AD-A037 224 COAST GUARD RESEARCH AND DEVELOPMENT CENTER GROTON CONN F/G 8/12
PHYSICAL PROPERTIES OF ICEBERGS. PART I. HEIGHT TO DRAFT RATIOS--ETC(U)
JUN 76 R Q ROBE, L D FARMER

UNCLASSIFIED CGR/DC-11/76 USCG-D-102-76 NL

1 OF 1
AD
A037224

END
DATE
FILMED
4-77

Report No. CG-D-102-76

(13)

PHYSICAL PROPERTIES OF ICEBERGS

PART I - HEIGHT TO DRAFT RATIOS OF ICEBERGS

R. Q. ROBE

PART II - MASS ESTIMATION OF ARCTIC ICEBERGS

R. Q. ROBE and L. D. FARMER

June 1976

Final Report

Document is available to the public through the
National Technical Information Service,
Springfield, Virginia 22161

Prepared for

DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD
Office of Research and Development
Washington, D.C. 20590

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The contents of this report reflect the views of the Coast Guard Research and Development Center, which is responsible for the facts and accuracy of data presented. This report does not constitute a standard, specification or regulation.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
USCG-D-102-76		

4. Title and Subtitle

PHYSICAL PROPERTIES OF ICEBERGS
PART I - HEIGHT TO DRAFT RATIOS OF ICEBERGS
PART II - MASS ESTIMATION OF ARCTIC ICEBERGS

5. Report Date: Jun[redacted] [redacted]76

6. Performing Organization Code

7. Author(s)

R.Q. ROBE (PART I); R.Q. ROBE [redacted] L.D. FARMER (PART II)

8. Performing Organization Report No.: CGR/DC-11/76

9. Performing Organization Name and Address

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

10. Work Unit No. (TRAIS): 65006.03

11. Contract or Grant No.

12. Sponsoring Agency Name and Address

Department of Transportation
U. S. Coast Guard
Office of Research and Development
Washington, DC 20590

13. Type of Report and Period Covered: Final Rep[redacted]rt

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

PART I - A study of height to draft ratios of icebergs near the Davis Strait reveals ratios which range from 1:1.28 to 1:10.56. The ratios of bergs dominated by their horizontal dimension, such as tabular or broken tabular icebergs, have average height to draft ratios of 1:4.46 and 1:4.26 respectively. Bergs with a more vertical nature, pinnacle or drydock bergs, have ratios averaging 1:2.31 and 1:2.41 respectively. The smallest ratios are found in domed bergs which average 1:6.30.

If we assume that the height to draft ratio of icebergs is characterized by a continuous distribution then using a Kruskal-Wallis one-way analysis of variance technique we can test the hypothesis that the average ratio of icebergs is not significantly different for gross visual shape classes. The result is that for the sample icebergs there is no significant difference. For summary purposes then the average of the averages (1:3.95) can be used as descriptive of the height draft ratio of icebergs regardless of visual shape class.

Between the berg heights of 10 meters and 60 meters, which is the range of this sample, the height is related to the height to draft ratio by the power curve

$$1/\text{Ratio} = 49.4\ (\text{Height})^{-.8}$$

PART II - Analysis of stereo pairs of twenty-two icebergs, in the region of Davis Straits, reveals that a reasonable estimate of total iceberg mass, in metric tons, can be arrived at by multiplying the gross dimensions of the iceberg (height x width x length) in meters together and then multiplying this product by a factor of 3.01. This factor accounts for the density difference between seawater and fresh water ice; it also accounts for the average shape and mass distribution of icebergs.

17. Key Words	18. Distribution Statement
height to draft ratios, icebergs, Davis Strait, mass determination, stereo photography, volumetric measurements	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	26	

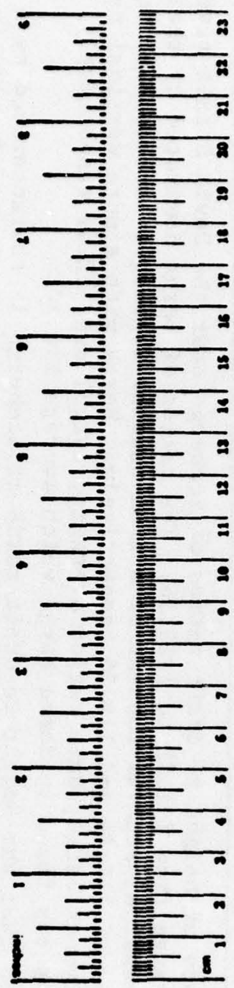
408730

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

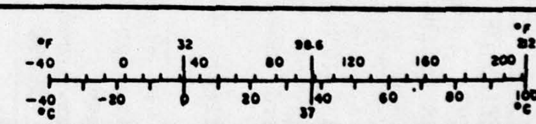


TABLE OF CONTENTS

PART I - HEIGHT TO DRAFT RATIOS OF ICEBERGS

1.0 INTRODUCTION

The draft of icebergs is of interest for a variety of reasons. In areas where pipelines or cables lie on the bottom, information on draft can be used to estimate the probability of a break. For the International Ice Patrol the draft is of interest because of the effect it may have on drift, groundings and deterioration. Approximately seven-eighths of the mass of an iceberg is submerged; however, this is not an indication that the height to draft ratio is necessarily 1:7.

Estimates of height to draft ratios were made as far back as the late 19th century. Steenstrup (1892) gives the ratio as 1:7.4 and 1:8.2; while Krümmel (1907) gives a ratio between the extremes of 1:8 and 1:4, with most falling in the range of 1:5 and 1:6. Grounded icebergs were used to obtain the earliest estimates of the ratio. Dawson (1907) found a berg stranded in the Strait of Belle Isle in 1894 which had a ratio of 1:3. Again in the Straits of Belle Isle, Rodman (1890) found a 30-meter pinnacle berg grounded in 29 meters of water for a ratio of nearly 1:1. To estimate draft, Smith (1925) used a drag wire strung between two heavy weights and towed at known depths by two small boats. The small boats, separated by about 137 meters, would pass on opposite sides of the iceberg and lower the weights till the wire passed freely under the iceberg. He found a ratio of 1:2. During the 1959 ice patrol, Budinger (1960) examined the underside of an iceberg by diving under it. He found that the berg had a height to depth ratio of 1:3.3. Budinger also observed another berg 55 meters high grounded in 175 meters of water off Cape Race (ratio of 1:3.2). Budinger erroneously states that the height to depth ratio cannot be smaller than 1:6. This was in conflict with earlier estimates by Steenstrup (1890) and Krümmel (1907) and also was not substantiated by data from the present study. Data collected by the submarine USS SEA DRAGON, which studied nine bergs, found height to draft ratios which ranged from 1:1.3 to 1:4.2 (Murray, 1960).

The height to draft ratio was highly dependent on the shape of the berg. The berg had to float so that seven-eighths of its mass was submerged and so that the berg was stable. If, for instance, the iceberg was tabular (flat top and bottom and vertical side) a ratio of 1:7 would be expected. If the above-water portion was rounded and smooth, while the underwater part was pointed, then a ratio smaller than 1:7 could be expected, even as small as 1:9 or 1:10. The other extreme was the case where the underside of the berg was rounded and smooth and the above-water portion had towering vertical walls. The most pronounced case of this type was the drydock berg, where an embayment was surrounded by walls of great height and little mass. These could have a height to draft ratio which approached 1:1.

The purpose of this study was to see if the above water shape of icebergs was related in a significant way to the height to draft ratios for those bergs. Height to draft ratios were obtained for a total of 30 icebergs.

2.0 METHODS

Measurements of iceberg draft were taken with a Kelvin-Hughes Transit Sonar during a cruise aboard the CGC EDISTO, July 1974. The EDISTO was operating in the Davis Straits area and along the west coast of Greenland. The Kelvin-Hughes Transit Sonar was designed to conduct bottom surveys; however, we were interested in vertical targets rather than in horizontal ones. The sonar transducer produced a fan-shaped beam 1.5° wide in the horizontal and 52° wide in the vertical, both being to the 3db level. For our purposes the transducer was pointed down by 26°, so that the top of the fan-shaped beam would just pass under the surface of the water and the bottom of the beam would be depressed at 52°. The transit sonar was designed for use from a small boat with only a few feet of freeboard. It was first mounted on the EDISTO's ASB (arctic survey boat). This arrangement worked well, providing cover for the deck gear and personnel, along with high maneuverability and good speed control. The first five bergs were surveyed from the ASB with great success. Use of the ASB was then discontinued because the single point bridle used to raise and lower it was hazardous in any but the calmest weather. For the next two bergs the MSB (motor surf boat) was used. It was inadequate because the equipment was exposed to the weather and because the boat had such little stability that it was difficult to maintain the transducer orientation with respect to the iceberg. The MSB was retired due to a failure of the boat davit.

Finally, a method for using the transducer from the EDISTO itself was devised. The freeboard of the EDISTO was approximately eighteen feet from the rail to the water line aft of midship. A 21-foot pipe was fabricated that would support the transducer three feet below the water line. The transducer was mounted on the bottom of the pipe, and the pipe was manhandled from the deck to the outboard position for each run. Small chunks of ice were a constant problem and once sheared the transducer off the supporting pipe. A safety line attached to the transducer prevented loss of equipment. With the sonar on the EDISTO it was possible to have the deck gear in the oceanographic laboratory and also to operate from a very stable platform.

When the ship was positioned near enough to the berg (Figure 1a), the beam of the sonar was completely intercepted by the iceberg. As the ship circled the berg, it increased the distance from the berg so that at some point part of the sonar beam passed under the berg. The distance increased till the ship was at maximum range (550 meters slant distance from the bottom of the berg) or a good echo was no longer received.

Five assumptions were made in interpreting the record, a sample of which is given in Figure 2. First, that the first echo was returned from the near surface portion of the berg; second, that the strong echos were reflected from vertical surfaces on the underwater portion of the berg; third, that weak returns came from walls which slope away from the observer along a radial of the sonar beams; fourth, that blank areas in the return were the results of shadow areas caused by caves, holes or ridges in the iceberg; and fifth, that if the transducer was far enough away from the berg the last return from the berg comes from the deepest portion of the berg.

The entire record of the iceberg sonar trace was examined and points which were representative of the deepest point on the berg were chosen. These points were plotted on a radial grid so that the radial distances to the various portions of the berg could be converted to vertical measurements of berg draft. These estimates of draft were plotted versus distance to the berg. As the distance to the berg increased, the draft estimates approached an asymptote which was assumed to represent the true draft of the iceberg.

3.0 DISCUSSION

The subaerial shapes of icebergs are extremely varied, sometimes displaying fantastic forms. Some bergs have "windows" in high vertical walls, while others

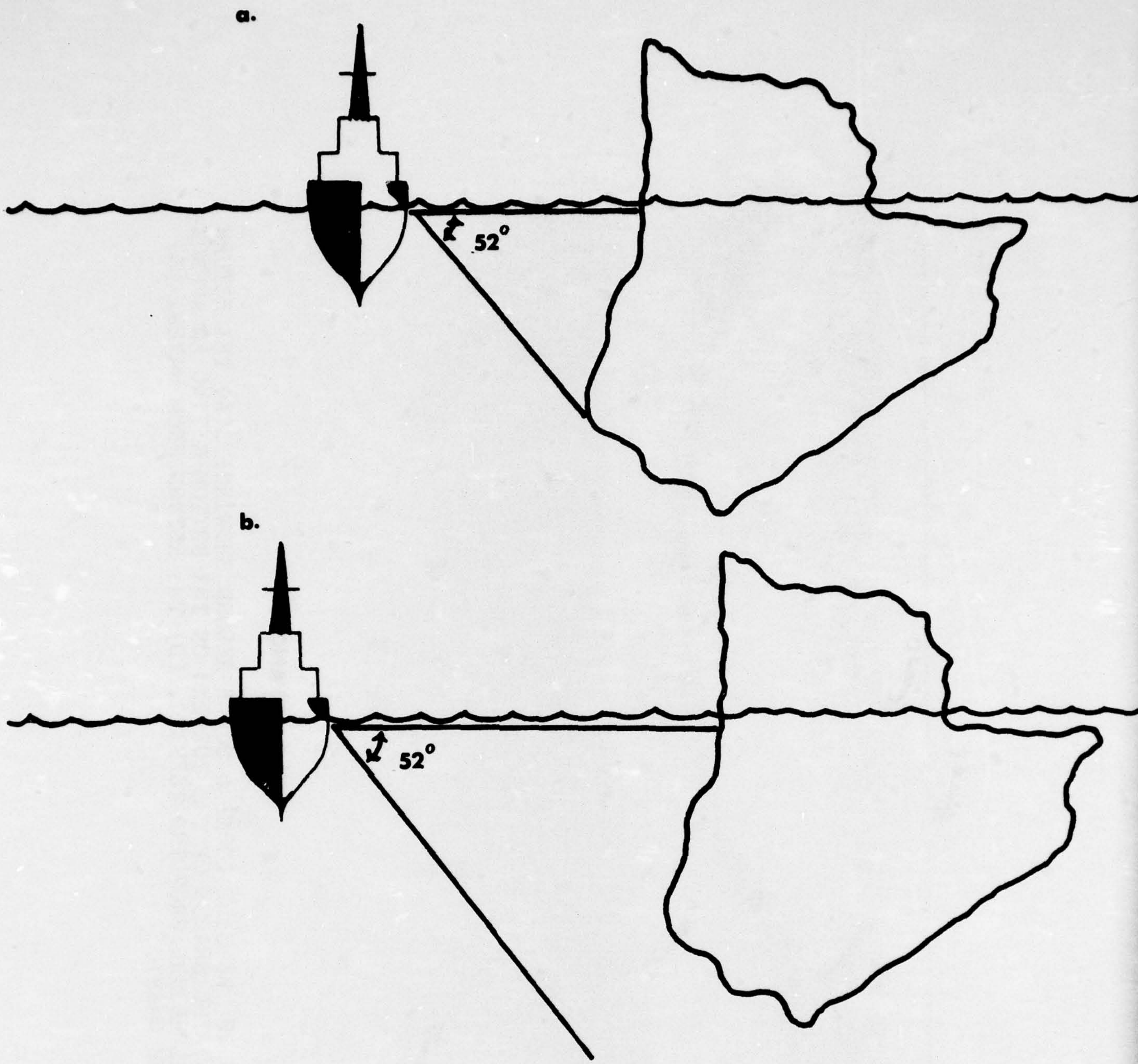


FIGURE 1. (a) THE BEAM FROM THE SIDE-LOOKING SONAR IS COMPLETELY INTERCEPTED BY THE ICEBERG AT VERY CLOSE RANGE; (b) AT A GREATER RANGE A PORTION OF THE SONAR BEAM WILL PASS UNDER THE ICEBERG AND NOT RETURN TO THE TRANSDUCER.

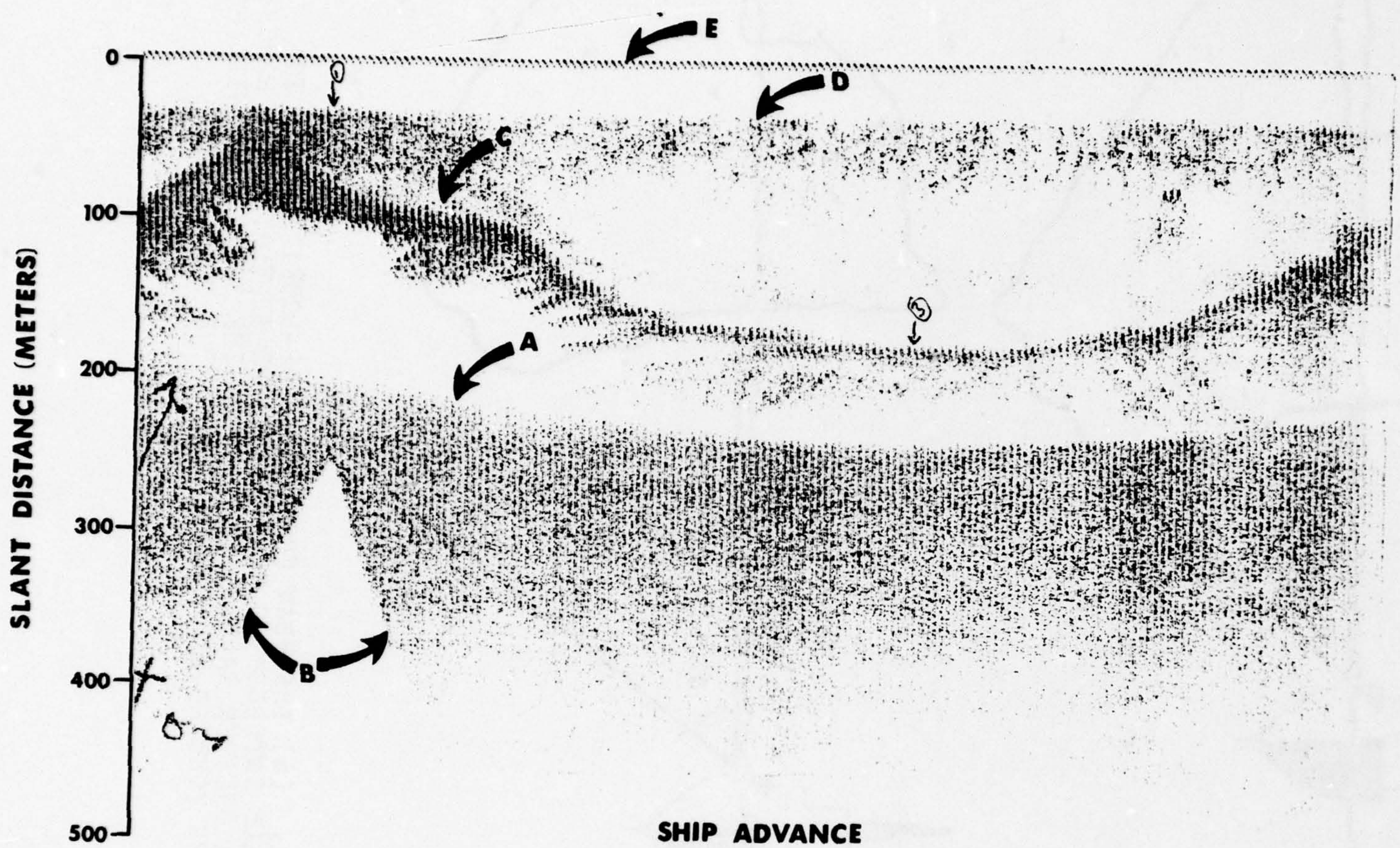


FIGURE 2. A SAMPLE OF THE SIDE LOOKING SONAR RECORD SHOWING: (A) THE RETURN FROM THE BOTTOM, (B) THE SHADOW OF THE ICEBERG ON THE BOTTOM GIVING AN APPROXIMATE SHAPE, (C) THE RETURN FROM THE ICEBERG, (D) THE RETURN FROM WAVES, (E) THE ZERO LINE ON THE CHART.

are pockmarked like a piece of Swiss cheese, and still others have huge grottos or voids. As a means of organizing the shapes of the visible portion of icebergs into some system certain prominent characteristics have been chosen and used for typing icebergs into classes. These classes are based solely on visual identification.

This study examines whether or not the visual classification of icebergs is a meaningful way to classify the height to draft ratios of these bergs. Based loosely on Murray (1968), the icebergs of this study were separated into five general categories based on gross visual shape characteristics.

1. Tabular bergs were horizontal, flat-topped bergs.

2. Broken tabular bergs were those that had a horizontal orientation, but whose surface was highly fractured.

3. Pinnacled bergs had a large central spire or a pyramid of one or more spires dominating the shape.

4. Drydock bergs had an eroded U-shaped slot cut by wave action surrounded by high vertical walls or pinnacles.

5. Domed bergs had a smooth, rounded top which had once been either submerged or highly weathered.

The mean height to draft ratio for each of the five visual classes was computed and compared statistically to the mean ratio for all other classes. The null hypothesis is that there is no significant difference between the height to draft ratios for the visual classes of icebergs.

The height to draft ratios for the icebergs studied ranged from 1:1.28 to 1:10.56. (See Tables 1 through 5.) The 1:1.28 value was in line with previous measurements, but the 1:10.56 value was smaller than any of the previously reported ratios. The 1:10.56 ratio was associated with a domed berg where the rounded above-the-water portion had the maximum mass in the minimum height. To attain this value the underwater portion probably had a taproot-like formation.

The tabular and broken tabular (Tables 1 and 2) had almost identical characteristics. These were the most massive of the bergs, having lengths which were observed to reach 600 meters and masses in excess of nine million metric tons. The mean heights for the tabular and broken tabular were both 28 meters. The mean drafts being 108 and 107 meters respectively. Of course, the height to draft ratios were quite similar also, being 1:4.46 for the tabular and 1:4.26 for the broken tabular. The range of height to draft ratios was 1:2.00 to 1:9.58 for the tabular bergs and 1:2.93 to 1:7.23 for the broken tabular bergs.

Table 1 - Height To Draft Ratios For Tabular Bergs

	Height (meters)	Depth (meters)	Ratio (1:)
	35	122	3.48
	40	80	2.00
	30	137	4.57
	21	97	4.62
	32	84	2.62
	12	115	9.58
	28	121	4.32
	28	108	4.46
Mean Range	12-40	80-137	2.00-9.58

Table 2 - Height To Draft Ratios For Broken Tabular Bergs

	Height (meters)	Depth (meters)	Ratio (1:)
	41	139	3.39
	18	60	3.33
	13	94	7.23
	30	111	3.70
	55	161	2.93
	21	88	4.19
	20	126	6.30
	21	78	3.71
	30	107	3.57
	28	107	4.26
Mean Range	13-55	60-161	2.93-7.23

Pinnacle bergs (Table 3) and drydock bergs (Table 4) also appear to have had average height to draft ratios which were quite similar. Both berg types were generally vertical in aspect and had the largest height to draft ratios of any of the visual groupings. The range of the ratios was also more limited than for the other visual groups. Perhaps the range was more limited because the physical characteristics of these groups were less ambiguous than was the case for the tabular or domed bergs.

Table 3 - Height To Draft Ratios For Pinnacle Bergs

	Height (meters)	Depth (meters)	Ratios (1:)
	16	37	2.31
	59	111	1.88
	32	84	2.62
	34	83	2.44
	35	79	2.31
Mean Range	16-59	37-111	1.88-2.62

Table 4 - Height To Draft Ratios For Drydock Bergs

	Height (meters)	Depth (meters)	Ratio (1:)
	53	68	1.28
	44	103	2.34
	30	108	3.60
	42	93	2.41
Mean Range	30-53	68-108	1.28-3.60

Domed bergs (weathered, smoothed, deteriorated bergs) were the most deceptive. (See Table 5.) A few penetrated the water's depth as the pinnacle bergs penetrated the air. The domed bergs had a range of height-draft ratios far greater than the other classes (1:2.63-1:10.56) and also by far the smallest average ratio (1:6.30) of any of the visual classes. Domed bergs were generally the smallest in size as a class.

Table 5 - Height To Draft Ratios For Domed Bergs

	Height (meters)	Depth (meters)	Ratio (1:)
	30	79	2.63
	16	52	3.25
	12	65	5.42
	21	157	7.48
	13	92	7.07
	9	95	10.56
	12	92	7.67
	16	90	6.30
Mean Range	9-30	52-157	2.63-10.56

4.0 CONCLUSION

The assumption was made that the height to draft ratios of icebergs form a continuous distribution. Using a Kruskal-Wallis one-way analysis of variance technique, Welsh (1975), the hypothesis that the average ratio for icebergs was not significantly different for the gross visual shape classes was tested. This resulted in the conclusion that, for the sampled icebergs, there was no significant difference between classes. For summary purposes the average of the visual class averages (1:3.95) can be used as descriptive of the height to draft ratio of icebergs regardless of visual shape class.

Since one visual class was not significantly different from another with respect to the height to draft ratio, all classes were combined and the ratios were plotted against iceberg height. The distribution was by no means linear and was best represented by the power curve. (See Figure 3.)

$$1/\text{Ratio} = 49.4\ (\text{Height})^{-.8}$$

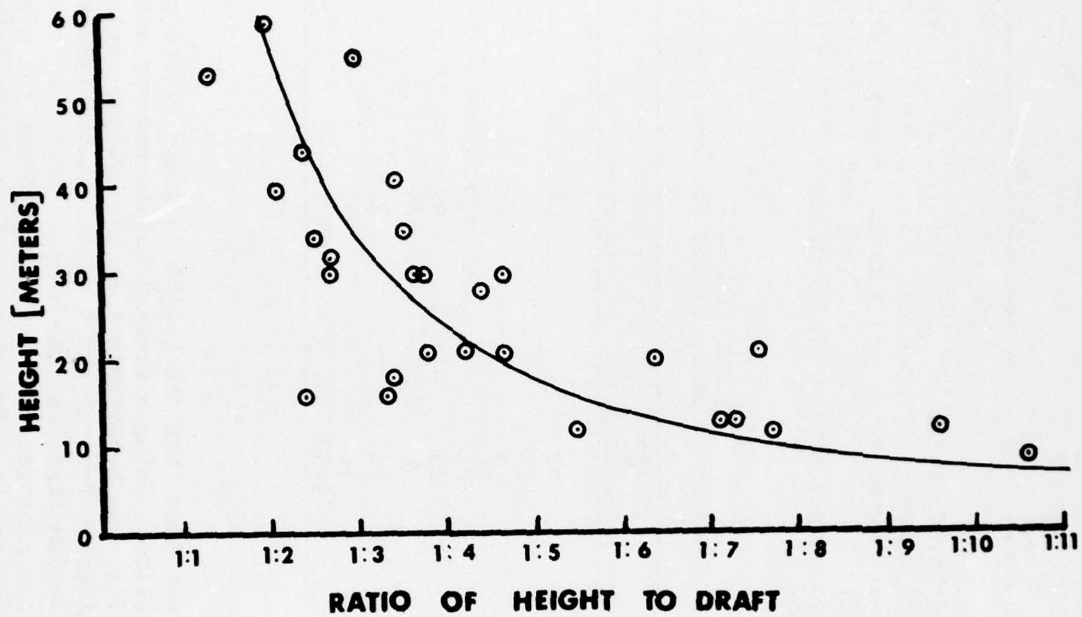


FIGURE 3. THE DISTRIBUTION OF HEIGHT TO DRAFT RATIOS OF ICEBERGS AS A FUNCTION OF ICEBERG HEIGHT.

The taller bergs had a narrower range of height to draft ratios than the lower bergs, which had height to draft ratios which spanned the entire range. Icebergs with the greatest height had the largest height to draft ratios. The draft for tall icebergs was proportionally less than for low bergs. The reasons for this were conjectured to be as follows:

a. The tallest bergs generally had spires and pinnacles which add great height with minimum mass, while the lowest bergs tend to be worn and smooth, having maximum mass for minimum heights.

b. The lowest bergs were worn and have only the most dense ice remaining, all unconsolidated ice and snow having been washed away, and most voids having disappeared causing them to float lower in the water.

REFERENCES

Budinger, T. F., Wind Effect on Icebergs (U. S. Coast Guard, unpublished manuscript, 1960).

Dawson, W. B., The Currents in Belle Isle Strait (Department of Marine and Fisheries, Ottawa, Canada, 1907), pp. 43.

Krummel, O., Handbuch der Ozeanographe (Leipzig, 1907), Volume 1, pp. 526.

Murray, J. E., The Drift, Deterioration and Distribution of Icebergs in the North Atlantic Ocean (Ice Seminar: A Conference sponsored by the Petroleum Society of CIM, Calgary, Alberta, May 1968).

Rodman, H., Reports on Ice and Ice Movements in the North Atlantic Ocean (U. S. Navy Hydrographic Office, No. 93, 1890), pp. 26.

Smith, E. H., "International Ice Patrol," The Meteorological Magazine (The Meteorological Committee, Air Ministry), Volume 60, No. 718.

Steenstrup, K. J. V., Bidrag til Kjendskab til Braeerne og Brae-Isen i Nord-Gronland, Meddelelser om Gronland (1893), Volume 4, pp. 71-112.

Welsh, J. P., Personal Communication (1975).

PART II - MASS ESTIMATION OF ARCTIC ICEBERGS

1.0 INTRODUCTION

Before a model for the deterioration of icebergs can be constructed and verified, it is necessary that actual observations be made of icebergs melting and calving. A prerequisite for deterioration observations is a simple technique for the determination of iceberg mass. Kollmeyer (1966) determined the mass of icebergs by constructing a contour map of the berg using horizontal photographs taken at intervals of every 30° of arc around the berg. This technique was very laborious, not very accurate, and could not be used to cover many bergs. We felt that a more practical approach was to use aerial photography and construct a topographic type map of the bergs from stereo pairs. Since we lacked any vertical control points, such as exist on land, horizontal and oblique photographs were taken to provide a measure of vertical scale.

In order to obtain the necessary photography, the CGC EDISTO was used for a platform for two HH52 helicopters. The EDISTO was assigned to this project from approximately 16 July 1974 until 4 August 1974. The first icebergs photographed were just north of Goosebay, Labrador. From there the EDISTO proceeded north, until just north of the Arctic Circle, working icebergs as we went. From the Davis Straits area just north of the Arctic Circle we proceeded south and then east in order to pick up icebergs off the west coast of Greenland.

2.0 DATA COLLECTION

A total of 32 icebergs were photographed; of these, 23 had photography of high enough quality to determine the above water volume. Hydrographic stations were taken near each iceberg studied to measure the average density of the seawater in the area.

Aerial photography was acquired from USCG HH52 helicopters, using 500 EL/M Hasselblad, 70 mm format cameras with 100 mm f3.5 lenses. These cameras were installed in a lightweight aerodynamic camera mount designed at the Coast Guard Research and Development Center. (See Figure 1.) The mount is a lightweight (85 pounds with four cameras), multi-purpose unit which requires no airframe modifications for installation. Design limits are air speeds 140 knots or less and unpressurized flight altitudes. The practical limiting altitude is 6,000 feet. The mount is designed to fit all Coast Guard aircraft capable of meeting these limits.

Parallax measurements used in determining heights of points on the iceberg were made on stereographic photographs with the model 121 GE stereo comparagraph. Sea level cross sectional area was measured with the Bausch and Lomb photo data quantilizer.

In order to accurately determine the total mass of an iceberg, the above water volume and mass must first be determined. This involved acquisition of three types of photographs, horizontal, oblique and vertical. In all cases the 500 EL/M 70 mm cameras were used. Black and white negative film was used, with all analysis done from positive prints.

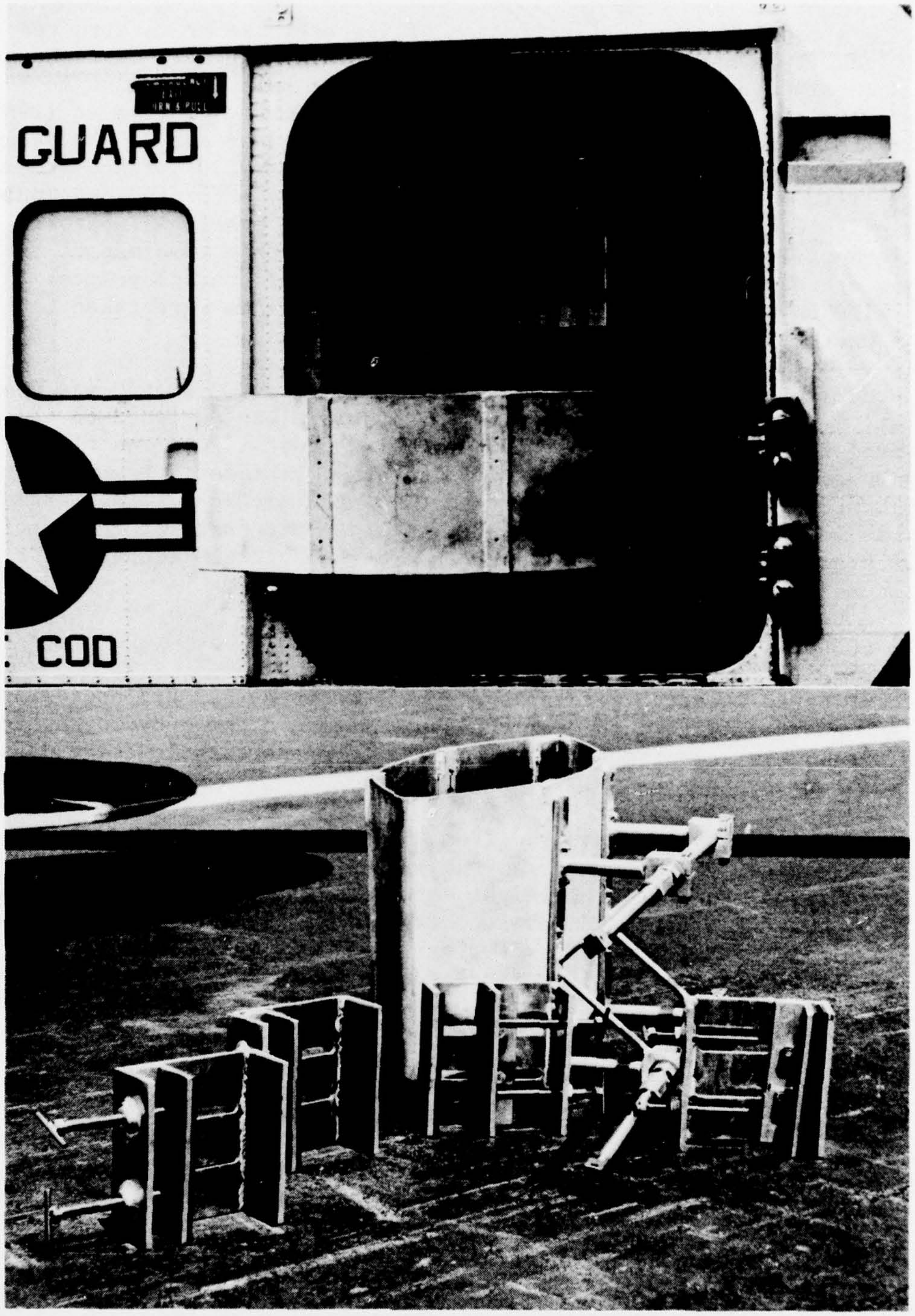


FIGURE 1. MULTI-PURPOSE, PORTABLE CAMERA MOUNT.

Horizontal and oblique photography was obtained by using a leveled tripod from inside the helicopter. Slow, level passes at selected altitudes and offset distances were made at four locations around the iceberg being studied. These were usually 90 degrees apart. Both horizontal and oblique photographs were obtained at each station. Examples of the type and quality of photography obtained is shown in Figure 2. Vertical photography was obtained using the previously described camera mount. Adequate overlap was obtained by taking repetitive frames at predetermined time intervals. An example of the stereo photography obtained is shown in Figure 3. Utilization of each type of photography is explained in the pilot study and analysis sections which follow.

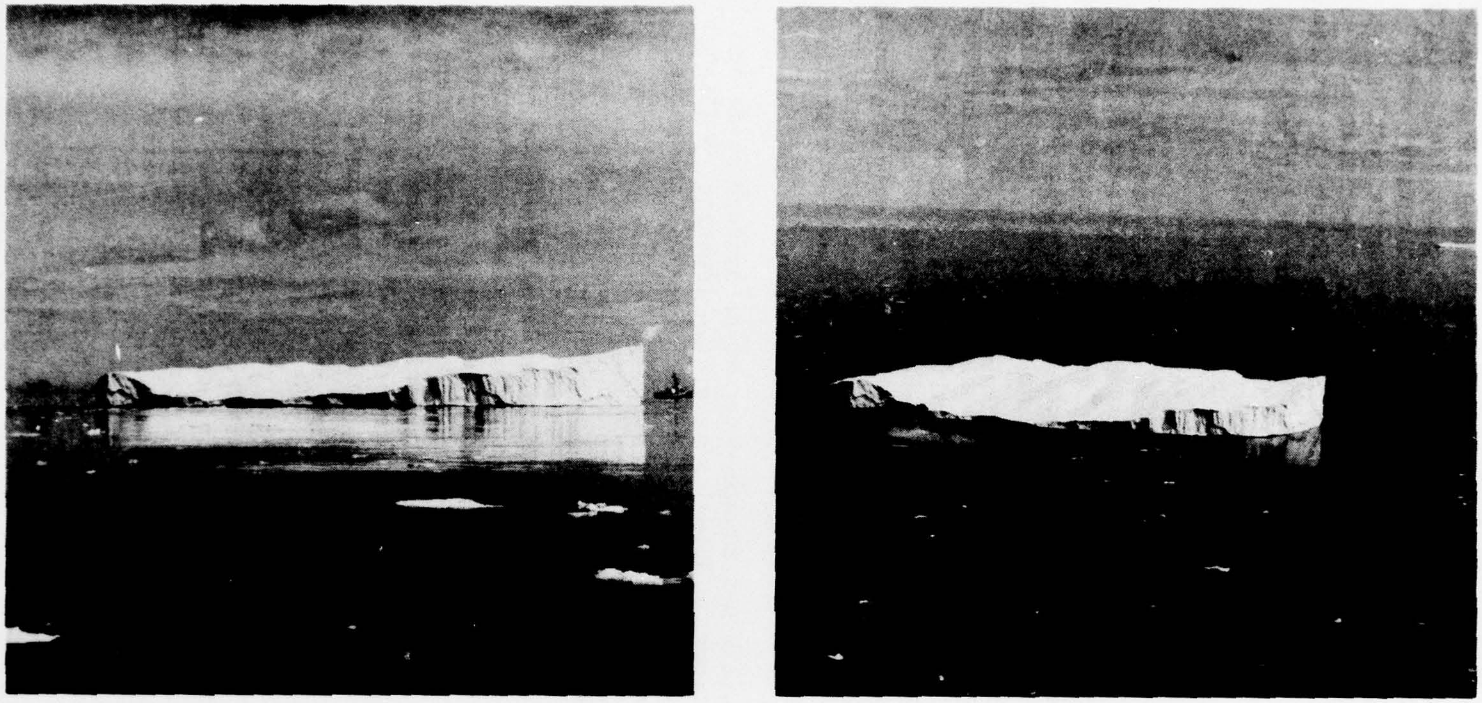
3.0 PILOT STUDY

After several attempts to contour the iceberg in a manner similar to a topographic map, we came to the conclusion that such a straightforward method was impossible due to the extreme surface gradients found on a typical iceberg. A new approach was then tried which proved successful. A grid of randomly selected points was used to locate the position of the parallax measurements. (See Figure 3.) Since no point on the berg was more likely to be sampled than any other, it was possible by sampling a sufficient number of randomly selected points to determine the average height of the iceberg to any desired accuracy. An accuracy of better than ±2 meters was chosen, and a pilot study was conducted to determine the sampling density required. It was determined in the pilot study that a sampling density of .02 points per square meter would give a mean height that had a standard error of less than two meters.

A grid of .02 random points per square meter at an average scale of 1:2000 was used. The variations in actual size of the icebergs resulted in variations of photographic scale. In all but a few cases, the number of random sample points exceeded the minimum density.

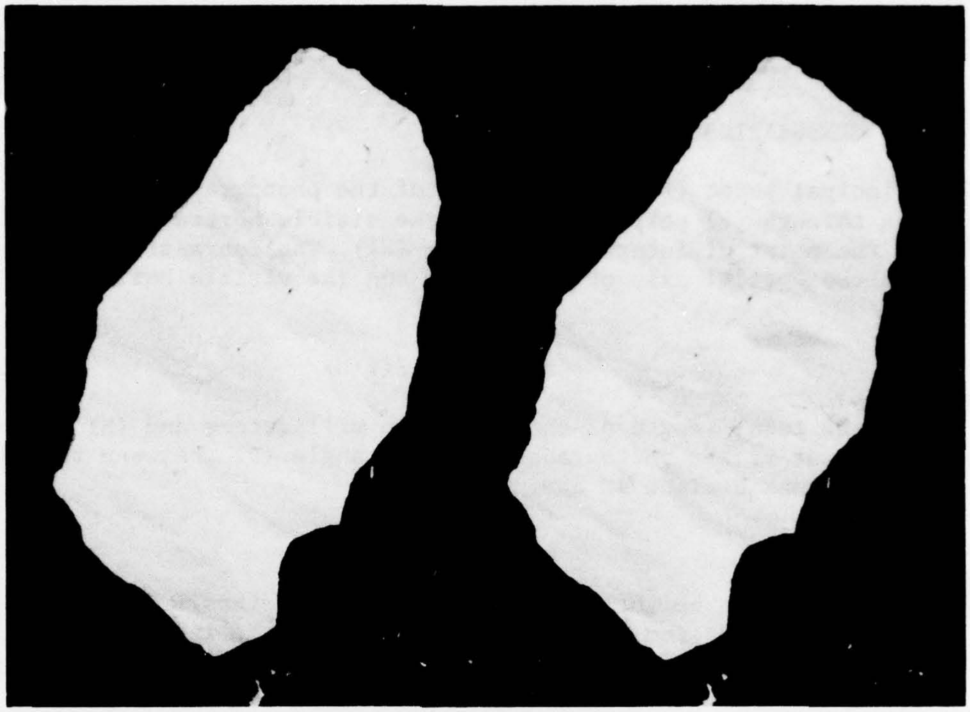
4.0 CHANGE IN HEIGHT VS. CHANGE IN PARALLAX

The stereo pairs we used had no real reference level since the sea surface had no detail in the photographs. Therefore, it was necessary to construct a linear relationship between the change in height (Δh) and the change in parallax (Δp) for each iceberg. To construct such a graph points on the iceberg were chosen on the horizontal and oblique photographs and the actual heights of these points were computed. These same points were then located on the stereo pair and the parallax was measured. Using a least square fit to these points (four to eight for each iceberg) a ratio of Δh to Δp was established for each iceberg. This ratio was used to convert the iceberg's mean parallax ($\overline{\Delta p}$) to mean height ($\overline{\Delta h}$). By comparisons with actual height measurements we determined that the heights from the oblique photographs were more reliable than those from the horizontal photographs. This was due to the fact that the only scale reference for the horizontal photography was the presence of the helicopter in the field of vision.

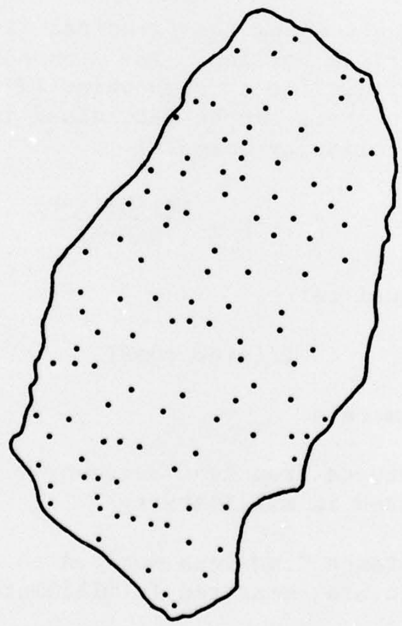


HORIZONTAL OBLIQUE

FIGURE 2. HORIZONTAL AND OBLIQUE PHOTOGRAPHS OF AN ICEBERG.



STEREO PAIR



EXAMPLE OF RANDOM SAMPLE POINTS

FIGURE 3.

Depth of field, orientation of the helicopter (e.g., level or not) and its position in relation to the plane of the iceberg were not constant or definable. The oblique mensurations on the other hand did not require a scale reference. (See Figure 4.) Therefore, we used only the oblique photography to determine the ratio of Δh to Δp.

5.0 OBLIQUE MENSURATIONS

The principal point (P) is the center of the photographic format. A line drawn through (P) perpendicular to the visible horizon is the principal line (PH_1), the point of intersection being (H_1). The depression angle (θ_1) between the optical axis of the camera and the visible horizon is calculated:

$$\tan \theta_1 = PH_1/(f \cdot M)$$

where (f) is the focal length of the camera in millimeters and (M) is the enlargement factor of the photograph. The dip angle (D) between the visible horizon and the lens horizon is computed:

$$D = 9.03\sqrt{H}$$

where (H) is the flying height of the helicopter in meters. The depression angle (θ) between the optical axis of the camera and the lens horizon is found by $\theta = 0_1 + D$. The distance (PH) measured along the principal line to the lens horizon is calculated:

$$PH = f \cdot \tan \theta \cdot M$$

This distance is laid out along the principal line through point H_1 in the direction of the visible horizon. The lens horizon is then drawn perpendicular to the principal line through point (H). Heights, in meters, of selected points on the iceberg can be determined in relation to the lens horizon by using the following formula:

$$h = \frac{(K)(H)(a-b)}{a(K-b)}$$

where (K) is a constant equal to:

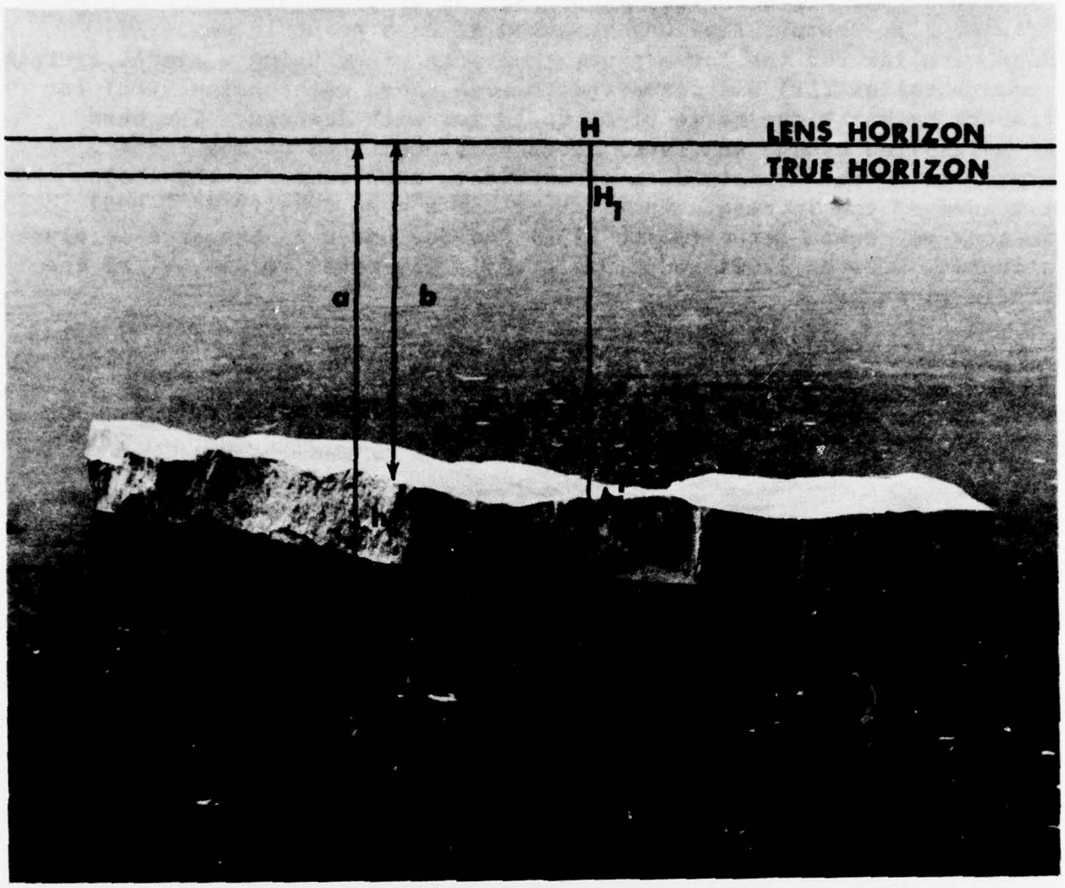
$$f/(\sin\theta \cdot \cos\theta)$$

H = Flying height in meters.

a = Perpendicular distance from lens horizon to the water line, measured in millimeters.

b = Perpendicular distance from lens horizon to the top of selected points, measured in millimeters.

All angles are in degrees, and all photographic measurements are in millimeters. An example of the use of this method is shown in Figure 5.



$H = 152m$

$PH_1 = 55mm$

$f = 100mm$

$M = 3.5X$

$\tan \theta_1 = PH_1/(f \cdot M) = .15714$

$\theta_1 = 8.93°$

$D = 0.03\sqrt{H} = .37°$

$\theta = 9.30°$

$PH = f \cdot \tan\theta \cdot M = 57mm$

$K = f/(\sin\theta \cdot \cos\theta) = 627$

$$h = \frac{(K)(H)(a-b)}{a(K-b)}$$

$h = 32m$

FIGURE 4. OBLIQUE MENSURATIONS

5.0 ANALYSIS

A stereo pair for each iceberg was set up with a random sampling grid. (See Figure 3.) The parallax was measured at each point in the grid. The mean parallax for the iceberg was then determined using a simple average. This mean parallax ($\overline{\Delta P}$) was converted to mean above water height ($\overline{\Delta h}$) for the iceberg by using the ratio of Δh to Δp for each iceberg. The mean height multiplied by the sea level cross sectional area of the iceberg, as determined on the photo data quantitizer, then equalled the above water volume of the iceberg. The iceberg has a mean density of 0.8997 metric tons per cubic meter (Smith 1931) and sea water in the area of study had a density between 1.024 and 1.027 g/cm^3. The total volume, V, of the iceberg is given by

$$V = V_1 + V_2 \qquad (1)$$

where V_1 is the above water volume and V_2 is the below water volume. The mass, M, of the iceberg is then given by its total displacement

$$M = \rho_{sw} V_2 \qquad (2)$$

where ρsw is the density of seawater. The mass of the iceberg is also given by the expression

$$M = \rho_i V = \rho_i (V_1 + V_2) \qquad (3)$$

where ρ_i is the density of glacial ice. Equating (2) and (3) gives

$$\rho_{sw} V = \rho_i (V_1 + V_2) \qquad (4)$$

Solving for V_2 in terms of V_1 and using $\rho_i = .8997$ gm/cm^3 and $\rho_{sw} = 1.0255$ gm/cm^3 yields a result

$$V_2 = 7.15 V_1 \qquad (5)$$

or

$$V = 8.15 V_1 \qquad (6)$$

from (1) and (5). From equations (3) and (6), assuming a uniform density for the iceberg, the total mass in metric tons of the iceberg is then 7.33 times the above water volume of the iceberg in cubic meters.

$$M = 7.33 V_1 \qquad (7)$$

A least square analysis of V_1 as related to product of the longest side (L), shortest side (W), and the height of the highest point (H), indicates that

$$V_1 = .41\ LWH \qquad (8)$$

Combining (7) and (8) yields

$$M = 3.01\ LWH \qquad (9)$$

The errors which contribute to the total error of iceberg mass measurements originate in the following ways.

a. The measurement of the heights of selected point on the berg has an error estimated at ±5%.

b. The parallax measurements using the stereocomparagraph have an error of ±2%.

c. Calculations of the mean berg height from heights taken at random points have an error of less than ±9% associated with it.

Defining the standard error (E) as the square root of the sum of the squares of the component errors (e), i.e.,

$$E = \sqrt{\Sigma e^2}$$

the E = ±10.5%.

7.0 RESULTS AND CONCLUSIONS

The purpose of this study was to develop a technique for easily and quickly estimating the mass of an iceberg. Several relationships were tried, such as separating bergs into visual shape classes, plotting height against berg mass, and using a combination of these two approaches. The correlation that appears to be most satisfactory both from the point of view of simplicity and also accuracy is the correlation between the product of the longest side, shortest side, and height of the highest point with the total mass of the iceberg. This approximates the above water portion of the berg with a rectangular box. If the length, width and height are measured in meters, then the total mass of the berg in metric tons is estimated to be 3.01 times the product. (See Figure 5.)

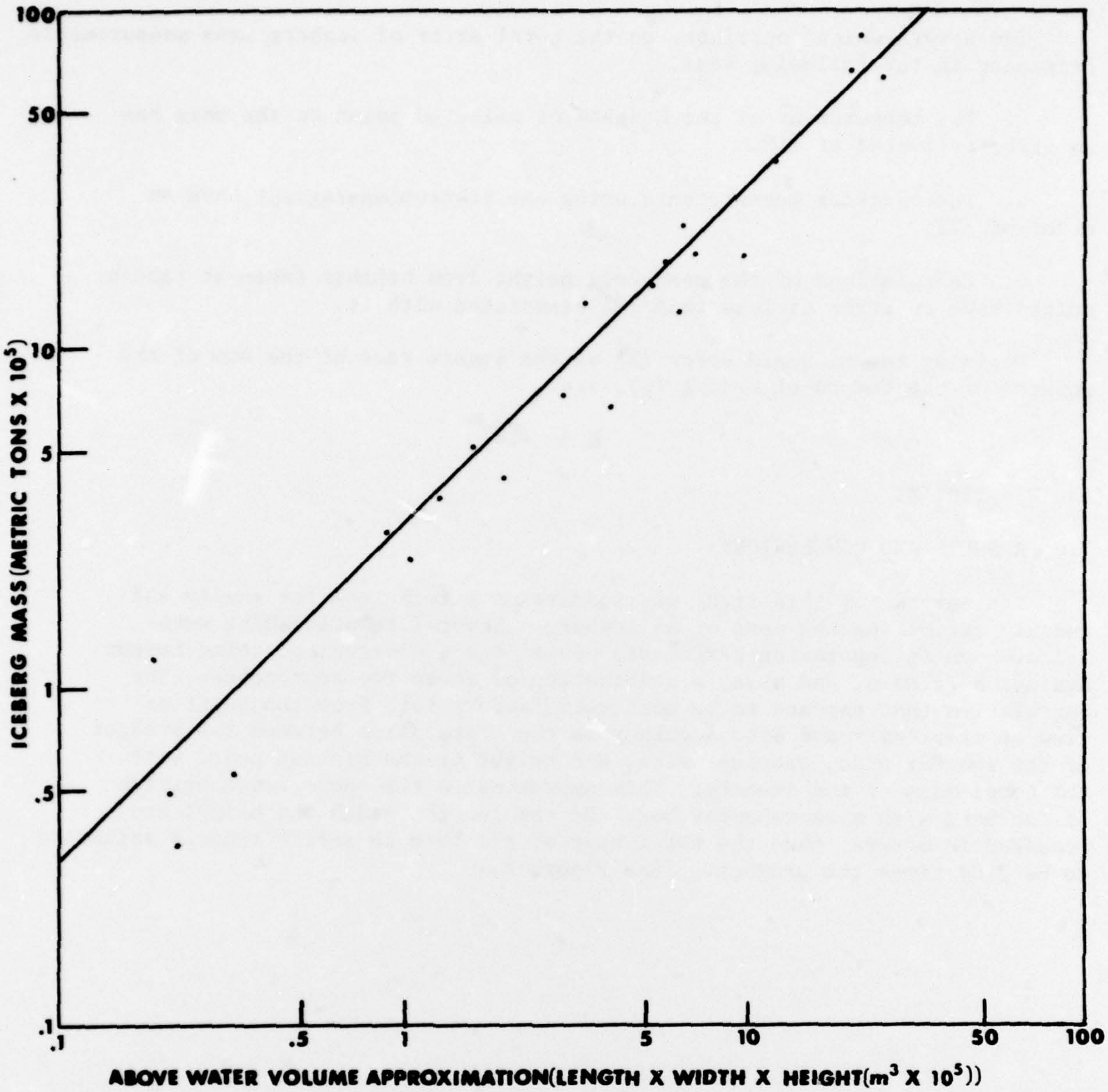


FIGURE 5. LEAST SQUARES FIT OF THE ABOVE WATER VOLUME APPROXIMATION (HEIGHT OF THE HIGHEST POINT X LONG HORIZONTAL AXIS X NARROW HORIZONTAL AXIS) VERSUS THE TOTAL CALCULATED ICEBERG MASS.

REFERENCES

Kollmeyer, R.D., Iceberg Deterioration, USCG Oceanographic Report No. 11, CG 373-11 (1966), pp. 41-64.

Smith, E.H., "The Marion Expedition to Davis Strait and Baffin Bay," U.S. Treasury, U.S. Coast Guard, *Bull. 19*, pt. 3, *Report of the* International Ice Patrol Service in the North Atlantic Ocean (1931), p. 221.