AIR NAVIGATION BY RADAR IN SOUTHEASTERN ALASKA

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SUMMARY

This report describes the installation and initial service tests of an APS-10 airborne radar equipment in airplane NC28369, a Grumman JRF-6B seaplane, operated by the Alaska Coastal Airlines in the southeastern Alaska area

INTRODUCTION

In March 1946, a request was made by Alaska Coastal Airlines to the Technical Development and Evaluation Center for the loan of an airborne radar Mr Sheldon Simmons, co-owner and operator of Alaska Coastal Airlines, first became interested in the possibilities of radar as an aid to air navigation after witnessing a demonstration of the APS-10 radar sponsored by American Airlines under a Navy contract During the course of this demonstration, the flight proceeded over the Long Island Sound area and Mr Simmons was particularly impressed by the distinctive contrast patterns produced on the radar indicator by land and water boundaries Since all scheduled flights of ACA are conducted in a region characterized by such boundaries, viz , the well-known inside passage of southeastern Alaska, he recognized the potential value of airborne radar in such operations See Fig 1 The Technical Development and Evaluation Center welcomed the opportunity to obtain actual data along these lines and agreed to loan an APS-10 radar to ACA, and to furnish an engineer to assist in the final installation, flight tests, and indoctrination of ACA personnel in the operation and maintenance of the equipment It was felt that such effort would not be a duplication of experimental work already underway by various organizations inasmuch as the function to be served in this case was navigation by radar alone Much experimental work has been done and is still being conducted in connection with the adaptation of airborne radar as an aid for weather surveillance, terrain clearance, instrument approach and anti-collision, but, there has been very little emphasis on its possibilities as a self-contained navigational device The lack of interest in radar, as such, can be accounted for by the fact that most of the terrain within the United States is of such a nature that navigation by radar alone is generally unsatisfactory compared with a number of other means of air navigation already available The geography of southeastern Alaska is peculiarly adapted to radar navigation because of the contrast displayed by the land and water boundaries

At the time of the ACA request, the TDEC had two Type APS-10 radars which were being used for current experimental investigations A request was made to the General Electric Co , manufacturers of the APS-10, for the loan of an additional radar for this experimental project This request was granted, and in addition, General Electric Co offered to furnish an adequate supply of spare parts

INSTALLATION

Delivery of the APS-10 radar and spares to Juneau, headquarters of ACA, was delayed somewhat by a prolonged shipping strike, but in the meantime, ACA was proceeding with modifications to NC28369 required to adapt it for radar installation The major changes to be accomplished were redesign of the nose section to permit installation of the radar antenna and associated radome, construction of the radome itself and conversion of the aircraft electrical system from 12 volts to 24 volts

The Grumman JRF-6B airplane is a twin engine, amphibious, 8-place airplane, with a cruising speed of about 150 mph The APS-10 radar is a lightweight, X-band airborne search radar comprised of five major units, the antenna, rectifier power unit, transmitter-receiver, synchronizer and indicator The total weight of the equipment, including cables and accessories, is approximately 140 pounds Operation of the equipment requires a power drain of about 25 amps at 24 volts dc, most of which is consumed in driving the alternator which must supply about 3 amps at 115 volts

Since no standard radomes were available, it was necessary to construct one to

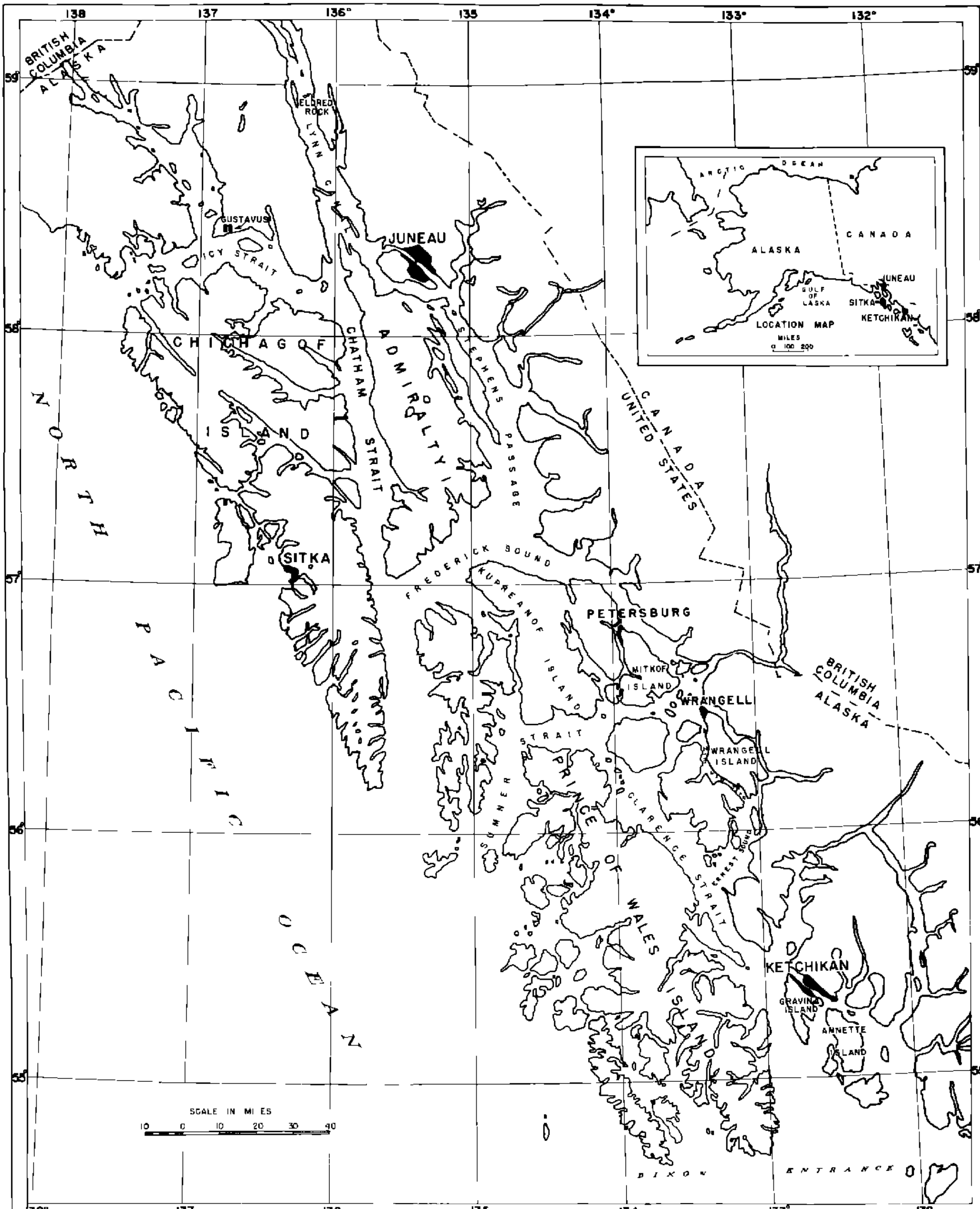

Fig 1 Map of Southeastern Alaska

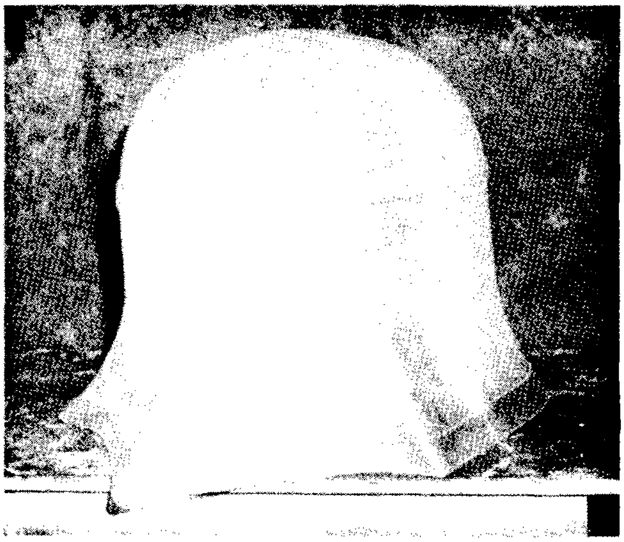

Fig. 2 Radome, Bottom View

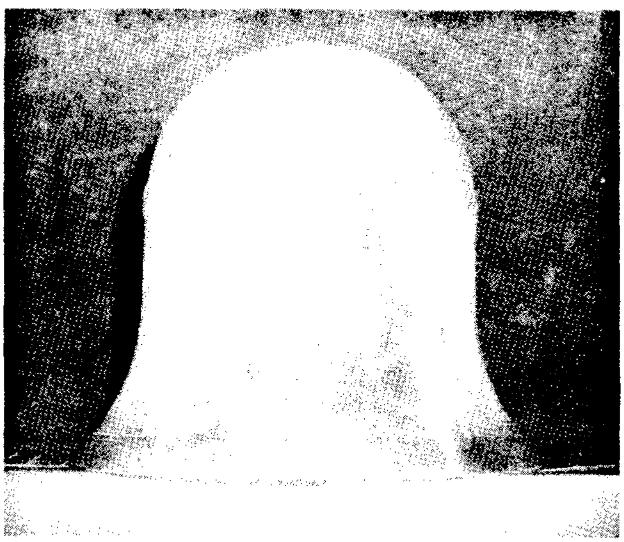

Fig. 3 Radome, Top View

meet the electrical requirements of the radar as well as the mechanical requirements imposed by the flight characteristics of the aircraft. The only materials available for fabricating the radome were plexiglass and plywood, both of which are suitable, but not ideal, from an electrical point of view. Since plexiglass has the lower dielectric constant, an important criterion in radome construction, and because a smaller thickness could be used while still meeting the mechanical requirements, this material was selected.

Structural design and molding of the radome were accomplished by ACA personnel and the completed dome is shown in Figs. 2 through 5. The plexiglass reinforcing strips which are used to secure the ten separate sections of the dome together were necessary since molding of the dome as a single piece was not feasible. All material used is 3/16 inch, giving a thickness of slightly over 1/2 inch at the reinforced junctions. The weight of the completed radome is approximately 17 pounds. It is secured to the airplane by a metal clamping ring drilled to align with threaded studs protruding from the radome mounting seat at the nose of the aircraft. A gasket and suitable sealing material are in-

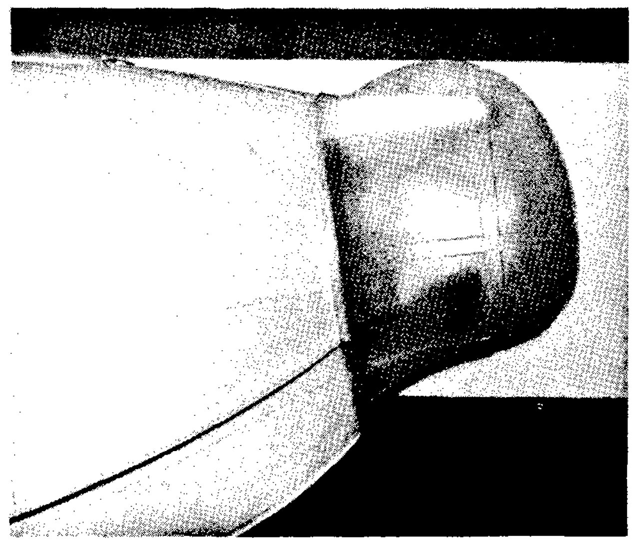

Fig. 4 Installed Radome, Side View

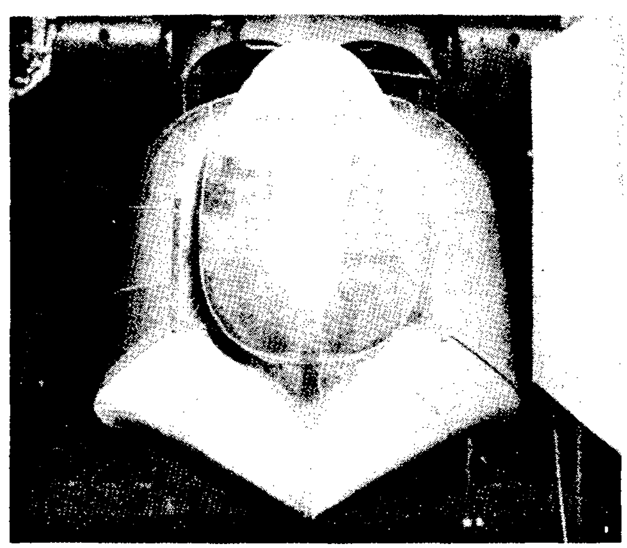

Fig. 5 Installed Radome, Front View

serted between the seat and the radome, and the assembly is tightened down with elastic stop nuts on each stud, making a very satisfactory watertight joint

Due to the general structure of the JRF-6B, it was necessary to install the radar antenna in the nose The fact that the airplane is water based naturally prohibited installation on the under side of the fuselage, from which position 360° of azimuth could be scanned Locations on the upper part of the fuselage or on a wing also were out of the question since any such location would result either in severe radar shadowing or obstruction of the pilot's normal view

Upon arrival of the TDEC engineer in February 1947, the previously mentioned work had been completed as well as mounting of the major radar units and fabrication of most cables Fig 6 shows diagrammatically, the relative positions of the larger components in the forward section of the airplane Figs 7 through 10 are photographic views of the installation In order to adapt the power input of the radar to the output of the alternator and to supply, simultaneously, a 24-volt source, it was necessary to install a special radar junction box

After final installation, all units were removed from the airplane for the purpose of setting up and operating the system on the test bench Space was provided in the ACA hangar where the radar antenna could be located in a window viewing Gastineau Channel and Douglas Island The equipment operated satisfactorily With the exception of a few indicator adjustments, the APS-10 appeared ready for flight testing

In order to determine the signal attenuation due to the unorthodox plexiglass radome, it was decided that some relative tests should be made, observing the return signals from a given target, with and without the radome installed Unfortunately, it was not possible to make entirely satisfactory tests of this type, since orientation of the airplane while out of the water was quite limited Removal of the radome while the airplane

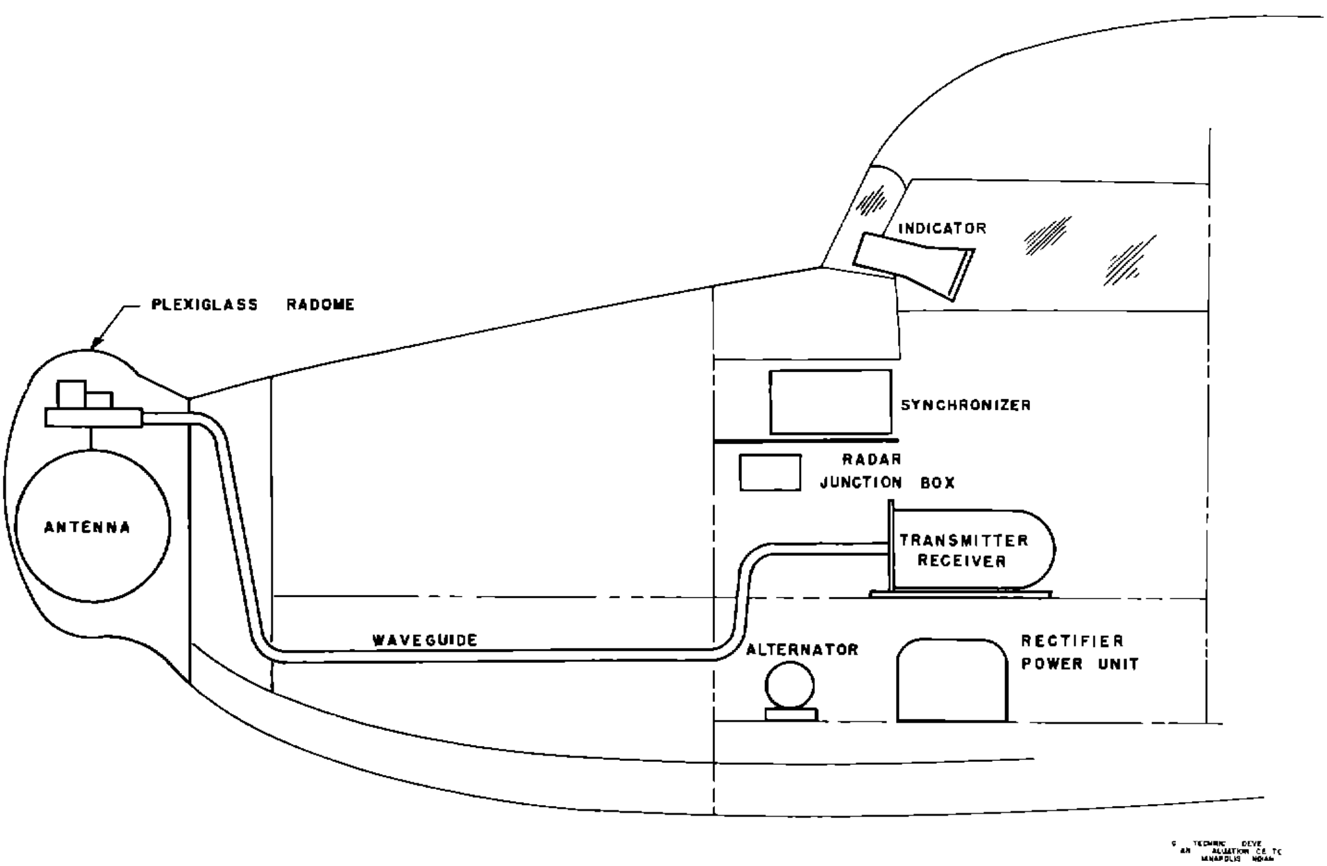

Fig 6 Nose Section of NC28369 Showing Location of Radar Units

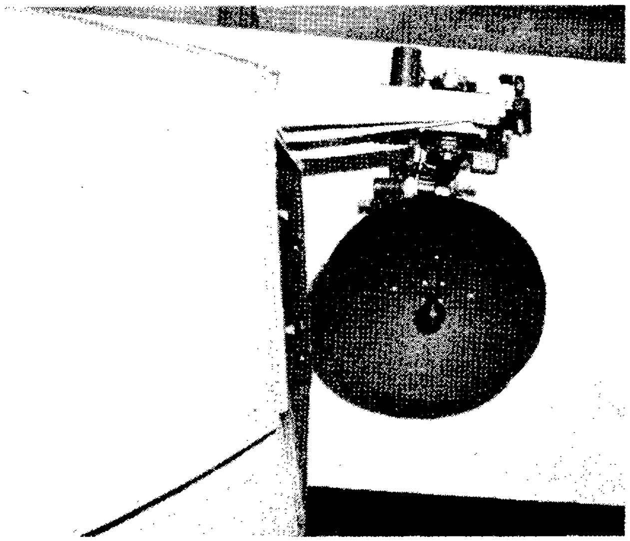

Fig. 7 Radar Antenna

was floating was not feasible. It was possible to locate the airplane in such a position that a 5° arc of unobstructed view could be obtained, but in this direction a large mountain, at five miles and clearly visible both with and without the radome, destroyed the effectiveness of the test to a large extent. A considerably less solid appearance of the target was evident when operating through the radome. On the basis of this observation an estimated reduction in range capability of 25 per cent was attributed to radome attenuation. As pointed out later in this report, the sensitivity of the radar is still well above that required for operations of the type performed in southeastern Alaska.

FLIGHT TESTS

After the previously described bench tests and ground checks had been completed, a number of preliminary flights were conducted. These flights were, for the most part, local in nature and were primarily for the purpose of indoctrinating ACA pilots in the operation of the equipment and in the interpretation of radar patterns as presented on the cathode-ray indicator. Very few of the pilots or observers had previously observed a radar in operation.

The areas covered by these preliminary flights were all within 100 miles of Juneau and were conducted largely up Taku Inlet, the Taku River, around Douglas Island and to Eldred Rock. Inspection of the map of southeastern Alaska will show that these routes are typical of the entire area.

One fact brought to light during these earlier checks was that geographical familiarity with the flight area is of extreme importance if any initial success is to be had at radar locating, and to a great extent can make up for lack of radar experience. It is believed, however, that five or six trips along any given route would be sufficient to enable any good instrument pilot to retraverse the route using instruments and radar alone. It must be borne in mind that this report is concerned only with radar navigation in a locality where natural geography supplies almost unmistakable continuous "radar airways." Attempting to navigate by radar over land areas, without the aid of ground beacons, where there are few distinctive radar targets (lakes, rivers, isolated mountain peaks, etc.) is a difficult operation and requires close scrutiny of the scope at all times. Flying "blind" through the inside passage, below the level of the mountains, requires only brief glances at the indicator screen, the pilot still having about 90 per cent of his time available for watching the instrument panel.

The question had been raised as to whether frozen bodies of water would give the appearance of water on the radar indicator. In order to answer this question, flights were made up the Taku River, which

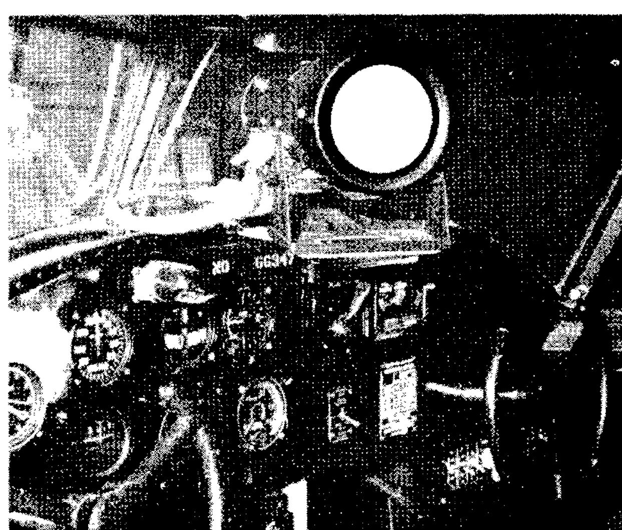

Fig. 8 Radar Indicator in NC28369 Cockpit

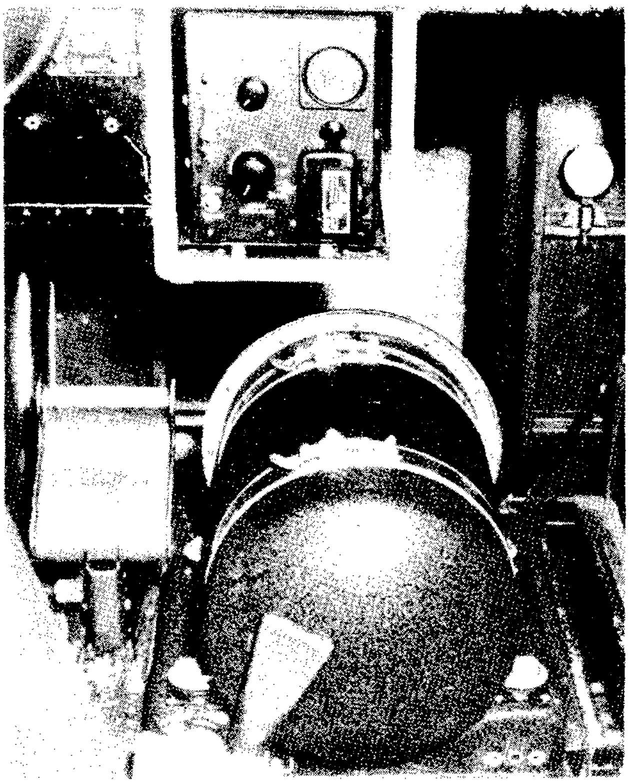

Fig. 9 Transmitter-Receiver and Synchronizer

was frozen solid, and also over the Taku glacier. Results were in accordance with reflection theory, viz., where the ice was smooth there was no visible return except from the point directly below the plane where the incident radar beam was normal to the surface. In the case of rough ice there was a visible radar return, but the intensity of this signal was considerably less than that of the surrounding land areas. This also was true of the return signals from the glacier.

After some flight experience had been obtained, both pilots and observers agreed upon a standard rule of by-passing all land areas. There are many small islands in the channels, most of which have no appreciable elevation, although a few of these are of sufficient height to present an obstacle to aircraft flying at altitudes commonly employed when passing through these areas. Actually, a pilot familiar with the route would unquestionably identify each island and know if it was safe to proceed directly over it. By careful observation of the radar scope, as the land mass is approached, it might be possible to determine (with sufficient reserve time for evasive maneuvers) whether the land is above or below the flight level; but, since there always is an alternate route around the island, this procedure is not considered worth the risk or effort. The fact that the antenna pattern employed is cosecant squared in the vertical plane (best for ground mapping) renders relative altitude determination somewhat difficult, and is another reason for applying the safe rule of by-passing when any doubt exists in the mind of the pilot.

Since the installation of an antenna stabilizing system in NC28369 was not feasible, there had been some doubt as to whether radar mapping along these routes could be successful because of the many turns involved. In practice the pilots quickly learned how and when to make their turns to best advantage, and the radar picture was seldom distorted for more than a few seconds. Use of the cosecant-squared antenna is a contributing factor in minimizing the need for antenna stabilization.

In spite of considerable signal attenua-

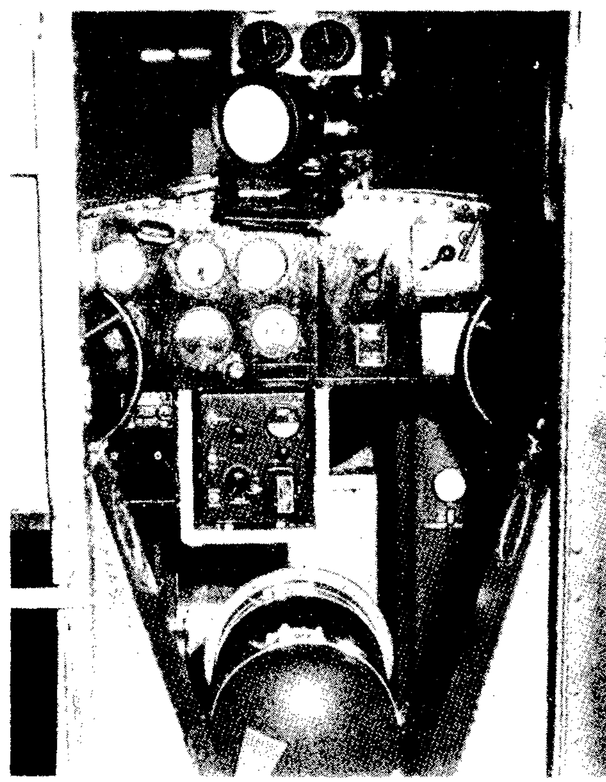

Fig. 10 Cockpit of NC28369 Showing Relative Positions of Transmitter-Receiver, Synchronizer and Indicator

tion due to the plexiglass radome, it was the practice to operate the receiver gain turned well down in order to obtain clear definition of the first five to eight miles of coverage. Too much gain results in excessive sea return when flying over moderately rough water and also tends to narrow the visible channel, as indicated on the radar scope, due to the halo effect of the strong adjacent land signals. In many cases, the pilot preferred to "hug" one of the two shorelines and reduce the gain to such an extent that the opposite shoreline (in wide channels) was not visible. Most pilots preferred to use the 4- to 10-mile range scales.

The radar antenna is mounted directly in front of a metal partition forming part of the airplane structure. For this reason, the back 120° on the indicator are of no value; however, this has proven no serious handicap to navigation. There has been no evidence of receiver crystal deterioration as a result of strong reflections from this bulkhead, although false radar echoes appear in this sector on the oscilloscope due to these reflections, forming a less intense duplication of targets in the forward sector. At the time of installation, no 3-centimeter, radio-frequency absorbent material, or so-called "harp," was available. It is intended to line the partition with this material to eliminate the false echoes as well as preclude the shifting of the magnetron frequency due to the change in effective loading.

After a few indoctrination flights, the pilots expressed a desire to attempt actual radar flight under simulated instrument conditions. The left-hand cockpit of the airplane was fitted with a hood to completely obstruct the pilot's vision, leaving the co-pilot with clear vision ahead and to the right. The procedure followed on such flights was to allow the pilot to take control of the airplane as soon as the radar had warmed up and commenced operating, the co-pilot thereafter serving as a monitor only. Flying in this manner, Mr. Simmons and Mr. Ray Renshaw made a number of local flights and others to Gustavus, Ketchikan, and in the vicinity of Sitka. During these flights, it never was necessary for the co-pilot to take control of the airplane to avoid collision.

Figs. 11 through 15 demonstrate how this sort of flying was accomplished. The particular channel indicated is typical of the entire area. By examining the photographs consecutively, the path of the airplane through this particular passage (between Pleasant Island and the Alaska mainland near Gustavus) can be traced. In all cases the top of the illustration represents 0° relative to the nose of the aircraft, the range scale used is eight miles, each concentric circle representing a distance of two miles. In Fig. 11 the aircraft has not quite reached the tip of Pleasant Island and Pt. Adolphus is just visible at about 70°, at a distance of 8 1/2 miles. In Fig. 12 Pt. Adolphus is blocked since the aircraft has proceeded about one mile be-

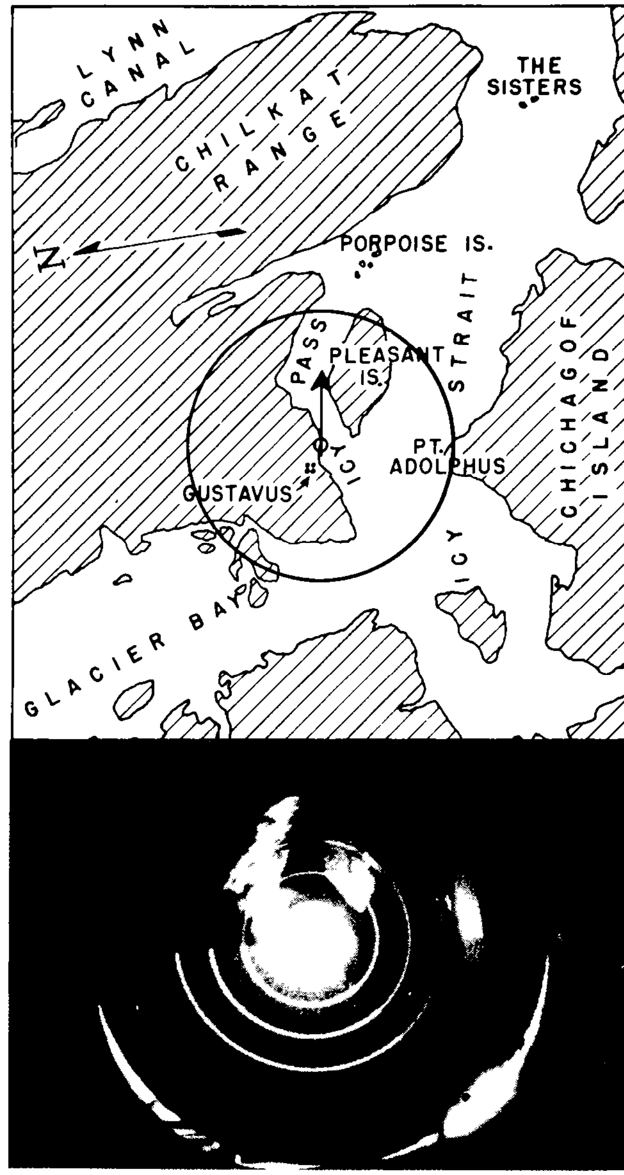

Fig. 11 Departing Gustavus

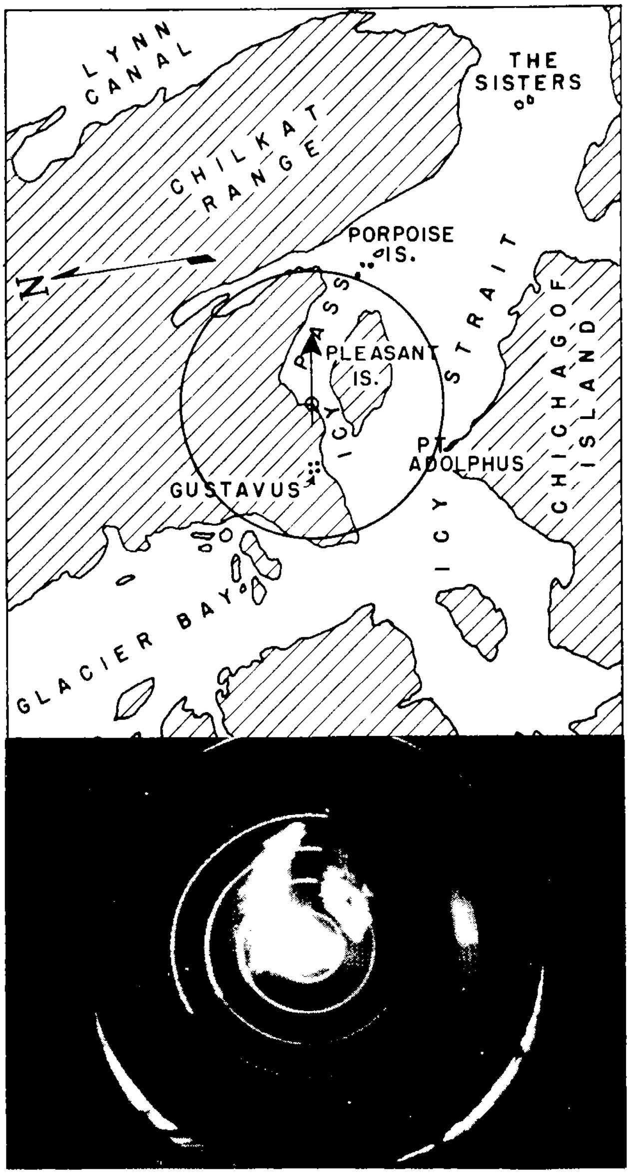

Fig. 12 Entering Icy Pass

yond its position as indicated in Fig. 11. Also visible in Fig. 12 is the first of the Porpoise Islands at 8 1/4 miles, at a bearing of 10°. Fig. 13 shows the scope after an additional mile of travel and all of the Porpoise Islands can be seen. The similarity between the radar picture of Pleasant Island and the actual shape of the island should be noted. The discontinuities on the far side of the island are due to partial shadowing by the higher land at the center. The altitude at this time was approximately 500 feet. Fig. 14 shows the nearest island of the Porpoise Group at 6 1/4 miles, while the land appearing to the left and at 5° is the Alaskan mainland. Excursion Inlet appears as a discontinuity between these two land signals. Fig. 15, taken 2 1/2 miles later, shows more of the mainland to the left and ahead, with Excursion Inlet now showing very clearly, and the Porpoise Islands at about 4 1/2 miles. To reach Juneau, the pilot only needs to keep this shoreline in sight and follow it around the peninsula, at which time he will pick up Pt. Retreat, round it and then proceed along the new shoreline around Douglas Island and into Juneau. This route is illustrated in part

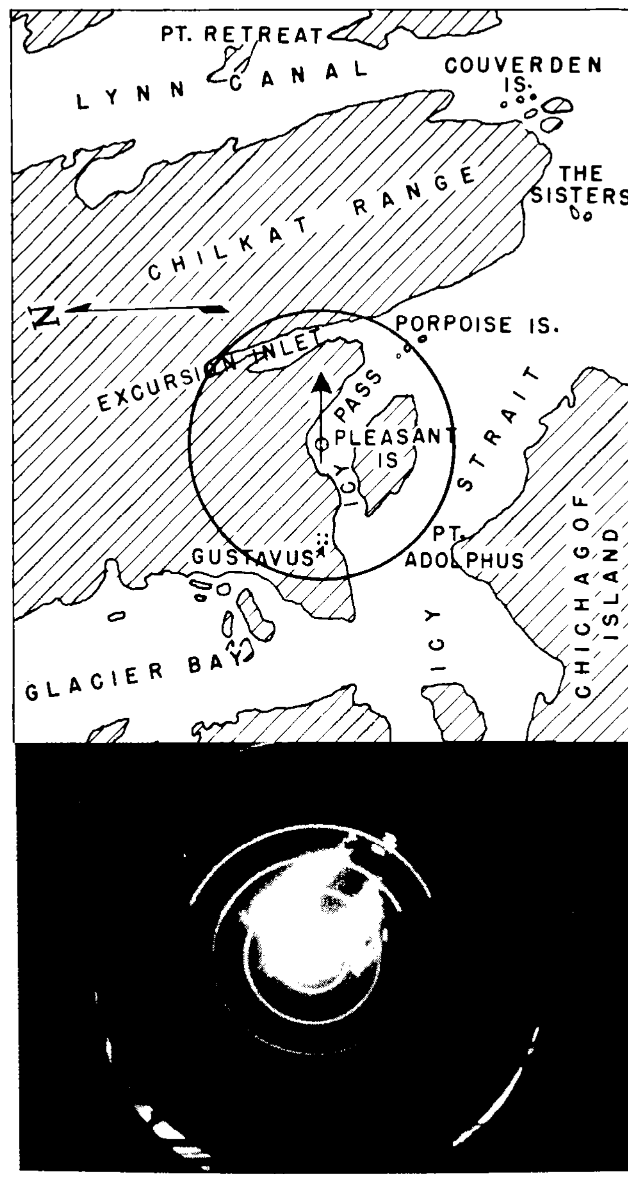

Fig. 13 Continuing on Present Course is Not Indicated

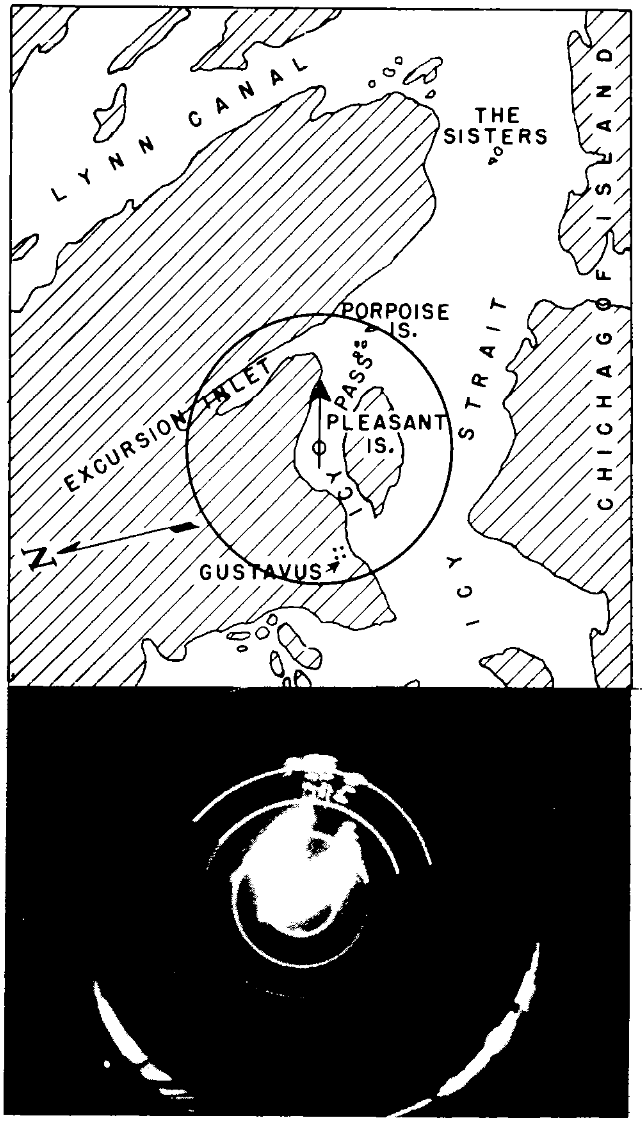

Fig. 14 Traversing Icy Pass

by Figs. 16 through 19. He can verify his approach to Juneau by the distinctive signal he will receive from the bridge across Gastineau Channel. It may be observed that a shorter approach to Juneau would be down the northern half of Gastineau Channel, rather than circling Douglas Island and entering the channel from the south. The latter procedure is used since at low tide the width of the northern end of the channel is extremely small, and can be detected on the radar screen only with difficulty. Since the longer route requires inappreciable additional time, it has been adopted as the standard radar approach to Juneau.

Reference to Fig. 1 will illustrate the routes which should be taken between any two points in southeastern Alaska. For example, in flying from Juneau to Ketchikan the flight proceeded south through Stephens Passage, then through the eastern branch of Frederick Sound, past Petersburg and Wrangell, through Zimovia Strait, Ernest Sound and Clarence Strait to Ketchikan.

Sitka presents more of a problem be-

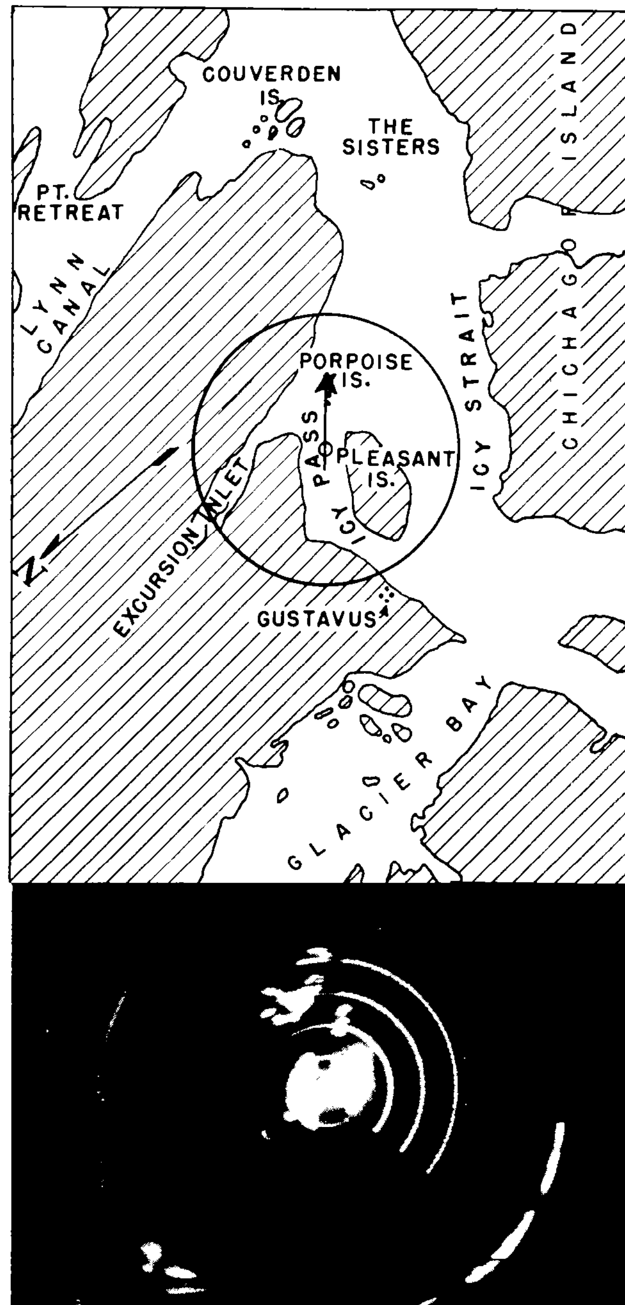

Fig. 15 Closing on the Porpoise Islands

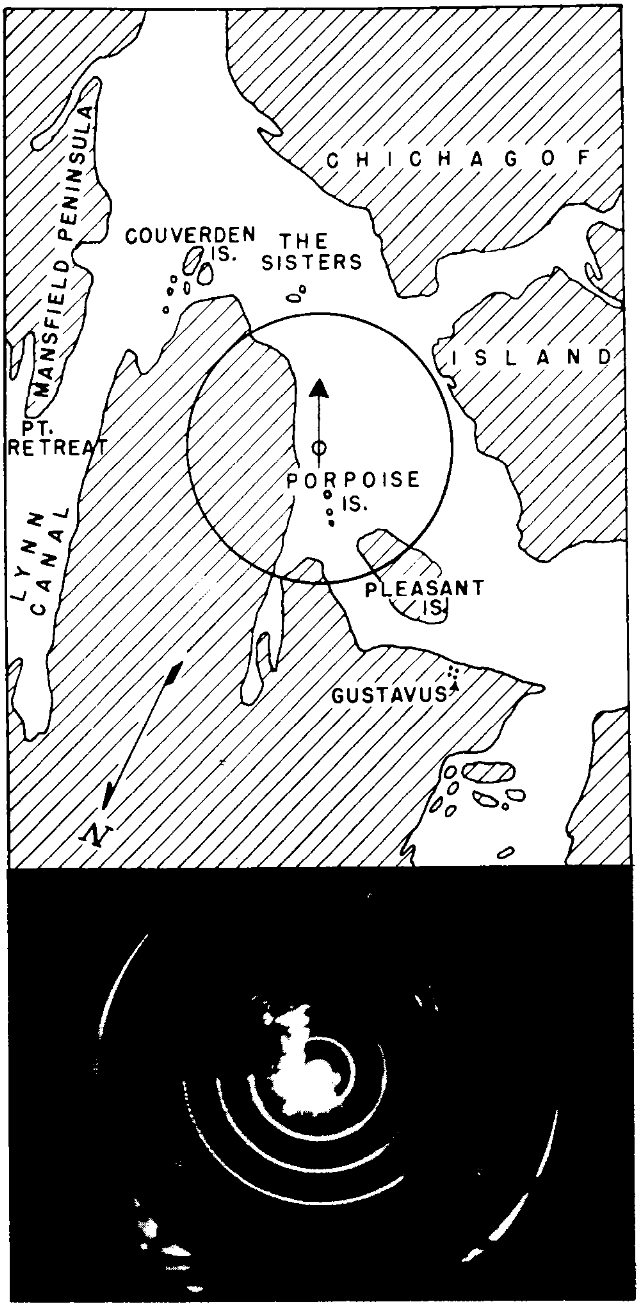

Fig. 16 Hugging the Shoreline Prior to Rounding the Peninsula.

cause of the very narrow channels along the shortest route; but could be reached with little risk by proceeding around the northern tip of Chichagof Island, and following the outside coast south to Sitka.

Figs. 20, 21 and 22 are reproductions of additional photographs taken in southeastern Alaska which further illustrate the ease with which radar navigation can be accomplished.

It was the policy to invite representatives from interested organizations to witness these demonstrations whenever feasible. Among these observers were representatives from the Civil Aeronautics Administration Eighth Region, Pan American Airways, Petersburg Air Service, Alaska Game Commission

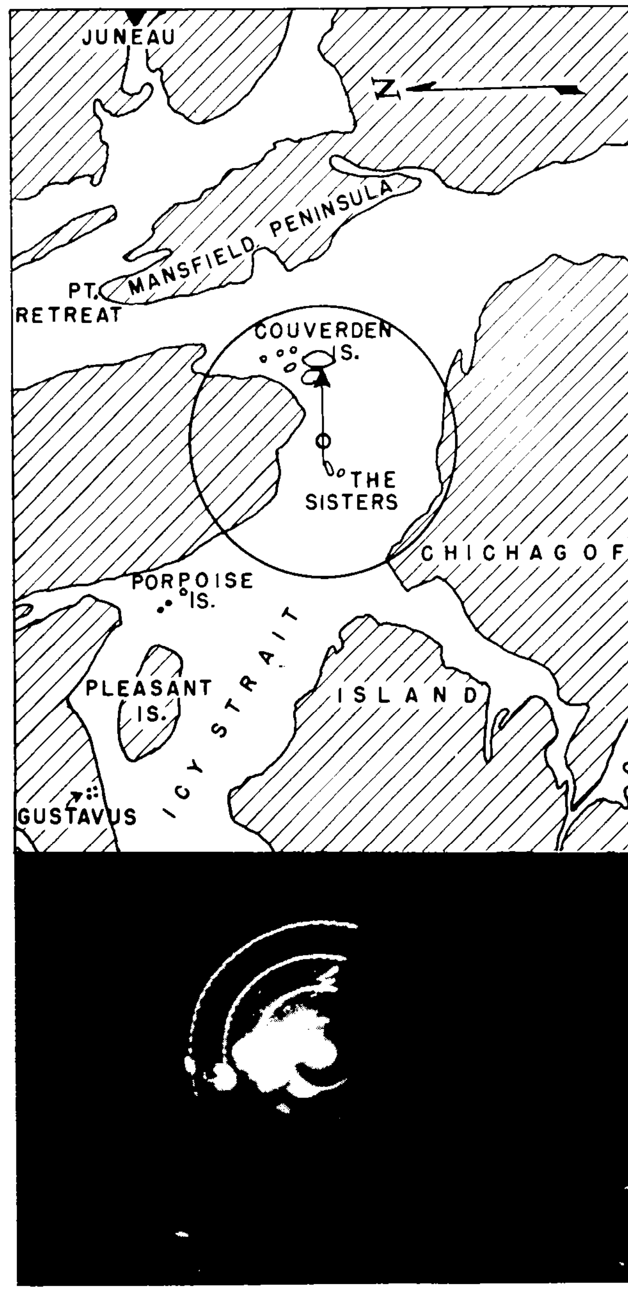

Fig. 17 Couverden Island Dead Ahead

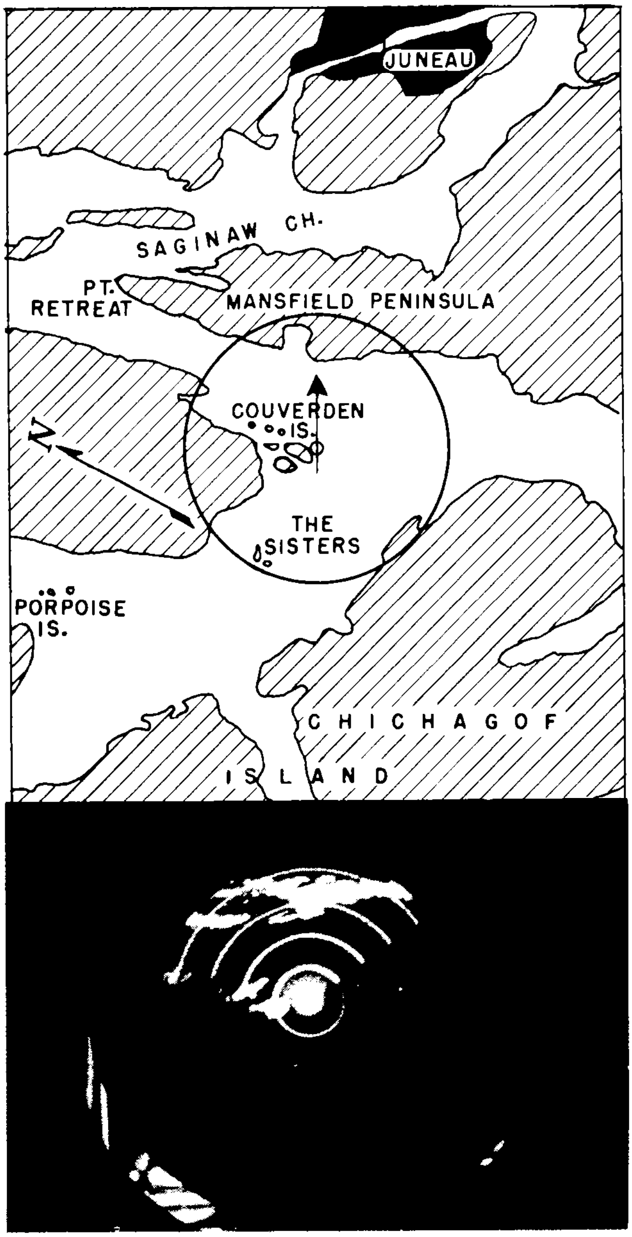

Fig. 18 Just Before a Left Turn up the Channel

(Air Division), Federal Communications Commission and Ellis Airlines. Without exception, these observers were highly impressed with the effectiveness of the radar in mapping open water channels.

DISCUSSION

As stressed frequently in the body of this report, there are many limitations in the use of radar equipment, awareness of which can make the difference between a successful radar pilot and an unsuccessful one.

One obvious limitation of radar is its inability to classify targets. The radar scope can only indicate the absence or presence of a reflecting surface at any given point, and it must be remembered that orientation of the surface with respect to the

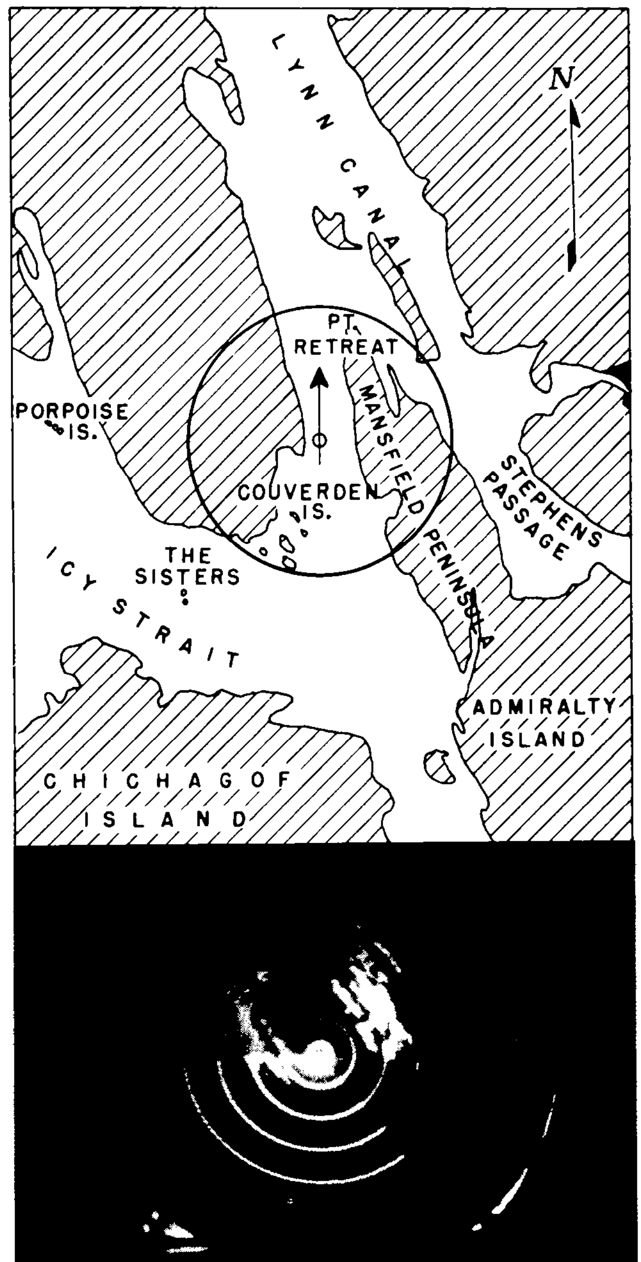

Fig. 19 The Next Maneuver Will be Rounding Pt. Retreat

Fig. 20 Fly Clear of any and all Radar Returns

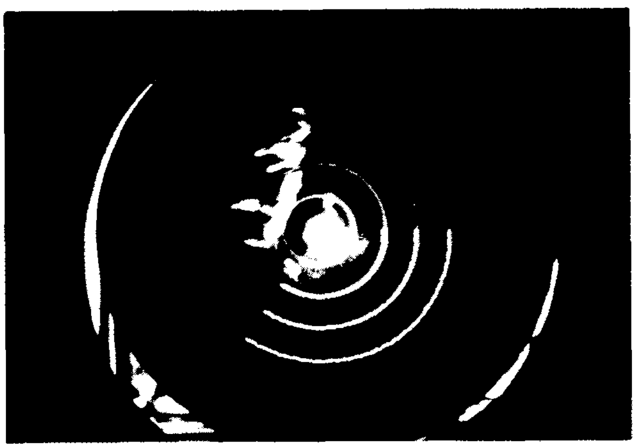

Fig. 21 For Safety Bypass the Small Island at Two Miles Dead Ahead

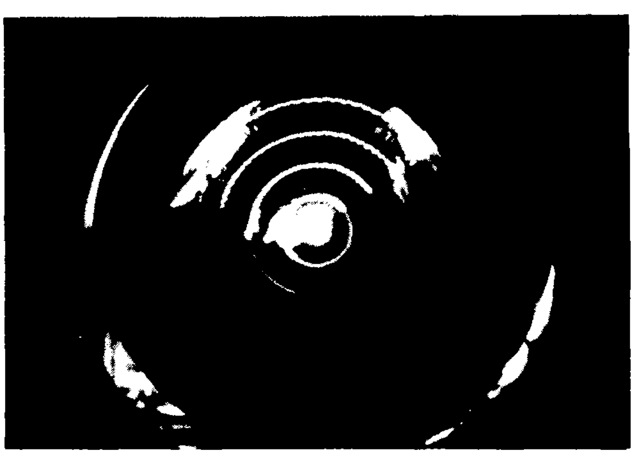

Fig. 22 Entering a Wide Channel

Typical Southeastern Alaska Radar Photographs

antenna, as well as its physical properties, determine the amount of reflection in a direction toward the antenna. If a given reflecting surface is not perfectly symmetrical, it will not present the same radar return when approached from opposite directions. Basic understanding of this sort is valuable when unfamiliar echoes appear on the indicator.

An echo received from another aircraft will resemble that returned from a boat or small island. The only means of determining that it is neither, is to observe the rate of change of range. To do this requires more time than is available to the pilot, and could possibly result in insufficient reserve time to avoid collision. This is another example of the advisability of by-passing targets appearing in the channels.

Reflection from rain and snow, when the fall is considerable, can decrease the range capabilities of 3-centimeter radar appreciably. By adjusting the receiver gain and antenna tilt control for the particular situation, it is almost always possible to obtain a signal-to-noise ratio that renders the desired targets clearly visible above the return clutter from the weather. This is particularly true when the closest echoes are the ones in which the pilot is interested, which usually is the case. On some occasions it also is necessary to reduce the gain to eliminate heavy sea return. On no occasion during the flights herein described was the operation of the radar seriously affected as a result of either of the previous causes, although heavy sea and weather were encountered on several occasions.

As with any type of mechanical or electrical equipment, radar is subject to breakdown. Probably, due to its relative newness and at the same time its relative complexity, the percentage of such failures encountered is well above average. Several failures were encountered during the period of these tests, but only one occurred while operating in flight, and on this occasion the failure was "slow," giving warning about 20 minutes before complete breakdown.

Two additional failures were traced to faulty assembly of the time-delay unit of the radar in production, and two more to tube failure. It is believed that mechanical shock during a rather lengthy period between shipping and actual installation may have been responsible for some of these failures. The manufacturers of the equipment have stated that the average operational life between breakdowns should be in the neighborhood of 200 hours provided certain preventive maintenance precautions be observed every 50 hours

CONCLUSIONS

On the basis of flight tests thus far completed, it has been effectively demonstrated that air navigation, by means of radar alone, may be easily accomplished, assuming the geography of the area over which guidance is desired meets specific radar requirements It is probably true, that regardless of geography, almost any area could be traversed safely by radar, provided radar familiarity with the locality is possessed by a qualified radar operator acting as navigator, who could devote his time solely to observing the radar indicator Employment of radar in this fashion by commercial aircraft would be impractical, since there are easier means for providing the pilot with adequate navigational guidance, without detracting from his primary job of flying the airplane

The demands imposed by radar navigation, over any but geographically ideal localities, naturally would prohibit its use in smaller aircraft, and particularly in aircraft carrying only a single pilot with no additional crew members Where these ideal conditions do exist (southeastern Alaska is only one example) radar navigation is held to be feasible Other examples of good radar areas might be any lengthy coastline, sizeable river or lake region

The use of 3-centimeter ground beacons in conjunction with the APS-10 radar has not been discussed in this report since such a navigational system is not well adapted to commercial air operations through the inside passage This is due to the short line-of-sight distances imposed by low flying, high mountains and frequent turns

It is not intended to pass judgment on airborne radar as a practical aircraft instrument for performing any function other than that of navigation by radar search Much experimental work is being devoted by various interested organizations investigating the possibilities of the APS-10 with respect to terrain clearance, weather surveillance, instrument approach (with beacons), anti-collision and other functions Results of such tests have been promising and are continually indicating modifications which must be incorporated into any future airborne radar to render it a suitable and versatile device for civil use Naturally, any such radar also will be capable of performing the job described in this report

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