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Cost of Aerial Photography *

Small scale aerial photography may have a cost advantage over medium scale aerial photography.

Abstract: *The costs for obtaining small scale resource aerial photography compared to those for obtaining medium scale resource aerial photography are analyzed. Given the assumption that certain information needs are met, it can be demonstrated that high-altitude aerial photography has a cost advantage for some large projects.*

Introduction

With increasing demands on natural resource land managers to provide goods and services, because of increased population and increased per capita consumption, there is a need to intensify the management of natural resource lands. Once management information needs are defined, the initial step toward rational use of natural resources requires an inventory — usually accomplished with the aid of aerial photographs. Even with the use of present day aerial photography, usually at scales of 1:12,000 to 1:25,000, much of the world's natural resources have not been adequately inventoried. That which should be inventoried is beyond the budgets of many agencies and countries, even using medium scale aerial photography. With the advent of improved equipment, and changing cost relationships, there appears to be an ability, for some situations, to obtain adequate information at less cost using high altitude — small scale aerial photography for natural resource inventory.

Where applicable, small scale photography appears to offer the following advantages over medium scale resource aerial photography. Depending upon the camera focal length, small scale photography usually implies higher altitudes.

- Broad classification of resources can be more readily interpreted because a large area is covered by one photograph. This continuity of observation enables an interpreter better to judge the significance of various patterns or trends.
- Topographic displacement will be less of a problem because the higher altitude will show objects in a more vertical perspective and therefore more to their true plan position; also, problems of topographic shadow will be lessened.
- Tone and contrast will remain more uniform over a larger area.
- There will be fewer prints to handle. For example, Table 1 shows the number of prints required, using a 9 × 9-inch format, 60 per cent endlap, and 30 per cent sidelap for the listed scales.
- The time involved in preparing photographs, outlining effective areas, tying in resource type boundaries between photographs, or vegetation overlays for transferring of detail or mapping will be reduced because of the decreased number of prints.
- Photographic flights will require less time to cover the same area, a great advantage on large projects where poor weather conditions provide little flying time.
- As a sampling tool, small scale photography can provide a means for selecting critical areas for closer examination by larger scale aerial photographs or ground methods.
- Costs should be reduced because of significant reductions in flying time, film quantity, processing time and material, number of prints, storage space, and man-hours of handling and interpretation.

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There are a few significant disadvantages of small scale aerial photography, some of which can be corrected and others not.

- Altitudes above 16,000 feet require more powerful aircraft and special equipment. With improved technology, this obstacle is being overcome, especially for large projects (Bock, 1968).
- At higher altitudes, there is a greater proportion of the atmosphere between the camera and the earth. At 30,000 feet, almost 70 per cent of the atmosphere is below the camera. This problem is partly alleviated by requiring aerial photography on days with little atmospheric attenuation and by the use of higher cutoff haze filters.
- As scale decreases, it is more difficult to locate oneself exactly on the ground using the photographs as a guide. In most situations, it is necessary to make ground checks, and with small scale photos this is even more evident.
- Delineating the same amount of information on small scale photographs as on medium scale photographs increases the data clutter per unit photo area. Symbolizing for very small areas may be very difficult unless the symbols are very simple or written very small.
- There is one final disadvantage which can override all the advantages of small scale aerial photography. If resolution or contrast differences do not satisfy information needs, then it is best to use a more appropriate scale. Such a situation requires testing of numerous scales of photography for a multitude of purposes. Axelson (1956), Eyre (1971), Howard (1967), Paijmans (1966), Ulliman and Meyer (1971), Young, *et al.* (1963), and many more recent investigations (the American Society of Photogrammetry, 1972) show that interpretation on small scale photography is feasible for certain studies.

In many areas throughout the world natural resources can be directly photo-interpreted only on the basis of characteristics of tone, texture, site, etc. Where they cannot, ground checks can provide sufficient information for interpretation. This is a key point in the use of aerial photography. Since the interpretation of aerial photos is basically a sampling technique, ground checks will be required to correlate what is seen on the ground with what is seen on the photograph and, depending on the accuracy required, more or fewer ground checks may be required or a greater or lesser resolution will be required. All of these alternatives will be weighed by economic considerations.

The purpose of this investigation was to define and enumerate some of the cost differentials of acquisition between medium scale and small scale aerial photography.

Costs for Obtaining Aerial Photography

Cost comparisons for obtaining aerial photography are very difficult, because there is little published data and commercial firms are reluctant to release data they hold as confidential in their determination of bids. Since there are no exact figures, the following guidelines will be used: reference data from Avery and Meyer (1962), and the American Society of Photogrammetry (1966); and the author's knowledge and experience in relations with commercial aerial survey firms.

There are generally three ways in which costs of obtaining aerial photography could be compared: (1) in contracts with commercial firms; (2) purchasing existing photography; or (3) obtaining one's own photography by the best means available. Because the last method depends greatly on experience, availability of equipment, and need of the users, costs are so variable that they will not be discussed separately in this analysis. But given one person's or group's ability to do aerial photography, the same analysis as for "Contracting for Photography" will apply.

Purchasing Existing Photography

Purchasing existing photography is one of the cheapest means of obtaining aerial photography. For example, three agencies of the federal government offer individual prints of 1:20,000 scale aerial photographs for \$1.75 per print. Commercial firms charge approximately ten dollars for the first print in obtaining aerial photographs, with decreasing costs for an increased number of prints. One firm having small scale (1:90,000) photography for a large area indicates the following prices (MHAS, 1969):

First print	Next 2-10	Next 11-100	All over 100	Duplicates same order
\$10.00	\$6.00 ea	\$4.00 ea	\$3.00 ea	\$2.50 ea

The minimum order charge is \$25.00.

Prices for all other conventional photography from the same firm (excluding customer re-ordering contracted photography) are:

First print	Next 2-50	Next 51-100	All over 100	Duplicates same order
\$10.00	\$4.75 ea	\$3.50 ea	Special consideration	\$2.50 ea

This suggests that small scale aerial photo prints, depending on the number ordered, are generally no more expensive than medium scale aerial photo prints. In fact, on a per acre or square mile basis, they are far more favorably priced. The low cost for the

TABLE 1. AERIAL PHOTO PRINTS REQUIRED FOR VARIOUS SCALES.

Scale	Photos per 10 lineal miles	Photos per 100 square miles
1:5,000	35	700
1:15,840	11	77
1:63,360	3	6
1:90,000	2	4

small scale in this case can be partly attributed to the fact that the entire State of Minnesota was flown at 1:90,000 scale. Even though resolution capabilities may be satisfactory for many users, the film-filter combination or the time of year of the overflight may not be suitable. In purchasing existing photography, one is limited to what is available. But based on what is *presently available*, small scale is less expensive per unit area than medium scale aerial photographs.

CONTRACTING FOR PHOTOGRAPHY

Contracting for aerial photography involves many considerations, (Avery and Meyer, 1962; American Society of Photogrammetry, 1966). The variables used for determining costs are very complicated. Two of the most important are the scale of the photography and the size of the area to be photographed. Avery and Meyer (1962) indicate that as scale increases (becomes larger), or as the size of the area decreases, costs per unit area increase. This may not necessarily hold true for high altitude photography because higher altitudes require more powerful, more expensive aircraft. The *Manual of Photogrammetry* (American Society of Photogrammetry, 1966) indicates that the cost of producing high altitude aerial photography increases geometrically with altitude; that the cost of 30,000 foot altitude aerial photography is twice that of 20,000 foot altitude aerial photography. The reasons stated for this increased cost are larger aircraft, increased maintenance and down time, and the need for more ideal atmospheric conditions.

Approximate costs for various types of aircraft which may be used in obtaining high-altitude aerial photography are given in Table 2 (*Flying Annual and Pilot's Guide*, Aviation Division, 1968). Indicated in the table are the types of aircraft, service ceilings, top speeds and basic costs, not including avionics or modification of aircraft for aerial photography.

Some single-engine piston aircraft can attain an altitude of 30,000 feet, with a few turbocharged single-engine aircraft attaining as high as 32,000 feet; their cost range is under $50,000. Normally though, most aerial survey firms use a twin-engine aircraft for altitudes above 18,000 feet for reasons of safety, speed, range of aircraft, and comfort of crew. Twin-engine aircraft may vary in cost between $30,000 and $260,000. Turbo-prop aircraft, although generally more expensive, cannot attain altitudes much above 30,000 feet. To attain much more than a 30,000-foot altitude requires the use of a turbo-jet aircraft which costs more than $600,000. The 1:90,000 scale high altitude photography discussed previously was flown with a Lear Jet.

In contracting for aerial photography there are many factors involved, but most will be considered constant between the larger and smaller scales. The cost factors remaining constant for both scales and together defined as C_o are:

1. Internal to the firm
   a. Business activity
   b. Depreciation
   c. Insurance
   d. Facilities available

TABLE 2. APPROXIMATE COSTS, SERVICE CEILING, AND TOP SPEED FOR VARIOUS TYPES OF AIRCRAFT.

Type Aircraft	Service Ceiling (ft)	Top Speed (MPH)	Basic Cost (Thousands $)
Cessna 180, single engine piston	19,500	170	18
Single-engine pistons (class)	19,000-24,500	130-216	10-25
Single-engine pistons (class)	25,000-30,000	200-255	28-30
Riley Turborocket twin-engine piston	32,000	302	74
Twin-engine pistons (class)	18,000-34,500	168-310	30-260
Turbo-props (class)	16,500-30,400	250-357	159-1,300
Lear turbo-jet	45,000	553	650
Turbo-jets (class)	37,000-45,000	495-553	600-823
Turbo-jets (class)	42,000-48,000	515-570	1,000-1,590
Turbo-jets (class)	35,000-46,500	550-600	2,525-3,600

2. Personnel
   a. Management
   b. Crew
   c. Lab personnel
3. Equipment
   a. Aircraft available (would consider firms already having desired capabilities)
   b. Cameras, lenses, filters, etc.
4. Specifications of contract
   a. Area coverage
   b. Type photos (vertical, oblique)
   c. Camera and lens specifications
   d. Film type
   e. Stereo coverage (overlap)
   f. Standards of accuracy (crab, tilt, drift, flight line positioning and orientation)
   g. Final product (negatives, prints, mosaics furnished)
5. Physical elements
   a. Weather
   b. Season (ground conditions)
   c. Condition of vegetation
6. Flying
   Distance to project area
7. Processing
   Distance film shipped for processing

Actually some of these factors may vary: (a) at higher altitudes, a higher haze cutoff filter may be required; if the firm does not have the filter on hand, purchasing it would be an additional expense; (b) at higher altitudes, flight line positioning, orientation, and altitude determination may be more of a problem, but this could be handled through more experience by the pilot and crew; at higher altitudes, there is usually less turbulence, therefore tilt may be less of a problem; (c) by using more powerful aircraft at high altitudes, aerial photography may be more quickly accomplished between times of poorer weather; disadvantageously, higher clouds may interfere with higher altitude photography.

The principal cost differentials between a larger and smaller scale of photography will be affected by the following factors: (1) Aircraft cost (C_A) which includes the hourly cost of the aircraft (A), the speed of the aircraft (S), and total aircraft miles (M); (2) Number of exposures or total film and print cost (C_F), and (3) Cost of lab personnel time in processing and drying of film and prints, titling, inspecting and indexing (C_L).

The hourly cost of the aircraft (A) times the total aircraft miles (M) divided by the speed of the aircraft (S) will determine the total cost (C_A) of the aircraft for the project, so that:

$$\frac{A}{S}(M) = C_A \tag{1}$$

Total photography cost (C_{TP}) will be determined by:

$$C_A + C_F + C_L + C_O = C_{TP} \tag{2}$$

where: C_A, C_F and C_L equal those costs which vary significantly between different scales of photography, and C_O represents those other costs which remain relatively constant between different scales of photography.

By determining the relative cost change between different scales and multiplying it times the per cent of the total cost for that factor, the total relative change in cost can be determined and hence the total cost. The relative factor (′) can be stated as:

$$C'_A\,(C_A/C_{TP}) + C'_F\,(C_F/C_{TP}) + C'_L\,(C_L/C_{TP}) + C'_O\,(C_O/C_{TP}) = C'_{TP} \tag{3}$$

where: C_A/C_{TP}, C_F/C_{TP}, C_L/C_{TP}, and C_O/C_{TP} equal the per cent of the total cost for that factor.

The factors which change cost significantly between the different scales will be analyzed to determine the influence of scale on them.

Aircraft Cost (C_A). For purposes of this analysis, the first factor, hourly cost of aircraft, will be based on the hourly rate of aircraft stated in ASP (1966) and listed in Table 3.

These rates are grouped by type of aircraft and have surely risen since originally determined, but they can be used if, as assumed, the relative differences between types has remained relatively constant. A relative cost factor is determined between each of the aircraft and is shown in Table 4.

As altitude for obtaining photography is increased and more powerful aircraft are used, total flying time may be decreased because of greater flying speeds. This factor can have a significant influence on costs for large projects. Using the average aerial photo cruising speed from Table 3, the speed factor is determined and is also listed in Table 4. The

TABLE 3. HOURLY AIRCRAFT COST AND CRUISING SPEED.

Type Aircraft	Hourly Rate	Average Aerial Photo Cruising Speed (mph)
Single-engine	$ 17	135
Light twin-engine	$ 45	160
Large twin-engine	$ 90	185
Four-engine	$260	200
Lear Jet	$500*	540

* J. Ward, Mark Hurd Aerial Surveys, personal communications, 1969.

TABLE 4. RELATIVE COST AND SPEED FACTORS.

	Hourly cost factor (A)	Speed factor (S)	A/S
Light twin-engine vs. a single-engine	2.65	1.19	2.22
Large twin-engine vs. a single-engine	5.29	1.37	3.86
Four-engine vs. a single-engine	15.29	1.47	10.40
Lear Jet vs. a single-engine	29.41	4.00	7.35
Large twin-engine vs. a light twin-engine	2.00	1.16	1.72
Four-engine vs. a light twin engine	5.78	1.25	4.62
Lear Jet vs. a light twin-engine	11.11	3.33	3.34
Four-engine vs. a large twin-engine	2.89	1.09	2.65
Lear Jet vs. a large twin-engine	5.56	2.94	1.89
Lear Jet vs. a four-engine	1.92	2.70	0.71

combined cost and speed factors indicate the relative increase in cost for using a more powerful aircraft. These are average figures for a broad range of aircraft in most cases and must be conditioned on this fact.

The third factor to consider under aircraft costs is the total aircraft miles, which is dependent on the number of flight lines. The number of flight lines N_L for a project area is determined by:

$$N_L = \frac{\text{width of project area (W)}}{\text{net side gain in ground distance (NSG)}} \quad (4)$$

where: NSG = per cent side gain (PSG) × photo distance (PD) × photo scale reciprocal (PSR)

$$\text{or: } N_L = \frac{W}{PG \times PD \times PSR} \quad (5)$$

Any fractional number is rounded to the next highest whole number. By keeping constant W, PG, and PD, it will be noted that as PSR is doubled, N_L is halved. For a large project area over 1,000 square miles, the total aircraft miles also will be halved if the cross-country aircraft mileage is disregarded.

Film and Print Cost (C_F). The second major factor is the number of exposures or resultant amount of film and print material used in the project. The total number of exposures for a project area is the number of exposures per flight line times the number of flight lines. The number of exposures per flight line (N_E) is determined by:

$$N_E = \frac{\text{length of area (L)}}{\text{net forward gain in ground distance (NFG)}} \quad (6)$$

where: NFG = per cent forward gain (PFG) × PD × PSR

$$\text{or: } N_E = \frac{L}{PFG \times PD \times PSR} \quad (7)$$

Any fractional numbers are rounded to the next highest whole number and four photos are added per flight line to insure complete coverage. Again, note that by doubling PSR, N_E per line is halved. (This is not exact for short flight lines because of the addition of four photos, which would be a relatively greater amount in the case of the small scale photography.) It can be shown then, that if PSR is doubled, the total number of exposures required for the project is reduced to approximately one-fourth the original.

Lab Labor Cost (C_L). Finally, the lab personnel time for processing and drying the film and prints, and for titling, inspecting and indexing is considered. Personnel will be handling and processing one-fourth the materials for each doubling of the photo scale reciprocal. Because of basic set-up times for various procedures, total cost may not be reduced one-fourth, but for large projects, it will approach this figure.

In any analysis of cost between large or medium scale and small scale aerial photo contracts, it will be assumed that only relatively large aerial survey firms with experience and expertise will be considered, and that the project area will be larger than 1,000 square miles.

COST EXAMPLE

The cost for a change in scale and type of aircraft can be estimated if cost relationships are known for a larger scale of photography. For example, given the following information, the costs for small scale photography can be determined:

Former scale — 1:20,000
Former aircraft — Cessna 180
Desired scale — 1:80,000
Total cost for obtaining 1:20,000 scale photography — $50,000.

TABLE 5. AERIAL SURVEY EXPENDITURES (IN U.S. $/100 SQ KM). (PER CENT OF TOTAL IN PARENTHESIS)

Scale	1:70,000	1:40,000	1:20,000	1:10,000
Flying	40 (87)	110 (85)	270 (79)	605 (68)
Photography	2.5 (5)	7.5 (6)	30 (9)	120 (13)
Interpretation	3.5 (8)	10 (8)	42 (12)	171 (19)
Total	46.0	127.5	342	896

Per cent of total cost for the factors used in obtaining the 1:20,000 scale photography:

Aircraft cost	C_A/C_{TP} = 10 per cent
Film cost	C_F/C_{TP} = 10 per cent
Lab cost	C_L/C_{TP} = 10 per cent
Other cost	C_O/C_{TP} = 70 per cent

These cost percentages are general figures and vary with each project. (Personal communication: Mr. Robert Sporrong, Mark Hurd Aerial Surveys, Inc. 1971)

A more powerful aircraft is required to attain the 40,000-foot altitude desired for this example if a 6-inch focal length camera is used. In this case, a Lear Jet, which is 29.41 times the cost of a Cessna 180 but has four times the photographing speed, will be used. The cost for the Lear Jet then is 7.35 times the single-engine aircraft (refer to Table 4, column A/S). The total aircraft miles for a four-times scale change (1:20,000 to 1:80,000) is, using formula (5), one-fourth the number for the larger scale which used the Cessna 180. The factor cost of the aircraft $C'_A = 7.35 \times 0.25$ or 1.84.

Using formula (7), it is determined that the number of exposures is reduced 1/16th and therefore:

the factor cost of film material and prints $C'_F = 0.0625$, and the factor cost for lab personnel time $C'_L = 0.0625$.

If all other factors are considered equal, i.e., $C'_O = 1.0$, between the two scales of photography, then the total relative cost factor, using formula (3) and substituting the appropriate values, is:

$$C'_{TP} = 1.84\,(0.10) + 0.0625\,(0.10) + 0.0625\,(0.10) + 1.0\,(0.70)$$

$$C'_{TP} = 0.184 + 0.00625 + 0.00625 + 0.7$$

$$C'_{TP} = 0.8965.$$

The total relative cost factor times the total cost of the 1:20,000-scale photography equals the total cost for obtaining the 1:80,000-scale photography.

$$C_{TP} = 0.8965 \times \$50,000 = \$44,825.$$

For this example, the small (1:80,000) scale photography would be cheaper to procure ($44,825) than the medium (1:20,000) scale photography ($50,000).

Stellingwerf (1969) also provides some cost comparisons between scales of photography. The source or situation under which the photography was obtained is not known except that it was obtained primarily for mapping. These cost are listed in Table 5.

The use of any aircraft less expensive than a Lear Jet will further reduce costs for the small scale photography. This was probably the case for the costs of *flying* stated by Stellingwerf, whereby a doubling in the photo scale reciprocal reduced *flying* costs by an average of 2.3× (605/270, 270/110, etc.). His *photo* costs are reduced 4.0× (120/30, 30/7.5, etc.) for each doubling of the photo scale reciprocal, which is in agreement with those stated here.

Kummer (1964) describes a project in Washington in which three million acres were photographed at a scale of 1:56,000 using a supercharged single-engine aircraft. In comparison to photography at a scale of 1:12,000, flying cost was reduced by a ratio of 5:1, mainly due to the reduced flying time. Lab cost for contact prints was reduced by a factor of 20:1; this is considerably more than might be expected.

Precedent does indicate potential cost savings for higher altitude aerial photography.

SUMMARY

The costs for obtaining small scale resource aerial photography compared to those for obtaining medium scale resource aerial photography have been analyzed. The factors involved in obtaining aerial photography are quite variable and therefore will differ with each project depending on the conditions existing at the time. But given the fact that certain information needs can be met, and under the assumptions used in this study, high-altitude aerial photography can have a cost advantage for some large projects.

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