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A FEASIBILITY STUDY OF AERIAL IMAGING TECHNIQUES FOR PRECISE AI--ETC(U)
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A FEASIBILITY STUDY OF AERIAL IMAGING TECHNIQUES FOR PRECISE AIDS TO NAVIGATION POSITION DETERMINATION

F. Giovane
U. S. Coast Guard Research and Development Center
Avery Point, Groton, Connecticut 06340

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D. L. Birkimer

DONALD L. BIRKIMER, Ph.D., P.E.
Technical Director
U.S. Coast Guard Research and Development Center
Avery Point, Groton, Connecticut 06340

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16. Abstract

An investigation of the feasibility of using aerial imaging techniques for veryifying precisely the positions of aids to navigation was conducted. It was determined that such a method is technically feasible using cartographic aerial photography and precise photogrammetric data reduction. However, such a system would be impractical and expensive for Coast Guard use on a routine basis.

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METRIC CONVERSION FACTORS

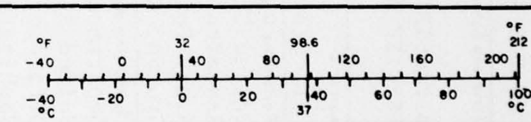
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1.0 INTRODUCTION

The purpose of this study was to investigate the feasibility of using aerial imaging techniques for verifying precisely the positions of aids to navigation.

Background information on the various aerial imaging systems available is contained in the formal final report, "Semi-Precise Aerial Audit of Buoy Positions", completed by the U.S. Coast Guard R&D Center on September 1977.

2.0 APPROACH

Aerial imaging systems such as IR (Infrared Scanners), SLAR (Side Looking Airborne Radars), and Cartographic Aerial Photography were investigated to determine their suitability for a precise aerial audit. In a previous report, "Semi-Precise Aerial Audit of Buoy Positions," it was determined that the currently available IR and SLAR systems lack the resolution and control required for a precise aerial audit, and that aerial photography was the most precise method available for verifying positions of aids to navigation. Therefore, major emphasis was placed on Cartographic Aerial Photography.

In order to obtain realistic cost figures for a cartographic aerial audit, two coastal areas representing extremes of coastal geography were selected for evaluation. Using the scale, resolution, and control requirements determined during the study, a cost analysis was done for each category of buoys and for each category of desired accuracy.

3.0 DISCUSSIONS

3.1 Definitions

Candidate systems must be suitable for routine audits which cover large areas and enable one to precisely determine the positions of buoys. Three classes of positional accuracy investigated are:

Class	Accuracy
I	0 to 10 feet
II	11 to 50 feet
III	51 to 100 feet

Aids to navigation are either floating or fixed. Floating aids are buoys or lightships moored to the bottom, and therefore do not occupy a fixed position, but rather move about in an area defined by the depth of water, length of mooring chain, and environmental forces. These aids move about their sinkers or anchors due to external forces such as wind, current, collisions, etc. For the purpose of this study, floating aids are separated, arbitrarily, into two categories by size.

Small floating aids are those less than or equal to five feet in diameter while large floating aids are those greater than five feet in diameter.

Fixed aids are those which are permanently embedded in the seabed or ashore, and maintain fixed geographical positions. A major cause of damage to these aids is collision. Fixed aids range in size from 1 foot diameter poles to metal towers about 15 feet on a side.

In dealing with photographic data reduction, the detection and identification of the object are two important concepts. The smallest photographic scale at which an object can be separated from its background is the limiting scale for detecting the object. The smallest photographic scale required to positively identify the object (as an aid to navigation) is the limiting scale for identifying the object.

3.2 Precise Auditing Systems

Cartographic Aerial Photography is the only method currently available for achieving acceptable results for precise position determination of aids in wide areas of coverage. The ability to detect, identify and accurately measure the position of aids on a photograph is determined by the photographic system resolution, and differential spectral reflectivity, and the size of the aid. These factors determine the scale of the photography to be used. The types of cameras and films involved are explained in Appendix II of "The Semi-Precise Audit of Buoy Positions" formal final report of October 1977. Based on theoretical calculations and discussions with several commercial firms, practical and achievable limits of photographic scale have been determined. These are shown below by class of accuracy for each type of aid.

	Position Accuracy	Type of Aid	Photographic Scale
Class I	To 10 feet	Small	1:12,000
		Large	1:24,000
		Fixed	1:24,000
Class II	11 to 50 feet	Small	1:18,000
		Large	1:30,000
		Fixed	1:30,000
Class III	50 to 100 feet	Small	1:18,000
		Large	1:30,000
		Fixed	1:30,000

The photographic scale required for Class II and Class III accuracies are the same for respective types of aids because they are the limiting photographic scales for detection and identification of the aid. The photographic scales for Class I accuracy are larger because the images of the aids must be larger for more accurate work.

There are two common ways of acquiring suitable photography for precise audit of aids:

(1) All photography could be acquired at the smallest scale which allows detection and identification of the smallest aid in the area. For example, a scale of 1:12,000 (using a 6-inch focal length lens of cartographic quality at a flying height of 6,000 feet) would be required to determine the position of small aids for Class I accuracy. This, in turn, requires a large number of exposures per unit area, all of which would be used for mensuration.

(2) The second method uses two cameras simulataneously to acquire photography at two different scales. One photographic scale is the smallest scale that allows detection of both large and small aids, and identification of large aids. The supplemental large scale photography is used to identify the small aids. For example, cartographic quality photography at a scale of 1:24,000 (using the 6-inch focal length lens at a flying height of 12,000 feet) could be combined, simultaneously, with supplemental photography at a scale of 1:12,000 (using a 12-inch focal length lens at the same flying height of 12,000 feet), covering one-fourth the area on a single photograph. The large-scale photography is taken over those areas that contain small aids.

The cost of an aerial audit is based not only on the number of exposures taken, but also on the number of exposures used for mensuration. Method two would require the same number of exposures per unit area as method one, but only one-fourth of these (the small-scale photography) would be used for mensuration. A substantial overall savings could be made by using Method Two in lieu of Method One. Method One ensures a high level of success at high cost, while there is a greater likelihood of missing aids using Method Two, but the cost would be considerably less.

3.3 Data Reduction Methods

The accuracy of positions determined using aerial photography and photogrammetry is dependent on the identification of the horizontal control points on the aerial photography. Ground control points must be selected prior to the audit so that they are easily observable on the photography, and must have good vertical relief. Lighthouses, water tanks, oil storage tanks, monuments, flagpoles, and large fixed aids which have known geographical positions are some examples of good ground control points. The vertical relief of the ground control point is important to the stereocompiler as it enables him to utilize the full precision of his instrument in establishing the center of the horizontal control point. Improper identification of a control point invalidates the control on which aid positions will be based and creates problems and uncertainties which waste time and effort. Specially designed cloth or canvas targets are used to enhance critical control points that are not expected to be readily identifiable on the photography. They are also used when special geodetic control points must be established. This type of target enhancement (paneling) is relatively simple and many shapes and types are commercially available.

These targets are subject to disturbance by weather, animals, and people. This happens quite frequently, and a certain amount of maintenance may be needed. Paneling and the establishment of geodetic control points adds considerable expense to the operation (about $500 per day).

Having obtained suitable aerial photography, one must then measure the locations of the aids in question. It must be realized that:

(1) The location obtained for the aid is good only for that instant of time at which the exposure was taken.

(2) To obtain the accuracies required, the data reduction must be done analytically with no reference measurements made from maps or charts.

The position of an aid on the photography may be determined relative to points of known location (control points) by two methods. The method most commonly used is trilateration. Trilateration is a method of determining the relative position of the aid by effectively measuring the distances from the aid to the control points. Triangulation is a method which requires measuring angles from the control points to the aids. Both triangulation and trilateration could be required to extend the horizontal control network from exposure to exposure to permit the establishment of the location of offshore aids. The accuracy of the new positions will be dependent upon the accuracy limitations of the extended control network.

The type of equipment used to establish stereo-models for photogrammetric triangulation and/or trilateration is extremely expensive and requires years of experience to operate at the level of accuracy required for the precise audit.

3.4 Costs

The expense of the aerial audit includes acquisition and processing of suitable photography, ground control surveys, and reduction of the photographic data. The cost of acquisition and field surveys is affected by the location of the work, time of year, and the overall size of the area being audited. The data reduction costs vary depending on the contractor. Several sources of contractors are available, both commercial firms, of which there are many, and federal agencies.

A comparison of the cost differences for the extremes of coastal geography was made. These costs estimates of the audit were based on required photographic scales, number of exposures needed and cost per exposure for acquistion and reduction. Preparatory costs such as pre-mission planning and ground control surveys are included. The two areas selected to represent these extremes were: Cape Fear River, NC; and Buzzard's Bay, MA (Figures 1 and 2 respectively).

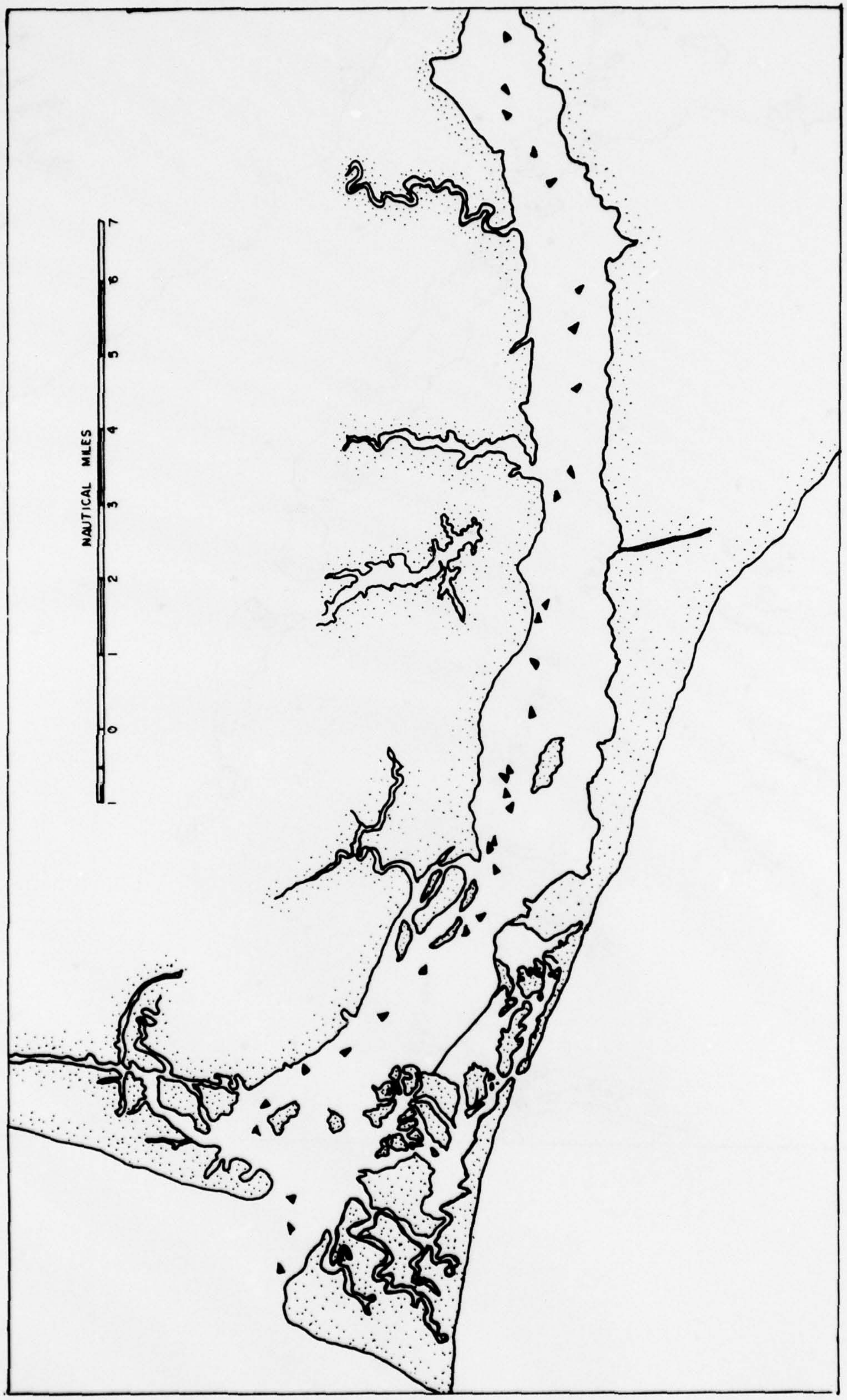
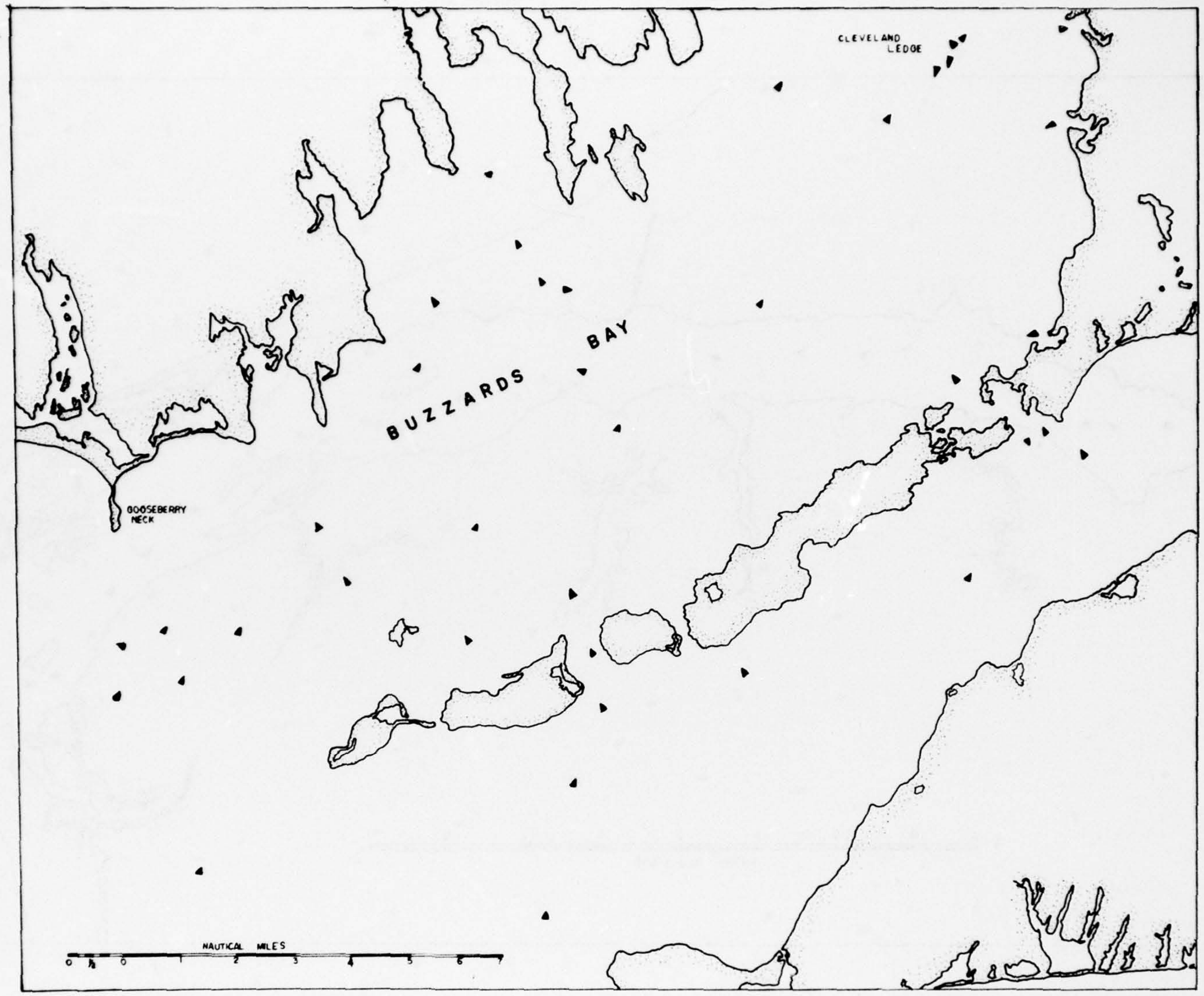


FIGURE 1



CLEVELAND
LEDGE
BUZZARDS BAY
GOOSEBERRY
NECK
NAUTICAL MILES
0 1 2 3 4 5 6 7

FIGURE 2

4.0 RESULTS

4.1 Cost Comparison

The results of the cost comparisons made are shown in Tables 1 and 2 for the Cape Fear, NC and Buzzard's Bay, MA areas respectively. The commercial costs are based on discussions with several image mapping firms. These estimates are given as the cost per exposure: $10 per exposure for acquisition, and $70 per exposure for data reduction. Ground control surveys will cost about $500 per day. This works out to be about $50 per square mile.

National Ocean Survey (NOS) costs are based on previous work done for the Coast Guard and on estimates received from NOS. An example of NOS costs are presented in Table 3, where a cost breakdown of a survey of the Delaware River (Figure 3) made for the Third Coast Guard District, is shown. NOS costs were quoted as $15 per exposure for acquisition and processing and $65 per exposure for data reduction. These costs are essentially the same as those quoted by commercial firms, and with ground control surveys, come to about $50 per square mile.

For the Cape Fear River area, about one day of ground control survey work would be required, increasing the total cost for Class I accuracy by about $500. As shown in Table 1, a Class I audit to include all sizes of aids would cost about $7,500. If only large aids were audited, the cost would be reduced to about $3,900. Class II and Class III accuracy would cost about $1,300 for large aids and $4,600 to include small aids. Historical climatological data indicates that an average of two days delay due to weather should be expected.

A greater amount of ground control survey (about three days effort) is required for the Buzzard's Bay area. Class I accuracy costs would be increased by about $1,500 above the totals shown in Table 2. For this area a Class I audit to cover all aids would cost about $22,500, and about $7,500 for only large aids. Class II and Class III audits would cost about $3,200 for large aids only, and about $10,000 for all aids. Historical climatological data indicates that an average of three days delay due to weather should be expected.

NOS surveyed the Delaware River from Trenton to Arnold Point (Figure 3), a distance of about 85 river miles in 1974. The actual area of photographic coverage varied from 3 miles wide to about 7 miles wide for a total of about 330 square miles. There are 233 floating aids and 174 fixed aids along this stretch of the Delaware River. The actual NOS costs, including extensive field survey method for their charting purposes, is compared with the estimated NOS costs in Table 3. The estimated costs are based on Coast Guard needs only, and NOS cost quotations of $15 per exposure for acquisition, $65 per exposure for data reduction and $500 per day for the necessary paneling. A photographic scale of 1:24,000 is assumed.

TABLE 1

COST ANALYSIS FOR THE CAPE FEAR RIVER FROM CAPE FEAR TO WILMINGTON, NC

The total area is about fifty square miles (two miles wide and twenty-five miles long). Those totals with the asterisks include an additional 10 percent to cover the added cost for extending control to the outer channel aids. There are 85 fixed aids and 45 floating aids in the coverage area.

Scale	Exposures needed	Aquistion cost	Data reduction	Total
1:36,000	13	$ 130	$ 910	$ 1,040
1:30,000	16	160	1,120	1,280
1:24,000	38	380	2,660	3,350*
1:18,000	52	520	3,640	4,600*
1:12,000	78	780	5,460	7,000*

TABLE 2

COST ANALYSIS FOR BUZZARD'S BAY FROM GOOSEBERRY NECK EAST TO CLEVELAND LEDGE

The area is about one hundred twenty square miles (six miles wide and twenty miles long). Those totals with asterisks include an additional 20 percent to cover the added cost for extending control stations to aids located greater than two miles offshore. There are 15 fixed aids and 110 floating aids in this coverage area.

Scale	Exposures needed	Aquistion cost	Data reduction	Total
1:36,000	21	$ 210	$ 1,470	$ 1,680
1:30,000	39	390	2,730	3,120
1:24,000	64	640	4,480	6,016*
1:18,000	105	1,050	7,350	9,870*
1:12,000	217	2,170	15,190	20,898*

TABLE 3

COMPARISON OF DELAWARE RIVER SURVEY COSTS

There is a difference of $55,200 between these two sets of figures. The first order survey completed by NOS for their needs is in excess of the needs of the Coast Guard for buoy auditing. The number of exposures taken by NOS was twice the number since they require data for both mean and high and mean low water.

A		B
Estimated Costs For CG Needs		Actual Costs for NOS Needs
$4,950	Photo Acquistion	$21,000
$5,000	Field Work	$50,000
$21,450	Data Reduction	$15,600
$31,400	TOTAL	$86,600

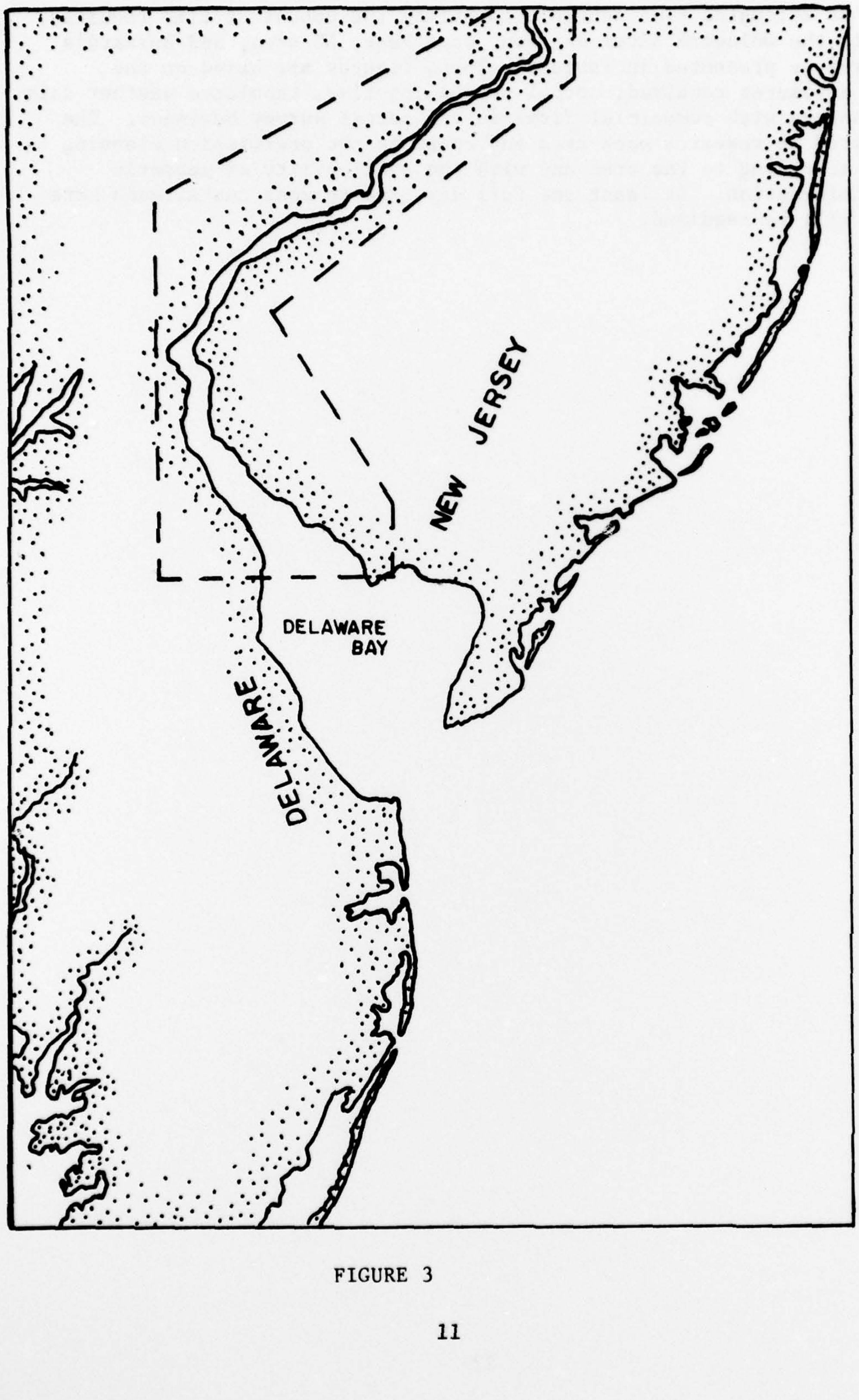


FIGURE 3

An estimated time schedule comparing the amount of time required to complete the Delaware River section, Cape Fear, NC area, and Buzzard's Bay, MA area is presented in Table 4. These figures are based on the number of exposures required, normal processing time, tabulated weather data and discussions with commercial firms in the aerial survey business. The time required to research each area and complete the pre-mission planning will vary according to the area and with the availability of geodetic position information. At least one full day, and in most cases, much more than this will be required.

TABLE 4
TIME IN DAYS

	Cape Fear, NC	Buzzard's Bay	Delaware River
Field Investigation	1	2	2
Flight Time	1	1	1
Average Weather Delays	2	3	3
Processing	3	3	3
Data Reduction	2	4	10
Total	7	13	19

* Pre-mission planning and research time is not included.

The 19 days does not represent the total time required to obtain the results from NOS. From the time the agreement was made by NOS to do the work for the Coast Guard, until the final results were made available, approximately three years elapsed. This is due to NOS doing this work on a routine basis, including their extensive review process to ensure that no mistakes have been made.

5.0 CONCLUSIONS

5.1 A precise aerial audit is technically feasible for the three stated classes of accuracy. Cartographic aerial photography coupled with precise photogrammetric mensuration can be used to determine the location of aids relative to known geodetic control points within ±10 feet (Class I accuracy).

5.2 The cost for Class I audit of all aids would range from $150 to $200 per square mile depending upon the area to be audited. Both Class II and Class III audits must be done at the same photographic scale. Therefore, the cost for both classes would be equal and would range from $150 to $100 per square mile depending upon the area. These costs figures are only approximations based on two extremes of coastal geography. The vast differences in coastal geography preclude an expansion of cost estimates to cover precise aerial audits for the entire Coast Guard areas of responsibility.

5.3 The precise aerial audit is a practical tool in certain circumstances. (1) An audit of all fixed aids is being done by NOS as a part of their map and chart update program. Liaison with the Coast Guard has been established to insure that maximum utilization of the program is obtained. (2) A precise audit might be practical in special areas or circumstances to assess the amount of damage caused by severe storms, floods or heavy ice conditions.

5.4 The results of an earlier study, appended to Commandant (G-DAS) memo 3260 of 24 June 1971, arrived at the same basic conclusions. A copy of this report, accompanied by updated responses to the questions asked, is attached as Appendix I.

6.0 RECOMMENDATIONS

6.1 Aerial imaging techniques are impractical and expensive for routine, wide area, precise audits of aids to navigation, and should not be given further consideration for use as a routine procedure. This seems to be in contradiction to high cost and time.

GLOSSARY OF TERMS

CARTOGRAPHY - The art of map construction and the science upon which it rests.

CAMERA, CARTOGRAPHIC - A camera specially designed for the production of photographs to be used in cartography. The camera is equipped with mechanisms to maintain and to indicate the interior orientation of the photographs with sufficient accuracy for map compilation purposes.

CONTRAST - In general, the degree of differentiation between tones. Subject contrast is the difference in luminance between an object and its background.

CONTROL - A system of accurate measurements used to determine the distances and directions or differences in elevation between points on the earth.

CONTROL, GEODETIC - Control which takes into account the size and shape of the earth. Geodetic implies a reference spheriod representing the geoid and horizontal and vertical control data.

CONTROL, GROUND - Control obtained by ground surveys.

CONTROL, HORIZONTAL - Control which determines horizontal positions only, as with respect to parallels and meridians, or to other lines of reference.

CONTROL, PHOTOGRAMMETRIC - Control established by photogrammetric methods as distinguished from ground control established by ground methods. Often referred to as "minor control" and "extension".

CONTROL POINT - Any station in a horizontal/vertical control system that is identified on a photograph and used for correlating the data shown on the photograph.

COVERAGE - The ground area represented on aerial photographs, photomosaics or maps.

COVERAGE, STEREOSCOPIC - Aerial photographs taken with sufficient overlap to permit complete stereoscopic examination.

DISPLACEMENT, RELIEF - The difference in the position of a point above or below the datum, with respect to the datum position of that point, owing to the perspective of an aerial photograph. Used to define elevation with respect to sea level as the datum.

PHOTOGRAMMETRY - The science or art of obtaining reliable measurements by means of photography.

SCALE - The relation between map or photo distance and ground distance, expressed as a fraction (1/24,000) or often as a ratio (1:24,000).

RESOLUTION - The ability of the entire photographic system, including lens, exposure, processing, and other factors, to render a sharply defined image.

STEREOCOMPARATOR - A stereoscope with special attachments for measuring parallax. Used in stereocompilation.

STEREOCOMPILER - Individual who operates a stereocomparator.

STEREO MODEL - Two photographs with sufficient overlap and consequent duplication of detail to make possible stereoscopic examination of an object or area common to both.

TRIANGULATION - A method of surveying in which stations are points on the ground at the vertices of a chain or network of triangles whose angles are observed instrumentally and whose sides are derived by computation from select triangle sides called base lines, whose lengths are obtained from direct measurements on the ground.

MENSURATION - The science or art of making precise measurements.

PANELING - A technique whereby cloth or canvas panels are placed about a control point to enhance its identification on the photograph.

TRILATERATION - A method of determining horizontal ground positions by measuring the sides of triangles, in lieu of angles.

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