadcasting would depend on FCC regulatory structure. However, the complexities of FCC policy are beyond the scope of this report.

3.5.4 Satellite Direct Broadcast Alternative

Another alternative for wide area broadcast is a direct broadcast satellite. Consider, for example, a satellite using the technology of the Japanese Broadcast Satellite. To be generous to the satellite system, assume that sufficient on-board power is available so that one satellite can cover the entire continental United States with the same field strength as in the comparatively small beam required to illuminate the Japanese archipelago.

Home TV reception of signals from the Japanese Broadcast Satellite requires an adapter consisting of a small dish antenna and signal conversion electronics. The cost of this adapter is about \$350. There are approximately 70 million households in the continental United States. If half of these each equipped one TV with a special adapter and if the adapters last 10 years, then the total yearly cost of the adapters is:

$$\frac{\$350}{10} \times 35 \text{ million} = \$1225 \text{ million} \quad .$$

The yearly cost per viewer (assuming that all 215 million people in the U.S. are viewers) is \$5.70. This is over two orders magnitude more expensive than the HAPP system, and includes only the cost of adapters.

3.6 Nationwide TV Distribution

The investigation of communications applications for the HAPP concept included analysis of a HAPP system to provide nationwide network television broadcast capability. The analysis considered two system configurations: one involving a spacecraft linked to a network of HAPP platforms, and another utilizing a network of HAPP platforms linked together by relays, with no spacecraft required. Two applications for the network were investigated: public service broadcasting, and subscription television. In each application, costs and capabilities were compared with those for existing systems. An investment analysis was included in the treatment of subscription television to determine the reasonableness of establishing a nationwide HAPP television capability in terms of return on invested funds. All dollar figures are presented as constant 1977 dollars.

3.6.1 Broadcast Configuration Alternatives

At an altitude of 21 km, a platform containing television transmitters would have a broadcast range of 520 km, or roughly the line-of-sight range to the farthest horizon above flat terrain. Above mountainous regions, the range would be reduced by intervening terrain, though optimum placement above the terrain would limit the effect of range reduction. For purposes of the analysis, a network of 13 HAPPs was selected based on horizon-to-horizon coverage (Figure 3-3). It is recognized that elimination of all "shadow" areas would require an increased number of platforms, but it is assumed for purposes of the analysis that the effect of shadow areas on network television broadcast could be minimized by locating the HAPP network to concentrate shadows in sparsely populated areas.

Each HAPP received television transmissions, and broadcasts within the coverage area defined by line-of-sight considerations. As many as eight channels may be broadcast by each HAPP, based on a 6-kw one-channel television transmitter payload of 735 kg, and a maximum 6000-kg payload weight.

From a main broadcast facility, there are two alternative methods of transmitting television signals to the HAPP: simultaneous transmission to the 13 platforms via geosynchronous satellite, and transmission from HAPP to HAPP via microwave relay without the use of a satellite. The first transmission option, employing a satellite, is shown in Figure 3-11. The signals are transmitted to a spacecraft similar to existing spacecraft (Westar, Satcom, etc.). A 13-channel transponder is employed. The spacecraft, in turn, transmits to the HAPPs. By using

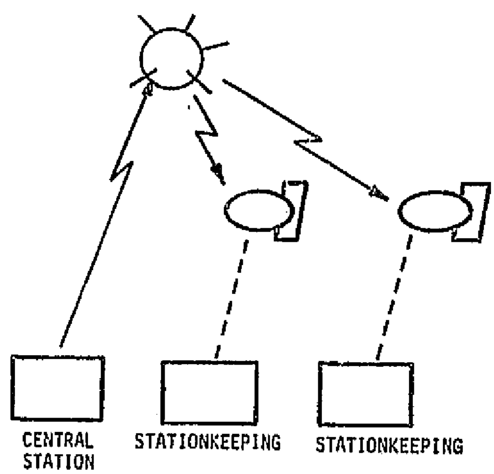


FIGURE 3-11. SATELLITE TO HAPP TRANSMISSION

13 channels, a number of broadcasting options are possible. One option would be to broadcast regionalized programming from the main facility, with each HAPP receiving a specific one of the 13 transmissions. Another option is one station of full-time coverage of news, for example, with four other different channels in three time zones transmitted to the HAPPs. Since any HAPP can receive any of the 13 spacecraft transmissions, numerous options are possible. The system provides considerable flexibility.

An issue raised during analysis of satellite transmission was why the HAPP network was needed at all, in view of the advancing state of direct broadcast technology. It would appear that to transmit to a spacecraft, then to a HAPP, then to a home television would only add an unnecessary link in the system. In order to directly access the satellite, however, television receivers must be equipped with a special "front end" adapter consisting of a small dish antenna and signal conversion electronics. In the case of the Japanese Broadcast Satellite, the cost of this adapter is about $350. The HAPP broadcast is made on conventional television transmitting equipment and, therefore, no added investment to each television receiver is required. With 68 million households owning at least one television[12], the investment to receive direct satellite transmissions using Japanese Broadcast Satellite technology without the HAPP capability would be 68 million households x $350, or $23.8 billion.

An alternative method of transmission to the HAPPs is a HAPP-to-HAPP repeater link. The main station would broadcast to the first HAPP, which would then broadcast to the second, and so on, throughout the network. This concept is shown in Figure 3-12. The repeater link

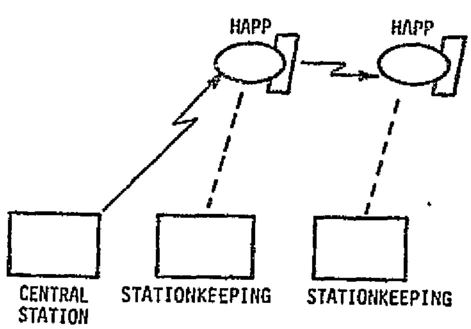


FIGURE 3-12. HAPP-TO-HAPP REPEATER LINK TRANSMISSION

transmission is attractive because the system involves no satellite cost. With the repeaters on each HAPP providing nationwide interconnection in a serial fashion, it is felt that digital transmission would be required to maintain picture quality throughout 13 links. The reliability of the network would be dependent on each HAPP in the transmission chain, and for each nth successive HAPP can be represented as:

$$r_{(n)} = r^{n} \quad , \qquad (3\text{-}4)$$

where $r_{(n)}$ is the reliability of transmission to the nth successive HAPP, and r represents the reliability of each HAPP taken alone. Reliability of each HAPP, including both platform performance and transmission operations, would have to be extremely high, to ensure overall system reliability. If r were 0.99, for example, system reliability after 13 relays would be 0.99^{13}, or 0.88.

3.6.2 Costs for Configuration Alternatives

An analysis of system capital requirements and operating costs was made for both the satellite-to-HAPP relay, and the HAPP-to-HAPP relay configurations. The data are summarized in Table 3-4. Common to both systems are the 13 HAPP platforms, television transmitters, and dedicated ground stations for power and stationkeeping functions. In the case of the satellite-to-HAPP configuration, spacecraft costs, satellite launch costs, broadcasting and stationkeeping facilities and operations are included. In the case of HAPP-to-HAPP relay, there are no space segment costs, but the digital repeaters and analog converters forming the relay links are included, as well as the cost of the main broadcast facility and operations, which in the case of the satellite configuration is included in the satellite stationkeeping facility. Overall, the satellite configuration would require about 8 percent more capital ($110 million vs $102 million) and would cost about 10 percent more to operate ($25 million vs $23 million, annually). The annual system costs include capital amortization, cost of capital, manpower, maintenance, and platform operating costs for a one-channel payload of 735 kg. Battelle feels that the first-order cost comparison summarized in Table 3-4 indicates a toss-up as to whether a satellite system or

TABLE 3-4. COST COMPARISON - SIGNAL TRANSMISSION OPTIONS FOR 13 HAPP NETWORK

		CAPITAL REQUIRED (MILLIONS OF 1977 DOLLARS)	
CAPITAL COSTS		SATELLITE TO HAPP RELAY	HAPP TO HAPP RELAY
SATELLITE - 13 TELEVISION CHANNELS		15.0	----
LAUNCH (SHUTTLE PRICE FOR ATLAS/CENTAUR CLASS PAYLOAD)		13.0	----
TT&C GROUND STATION (SATELLITE STATIONKEEPING & MAIN BROADCAST FACILITY)		10.0	----
HAPP TO HAPP MAIN BROADCAST STATION		----	4.0
HAPP PLATFORM AND GROUND STATION*	($2.5 x 13 HAPPS)	32.5	32.5
HAPP S-BAND RECEIVER & ANTENNA (13 CHANNEL CAPABILITY)	($1.0 x 13 HAPPS)	13.0	----
HAPP DIGITAL REPEATER, ANALOG CONVERTER, ANTENNAS	($3.0 x 13 HAPPS)	----	39.0
HAPP 6 KW TV TRANSMITTER (1 CHANNEL CAPABILITY)	($2.0 x 13 HAPPS)	26.0	26.0
TOTAL CAPITAL REQUIRED		$109.5	$101.5
		COST PER YEAR (MILLIONS OF 1977 DOLLARS)	
YEARLY COSTS			
CAPITAL AMMORTIZATION @ 10 YEARS		11.0	10.2
AVERAGE COST OF CAPITAL (STRAIGHT LINE @ 6%)		3.3	3.0
TT&C OPERATIONS (5 CREWS OF 4 MEN)		0.8	----
TT&C MAINTENANCE (EQUIPMENT)		1.0	----
HAPP MAIN BROADCAST STATION OPERATIONS (5 CREWS OF 2 MEN)		----	0.4
HAPP MAIN BROADCAST STATION MAINTENANCE (EQUIPMENT)		----	0.4
HAPP GROUND STATION OPERATIONS (5 CREWS OF 2 MEN)	($0.4 x 13 HAPPS)	5.2	5.2
HAPP PLATFORM OPERATING COSTS*	($0.25 x 13 HAPPS)	3.3	3.3
TOTAL SYSTEM COST/YEAR		$24.6	$22.5

* ASSUMES 6 KW 1-CHANNEL TELEVISION TRANSMITTER PAYLOAD OF 735 KG. EACH ADDITIONAL 1-CHANNEL TRANSMITTER ADDS $850,000 TO HAPP PLATFORM CAPITAL COST FOR ADDED WEIGHT CAPACITY PLUS $85,000 PER YEAR IN OPERATING COST.

relay network is employed for signal transmission. Since the capital and operating costs for either system are similar, the satellite system is recommended because of higher system reliability, and greater programming flexibility.

The costs presented in Table 3-4 are based on one 6-kw TV transmitter per HAPP. Table 3-5 indicates the requirements for each additional television channel, including cost of the transmitter, additional capital requirements due to increased capacity of the HAPP, and additional yearly operating costs. The total yearly cost, including

TABLE 3-5. REQUIREMENTS - ADDITIONAL TELEVISION CHANNELS

		Cost Per Year (millions of 1977 dollars)
6-kw TV Transmitter (735 kg) Capital Requirement	$2,000,000/10 Years	$200,000
735-kg Additional HAPP Capacity Capital Requirement	$850,000/10 Years	85,000
Additional Yearly Cost of Capital (Straight Line @ 6%)		86,000
Additional Yearly HAPP Operating Costs		85,000
Total Yearly Cost Per Additional Channel Per HAPP		456,000
Total Yearly Cost Per Additional Channel For 13 HAPPs		$ 5,928,000

capital amortization, is about 6 million dollars per additional channel for the 13-HAPP network. Since each HAPP is limited by payload weight to 6000 kg, a maximum of eight transmitters (735 kg each) could be installed in each HAPP. The yearly cost of a nationwide eight-channel network would be:

	Cost Per Year (millions of 1977 dollars)
13 HAPP + satellite system (Table 3-4)	$24.6
7 additional channels at 5.9 million each (Table 3-5)	41.3
Total system cost including capital amortization	$65.9

Similarly, capital requirements would be:

	Capital Required (millions of 1977 dollars)
13 HAPP + satellite system (Table 3-4)	109.5
7 channels/HAPP x 13 HAPPs x $2.85M/HAPP (Table 3-5)	259.4
	368.9

3.6.3 Application in Public Service Broadcasting

The Corporation for Public Broadcasting recently released a contract valued at $25.5 million to provide 165 Earth stations for a nationwide satellite-based television system servicing the Public Broadcasting Service (PBS). The Earth stations, operating in a receive-only mode with 10-meter antennas, will feed local affiliated broadcasting stations of the PBS. Under the terms of another recent contract, programming will be transmitted to three transponders on Western Union's Westar spacecraft, at an annual cost of $800,000 per transponder. Estimates of yearly cost for the PBS operations, including the local broadcasting affiliate operations, are shown in Table 3-6. The total yearly cost of the one-channel nationwide is $214 million per year.

A one-channel HAPP network for full nationwide television broadcasting would entail a total system cost of $24.6 million per year. This is an order of magnitude decrease in costs over the PBS operation. It is estimated that 165 local affiliate stations have the capability of reaching 60 to 70 percent of the population, while the HAPP network could reach the entire continental United States, with the exception of a few sparsely populated shadow areas.

With the satellite-HAPP configuration discussed above, up to 13 channels of different programming could be transmitted to the satellite, allowing considerable programming flexibility within each of the 13 HAPP

TABLE 3-6. PUBLIC SERVICE BROADCASTING - EXISTING SYSTEM COST

	Typical Public Service Station Cost Per Year (thousands of 1977 dollars)	
Ground Station & Antenna	15	
Building & Equipment Amortization	167	
Technical Expenses	102	
Personnel	400	
Total Operating Expenses	684	
Programming Expenses	600	
Total		
Total Expenses Per Station	1,284	x 165 Stations = $211.9 Million/Year
Transponder Lease	800	x 3 Transponders = $2.4 Million/Year
Total System Cost		$214.3 Million/Year

regions since any HAPP could access any of the 13 channels from the satellite. A disadvantage with the HAPP network when compared to PBS is the loss of local programming option, since the 165 local stations would not be required. Regional programming, however, is possible by using a specific satellite transponder for each HAPP region. Programming for each of the 13 regions would be performed at the main broadcast facility such that each region could achieve tailored coverage. It is estimated that about $13 million would be added to yearly system costs to perform the regional programming, but no additional capital would be required.

If local programming were desired, local stations could be added to the system which directly access the satellite and rebroadcast in a conventional manner without the use of a HAPP. Up to 130 local stations could be added to the HAPP network for the same yearly cost as current PBS network operations:

	Cost Per Year (millions of 1977 dollars)
HAPP network with satellite	24.6
Regional programming	13.0
130 local stations @ 1.3M/year	169.0
Total system cost/year	$206.6
PBS current cost	$214.3

Fifty-four percent of the population resides within the 50 largest metropolitan areas, with the next 25 largest metropolitan areas adding an additional 7 percent of the population. Increasingly smaller increments of population are added per metropolitan area beyond that. It is felt that a reasonable mix of local programming into the nationwide HAPP network could be accomplished with 50 local stations in large metropolitan areas. The total system would cost less than one-half of the existing PBS network, and would provide expanded coverage and programming flexibility:

	Cost Per Year (millions of 1977 dollars)
HAPP Network with satellite	24.6
Regional programming	13.0
50 local stations	65.0
Total yearly cost	$102.6
PBS current cost	$214.3

3.6.4 Application in Subscription Television

The cable television industry currently serves 10.8 million subscribers paying estimated fees of $7.00 per month. This generates a yearly revenue stream of about $900 million for the industry, exclusive of other revenues such as those derived from local and network advertising. To service the current number of subscribers, the industry has financed almost a billion dollars in plant and equipment, bringing up to 12 channels of programming to over 7700 communities in the United States.

Within metropolitan areas, cable subscriptions are generally sold on entertainment value (added channels) rather than picture quality.

Local broadcast quality of non-cable television in metropolitan areas is typically quite good, so viewers subscribing to the cable service, which also carries the three or four major local broadcasts, increase selection by eight or nine channels as a maximum. In fringe areas, or urban areas subject to interference, cable systems are sold both on entertainment value and signal quality.

In the above section, it was shown that a 13-HAPP network linked by a satellite could be operated in an eight-channel configuration for a yearly cost of $65.9 million. The HAPP network would require only about one-third of the current $1 billion dollar capital investment in cable systems. Further, the HAPP network would provide nationwide coverage not limited to cable serviced areas.

An investment analysis was performed to determine the annual cash flow and revenue required per subscriber to support an eight-channel HAPP network on the basis of subscription fees only, exclusive of advertising and other revenues. Results of the analysis are shown in Table 3-7.

TABLE 3-7. SUBSCRIPTION TELEVISION INVESTMENT CONSIDERATIONS

	1977 Dollars
Capital Investment Required for 13-HAPP 8-Channel Network	$369 Million
5 Year Payback @ 15% Return on Investment	$166 Million
Total Investment + ROI	$535 Million
Capital + ROI Per Year for 5 Years	$107 Million/Year
Operating Expenses	$18 Million/Year
Programming Expenses	$24 Million/Year
Total Revenue Requirment	$149 Million/Year
Number of Subscriptions	10.8 Million Households
Revenue Required Per Subscription	$13.79/Year

The analysis assumes an annual return of 15 percent on invested capital, and a 5-year payback period, terms which could be attractive to industry. Capital payback, return on investment (ROI), and operating expenses total $149 million per year for the network. Assuming the same user base as the current cable TV network, 10.8 million houselholds, revenue per subscription would be $13.79/year to achieve investment objectives. The current fee for cable television is approximately $84/year per subscription. The HAPP network could provide eight-channel service for one-sixth of this cost, and still represent an attractive opportunity for investors.

SECTION 4. CONCLUSIONS AND RECOMMENDATIONS

A large part of this study was devoted to a search for good remote sensing applications for HAPPs. Few were found, primarily because of the high annual operating cost of a HAPP. For most remote sensing applications, aircraft are less expensive than HAPPs and enjoy the added advantage of considerable flexibility not offered by HAPPs. However, there is a class of remote sensing tasks for which HAPPs are well suited. Where wide angle sensors are applicable so that a large area can be viewed from the stationary position of a HAPP and where very frequent coverage (more than once per day) is required, HAPPs are competitive with aircraft. In fact, the ability of HAPPs to provide essentially continuous observation gives them a substantial advantage over aircraft in some applications.

Of the remote sensing applications studied here, forest fire detection appears to be the area where HAPPs could make the largest contribution. While HAPPs are not likely to be cost effective for use in areas of modest timber value, the analysis done in this study indicates that they would probably pay for themselves several times over if used in areas where timber is particularly valuable. It should be cautioned, though, that these results are somewhat tentative since the amount of timber that could be saved by continuous surveillance is hard to estimate.

Marine traffic surveillance for enforcement of the 200-mile limit and other purposes is also a potential application for HAPPs. The patrol aircraft required to provide surveillance comparable to that available with HAPPs would be much more costly than a HAPP system.

A third application for which HAPPs are well suited is Great Lakes ice mapping. Aircraft could do the ice mapping at about the same cost as HAPPs but the HAPP system, because it can provide continuous surveillance, could also be used for traffic ocntrol and search and rescue.

While it was difficult to find good remote sensing applications for the HAPP, communications has proved to be a much more fertile field. It appears that the communications applications examined in this study are but a few of many to which HAPPs are well suited. Of the applications studied, direct broadcast to home TVs has by far the most potential. The ability of HAPPs to broadcast over large regions to unmodified home TVs (or, at worst, TVs modified by the addition of standard fringe area antennas) could lead to a new era in broadcasting.

The use of HAPPs as platforms for communications experiments, while perhaps less exciting than their use for TV broadcasting, also offers many worthwhile possibilities. The low cost and high flexibility of a HAPP as compared to a satellite platform would allow NASA to carry out many experiments which might otherwise be considered too costly.

The Rocky Mountain States Education Experiment scenario points up the fact that in some applications to which HAPPs at first appear well suited, it turns out that satellites are less costly. The maturity of satellite communications technology has made space communications a very cost effective solution to many problems.

The poor showing of HAPPs in the Rocky Mountain scenario and the good results for TV broadcasting lead to another conclusion. The strong point of HAPPs is their ability to lay down a very strong signal over a fairly broad area. Since the signal is much stronger than currently achievable with geosynchronous satellites, the cost of receiving equipment for use with HAPPs is much lower than for equipment used with a satellite. The HAPP itself is rather expensive, but the overall system cost will be less for a HAPP system than for a satellite system in cases where a great many receivers are used. In these cases, the low total cost of all the receivers offsets the high cost of the HAPP itself.

Another important conclusion stems from the fact that the cost of a HAPP rises rather slowly as palyoad weight increases. For example, a HAPP which can carry a 500-kg payload costs about $500,000 per year to operate, but doubling the payload only raises the cost to $600,000 per year. One result of this fact was demonstrated at the end of the Rocky Mountain scenario. In the original scenario, one TV channel was to be supplied and it was found that leasing a transponder on a commercial domestic satellite was less expensive than using HAPPs. However, if the scenario is changed so that 12 channels are required, then the HAPP system is much less expensive than leased transponders. So the conclusion is that HAPPs which supply many channels or many different services are likely to be more cost effective than HAPPs which supply few channels or only one service.

On the basis of the conslusions presented here, it is recommended that the best applications in both remote sensing and communications should be examined in greater depth. Cost/benefit analyses should be carried out since, for the most part, the current study presents only cost comparisons with alternative systems. Priority should be placed on communication applications, with particular emphasis on direct broadcast to home TVs.

Another recommendation concerns the cost of HAPP payloads. Because HAPP payloads have different requirements than payloads used on any existing platform, they will have unique characteristics. This makes their cost difficult to estimate. But the cost of the payloads is a significant element in overall system cost, so any future studies of HAPP systems should include in-depth analysis of probable payload costs.

If the application of HAPPs to forest fire detection is to be used as an argument for development of the HAPP concept, then a much more elaborate study of this area should be undertaken. Estimating the value of timber which might be saved by continuous surveillance is a complex and difficult tasks. Within the bounds of the present limited study only a rough approximation could be made. This approximation leads, in certain situations, to very large ratios of benefits to costs, and this suggests that even if the analysis is too optimistic, the overall conclusion that HAPPs would be cost effective is correct. However, a more elaborate analysis would be necessary to construct a totally convincing argument.

The favorable results for direct TV broadcast suggest that other applications involving large numbers of low cost receivers should also be investigated. One example is land mobile communications. Current mobile communications systems have very limited ranges. A HAPP relay station could provide mobile communications over a multistate area. Another exciting prssibility is personal mobile telephone service, where a personal mobile telephone is defined as a battery-powered radio telephone small and light enough to be easily carried on the person. The technology for such a telephone, weighing perhaps a pound or two, is already here (or nearly so) and HAPPs could be used as relay stations to allow such telephones to be used over very long ranges.

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APPENDIX A

HAPP PAYLOAD WEIGHT
AND COST ESTIMATION

APPENDIX A

HAPP PAYLOAD WEIGHT AND COST ESTIMATION

Since HAPP is a new type of platform not completely like any existing vehicle, its payloads will have to meet requirements unlike those for any platform now in operation. This makes the estimation of HAPP payload weights and costs difficult. The general characteristics of HAPP payloads will probably lie somewhere between those of airborne payloads and spacecraft payloads. The important question is where in this spectrum HAPP payloads will fall. The answer will help determine probable weights and have an important impact on costs. Requirements for light weight and high reliability will both drive costs up.

The cost of operating a HAPP is high, and goes up as payload weight increases. For example, a HAPP whose payload is 1000 kg costs about $600,000 per year to operate. This is $600 per kg or, over an assumed 10-year life of the payload, $6000 per kg. For comparison, consider a Delta launch into a 1000-km Sun-synchronous orbit. The Delta 2910 can deliver 2500 kg to this orbit. Taking $15 million as an approximate launch cost, this also works out to $6000 per kg. So there is as much economic justification for light HAPP payloads as for light satellite payloads.

Reliability is another area where HAPP payloads will be similar to satellite payloads. The HAPP platform itself is expected to be able to stay aloft for a year between overhauls. Launch and recovery are expected to be technically risky, especially for large vehicles, making payload repairs undesirable from an operational standpoint. The missions best suited to HAPPs also require very reliable payloads. The remote sensing missions require observations at least several times per day, and their interruption could be costly. The communications missions involve relay of broadcast TV, and here again, high reliability is important.

A further point of similarity between HAPP and spacecraft payloads is that they must be monitored and operated remotely for extended periods of time. Therefore a telemetry and command system not unlike a satellite's will be required.

For all these reasons it is assumed in this study that HAPP payloads will be quite similar to satellites in terms of both weight and cost. Therefore, satellite weights and costs have been used as starting points in estimating HAPP payload weights and costs.

Table A-1 shows weight statements for four communications satellites which are typical of current design practice. It is assumed that the average HAPP payload will be much like a satellite except for certain systems and components not required on the HAPP. The HAPP payload does not require propulsion or attitude control. (Experience with scientific balloons indicates that payloads are stable to within a degree or less. This is adequate for payloads considered in this report.) The rotary joint used in spin-stabilized satellites is not needed, nor is ballast.

To estimate the weight of supporting structure in HAPP payloads, the ratio of structure weight to total weight has been calculated for the four spacecraft shown. It ranges from 0.16 to 0.23, with an average of 0.20. This value has been used for HAPP payloads. Similarly, the ratio of thermal control weight to the total weight of electronic components (defined here as telemetry and command plus transponder plus power generation and utility electronics) was computed. This ratio ranged from 0.11 to 0.20, and the mean value of 0.15 was used for HAPP payloads.

Payload costs are the hardest parameter to estimate. The starting point used in this study is to estimate the cost of the key payload item (communications transponder or remote sensing instrument) from the cost of a similar item as used on a spacecraft, assuming that for the HAPP the cost will be less because of larger numbers produced and because of the fact that HAPP payloads need not survive the rigors of a launch. The cost of supporting hardware is estimated from spacecraft bus costs, again with the assumptions just stated.

How much less HAPP payloads will cost than satellite payloads is difficult to estimate. One worthwhile data point is the comparison of scientific balloon payloads with satellite payloads. A report of the National Academy of Sciences* states that "construction of a scientific instrument for a satellite typically has cost three to ten times as much as for a comparable instrument on a balloon. This difference is partly

*"The Use of Balloons for Physics and Astronomy", National Academy of Sciences, Washington, D. C., 1976.

TABLE A-1. SPACECRAFT WEIGHT STATEMENTS

Component	Weight (kg)			
	ATS-6	Japanese Broadcast Satellite	Intelsat V	Marisat
Propulsion/Attitude Control	186	75.4	236	99
Telemetry and Command	43	10.6	30	13
Communications				
Transponder	121	62.5	168	60
Antenna and Feed	114	7.0	61	5.4
Other Experiments	216	N.A.[a]	N.A.	N.A.
Electrical Power and Utilities				
Power Generation	100	--[b]	--	--
Utility Electronics	17	--	--	--
Solar Array and Deployment Mechanism	144	--	--	--
(Electrical Total)	(261)	(72.6)	(138)	(54)
Structure	212	77	137	76
Thermal Control	64	22	29	17
Wiring Harness	140	--	35	18
Rotary Joint	N.A.	N.A.	N.A.	6
Ballast	N.A.	2.5	N.A.	1.9
Total Spacecraft[c]	1360	329	834	387
(Structure) ÷ (Total Spacecraft)	0.16	0.23	0.20	0.20
(Thermal Control) ÷ (Electronics)	0.13	0.20	0.11	0.17

(a) N.A. = Not Applicable
(b) Entries marked "--" were not available.
(c) Total weight shown excludes apogee kick motor.

attributable to the more severe environment of a satellite launch and partly to requirements for high reliability and quality assurance dictated by the one shot, throwaway nature of satellite instruments." However, typical mission duration for a scientific balloon is a few hours or days, so HAPP reliability requirements are higher than for these balloons. In this study, payload costs are estimated at anywhere from about one-third of a satellite cost up to the full cost of a satellite, depending on the application and the nature of the hardware involved.

Within the scope of the current study it was not possible to make highly accurate estimates of payload costs, but it is believed that the accuracy of the payload cost estimates given in this report are commensurate with the accuracy of the cost estimates for the HAPP itself, which are themselves necessarily uncertain.

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APPENDIX B

IMAGING RADAR FOR ICE RECONNAISSANCE AND MARINE TRAFFIC MONITORING

APPENDIX B

IMAGING RADAR FOR ICE RECONNAISSANCE AND MARINE TRAFFIC MONITORING

An imaging radar suitable for use on a HAPP platform for Great Lakes ice mapping as well as ship monitoring for traffic control and search and rescue will require a real aperture antenna of sufficient size to provide the required resolution. A mechanically scanned array would be far too heavy, thus an electronically scanned phased array is required. A phased array can be scanned over a range of about ± 60 deg around boresight without serious beam degradation, and for azimuthal coverage of greater than 120 deg, more than one array face will be required.

The present project ICEWARN uses airborne radars having an azimuthal resolution of 450 m. This will require an array having a 15-meter aperture at a radar frequency of 10 GHz. A radar using 1-μsec pulses would provide a 150-m resolution in the long range direction, and these parameters constitute the basic design criteria for configuring the HAPP real aperture imaging radar.

To obtain a false alarm rate of 10^{-9} and a detection probability of 0.9 requires an integrated signal-to-noise ratio of 14.7 dB. This minimum signal-to-noise ratio, the resolution cell size, the maximum range required, and the minimum ice return or target cross section dictate the radar parameters.

The parameters for a real aperture imaging radar meeting the requirements for ice mapping and large ship monitoring from a HAPP platform are given in Table B-1.

For a given set of radar parameters, the received signal-to-noise ratio is given by:

$$S/N = \frac{P_t G^2 \lambda^2 \sigma n \tau}{(4\pi)^3 R^4 L k T_o NF} ,$$

where

P_t = transmitter power output

G = antenna gain

λ = wavelength

σ = target cross section

TABLE B-1. IMAGING RADAR PARAMETERS

Frequency	10 GHz
Pulsewidth	1 μsec
Pulse Repetition Frequency	250 Hz
Peak Power	10 kw
Beamwidth	
Azimuth	0.1 deg
Elevation	15 deg
Scanning Rate, Azimuth	0.25 deg per sec
Integration Time	0.4 sec
Polarization	
For ice mapping	Vertical
For ship monitoring	Horizontal
Antenna	15 m by 10-cm phased array
Scan Angle (per array face)	$\pm$ 60 deg

n = number of pulses integrated

τ = pulsewidth

R = range to target

L = system losses

kT_o = $4 * 10^{-21}$ for 270° K ambient temperature

NF = receiver noise figure.

For ice mapping, the target cross section is the area within the radar resolution cell multiplied by the scattering coefficient, and is a function of polarization and angle of incidence. For the observation of ships, the target cross section depends upon the ship size and aspect relative to the radar. If a 100-m^2 target cross section is assumed with a system loss of 5 dB, 8-dB noise figure, 3-cm wavelength, 1-μsec pulse width, 100 pulses integrated, 10-kw power output, and 40-dB antenna gain corresponding to a 15 m by 10-cm antenna at 10 GHz, then the resulting signal-to-noise ratio at a range of 500 km is:

$$S/N = \frac{10^4 * 10^8 * 9 * 10^{-4} * 10^2 * 10^2 * 10^{-6}}{2 * 10^3 * 6.25 * 10^{22} * 3.16 * 4 * 10^{-21} * 6.3}$$

$$= 19.56 \text{ dB}.$$

This is sufficient to provide the required detection performance.

Of more concern than the signal-to-noise ratio is the signal-to-clutter ratio for ship detection, since the large surface area illuminated will contribute a significant clutter return. For horizontal polarization, the wave clutter scattering coefficient can range from -50 dB/m^2 for calm water to -30 dB/m^2 for sea state 5 or very rough water. These result in signal-to-clutter ratios of 21.7 dB for calm water and 1.7 dB for sea state 5 at maximum range and a 100-m^2 target cross section corresponding to a 100 to 130-ft freighter.

For ice mapping at a maximum range of 140 miles, an ice scattering coefficient of -42.2 dB/m^2 is sufficient to provide the required detection performance. This is realistic for vertical polarization and incidence a few degrees from grazing for relatively smooth ice. Rough ice will generally scatter more than smooth ice, resulting in a larger scattering coefficient.