AN ANALYSIS OF THE COST OF AIRCRAFT AND SATELLITE SYSTEMS EMPLOYED IN AN EARTH SENSING ROLE

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There is currently considerable interest in the comparative cost effectiveness of aircraft and satellites in providing photographic coverage of large areas (earth-sensing). This paper presents an analysis of the costs associated with the employment of aircraft and satellite systems in an earth-sensing role. The analysis is based on the use of the latest version of the U-2, the U-2R, in the aircraft role and the CORONA search system in the satellite role. The peculiar requirements of particular earth-sensing objectives, such as requirements for seasonal coverage for crop surveys or the need for synoptic coverage for certain water resources analyses, were not considered. Also the mission-peculiar data analysis and processing costs have not been included in this analysis. Some of these mission-peculiar requirements would introduce factors tending to favor the use of aircraft, others would tend to favor the use of satellites. On the whole, however, it is believed that the results of this analysis should be significant for a broad range of earth-sensing missions.

System Considerations

The U-2R, an improved version of the U-2 aircraft, equipped with the standard "B" type sensor, was selected as the aircraft system for this study. Nominally, the "B" camera, a 36" focal length sensor, is capable of providing $.126 \times 10^6$ square nautical miles of coverage (70 nm x 1800 nm) per sortie with a ground resolution of approximately two to three feet.

The standard CORONA vehicle was chosen as the satellite system for this study. With a nominal on-orbit lifetime of 14 days, this system is capable of providing 8.0×10^6 square nautical miles of coverage (150 nm swath width) per mission and producing ground resolutions of approximately 10 feet at nadir.

Area Considerations

A number of selected areas of the world are considered. These range in size from the smallest, less than $.5 \times 10^6$ square nautical miles (the country of Bolivia) to the largest, over 28.0×10^6 square nautical miles (virtually the entire non Sino-Soviet area of the world). A descriptive listing of these areas is provided in Table I.

Cost Considerations

Several cost factors, extrapolated from related U-2 operational experience, provide the basis for the costing of the U-2R aircraft sensor system. These include:

Operational Costs: [redacted] per aircraft per month

Staging Costs: [redacted] per staging

Processing/Exploitation Cost: [redacted] per sortie

Operational costs include personnel, fuel, maintenance, spares and amortization and are based on a utilization factor of 35 hours per month. An aircraft unit cost of [redacted] is amortized by the straight-line method over a period of five years.

Staging costs are estimated as an average cost of the deployment of a minimum of one aircraft and a maximum of 18 aircraft to any operating location anywhere in the world.

Processing/exploitation costs are based on the handling of a maximum product of $.126 \times 10^6$ square nautical miles of photography per sortie and include the processing of the original negative, orientation/indexing, and first phase interpretation.

Costing of the satellite system is based on an experience factor of [redacted] per mission, excluding the cost of product processing and exploitation. Processing/exploitation costs are estimated at [redacted] per mission and include processing of the original negative, orientation/indexing and first phase interpretation.

Development costs are not included in the consideration of either the aircraft or satellite system.

Methodology

The maximum attainable area coverage per sortie for the U-2R aircraft, equipped with the standard "B" camera, is $.126 \times 10^6$ square nautical miles. For each area considered, this maximum attainable value is reduced by the application of a factor which represents the climatological probability of success per access for the given area.

For the four larger areas (Cases I through IV) this probability factor is computed as the weighted average of the probabilities of success per access for each of the constituent parts.

Operational experience with this type sensor has shown that two additional factors tend to degrade the over-all efficiency of the system in achieving the probable coverage limit. One of the factors -- natural swath overlap -- accounts for an approximate 20% reduction in desirable coverage; the other, termed requirements inefficiency, accounts for an additional 20% reduction in coverage as a result of "over-take" from those operations for which the requirements are less than total area covered.

Consequently, the attainable coverage limit is reduced to a value which can be considered the practical attainable limit per sortie for this sensor system operating over a given area. This value is used, then, to determine the number of sorties required to obtain complete (defined as 100% imagery, 90% cloud-free) coverage of the selected area.

The methodology used in the analysis of the satellite system is again based on two prime factors -- climatology and over-all system efficiency, a combination of geometric (swath overlap), requirements, command and camera efficiencies.

For the four smaller areas (Bolivia, India, the U.S. and North America, including Mexico) satellite missions are optimally programmed for a selected coverage. The number of accesses required to achieve the desired (100% imagery, 90% cloud-free) level of coverage is computed on the basis of the probability of success per access (a climatological experience factor). This enables the determination of the number of missions required and the calculation of a cost per square nautical mile of coverage.

Several additional considerations are essential in the analysis of the four larger areas (Cases I through IV). The over-all size and geographical distribution of the constituent portions of these areas necessitate a subgrouping to permit the application of appropriate climatology and geometric efficiency factors. Sensor system film capacity further limits the attainable coverage for the first several missions over a given area.

The analysis of Cases I through IV begins, then, with the application of the appropriate climatological experience factor to the subgroups. Assuming one access to any given area for each nine days of operation, this value is increased by a factor of 1.5 to account for the additional 1/2 access over a 14 day mission. The over-all system efficiency percentage factor is then applied -- providing an indication of practical achievement in coverage for the given area. Successive missions are then "flown" in this same manner against the remaining available area.

This iterative process is continued to achieve the desired (100% imagery, 90% cloud-free) coverage. The number of missions required to attain that level enables the calculation of a cost per square nautical mile of coverage.

Results

The results of the analysis are presented in the following paragraphs.

Aircraft

Area	Size (Sq NM x 10^6)	Required No. of Sorties	Cost (Dollars per Sq NM)
Bolivia	0.32	9	[redacted]
India	0.96	20	
U.S.	2.75	76	
North America (including Mexico)	6.25	222	
Case I	12.1	536	
Case II	13.3	589	
Case III	21.7	868	
Case IV	28.2	1028	

Satellites

Area	Size (Sq NM x 10^6)	Required No. of Missions	Cost (Dollars per Sq NM)
Bolivia	0.32	1	[redacted]
India	0.96	2	
U.S.	2.75	3	
North America (including Mexico)	6.25	4	
Case I	12.1	22	
Case II	13.3	22	
Case III	21.7	22	
Case IV	28.2	22	

The analysis reflects an average cost Delete This per square nautical mile of coverage with the aircraft sensor system compared with an average cost Delete This per square nautical mile with a satellite sensor system.

The fluctuation in cost per square nautical mile of coverage by the aircraft sensor system is almost wholly attributable to the variance in climatological experience factors for the selected areas.

In the case of the satellite sensor system, the significant increase in cost per square nautical mile of coverage from that shown for a selected area of 6.25×10^6 square nautical miles to that based on 12.1×10^6 square nautical miles of coverage is the result of a combination of factors which includes: poorer over-all climatological conditions, limitations in the amount of film currently carried, and the resultant requirement for a number of additional missions to obtain the desired level of coverage.

A graphic presentation of costs is provided as Chart 1. The plotted values are discrete. They are not intended to fix a trend for the interpolation of costs for coverage of areas other than those specifically defined.

<u>Area Considerations</u>	<u>Square Nautical Miles x 10^6</u>
Bolivia	0.32
India	0.96
United States	2.75
North America (including Mexico)	6.25
Case I: The American Continent, Greenland, Iceland	12.1
Case II: The American Continent, Greenland, Iceland, Western Europe	13.3
Case III: The American Continent, Greenland, Iceland, Western Europe, Africa	21.7
Case IV: The American Continent, Greenland, Iceland, Western Europe, Africa, Greece, Turkey, Iran, Afghanistan, Pakistan, India, Nepal, Burma, Indonesia, Malaysia, Philippines, Australia, New Zealand, New Guinea, Saudi Arabia, Iraq, Syria, Lebanon, Jordan, Israel, and Southeast Asia	28.2

Table I

[redacted]

AREA OF COVERAGE ($NM^2 \times 10^6$)