*Aerial Survey of Graham Land**

The Falkland Islands & Dependencies Aerial Survey Expedition 1955-57

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ABSTRACT: *The paper describes the recent expedition during the two Antarctic summers of 1955/56 and 1956/57 carried out by Hunting Aerosurveys Ltd. under contract to the United Kingdom Government. Employing two Canso amphibean aircraft and a ship-based helicopter, the expedition completed full vertical air photo coverage of an area of 35,000 square miles over the peninsula of Graham Land and adjoining archipelago in the British sector of the Antarctic.*

Using a 950-ton freighter converted as a helicopter base, parties of ground surveyors were landed along the coast and islands of Graham Land, where they completed over 200 miles of fully-observed triangulation to serve as ground control for the preparation of photogrammetric maps covering the area photographed; these are now under preparation by the Directorate of Overseas Surveys.

The author, who organized and led the expedition, describes the equipment and methods employed for both photography and ground control, with special reference to the photogrammetric problems involved.

IN THE past quarter of a century air photography has played an ever-increasing role in the exploration and mapping of the Polar regions, so much so that it is a commonly held belief among the general public that one has only to point a camera out of the side of an aeroplane flying over unknown territory to be able to claim that it is mapped. As was later proved in the case of some of the early flights across Graham Land, aerial photographic reconnaissance alone may lead to conclusions that result in major topographical inaccuracies in an area where glacier and sea ice often merge together when viewed obliquely, and where successive features all encrusted in an over-all ice sheet are so numerous and so alike as to have a common resemblance. This statement is not, of course, to discredit the high spirit of enterprise and the remarkable achievements of Ellsworth and others who did so much to pioneer the way for more detailed studies to follow.

The first serious attempt to carry out a photogrammetric survey in the Arctic was, I believe, that of the Danish Government in Greenland, where a regular programme of air photography coupled with ground triangulation first began in the early 1930's and has since resulted in the production of a highly accurate series of 1/250,000 maps covering nearly the entire coastal strip of the world's largest island.

In the Antarctic the later expeditions of Admiral Byrd and the even more recent Operation Deep Freeze have carried out mainly trimetrogon photography covering a very large part of the main continental mass which, by itself, is probably the greatest single contribution to our knowledge of the Antarctic that has yet been made. I believe I am correct in saying, however, that the great majority of these photographs are as yet entirely unrelated to any form of ground control and must therefore be considered of limited value for mapping purposes until some form of control becomes available.

The Antarctic expedition which is the subject of this paper was, I believe, the first attempt at one and the same time to provide the desired elements of the photogrammetrist—vertical photographs tied to

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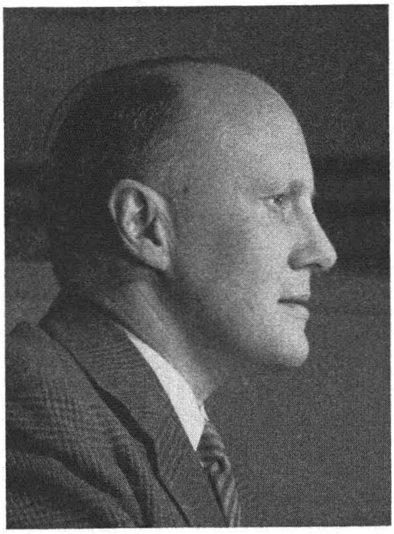

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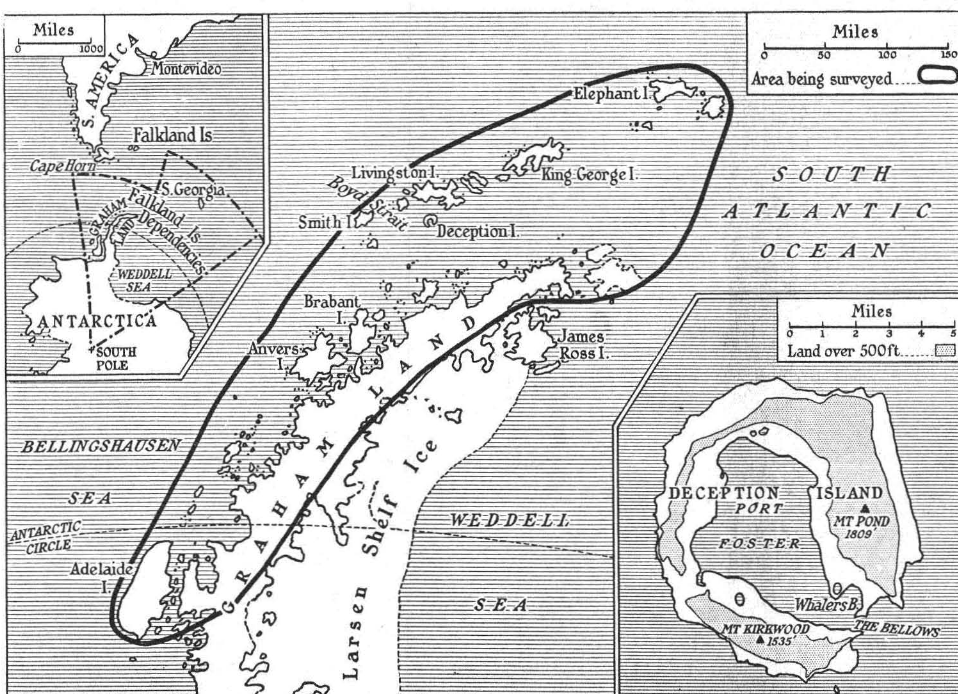
a pattern of identified ground points, the heights and positions of which were surveyed to within plottable accuracy. It also happened to be the first occasion in Antarctic history when a major survey of this kind was placed on contract to a civil operating company.

The Graham Land peninsula (or Palmer peninsula, as you prefer to call it in the United States) extends for 800 miles from the main mass of the Antarctic continent and is divided from South America by 600 miles of tempestuous sea known as Drake Strait. (Figure 1). A central plateau of ice between 4,000 and 8,000 feet above sea level forms the backbone of the peninsula, which descends abruptly on either flank in a complex system of mountain ridges divided by innumerable glaciers and deeply indented by fjords. The eastern coast of Graham Land is permanently blocked by pack ice that is compacted under great pressure by the prevailing easterly gales. During the summer months the west coast on the other hand is usually navigable to ships as far as latitude 68°S. In 1908 Britain formally laid claim to Graham Land as part of the Falkland Islands Dependencies. In the course of her administration of the area Britain has set up a number of permanent bases along the coast and surrounding islands for the purpose of



A. J. Thornton

Fig. 1

FIG. 2. Canso in flight over Graham Land coast.

providing a meteorological reporting service and to carry out various forms of scientific research, including survey. Due to the extremely difficult nature of the terrain and the limited working season, the extent of the mapping carried out by these ground parties was necessarily slow and by ground methods alone it would take a very long time indeed to produce even a moderately accurate map covering the whole area. In the early part of 1955 therefore the United Kingdom Colonial Office decided to put into effect a plan that had been maturing for some years, for an aerial survey of the more important parts of the area.

The combined programme of air photography and ground-control covering an area of approximately 40,000 square miles was put out to tender. In May 1955 the contract was awarded to Hunting Aerosurveys Ltd.

Our plan was to establish a base for two Canso amphibian flying boats at Deception Island, in the South Shetlands. The island is shaped like an atoll with a rim of ice-capped mountains containing an inner harbour, Port Foster, which is four miles across and seven miles in length. During the summer months this unique harbour becomes free of ice and forms the safest natural anchorage in the whole of Antarctica. Deception Island, which owes its name to a single narrow entrance known as Neptune's Bellows, that can easily be missed by a passing ship, is of volcanic origin and is still subject to thermal activity in the forms of hot springs and occasional tremors.

Our choice of aircraft was limited by the fact that no airstrip existed anywhere in the area from which a land plane with the required endurance and capacity could have been operated. A pure flying boat, on the other hand, would have been seriously endangered by ice floes drifting into the harbour from the open sea or from the terminal ice-cliffs of the glaciers descending from the mountains encircling Port Foster. By employing an amphibian we could beach the aircraft out of danger of ice and at the same time greatly ease the work of servicing and refuelling. The Canso has a range of 2,000 miles with an operational ceiling for photographic work of 13,500 feet; moreover, its rugged construction and proven reliability made it well adapted for a project of this nature (Figure 2). As an insurance against loss or damage, and in order to take the fullest advantage of the limited season of good weather, we took two aircraft which were specially modified in Canada by Kenting Aviation Ltd., and flown down via South America and the Falkland Islands to the expedition base, a transit of some 9,000 miles.

For the trans-shipment of stores and expedition personnel (with the exception of the Canso crews, who flew down with the aircraft) we chartered a 950-ton Danish freighter, the "Oluf Sven." Before departure the ship underwent extensive modifications in order to provide accommodation for 22 passengers, in addition to her normal complement of 14 crew. A steel bulkhead was constructed separating the fore part of the ship, to enable her to carry 60,000 gallons of high octane spirit. She had also to be fitted with a prefabricated helicopter deck, which during the voyage south was carried as part of the cargo in her holds, and could be reconstructed on arrival at the expedition base after unloading was complete. In addition to her normal navigational aids, the ship was fitted with Decca radar, an Anschutz gyro-compass and echo-sounding equipment reading to a depth of 300 fathoms. On the initial outward voyage she carried a total cargo of some 650 tons, including two crated helicopters, a 60-foot long prefabricated hut, a complete radio station and literally hundreds of items of stores varying from aero engines and a 4-ton tractor to sacks of coal.

Directly the base installations at Deception Island were ready for the operation of the Cansos, we planned to use the ship as a mobile platform from which we could fly off parties of surveyors from the deck on to selected points on shore, thereby overcoming the major obstacles of terrain and weather. We believed that by using helicopter transport it should be possible to provide a close network of triangulated control connecting the mainland of Graham Land and the coastal islands. Although no similar operation had been attempted before in Antarctic conditions, helicopters had already been used for control surveys in the Canadian Arctic, and we felt confident that the same techniques would prove equally successful in Graham Land.

The area to be photographed covered that part of the Graham Land peninsula between 62° and 68° latitude S., including the South Shetland Islands and the Palmer Archipelago lying west of Graham Land.

The specification called for complete vertical coverage over the whole area to be surveyed. In addition, a continuous series of fixed side obliques was to be taken with the camera axis depressed 30° from the horizontal.

For the vertical cover we used a Williamson Eagle IX camera fitted with the Ross 6-inch lens on a 9-inch format negative, and for the obliques the Williamson F.24 fitted with a lens of $3\frac{1}{4}$-inch focal-length on a 5-inch square format. The time interval for the obliques was set to give a 10 per cent overlap in the foreground of successive pictures, while the wide-angle of the lens provided for a generous lateral overlap between vertical and oblique, which incidentally made the identification of the obliques far easier than it would otherwise have been. Only one oblique camera was used at a time, the normal procedure being to leave the camera in either the port or starboard mounting, so that when the aircraft was flying in a northerly direction the obliques would be taken say to the east, and on the adjacent strip (flown south) the camera would be directed to the west.

The purpose of the obliques was to assist in the interpretation and identification of features, to help in the study of ice conditions and sledging routes to the plateau from the coast, and with the possibility that in some areas they might be used to carry out reconnaissance mapping beyond the area of vertical cover. In cases where an area was already well covered with obliques, we did not therefore continue to use the oblique camera in subsequent vertical sorties.

FIG. 3. Eagle IX camera and mounting in Canso.

The camera compartment was located immediately aft of the step in the hull of the aircraft, where it was normally free of contact with the water. The mounting of the Eagle IX was fixed to a sliding carriage, so that it could be moved forward leaving the opening in the hull to be filled by a hinged port which, when lowered and bolted down, provided a water-tight hatch (Figure 3). The design and manufacture of this installation was carried out by Kenting Aviation in Toronto and proved highly satisfactory. For navigation the nose compartment was fitted with the bomb-aimer's glass window, and a special hatch with a removable water-tight cover was provided to allow a prismatic drift sight to be projected below the hull during flight.

Considering we had only five months in which to organize and equip the expedition from scratch, it took some pretty hard work by all concerned to ensure that nothing was left behind. It was only through the whole-hearted assistance of Government and Service departments, the combined resources of the Canadian and British companies of the Hunting Group, and the practical help and advice of a very large number of manufacturing firms, consultants and friends, that this preparatory

FIG. 4. Landing steel plate for construction of slipway.

work got done in time. We were also exceptionally fortunate in being able to offload the whole of the highly complex task of radio communications including radio and radar aids to Messrs. International Aeradio Ltd., while responsibility for the supply and operation of the helicopters was undertaken by Messrs. Autair Ltd., and the extensive refitting of the ship by the Mercantile Dry Dock Company of Jarrow.

The expedition ship "Oluf Sven" finally sailed from London Docks on 21st October 1955, and after calling at Montevideo to bunker and load our total supplies of aviation fuels reached Port Stanley in the Falkland Islands on 27th November. From there she sailed to Deception Island and in the early hours of Saturday, December 3rd, we dropped anchor in Whalers' Bay, opposite the wreckage of the old whaling factory, which was abandoned a quarter of a century ago on the introduction of pelagic methods of whaling. In the centre of the bay the ice-covered slopes forming part of the main mountain ridge of the island give way to a broad, gently sloping beach of volcanic ash. Although too soft to bear the weight of a heavy aircraft, we were later able to lay some 20 tons weight of perforated steel plates to form a metal slipway extending well below low water and providing a complete taxying circuit on land for the two aircraft (Figures 4 and 5).

On our arrival the only habitable building left of the whaling station was the large hut occupied by a small party of the Falkland Islands Dependencies Surveys, who are permanently stationed there throughout the year. Through their assistance our shore party were able to find sleeping accommodation in the loft of the F.I.D.S. hut and we were also able to take over another partly dilapidated hut near the shore, which we renovated and used as a radio station. The new hut which we had brought down with us on the ship was designed to provide a generator room, kitchen and canteen at one end, while the remainder was divided into laboratory accommodation for processing the aerial films.

There was, of course, no proper jetty or facility of any kind for landing our equipment. Some 350 tons of stores and equipment had therefore to be landed by means of a military type of pontoon raft towed by a motor-boat. Individual loads up to six tons including a large tractor, aero engines, hut parts, aviation fuels and oils, and several thousand different items were successfully ferried ashore using this equipment, without loss or damage. While the unloading continued the rest of the party was engaged in the construction of the prefabricated hut, in setting up the radio station and in providing the essential installations in readiness to receive the aircraft.

Deception Island has a reputation (well-earned!) for orographic cloud which hangs round the mountain rim and, when the temperature drops, sinks into the central

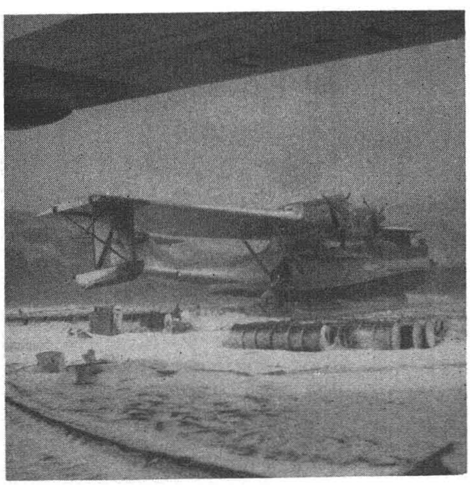


FIG. 5. Canso aircraft on slipway at Deception Island.

"crater" of the island, descending at times to sea level. Since the southern limit of the area to be photographed was 400 miles distant from our base and there was no alternative haven, it could happen that an aircraft, having taken off in good weather, might return from a long sortie to find the whole landing area smothered in cloud. To offset this danger we had to provide two forms of approach aid; the first a radio MF beacon, and the second a radar device known as Rebecca-Eureka which gives the pilot both bearing and distance during approach. For long-range communications between the base, the aircraft and the ship we installed an HF transmitter of 300 watts output. Finally, to provide local communication between ship, motor-launch, aircraft, field parties, helicopter and control-base, a 50-watt VHF system was installed at the base with a 15-watt set on the ship.

A land line from the radio hut was laid for two miles up to the highest point of the cliffs commanding "The Bellows," the entrance to Port Foster, in order to ensure unrestricted response to the Rebecca units of an approaching aircraft in thick weather.

All this preliminary work occupied the whole of December and it was not until January 7th that we were at last able to signal the two aircraft waiting in the Falkland Islands that we were ready to receive them. By this time, however, the brief season of good weather had already passed and almost to the day with the arrival of the planes there began three weeks of continuous high winds, cloud and snow. It was not, therefore, until early in February that the first productive flights took place, when several islands of the South Shetland Group and some coastal strips along the Graham Land peninsula, including the whole of Trinity Island, were sucessfully covered.

On these early flights we learned a good deal, which proved of untold value in the following season. The fact that the ceiling of the aircraft was limited to 13,500 feet over terrain which often rose with appalling abruptness from sea level to 7,000 feet and over, in a distance of only one or two miles, made it necessary at times to increase the lateral overlap at the start of a run to 60 per cent, and even then it was possible to get a gap only a few frames later. Forward overlap in such areas gave similar difficulty and required a very high concentration on the part of the camera operator, the interval dropping as low as 14 seconds over high ground, compared with 35 seconds over average terrain.

Navigation was, of course, the greatest problem, particularly over the central plateau of Graham Land, which in places is a featureless expanse of snow broken only here and there by a line of crevasses or an occasional line of nunataks. As we were working at the end of the operational season, we had to take the fullest advantage of the few remaining days, and several of the islands were flown in one sortie without resorting to navigational strips. Along the mainland we reverted to the system of flying long control strips up to 120 miles in length employing a gyro-controlled D.R. compass combined with computed drift to maintain course. On return to base, these control strips were immediately processed and printed overnight, every alternate print being stapled to the next in a continuous roll which was subsequently used by the navigator to track the adjacent strips on either side. By this means there was no need to rely on the navigator's memory, and even in areas of limited detail straight flying and lateral overlap could be maintained.

Another matter on which we had to gain experience was exposure and development. All photography was carried out on Ilford Hyperpan film using a minus blue filter (comparable to Wratten G). Stop F.11 was used throughout with a normal exposure time of 1/200 second, though in the latter part of the season this was increased to as slow as 1/50 second, and also in some of the long sorties carried out in the second season, when photography was continued until 8 o'clock in the evening.

Over the high plateau, the glaciers, the shelf-ice and ice-domed islands, the unrelieved sameness of texture and tone require the most exacting assessment of development, without which variations in relief become indistinguishable, whereas in the areas of high relief there is an excessive amount of contrast between the brilliance or reflected light off the snow compared with vertical faces of exposed rock and the deep shadows cast by the mountains. All along the coast lie literally thousands of rocky islets washed by the sea, which require entirely different treatment to the adjacent ice-cliffs and glaciers. For development of the first Eagle IX film Kodak 19B was used, but was found to give such high contrast that detail in the snow areas was lost. By trial and experiment it was found that D76 gave a much softer negative and by varying development times between 20 and 40 minutes even the most contrasting detail could be recorded on the negative. The obliques were found to require entirely different treatment to the verticals. D76 would barely produce an image on the obliques, even after 50 minutes of development, and the best results were obtained using D19B at quarter strength with an average development time of 15 minutes.

The facilities provided for processing the films in the expedition hut could scarcely have been bettered. The darkroom was divided into two compartments, one half being used for development of the films using standard Morse units, and the other for contact printing. A third room contained two rotary film drying units and one large print dryer with shelving and a large table for sorting and checking cover. The power required for working the equipment was provided by two Enfield 6.5 k.w. diesel generators working on independent circuits. Water, of which we often required 500 gallons a day, was pumped from an existing catchment "well" into a series of old aircraft fuel tanks built in between the rafters of the hut, where the water was stored at maximum head and was prevented from freezing by the warmth of the rooms below. Luckily, during our whole stay at Deception the so-called "well" never dried or froze up, possibly due to the influence of thermal heat. At the warmest period of the summer we were also able to use the local melt streams for washing the rough prints.

Due to the lateness of the season, from 12th January until 25th March when the aircraft left, only eight days occurred which were in any way suitable for vertical photography, and of these only one day was sufficiently clear to permit both aircraft to carry out a productive sortie. By March, conditions both as regards weather and photographic light had rapidly deteriorated. In a violent gale on the night of 13th March, both aircraft received severe damage to their ailerons while picketed on shore. Using the workshop on board the "Oluf Sven" and some iron salvaged from the whaling factory, the engineers managed to fabricate new parts to replace those damaged, which enabled the Cansos to be flown out. We had our lesson, however, that any attempt at photographic flying beyond the end of February is not only a waste of effort but might easily result in the aircraft being unable to withdraw before winter sets in.

In the following season the "Oluf Sven" returned to Deception on 26th November. Compared with the enormous labour involved in setting up the shore installations the previous year, the re-opening of the base in November 1956 was a relatively simple matter, and was completed in under a week.

On their way south the two Cansos spent six weeks in the Falkland Islands, where they managed to obtain stereo coverage at 1/25,000 scale over the whole of the island group, an area of some 4,500 square miles. The weather in the Falklands is notoriously cloudy, and the area subject to almost continuous winds of very high velocity. The angle of drift on occasions reached 29° and in a single run could vary from 10 degrees starboard to 10 degrees port, while the time interval changed from 30 seconds to 90 seconds between successive runs. Despite these difficulties, a remarkably high standard of flying was achieved, and in the only eight days of clear weather over 5,000 effective negatives were exposed.

Following this good start, the aircraft flew the remaining 800 miles to Deception on 9th December. On the way they encountered some severe icing, and a large chunk of ice thrown off the propeller of one aircraft narrowly missed one of the crew when it tore an 8-inch hole in the perspex roof above the navigator.

The weather in the second season followed very closely that of the preceding year, the number of days suitable for photographic flying showing an almost exact parallel, as can be seen from the following table:—

	1955/56	*1956/57*
December	12	12
January	5	6
February	7	3
March	Nil	Nil
	24	21

With the assistance of a teleprinter, the fullest meteorological reports available from South America, the Falkland Islands and F.I.D.S. stations along the Graham Land coast were during the period of flying operations received daily by Deception Radio (as it became known), and plotted by the expedition met. officer on synoptic charts.

Within two days of their arrival both Cansos were airborne on their first productive sortie, and in the following six weeks a total of 238 hours was flown by the two aircraft. On one particularly good day (26th December) each aircraft was airborne for 11 hours, the total then covered amounting to 3,000 square miles with nine full magazines exposed.

The visibility on days of still clear weather was quite exceptional. I will always remember accompanying the aircraft on one of the long flights to the southernmost limit of the area. As we flew down the east coast of Adelaide Island the massive peaks of Alexander Land some 200 miles further south stood out clearly against a cloudless sky, and it was difficult to resist the temptation to fly on instead of using up our spare fuel in tracking back and forth along the photographic strips. Seen from the air it was difficult to appreciate the tremendous size of the landscape that extended below us for hundreds of miles with a brilliance so dazzling that one could scarcely look at it with the naked eye. Fifty miles distant to the east the central plateau of the peninsula at a height of 8,000 feet above sea level dropped in one violent step towards the Weddell Sea that must have been a sheer cliff face of 3,000 feet in depth, but appeared no more than a spade-cut in the snow. Many of the fjords were remarkably free of ice and mirrored the images of the surrounding peaks. Lallemand Fjord, to the south of Darbel Bay, was however completely blocked with close pack, as was the strait separating Hanussa Bay from Lambeuf Fjord. The limit of the main continental pack was clearly visible, lying at approximately lat. 69°S. We estimated on this flight that the height of Mt. Gandry, the highest summit of Adelaide, which had been shown at 7,600 ft. on some existing maps, was in fact over 10,000 feet; this makes it the highest peak in the whole area.

By the end of January the bulk of the air photography had been completed. In the meantime we had been honoured by a visit from the Royal Yacht "Britannia," bringing H.R.H. the Duke of Edinburgh, who carried out an inspection of the aircraft and installations at our Deception base, and took a deep and penetrating interest in all the aspects of our work.

The photographic operations were finally closed down on 28th February and the aircraft departed for Port Stanley on 4th March.

The areas photographed by vertical photography with full stereo coverage at a mean scale of approximately 1/20,000 included all the South Shetland Islands including Elephant and Clarence Islands, Joinville and D'Urville Islands and the whole of Trinity Peninsula as far as 63°S. The whole of the Palmer, Danco, Graham and Loubet Coasts, the whole of the Palmer Archipelago and Biscoe Island groups, the eastern half of Adelaide Island and Pourquoi Pas Island were also photographed. Only the western half of Adelaide Island and the high plateau lying east of the Danco, Graham and Loubet Coasts still remain uncovered by vertical pictures, but with the assistance of the obliques it should be possible to carry out precise photogrammetric mapping of 95 per cent of the specified area.

A total of 35,000 square miles of vertical cover was flown in the two months of operations. 113 vertical and 23 oblique films, totalling 12,000 effective negatives, were processed by our laboratory unit of two photographers, with what additional assistance they could muster. In addition they produced some 17,000 contact prints.

GROUND-CONTROL

Almost the entire coastline of Graham Land and surrounding islands is fringed with ice-cliffs 50–150 feet high, formed either by glacier snouts or what is termed Piedmont ice, which clings to the steep rock faces (Figures 6, 7 and 8). Inland, except for almost perpendicular cliffs, there is virtually no ice-free land and there is practically nowhere one can go which is free from the danger of hidden crevasses (Figure 9). The outer islands are in most cases as steep and unapproachable as the mainland and are moreover protected by uncharted reefs and treacherous currents. The weather is seldom fine and always unpredictable, while the wind can change from calm to hurricane force in the space of and hour. Generally speaking, the further north you are on the Graham Land coast

FIG. 6. Rock buttress on Liege Island with mainland of Graham Land beyond.

FIG. 8. Ice plateau of Graham Land with glaciers descending towards west coast. Fixed oblique taken with Williamson F.24 Rose $3\frac{1}{4}''$ lens from 13,500 ft.

the less settled is the weather, and in the northern areas the sea ice cannot be relied on for sledge travel, even in the depths of winter. In the past here and there a party had been landed by boat and observed a hurried astro-fix, and there had been one or two pockets of triangulation carried out in the vicinity of the F.I.D.S. bases.

By using a ship-based helicopter, we were able to overcome practically all the obstacles which had prevented previous parties from gaining a foothold, and at the same time to make use of every scrap of good weather, even if it lasted only a couple of hours.

In the first season we took out two S.51 Sikorsky helicopters stripped down into their main component parts and carried boxed in the hold on the outward voyage. It was not until the aircraft operations were under way, and all cargo had been discharged from the ship, that we were able to reconstruct the flight deck and assemble the helicopter in readiness for flight. In the meantime the surveyors measured a precise base-line of 3,000 feet along a straight volcanic beach on the west shore of Whalers' Bay. Although the base terminals were 10 feet above high water a considerable length of the base lay below the tide line, and measurement had therefore to be carried out within the period of $4\frac{1}{2}$ hours between ebb and flow.

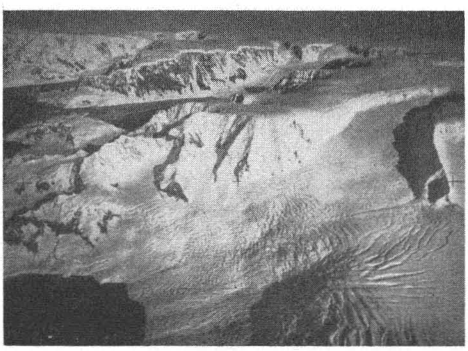


FIG. 7. Glaciers of Graham Coast. Fixed oblique photo taken with F.24 Williamson camera. $3\frac{1}{4}''$ f.1 on $5''\times5''$ format.

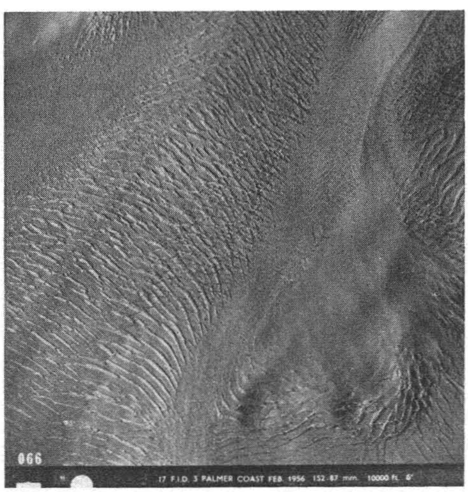


FIG. 9. Crevasse patterns on glacier—Palmer Coast (W. Graham Land). Eagle IX camera, Rose 6″ lens.

For the alignment of the base we drove in pegs at approximately 100 ft. intervals with a hardboard slat nailed to the top of each peg, the pegs being lined up, of course, by theodolite. Prior to staking out the line, the bulldozer was used to clear the beach of whalebone and flotsam and the line of measurement carefully graded. Final measurement was made three times, using a 100-ft. Invar tape on the flat under the calibrated tension of 20 lbs. The work was carried out with a team of six men, two at either end of the tape, one on the theodolite and the sixth man standing in the middle of the tape with a whistle. The ends of each tape length were simultaneously scratched with a sharp knife on the hardboard, the recorders being given the usual warnings, ending up with the whistle. After applying slope and temperature corrections, the agreement between three independent measurements of the base came out at 1 in 225,000.

From this initial base a well-braced triangulation net was extended to cover the whole of Deception Island, including the two highest peaks of the island, Mt. Kirkwood and Mt. Pond, and then across to points on Snow and Livingston Islands. The helicopter was used to lift a number of empty 44-gallon fuel drums, which were slung on a rope below the fuselage and dropped on the survey point. Using the drums we were able to build temporary beacons up to 9 ft. high and 6 ft. thick, which were clearly visible at a distance of 30 miles away (Figure 10). We had hoped that these beacons might have become encrusted with ice and drift and become a permanent feature of the landscape, but as a result of successive thaws and very high winds they were usually carried away in the course of a few weeks, and will have ended up half-way down the mountain side at the bottom of a crevasse. Nevertheless, they served their purpose very well indeed and though we tried other types of beacon, the barrels proved the most reliable.

The early sorties with the helicopter were an illuminating, if at times a rather sobering experience, for those taking part. A climb that had previously taken us several hours to make on foot would be accomplished in the same number of minutes by this remarkable form of transport. Not only is it possible by this means for the surveyor to seize every opportunity offered by short breaks in the weather, but it enables him to arrive at his destination unfatigued and free of the chilling effect resulting from getting overheated on the climb. By the same means it was possible to reconnoiter in a 2-hour flight an area of 400 square miles, or to beacon in one day of good weather 3 or 4 stations separated 10 to 20 miles apart.

FIG. 10. S.51 helicopter landing barrels on a mountain top to act as a signal for surveyors.

Using the air photos, wherever available, the points to be occupied were selected to conform to the following five requirements:—

1. Between 10 and 25 miles apart and inter-visible with other connected points in the scheme.
2. Not higher than 1,500 feet above sea level, in order to be below the average height of stratus cloud which predominates in the area.
3. On or near a satisfactory helicopter landing site.
4. Having a practicable route down to the coast in case of emergency in the event of failure of the helicopter.
5. Identifiable on the air photos (this had to be waived on several occasions but could be overcome by artificial beaconing followed by low-level air photography when necessary).

The ship would proceed to the area for a visual reconnaissance first from the deck, followed by a flight with the helicopter if conditions were suitable. The normal duration of flight from deck take-off to landing at the trig. station was usually

FIG. 11. Bell 47D helicopter landing to pick up surveyor.

about three minutes, one surveyor being carried at a time (Figure 11). On the first journey would be taken essential survival kit including 10 days' food, a tent, camp and climbing equipment and a short range radio; the survey instruments following with the second flight; the reverse procedure was followed on return of the party to the ship. In this way no one was ever left on shore without adequate protection and means of survival.

Landing a helicopter on a snow surface requires very great judgement and skill on the part of the pilot. Without some form of artificial marker there is often no means of gauging height above the ground. Initially we used a red flag attached to a stick which was intended to stick upright in the snow, but more often than not the stick fell over or missed the target. A better form of marker is a weighted box painted red and of known dimensions, at least two being carried in case the first misses the target and is carried down the mountainside. A solid object of this kind will also assist the pilot in judging the angle of slope, and give some indication of the nature of the surface. For the first few drops the helicopter never alighted at all and we soon effected a technique with the S.51 for clambering in and out at different hovering heights not exceeding five feet above ground. For convenience of loading and unloading equipment, however, it is desirable that the aircraft should land whenever possible, and with increased experience, plus the addition of snow shoes fitted to each of the wheels, this became the normal procedure.

By the middle of March conditions were rapidly deteriorating, and we were forced to abandon any further survey until the following year. Despite having been forced to operate at the tail end of the season under conditions of almost continuous cloud and high winds, we had nevertheless made a promising start and gained a great deal of experience that was to prove of tremendous value in the future.

The most important outcome of this experience concerned the housing of the helicopter on the ship. Since in the first season all available space on the ship was taken up on the outward voyage with stores and aviation fuel, it was impossible to make any provision for a hangar. Consequently, during the whole period of survey operations the helicopter had to remain on deck, its rotor blades supported on wooden stanchions standing on platforms cantilevered outside the ship's side and with its fuselage protected only by waterproof covers. In severe gales when the wind sometimes reached up to 80 miles an hour, we expected to see the aircraft carried off the side of the ship, and on one occasion following a four-day blizzard it took 36 hours to clear the fuselage of ice before it could be used. Maintenance on deck was at best a wretched job for the engineers and could only be carried out in conditions of comparatively mild weather when we could often have been flying.

In the second season we had no aviation fuel to transport and were therefore able to use the forward hold of the ship as a hangar. The forward section of the deck was replaced by a sliding steel (McGregor) hatch, giving access to the full opening of the hold. A lift operated by two handwinches was built to raise and lower the helicopter from deck level. By this means, the helicopter, this time a Bell 47D, was taken out from England fully erected and could be serviced in periods of bad weather, during which the engineers were able to work in conditions of relative comfort in the heated hangar below decks. The ship, free of the encumbrance of the helicopter on deck, was more easily maneuverable and the helicopter secure at all times when on the ship. All survey, field rations and camp equipment was also kept in the hangar, sorted into individual loads so that at a moment's notice they could be loaded onto the helicopter in readiness for take-off.

Unfortunately, due to budget limitations beyond our control, only one helicopter could be taken and as luck would have it, this crash-landed on the second day of operations and became a total wreck. While the ship returned to Montevideo to collect a replacement, a party of five surveyors was landed on King George Island, the largest of the South Shetland Group. The terrain on this island is less rugged than many, and the surveyors were to travel on ski, manhandling sledges and using small boats to cross Admiralty Bay, which divides the island almost in two. A base-line was measured on the ice-cap by similar means to those used for the Deception base, and despite meeting frequent conditions of high wind, blizzard and cloud, the triangulation of half the island was complete by the time the "Oluf Sven" returned. On the arrival of the ship, Bancroft and the team with the use of the helicopter were able to double the area already covered by them in five weeks of extremely hard travel. This direct comparison between the employment of air and ground travel is a measure of the vital role played by the helicopter in this type of terrain.

The ship returned with a new helicopter at the end of January and sailed immediately for the Palmer Coast where a fresh base-line was measured and the survey begun in earnest. Our object was to extend a fully observed triangulation from Cape Sterneck in latitude 64° southwards to include as many as possible of the coastal islands and reaching as far south as we could in the remaining six weeks of the season (Figure 12). Already the brief Antarctic summer was over and the weather during this period gave us very little relief. Almost every day brought either low cloud, high winds, or blizzard; often all three together. Nevertheless there were very few days on which no work was done, owing to the extraordinary speed and maneuverability of the helicopter, which enabled us to make use of even the shortest breaks in the weather when the wind might drop for an hour or two, and the cloud base lift sufficiently to give visibility between the observed stations. Often when conditions were impossible in one area we were able to continue working by moving the ship into the lee of an island or coastal

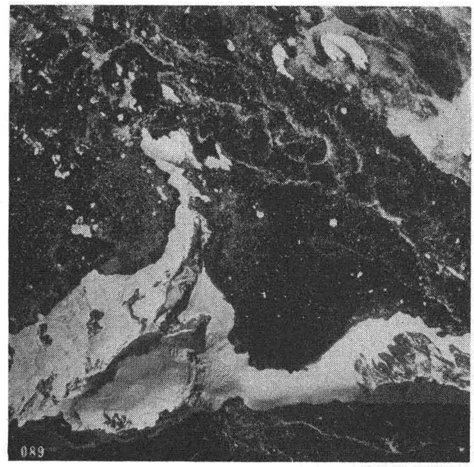


FIG. 12. Vertical photo Wiencke Island with brash and icebergs. Williamson Eagle IX camera, Rose 6 inch lens, flying height 13,500 feet.

ridge. One had to be continuously on the alert during the hours of daylight watching wind, cloud and sea, which in the space of an hour could change with unpredictable and provoking abruptness.

The usual day's routine began at 6 A.M., when there would be a discussion between the Captain of the ship, the senior pilot and the expedition leader. If it was decided that conditions were suitable to operate, the ship would move to within 2–3 miles of the point to be occupied. While the surveyors were breakfasting and packing their personal kit, the radio officer tested the field sets, the steel hatch over the hangar was opened by the crew, and the engineers made ready the helicopter.

All hands were then mustered to man the winches which operated the lift bringing the helicopter on deck. By 8 A.M. the helicopter was airborne on its first sortie and in less than ten minutes would be back to collect the second surveyor. The complete operation of landing two surveyors with 600 lbs. of equipment seldom took longer than 20 minutes and their evacuation required less time even than this. Before the helicopter returned from the second flight the ship would often be on its way to the next point so that a minimum of time was lost. We soon found, however, that it did not pay to land more than two parties at a time. On the few occasions when we broke this rule, we invariably finished up with one or more parties left on shore, as a result of a sudden change in the weather; several days might pass before they could be relieved, thus delaying the whole progress of the work.

In this manner the survey advanced steadily and by using every break in the weather, however short, we completed in the six-week period a belt of fully observed triangulation over a distance of 130 miles. A total of 84 control points, of which 24 were occupied stations, was established to an accuracy which is comparable to that of normal secondary-control. The theodolites used were Wild T2 and Cooke Troughton & Sims "Tavistock" reading direct to 1 second of arc. The average triangular closure was in the region of 5–10 seconds. The network was tied to a 16 star position-line fix carried out with great care and the base-measurement checked to 1 in 50,000. I do not think we can expect better in this type of country, and I believe it can be claimed that it is the most accurate survey yet made in the Antarctic. Had we been equipped with the Tellurometer it is possible that even more rapid progress might have been made, but unfortunately this instrument arrived just too late to be of use.

HYDROGRAPHIC WORK

As a by-product of ground control operations, the navigating officer of the "Oluf Sven" carried out a valuable hydrographic survey. Using the air photo cover, radar ranges and bearings to points, including those fixed by the triangulation, he replotted the coastline and from some 900 miles of soundings recorded on the ship's echo-sounder an accurate chart was produced covering the areas of Hughes Bay and the southern Gerlache Strait, neither of which had been previously sounded. When it is appreciated that many of the most prominent coastal features were found to be 10 miles out of position, let alone the hundreds of coastal reefs and islands which showed up clearly on the air photos but did not exist on any previous map, the reason why this expedition was necessary is not difficult to understand.

CONCLUSION

The measure of our success will perhaps best be judged by the eventual publication of the new series of mosaics and maps which are now under preparation by the Directorate of Overseas Surveys, based on the results of the expedition's work. Contact prints of the air photos are in the meantime already being widely used by the field parties of the Dependencies Surveys, for planning sledging routes and for geological, glaciological and other studies.

In these and other ways, it is to be hoped that all the money and effort expended on this first British photogrammetric survey in the Antarctic will have been fully justified. Whatever else we achieved, I am certain that our expedition has demonstrated beyond doubt that the long-range photographic aircraft with helicopter transport for the land surveyor are an indispensable combination in overcoming the tremendous obstacles of terrain and climate, if this last remaining unmapped continent is to be surveyed within a foreseeable period of time.