No. 2

Pan American World Airways Inc., Boeing 707-121B, N 708PA, accident on Chance Mountain, Montserrat, West Indies, on 17 September 1965. Civil Accident Report No. EW/B/019, dated September 1967, released by the Board of Trade, United Kingdom

1. - Investigation

1.1 History of the flight

The aircraft was operating Pan American World Airways Flight 292, returning from Fort-de-France (Martinique) to New York City, with intermediate stops at St. Johns (Antigua), St. Croix (Virgin Islands) and San Juan (Puerto Rico), scheduled to take off from Fort-de-France at 1100 hours GMT and to land at St. Johns at 1135 hours on 17 September 1965.

The flight crew involved in the accident took over the aircraft at 0145 hours on 17 September 1965, in San Juan during the outbound flight from New York City to Fort-de-France, Flight 295; this flight also included scheduled stops at St. Croix and St. Johns.

During the last sector of Flight 295 between St. Johns and Fort-de-France, the weather conditions included an electrical storm in the vicinity of Martinique of sufficient intensity to motivate the Pan American airport manager to consult with the Fort-de-France tower controllers as to the information to be passed to the captain of the aircraft.

Prior to take-off a navigational flight plan was prepared for a total flying time to St. Johns of 30 minutes and an ATC flight plan was filed for an IFR flight with a cruising flight level of 165 (16 500 ft at standard pressure) and St. Croix as the designated alternate. Weather data including area, terminal, wind and temperature forecasts were obtained from the local office of the Météorologie Nationale at Martinique and a despatch release message was sent from Miami at 0622 hours.

With Captain Henderson in the left-hand pilot's seat, the aircraft departed from the terminal at 1100 hours and it took off on runway 27 at 1104 hours. ATC clearance had been received for route D at flight level 165, to cross the terminal control area boundary at flight level 80 or above. According to the handwritten log kept in the tower at Fort-de-France, the aircraft reported at flight level 80 and climbing to flight level 165 at 1108 hours, after which it was told to contact Piarco. The transcript of the recordings at Piarco control centre, Trinidad, show that at 1106 hours the aircraft established contact with Piarco, and at 1109 hours it reported at flight level 165. There was no report of the aircraft being overhead the VOR at Pointe-à-Pitre (Guadeloupe) and descent clearance was recorded at Piarco as being given at 1112 hours and acknowledged at 1113 hours. The clearance was as follows:

> "Clipper two nine two is cleared descend to cross Coolidge* beacon at two thousand five hundred feet altimeter one zero one six contact Coolidge approach at one five no delay expected cross Guadeloupe beacon not below flight level eight five over."

* The airport at St. Johns, Antigua, is also known as 'Coolidge' Field.

According to the recollection of the controller at St. Johns, the aircraft called him at about 1115 hours and was cleared to Coolidge ZDX beacon (NDB) at 2 500 ft,and told to report at the beacon outbound leaving 2 500 ft or field in sight. During this exchange of messages, the aircraft indicated it was at flight level 115 descending. St.Johns tower then passed the landing conditions including the following information:

Wind:	about 090°, 12 kt
Cloud base:	estimated at 1 700 ft
Temperature:	27° in the tower
QNH:	1 016.1 mb

The aircraft was also advised that the runway in use was 07 and that there was a considerable build-up (of cloud) to the south through south-west moving westerly. This information was acknowledged by the aircraft. At approximately 1125 hours the aircraft reported through flight level 40 and gave an amended ETA of 1130 hours. The controller in the tower stated that he then asked the aircraft whether the field was in sight, and on receiving the reply "negative" he told the aircraft to continue the approach and to report when visual contact was established.

The recollections of two of the occupants of a Twin Bonanza aircraft which took off from St. Johns for St. Kitts at 1118 hours have provided accounts of what was said on the RT that are different in detail. Their aircraft was fitted with a speaker in the cabin roof and the radio was operating on St. Johns tower frequency. According to the pilot of the Twin Bonanza, Clipper 292 requested and received a "standard" descent clearance two or three minutes after his take-off from St. Johns but he was unable to remember whether Clipper 292 reported "coast in sight" or "visual contact". The passenger who was sitting in the right-hand front seat of the Twin Bonanza also heard the controller when he instructed Clipper 292 to report passing through 2 500 ft or field in sight. He stated that shortly after this he heard Clipper 292 tell the tower: "I have your coast in sight". There was no further RT contact with the aircraft.

A number of eyewitnesses at different points along the south-west coast of the island of Montserrat saw the aircraft approach and cross the coast in the vicinity of the radio station at O'Garra's estate. It was flying in rain below cloud with the landing gear extended and partial flap visible. One witness identified the PANAM insignia on the fin and rudder, and estimated that the aircraft was in his view for nearly one minute. Between this witness and the aircraft was one of two radio masts 263 ft high and the aircraft was seen to be aligned with a point 18 ft from the top of the mast. Taking into consideration the best available evidence of the horizontal distance between the witness and the track of the aircraft, the height has been deduced by simple trigonometry as being 1 089 ft above sea level when it crossed the line of sight of the witness near the coast. The observations of a second witness who saw the aircraft aligned with the top of one mast, indicated that the aircraft was 1 178 ft above sea level when calculated on the same basis. After crossing the coast, the aircraft continued to fly in a north-easterly direction and sight of it was lost as it entered cloud covering the high ground on the centre of the island. Shortly afterwards the engine noise, which had been continuous and loud, ended abruptly with the sound of an explosion.

The weather conditions at Montserrat at the time of the crash included heavy and thunder with cloud covering the high ground, but small patches of blue sky were visible towards the south-west. The time of the accident was probably between 1123 and 1128 hours and the location has been determined as 16° 42' 18" N and 62° 10' 58" W.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	9	21	
Non-fatal			
None			

1.3 Damage to aircraft

The aircraft was totally destroyed by impact and the subsequent fire.

1.4 Other damage

None.

1.5 Crew information

Captain Hugh James Henderson, aged 43, held an airline transport pilot certificate issued by the Federal Aviation Agency, which included ratings for Douglas DC-3, DC-4, DC-6/7, Convair 240-340-440, Curtis-Wright C-46 and Boeing 707/720 aircraft. On completion of Boeing 707 initial training, he passed a proficiency check on 5 March 1965 and carried out a line check on 22 June 1965. His last first-class physical examination took place on 9 August and there were no limitations imposed. Captain Henderson learned to fly in 1940 and had been employed by Pan American for about 20 years, in the course of which he had flown the route of Flight 292 on many occasions. His total flying experience in the employment of Pan American amounted to 15 354 hours of which 297 hours had been flown in Boeing 707 aircraft. The records show that in the last 90 days Captain Henderson flew 203 hours, and in the last 30 days he flew 78 hours. Following a rest period of 3 days, he had flown 9 hours 19 minutes in the 48 hours prior to the accident; of this 2 hours 30 minutes were within the final 24 hours.

First Officer John Aloysius McNicol, aged 43, held an airline transport pilot certificate issued by the Federal Aviation Agency, which included ratings for Douglas DC-4 and Boeing 707/720 aircraft. On completion of Boeing 707 initial training, he passed a proficiency check on 12 March 1965. His last first-class physical examination took place on 24 May 1965, and a limitation that the holder should possess adequate correcting glasses for near vision while exercising the privileges of his airman's certificate was imposed. Mr. McNicol had flown a total of 9 788 hours, of which 181 hours were in Boeing 707 aircraft. According to the records, Mr. McNicol flew 158 hours in the last 90 days and 50 hours in the last 30 days. Following a rest period of 12 days, he had flown 9 hours 19 minutes in the 48 hours prior to the accident; of this 2 hours 30 minutes were within the final 24 hours.

Second Officer Hugh Barr Miller, aged 32, held an airline transport pilot certificate issued by the Federal Aviation Agency, which included a rating for Douglas DC-6/7 aircraft. He passed a proficiency check on Boeing 707 aircraft on 11 May 1965 and his last first-class physical examination took place on 25 March 1965, and there were no limitations

imposed. Company records show that Mr. Miller had flown a total of 547 hours, of which 188 were in Boeing 707 aircraft. Following 11 hours 31 minutes rest at San Juan, he had flown 2 hours 30 minutes in the 24 hours prior to the accident. For the route involved there was no requirement for a third pilot crew member, and Mr. Miller was assigned no duties by the company except those desired by the captain.

Flight Engineer Norman Axel Carlson, aged 44, held a flight engineer's certificate issued by the Federal Aviation Agency. He passed a proficiency check on Boeing 707 aircraft on 13 May 1965, and his last second-class physical examination took place on 30 June 1965, and there was no limitation imposed. Mr. Carlson had flown a total of 8 782 hours, of which 481 were in Boeing 707 aircraft. Following 4 days rest, he had flown 2 hours 30 minutes in the 24 hours prior to the accident.

The pursers, Mr. J. Walsh and Mr. J. Tarre, and the stewardesses, Miss J. Green, Miss T. Johansen and Miss R.K. Mykland, had each received recent training in emergency procedures within the prescribed period.

1.6 Aircraft information

The aircraft was a Boeing 707-121B, constructor's No. 17586, registered in the U.S.A. under marks N708PA. It had been constructed as a model 121 in 1958 and went into service with Pan American Airways on 30 November of that year. The aircraft was converted to a model 121B by the Boeing Aircraft Corporation early in 1965, a revised certificate of airworthiness being issued by the Federal Aviation Agency on 4 March 1965. At the time of the accident the aircraft had flown a total of 19 127 hours.

The engines installed at the time of the accident were Pratt and Whitney JT3D-3B fan jets. Positions, serial numbers and time since last complete overhaul were as follows:

Position	Serial Numbers	Time since last Complete Overhaul
1	644673	1779 hours
2	644711	1690 hours
3	644715	1690 hours
4	644717	1690 hours

The last basic servicing (5 000 hours) was completed at Miami, Florida, on 1 August 1965, following a production test flight on 21 July 1965. The last terminal service (150 hours) was made at Miami on 4 September 1965, and prior to departure from Fort-de-France a lay-over transit service was completed.

The weight of the aircraft on take-off from Fort-de-France was 178 847 lb, of which 47 400 lb was fuel. The load was properly distributed and the centre of gravity was within the prescribed limits.

1.7 Meteorological information

A forecast made by the Station Météorologique de Martinique, which was issued for Flight 292 on the morning of 17 September 1965, included the following documentation:

(i) An area chart of the Caribbean valid from 0500 hours to 2400 hours, 17 September 1965. This showed for 0600 hours a depression centred near Panama with a trough line running north-east, traversing the intended route of the aircraft in the region of Guadeloupe. Associated with the trough line in the region of Guadeloupe, the chart gave the following cloud cover: cumulus, base 450 m, tops 5 400 m and isolated cumulonimbus, base 150 m, tops 12 000 m.

(ii) An area chart of the Caribbean valid from 0500 hours to 2400 hours, 17 September 1965, showing the winds and temperatures at altitude. For the route from Martinique to Antigua, these were as follows:

1 500 m	100° 15 kt	+ 18°C
3 000 m	100° 15 kt	+ 9°C
4 500 m	090° 15 kt	+ 1°C
6 000 m	080° 20 kt	- 6°C

(iii) Terminal and alternate aerodrome forecasts for the route, which included the following:

Station	Period of Validity	Surface Wind	Surface Visibility	Weather	Cloud Amount
Fort-de-France	1200/2400 hours	080° 10 kt	20 km	-	4/8 cumulus, base 500 m, tops 4 000 m 6/8 cirrus, base 9 000 m
	Temporary		6 km	Showers	2/8 cumulonimbus, base 4 000 m, tops 7 000 m. 5/8 cumulus, base 500 m, tops 4 000 m
	Intermittent		3 km	Thunder -storms	4/8 cumulonimbus, base 400 m, tops 7 000 m
St. Johns, Antigua	0500/0500 hours	100° 15 kt			3/8 cumulus, base 600 m
	Temporary		5-7 km	Showers	7/8 cumulus, base 450 m

A general appreciation of weather conditions in the Martinique/Antigua area at the time of the flight prepared by the Caribbean Meteorological Service includes the following:

A shallow trough or wave moved north-westwards across the Windward/Leeward Islands on 16/17 September, and at 1200 hours on 17 September its axis as indicated by surface observations extended north-eastwards and south-westwards from near Guadeloupe.

The hourly weather reports received on 17 September supported the surface analysis for 1200 hours. In particular, heavy build-ups of 6/8 cb or more based from 1 000 to 1 300 ft were reported at 0900, 1100, 1200 and onwards to 1700 hours from Guadelope, with associated showers and thunderstorms. It appears that unstable conditions were spreading north-westwards, although the 1200 and 1800 hours reports from St. Kitts and those from 1400 hours onwards from Antigua, indicated weaker convection. However, both Martinique and Dominica continued to report showers and thunderstorms for some time after 1200 hours.

It is to be inferred from the available reports that, between 1100 and 1130 hours, there was probably some 6-8/8 of medium and high cloud over the area under reference, with scattered cumulus and cumulonimbus based down to about 1 000 ft above mean sea level in showers, tending to concentrate about islands and massed into towering thundery formations over, and perhaps hiving off from, the most mountainous of them.

Mean upper winds were estimated as follows:

5 000 ft - 100° 20 kt

10 000 ft - 110° 16 kt

20 000 ft - variable, 12 kt

The crew of an HS.748 on a flight from Antigua to Guadeloupe which departed at 1058 hours, 17 September 1965, reported the weather conditions as follows:

> Broken cloud conditions were encountered over the south coast of Antigua at approximately 2 000 ft, but lower cloud was noticed to the west, obscuring the tops of the hills on the south-west of the island.
>
> Overcast conditions were entered at about 2 500 ft some eight miles south of the airport, and these conditions existed until about 40 miles south of Antigua. Cruising altitude was 5 500 ft. Moderate rain and turbulence were encountered.
>
> The aircraft was equipped with a Bendix RDR-1E radar. This showed heavy precipitation returns from Antigua to approximately 40 miles south extending laterally 60° on both sides (complete scope coverage laterally). Heavier returns were noted to the west.

Station weather reports from Guadeloupe and Antigua for 1100 hours and 1200 hours, 17 September 1965, gave 4/8 to 6/8 cumulonimbus cloud, and eyewitnesses on Montserrat reported that at the time of the accident there was low cloud with heavy rain and thunder and lightning.

A report made by the Head of the Sous-Région Météorologique de Guadeloupe and a panoramic chart drawn of the cloud echoes between 1100 hours and 1200 hours, 17 September 1965, on the scope of the weather radar situated at Raizet, Guadeloupe, show that there were thunderstorms in all directions but principally to the north-west of Raizet; the echoes to the north-west covered an area from Guadeloupe to Montserrat and to within ten miles of Antigua. The height of the tops of the thunderstorms measured by the radar were from 7 000 to 8 000 m. (see Appendix 1).

1.8 Aids to navigation

1.8.1 Radio facilities

There were two NDBs at Fort-de-France, the point of departure, FXF radiating on a frequency of 314 kc/s with an output of 300 watts and a locator FF radiating on 281 kc/s.

At Pointe-à-Pitre, on the track between Fort-de-France and St. Johns, there were two NDBs, FXG radiating on 300 kc/s with an output of 500 watts and a locator AR radiating on 402 kc/s. There was also a VOR radiating on 115.1 Mc/s.

At St. Johns, the destination, there were two NDBs, ZDK radiating on 369 kc/s with an output of 1 000 watts and a locator, ANU radiating on 351 kc/s with an output of 100 watts.

In 1956 the third Caribbean Region Air Navigation Meeting of ICAO called for the installation and operation of a VOR at Antigua, but no date for its implementation was notified. In July 1964 it was established that there had been a change in the characteristics of the traffic since 1956 and the requirement for a VOR/DME was accepted but, in view of the cost of this and the other projected development work in the region, it was not found possible to finance the installation at that time.

1.8.2 Aircraft equipment

Aircraft radio equipment relevant to this flight included the following:

ADF (duplicated)

VOR/ILS (duplicated)

Weather Radar

Compass system

Aircraft heading information was supplied to the captain and co-pilot by their respective radio magnetic indicators (RMI), the magnetic heading being shown by the position of the rotating compass card against the major index at the top of the instrument. Two pointers provided radio magnetic bearing information from either ADF or VOR radio signals. A pair of associated switches were on each pilot's instrument panel. One switch of each pair had VOR 1 and ADF 1 positions, the other switch VOR 2 and ADF 2 positions. The switches provided selection of radio bearing signals to be displayed on the RMI pointers.

Magnetic information was provided to the captain's and co-pilot's RMIs by the Nos. 1 and 2 gyrosyn compass systems respectively. Normally the captain's RMI received magnetic information from compass system No. 1 and the co-pilot's RMI was operated by compass system No. 2. A compass selector switch on each pilot's instrument panel permitted either or both RMIs to be operated from either compass system.

Compass comparator

The 'A' data synchro transmitter of the RMIs fed heading information into the compass comparator (see Appendix 2). The design intention was that if the two headings were not within 10° of each other, a signal would be transmitted to the instrument warning system which in turn would illuminate the compass warning light, the master instrument warning

light and operate the sounder. The signal from the captain's RMI positioned the rotor of the synchro receiver. A synchro control transformer was mechanically linked to and positioned by the synchro receiver and electrically excited by the 'A' data synchro transmitter in the co-pilot's RMI. The amount of difference between the mechanical and the electrical position of the synchro control transformer provided the signal which initiated the operation of the instrument warning system. A 25 000 ohms potentiometer was included in the circuit as a sensitivity adjuster.

The Pictorial Deviation Indicator (PDI)

The PDI displayed aircraft position with respect to ground radio facilities, i.e. VOR or ILS signals. The display was obtained by using a LOC/VOR deviation needle with an 'V'-shaped arrow and by automatically rotating the needle and its background indicator card to show the difference in selected course and actual heading. The course was selected by an omnibearing selector knob and was shown in a window in front of a digital type counter. A reciprocal course selector when turned resulted in a proper mechanical and electrical transfer of the course indicator by 180°. The heading information was obtained from the 'B' data synchro transmitters of the RMIs; the captain's PDI receiving its information from the No. 1 RMI and the co-pilot's PDI receiving its information from the No. 2 RMI. During VOR operation, TO/FROM indication was provided by a 180° reversal of the 'V'-shaped needle (and associated card). When the aircraft was flying on a course to the station the apex of the 'V' was at the top of the instrument, displacement of the aircraft from the centre of the beam being indicated by a horizontal movement of the needle with respect to the indicator card.

1.8.3 Maps and charts

Included amongst the maps carried on the aircraft was a topographical series covering most of the world on a scale of 1:5,000,000. The position of Montserrat was shown on this series, without indication of the elevation of its highest point. A U.S.A.F. Jet Navigation Chart of the relevant area but with a scale of 1:2,000,000 was also on board. This showed topographical features, and Montserrat was marked with a spot height of 3 002 ft. Both of the above were recovered from the chart case in the wreckage of the aircraft. Captain Henderson had been issued with a personal copy of charts covering the route he would fly and it appears likely that he had charts of the Caribbean area showing terrain heights similar, if not identical, to the U.S.A.F. Jet Navigation Chart with a scale of 1:2,000,000. The Latin America series of High/Low Altitude Enroute Charts published by the Jeppesen Company was also carried to provide radio facility information and the relevant chart for the flight Fort-de-France to St. Johns was designated LA(H/L)5. This chart was constructed on a Lambert Conformal Conic Projection on two standard parallels with a scale of 1 in = 60 NM, which in terms of a representative fraction is 1:4,377,600, and it covered an area from Cape Cod in the north to Paramaribo (Surinam) in the south. The distance between Fort-de-France and St. Johns on this chart was $2\frac{1}{2}$ in. The outline of Montserrat was discernable but no spot height was given for this island. Except for the coastlines, major rivers and a small number of spot heights, this chart was devoid of topographical information. The open chart measured 3 ft 9 in by 1 ft 5 in and it folded by a patented system to a size $8\frac{1}{2}$ in by 5 in. The original of this chart was not recovered from the wreckage, but it is considered most likely to have been in use by the pilots during the flight since it was the primary means of presenting en-route navigation information. Aerodrome approach charts listed in alphabetical order were contained in the Route Manual, and amongst the information included on the chart for St. Johns was a box containing the following:

SAFE ALTITUDE 20 NM 3 500 FT 40 NM 5 500 FT

The profile section for the NDB procedure showed a descent commencing over the 'ZDX' NDB at an undefined altitude, then a descent to 2 500 ft on a track of 340° followed by a procedure turn at 10 NM and an inbound track of 160° descending to 1 000 ft at 'ZDX'. The elevation of the highest ground on the island of Antigua is marked on the aerodrome approach chart as 1 330 ft.

1.9 Communications

VHF communications with the aircraft were maintained throughout the flight, commencing with the tower at Fort-de-France on 118.7 Mc/s, which was recorded in a hand-written log with notation of the time of each contact. En-route communications on 126.7 Mc/s were recorded with automatic time injections at Piarco Control Centre, Trinidad. No record was kept at St. Johns of the communications on 118.7 Mc/s with Coolidge tower, and as a result it has been necessary to depend upon the recollection of the tower controller in order to establish what exchanges took place. Soon after it became evident that Clipper 292 was overdue, the controller made notes of what he believed had been said on the R/T between Coolidge tower and the aircraft together with indications of the approximate times of the contacts.

1.10 Aerodrome and ground facilities

Not applicable.

1.11 Flight recorders

A Lockheed Aircraft Service Flight Recorder Model 109-C was installed in the left main landing gear wheel well of the aircraft. The unit was contained in a spherical case comprising inner and outer shells of stainless steel with heat protection material between them. The case was divided into two hemispherical sections connected by a stainless steel clamp ring about its equator. The aluminium foil recording medium was contained in a stainless steel cassette and wound on a supply spool from which it was fed over a flat plastic-covered platen on to a take-up spool. The following parameters were recorded: time, altitude, indicated airspeed, vertical acceleration and magnetic heading.

The recorder was recovered from the wreckage and sent to the Bureau of Safety of the U.S. Civil Aeronautics Board for examination and processing. The case was subject to severe crushing forces, and the upper hemisphere was separated from the clamp ring which remained in position round the lower hemisphere. With the exception of its hold down bolt, the cassette containing the foil recording medium suffered no mechanical damage. However, after the case had been broken open by the severe impact forces, the recorder suffered further damage internally from the extremely high temperature of the subsequent fire. On examination of the cassette, it was found that the part of the aluminium foil recording medium which had been positioned over the platen was missing and is presumed to have been consumed in the fire. The high temperature had obliterated the stylus traces from the record portion of the foil that was encased in the cassette, and only the point of take-off on the altitude trace was faintly discernable together with the time trace for a few minutes. This established that the recorder was functioning at the time of the last take-off, but fire damage precluded a readout of the remainder of the record of the accident flight.

1.12 Wreckage

The wreckage was located on the steep jungle-covered southern slopes of Chance Mountain with the point of impact 242 ft below the summit which was 3 002 ft above mean sea level. The magnetic bearing of the Pointe-à-Pitre VOR from the crash site was

136° and that of the ANU NDB on Antigua was 050°. The impact demolished the aircraft and fire destroyed most of the fuselage and wing between station 472 on the left-hand side and station 472 on the right. An imprint discernible as a head-on outline of the aircraft was left on the mountain side. This was identified from left to right as follows (see Appendix 3):

> Left-hand wing tip; the scar of leading edge of wing and section of left-hand wing and No. 1 engine; debris of the inboard aspects of the wing of the aircraft; No. 3 engine embedded in the face of the mountain; section of right-hand wing and No. 4 engine; scar of right-hand outer wing.

This span-wise distribution was of a symmetrical nature as was the break-up of the outer wing. The aircraft was in an attitude approximately level laterally and longitudinally when it struck the mountain in a direction normal in azimuth to the general topographical features of the mountain slope. This direction was assessed on the site to be approximately 025°M. The degree of disintegration and the fall-out of wreckage above and below the point of impact suggested that the aircraft was flying at a considerable speed at impact, although the distribution upwards may have been influenced by a nose-up attitude at impact. From the details of the extremities or near extremities of the aircraft recovered on the site, it was concluded that the aircraft was structurally complete at the time of impact.

It was established that the landing gear was down, that the flaps were set to 20° on both sides and that the wing fore flaps were extended. A dimensional check of the horizontal stabiliser actuator indicated a fore and aft trim setting of ½ unit aircraft nose-down. The rudder trim control box was recovered jammed at 2 units left rudder.

Examination of the wing tips and the extremity of the fin produced no evidence of lightning discharge. The fuel system surge tanks and their vents bore no evidence of fire, explosion or damage other than that attributable to the crash impact. All four engines were found to be in forward thrust and Nos. 1 and 4 bore readily apparent evidence that they had been rotating at impact. Examination of the turbine shrouds or the nacelle cowlings produced no evidence of penetration of centrifuging turbine material.

The examination on the site was limited because of the difficult terrain but every effort was made to recover significant components for further examination particularly those relating to navigation instruments. Detailed examination was carried out at the Pan American World Airways maintenance base at Miami, Florida, with the following results:

(a) Heading

The captain's RMI was not recovered. However, the readout of the synchro receiver of the compass comparator which receives heading information from the captain's RMI indicated an azimuth heading of 034°M ± 20° at the time of impact. During the initial examination of this synchro, it was found that the stator winding (yellow lead) was open circuited. This open circuit appeared to be buried in the matrix of the windings and further investigation was carried out at the manufacturers. After prolonged soaking of the windings to remove the sealing varnish, the open circuit was established to be a fracture between the third coil of the yellow phase and the junction with the other two phases. This fracture shows evidence of shear and electrical erosion. The evidence of erosion indicates that the disconnection, possibly of an intermittent nature, had existed for some (indeterminate) time and the evidence of shear, in the absence of evidence of impact damage, suggests that this may have occurred during manufacture.

Tests have shown that, with such a disconnection in the system, relationship between the captain's RMI (heading) and the receiver synchro of the comparator would exist only in the arc of azimuth of 0°M to 120°M. Further tests showed that the open circuit would not affect the heading of either of the RMI compass cards. A readout of heading indication of 051°M was obtained from the compass comparator control transformer. On inspection of the badly damaged compass comparator, it was found that the lock nut of the sensitivity adjustor was loose and that the resistance was set to 20 000 ohms. Tests showed that such an adjustment would permit the compasses to differ by up to 43° before a warning was given.

Damage to the dial of the first officer's RMI indicated that a compass reading within the band 030°M to 050°M existed at the time of impact. The 'A' data synchro transmitter gave a readout of 078°M but the drive gear was loose on its shaft which was free to rotate. This reading was therefore not considered to be a reliable indication of the compass reading at impact. A readout of 031°M was obtained from the 'B' data synchro transmitter and, because of the manner in which it had been damaged, was considered to be a reliable indication of the compass reading on impact.

(b) Altitude

Both pilots' altimeters were severely damaged and no readings were possible from the faces of the instruments, but in both cases it was possible to observe the positions of the 1 000 ft increment altitude drums by means of cutting inspection 'windows'. By comparing these positions with the equivalent on a serviceable instrument, it was deduced that each instrument was reading between 2 000 ft and 3 000 ft altitude at the time of impact. The positions of the respective scale error correctors were consistent with these readings. It was determined that the captain's altimeter sub-scale was set at 30.00 in of mercury or 1 016 mb.

(c) Speed

The captain's air speed indicator was not recovered. The co-pilot's air speed indicator had received severe impact and fire damage with many parts missing or burnt. It was not possible to determine the position of the airspeed pointer on impact. The maximum allowable airspeed pointer indicated 335 kt on the dial but this may well have been moved in the impact.

Examination of the Kifis Control chassis assembly led to the conclusion that the Mach meters were indicating in the range .29M to .32M on impact.

In the ambient conditions, at 3 000 ft this corresponds to an equivalent airspeed of 182 kt to 20 kt.

(d) Attitude

The pitch synchro gears of the No. 1 (captain's) Horizon Flight Director Indicator were meshed and impacted in a 7° to 8° nose-down attitude while the geared sphere roll axis mechanism indicated 5° left wing down.

The gear driven pitch cam mechanism of No. 2 (co-pilot's) Horizon Flight Director Indicator showed evidence of 7° nose-down attitude while a visual roll attitude indication of 5° left wing down is considered valid.

(e) ADF

The single ADF controller and receiver recovered from the wreckage had been installed in the No. 1 position. There was evidence that it was switched on and operating in the ADF mode with a moderately strong signal being received on a frequency a little higher than 346 kc/s.

(f) VOR

The front panel of one unidentified VOR receiver was recovered, indicating that a frequency of either 115.0 or 115.1 Mc/s had been selected.

(g) Radio bearing indications

No. 1 omnibearing indicator dial which was recovered, separated from its unit, had a reading of 121° which changed to 124° when the dial was re-centred in its housing. However, on test the resolver of the same unit gave a reading of 076° and the differential synchro gave a reading of 083°.

No. 2 omnibearing indicator dial was not recovered but the resolver of this unit gave a reading of 054° on test, while the differential synchro gave 057°. All these readings are omnibearings (magnetic bearing to the station).

No. 1 RMI was not recovered but is was possible to connect the pointer synchros of No. 2 RMI to a test stand and the following results were obtained. The readout of No. 1 pointer synchro corresponded to a relative bearing in the bracket 124° to 130°. If it is accepted that the compass card heading was 031°M, this would give a magnetic bearing in the bracket 155°M to 161°M. The readout of No. 2 pointer synchro corresponded to a relative bearing of 040° which would give a magnetic bearing of 071°M on a compass card heading of 031°.

Since the VOR/ADF selector switches were not recovered, it could not be determined whether these represented VOR or ADF bearings, but if they related to VOR bearings there should be a correlation between these values and the omnibearing indicator readings. The absence of such correlation places doubt upon their validity.

Tests made to establish the effect on the RMI No. 1 pointers, of the open circuited yellow phase of the receiver synchro of the compass comparator gave conflicting results. One test gave a maximum error of 6°, whereas another series of tests produced no error. The maximum error which could be induced by rotating the synchro rotor by hand, thereby simulating displacement by friction, with the yellow lead open or closed, was 22°.

(h) Pictorial deviation indicator

No. 1 (captain's) PDI counter mechanism showed that a course of between 000° and 009° or 180° and 189° had been selected. The TO/FROM indicator showed that the aircraft had been flying away from the station.

No. 2 (co-pilot's) PDI was not recovered.

(i) Other components

The N_2 tachometer indicator for engine No. 3 read 46.8%. This instrument may have been reading a higher figure, the impact having allowed the spring loaded pointer to return to a lower value before it came to rest.

The EPR transmitter for No. 3 engine showed evidence of a reading of 1.106 at the time the electrical power was cut off.

The gyrosyn compass control (directional gyro) showed evidence that the gyro rotor was spinning at the time of impact. No reliable evidence of aircraft heading could be derived from this source.

The rudder trim control unit was jammed on impact at a setting of two units LEFT rudder.

The right-hand aileron trim spool setting of $3\frac{1}{2}$ units LEFT wing down was not considered to be representative of the setting prior to crash impact.

1.13 Fire

No evidence was found of any in-flight fire. The aircraft caught fire on impact, and because of the remote nature of the crash site it burnt out without the intervention of any fire-fighting services.

1.14 Survival aspects

The violence of the impact, the extreme disintegration of the aircraft and the ground fire which ensued rendered the crash non-survivable.

1.15 Tests and research

A special study was conducted to investigate whether any of the known vagaries of radio wave propagation could account for large errors (20^{o} to 30^{o}) in VOR bearing information.

The report of this study is summarized in Appendix 4, and it indicates that only minor transitory errors might be accountable to known radio propagation phenomena and the VOR should have remained mostly unaffected by the conditions prevailing at the time of the accident.

1.16 Maintenance records

The aircraft maintenance log was salvaged from the accident site. In addition to the maintenance log sheets, it was found to contain continued item supplement sheets. Of these, two sheets contained five items of work to be done at the next equalized service. Five other sheets contained several items of work to be done at the next terminal service. The first sheet of these five sheets was mutilated, only the top of the sheet bearing item 1 being recovered. An entry for information (INFO) dated 7 September 1967 drew attention to the PDI/VOR instruments and the system was checked and found satisfactory. Of the remaining items, nine remained uncleared and none of these nor any of the uncleared equalized service items are considered to have been prejudicial to the serviceability of the aircraft.

Recent maintenance log sheets recorded that divergence of the C-6 compass (RMIs) without the appropriate warning had been experienced and that the VOR indications had been in error. A review of the maintenance log sheets back to 1 February 1964 produced the following results:

A. The following number of pertinent navigation (radio and instrument) malfunctions -

11 VOR malfunctions in 1964
15 VOR malfunctions in 1965 (the last one on 11 September 1965)
5 compass comparator malfunctions in 196
4 compass comparator malfunctions in 1965 (the last one on 12 September 1965)
4 RMI compass malfunctions in 1964
12 RMI compass malfunctions in 1965 (the last one on 12 September 1965)
8 ADF malfunctions in 1964
7 ADF malfunctions in 1965 (the last one on 23 August 1965)

B. The following were the VOR write-ups and corrective action in 1965 -

2-5-65 "Co-pilot's PDI not receiving VOR signal. OK when cross switched. Change VOR receiver."

"Changed No. 2 VOR Rec."

2-5-65 "Background of co-pilot's PDI hangs up in turns as much as 10-15°. Same crossed over."

"Could not duplicate item except as follows:
Momentarily observed that PDI background would not follow when C-6 card was rotated. Thereafter syst. operated normally. Movement of wires and plugs at both instr. and back of ILS rack showed no reaction. Switched ILS racks and replaced both No. 2 RMI and No. 2 PDI indicators precautionary PSE observe."

2-6-65 "Co-pilot's VOR goes 45° out from normal suddenly will remain there on crossover also."

"PDI indicator replaced."

2-7-65 "Co-pilot's VOR still same as reported page 408 still goes out 45° - Chnging inst. N.G.."

"Replaced 51-R, 351A & ILS."

2-28-65 "No. 2 ADF needles on VOR gives erroneous reading."

"Replaced VOR Acc unit Cks OK."

3-5-65 "No. vol. control No. 2 VOR on-off sw. OK. Ck. control panel."

"Checks normal pls obs further."

3-9-65 "No. 1 VOR needle jumps back and forth 60° - PDI ind. normal."

"Unable to duplicate malfunction of No. 1 VOR needles. Please observe further, operation OK."

4-25-65 "VOR No. 1 needle No. 1 rotates slowly to 90° position on freq. 111.0 Sw. will reposition needle, PDI operation normal."

"Found No. 1 VOR operation normal on freq. 111.0 mc. At V.T.B. head is correct at 260°, please observe further."

5-19-65 "Captain report No. 1 VOR needle hangs up and gives erratic readings."

"Could not duplicate. Used 113.1, 115.9, 112.0 mc. All ck'd normal, please observe further."

7-9-65 "Captain's PDI - with VOR signal wng indicates ½ flag until very close to the VOR."

"Couldn't duplicate - Replaced revr precautionary - cks normal."

8-7-65 "Capt. & F.O. VOR are 4° apart. F.O. VOR seems to be correct. When F.O. VOR shows on track, Capt. VOR shows 4° left of track.

"Replaced accessory unit."

8-21-65 "No. 1 VOR receiver weak."

"Replaced No. 1 VOR Rec. Cks. OK."

8-31-65 "Capt's PDI gave warning flag when switched to approach freq. Believe No. 1 VOR Rec. is at fault."

"Changed No. 1 VOR receiver."

9-9-65 "Capt.'s PDI/VOR reads 145° while F.O.'s reads 145° F.O. correct by radar outbound NYC."

"Noted system cks OK. Please observe is not clear if capt.'s 145° co-pilot."

9-11-65 "Replace capt.'s VOR rcvr. Was off 10° coming into SJU."

"Replaced VOR No. 1 RCVR GND CKS OK."

C. <u>The following were the RMI compass write-ups during 1965</u> -

2-16-65 "Co-pilot reported RMI unreliable."

"Replaced ILS rack."

3-5-65 "1st officer's RMI inop. No annunciator X over OK. Replace slaving amp. and Gr. Ck."

"Replaced No. 2 RMI Cks OK."

3-13-65 "Co-pilot's RMI card sticks on west hdg. at times. Annunciator sig. OK - Suspect inst."

"Changed RMI No. 2"

3-13-65 "Co-pilot's RMI still becomes inop. at times - seems to be sticking - see prev. item page 551 - Becomes inop. in any heading -"

"Replaced No. 2 gyrosyn compass amp."

3-13-65 "Co-pilot RMI still not dependable - Will frequently stop during turns - Later can reset and appears to work again - See previous write-ups page 554/551."

"Replaced control gyro system. Checks OK."

4-15-65 "Capt. RMI slow slaving suggest replace slaving amp."

"Swapped servo amplifiers and slaving amplifiers but to no avail, system same as before. Replaced both transfer relays. System checks normal."

7-6-65 "Co-pilot's RMI drifts off heading over 10° with no annunciation. Will reset OK with sync knob then drift off again. Check D.G. for proper operation."

"Replaced directional gyro."

9-6-65* "Co-pilot compass on turn for final approach would not take up heading syn knob inop. on block compass OK crossover OK - Suggest cking compass system cannon plugs etc. for loose connexion."

"Checked RMI - DG & ampl connexion OK. Precautionary replaced co-pilot's RMI operational check OK."

9-10-65* "On approach into ANU co-pilot's RMI off hdg. 90° with no warning. Unable determine RMI or gyrosyn - operation OK after reset. Recco change RMI & continue observe."

"Checks out OK. However checked RMI cannon plug, slaving amp. & ILS amp.& found all OK. Please observe further."

9-11-65* "Replace co-pilot's RMI - see item 1 page 135 - Unit again off heading on CUR approach and unable reset in flight after switching to No. 1 sys. Reset OK on ground."

"Replaced co-pilot's RMI Checks OK."

9-11-65* "Note see P. 141. Same RMI problem. Still exists into SJU at approach, RMIs differed by 40°. No warning light or sounder."

"Replaced VOR No. 1 RCVR. End cks. OK."

9-12-65* "Note - outbound crew see note page 143."

No clearly defined cause of these defects was established and most of the units replaced were subsequently found to function correctly.

* The account of the flight recording readouts in paragraph 1.18 relates to these flights.

1.17 History of the VOR Accessory Unit and Compass Comparator

The VOR Accessory Unit Serial No. 4149 was installed in the subject aircraft on 7 August 1965. The unit had been overhauled by PAWA on time limit on 29 June 1965, during which the No. 2 OBI was replaced. The compass comparator, Serial No. 112, which was contained in the VOR Accessory Unit was overhauled and calibrated by PAWA on 15 October 1964, following a report of excessive divergence of the compasses prior to operation of the instrument warning system. The unit was found to be subject to excessive friction and to be out of specification. The synchro receiver was amongst the units that were replaced during the overhaul.

1.18 Flight recording readouts of earlier flights

In the light of the record of No. 2 compass system malfunctions, the section of the flight recording concerned with previous flights was read out for correlation with the maintenance log sheet write-ups, since the flight recorder heading information comes from the No. 2 compass system.

(a) Flight of 6 September (9-6-65), New York to San Juan

Log sheet summary: "Co-pilot's compass on turn for final approach, would not take up heading."

The readout indicated that the RMI seized on 172°M for six minutes at 5 500 ft on San Juan approach after a left turn from 179°M, then after touchdown it jumped to 244°M (runway 070°-250°).

(b) Flight on 10 September 1965 (9-10-65), St. Croix to San Juan

Log sheet summary: "On approach to Antigua, co-pilot's RMI off heading 90° without warning."

Flight recording not read out.

(c) Flight of 10 September 1965 (9-10-65), Martinique to Antigua

The flight recording relating to this flight was read out instead of the St. Croix to San Juan flight when it was learned from examination of the heading trace that the co-pilot's compass (which operates the heading trace) had seized and since this flight duplicates the accident flight it was most pertinent.

The readout showed that the co-pilot's RMI seized on a heading of 002°M at an altitude of 3 500 ft during the approach to Antigua and remained there until the aircraft was 1 minute 6 seconds from touchdown on the final approach to runway 07. At that time there were two sharp jogs in the trace, after which it remained on approximately 085°M throughout the landing roll. Another possible seizure for five minutes on 000°M occurred at 16 500 ft after a 15° right turn. Slight occasional variations in the trace precluded determination as to whether this was seizure of auto-pilot operation.

(d) Flight of 11 September 1965 (9-11-65), Aruba to Curaçao

Log sheet summary: "See page 135. Unit off heading on Curaçao approach."

The readout did not verify the seizure. The heading trace generally waivered around the 111°M airway heading until the approach, when it waivered around a 106°M heading during the final approach and was on 110° during the landing roll (runway 110°-290°). There was an approximate five minute period en route where the trace moved 10° to the left then 20° to the right and back on to 106°M.

(e) Flight of 11 September 1965 (9-11-65), New York to San Juan

Log sheet summary: "Captain's VOR off 10° coming into San Juan. See page 141. Some RMI problem exists. Into San Juan at approach RMIs differed by 40°. No warning."

An interview with the crew of this flight disclosed that they were advised by the San Juan radar operator of being 10° to the left of course while 100 miles out and they verified it by tuning in a radial 10° to their right in order to get back on course, but that they did not notice the VOR needle on the RMI. The trace revealed a heading change from 176° to 190°M beginning 21 minutes from touchdown. The trace also revealed that the co-pilot's RMI seized at 1 500 ft for 1½ minutes on 086°M during the approach while turning left from the 184°M course. At touchdown the trace jumped to 072°M (runway 070°-250°). Another temporary seizure was indicated on 136°M about 2½ minutes prior to touchdown, and two other extremely straight traces indicated about two-minute and one-minute seizures at 20 000 ft and 20 500 ft about 20 and 22 minutes before touchdown respectively.

(f) Flight of 12 September 1965 (9-12-65), St. Croix to San Juan

Log sheet summary: "Outbound crew see note page 143."

There was no definite indication of seizure of the compass in the readout.

2. - Analysis and Conclusions

2.1 Analysis

There is no evidence from the records of the communications, observed or apparent manoeuvres of the aircraft or examination of the wreckage that the aircraft and its engines were other than mechanically sound and capable of responding to the control actions of the crew at the time of the accident. Its collision with high ground is consistent with the aircraft descending under the control of the pilots when they believed its position was such that an altitude of 2 760 ft provided a safe margin above the terrain. It is therefore necessary to examine in detail whether there was a faulty presentation of navigational information by the relevant instruments, which may have misled the pilots into believing the aircraft was in a different position, or whether there was a faulty interpretation or application of correct navigational information on the part of the pilots.

2.1.1 Reconstruction of the flight

The circumstances of the aircraft's departure from Fort-de-France were unremarkable but consideration of all the relevant meteorological data indicates that there was a substantial area of cumulonimbus cloud and thunderstorm activity on the route during the period of the flight, particularly to the north and west of Guadeloupe and extending as far as 30 NM to the west of the direct track to St. Johns. This activity would have been visible to the pilots and apparent on the aircraft weather radar. While the destruction of the flight recording precludes certain knowledge of the route followed, the position of the crash can indicate that the captain elected to deviate to the west of the direct track

to avoid the worst of the weather and it is accepted that in the prevailing conditions this was a prudent course to take. The undefined extent of the deviation invalidates any detailed analysis of the flight on a time/distance basis, but the RT records provide sufficient data relating to a time/altitude analysis to conclude that the flight profile was normal for a short sector (158 NM by the direct route), that is, a climb to flight level 165 followed by a cruise for 3 or 4 minutes at altitude and then a descent. However, there are some inconsistencies in the record which merit examination in order to gain an appreciation of the evidence in the correct perspective.

The handwritten log at Fort-de-France records take-off time as 1104 hours and the attainment of flight level 80 at 1108 hours, after which the aircraft was told to contact Piarco, but the recordings at Piarco registered 1106 hours as the time contact was established with that station. It is possible, with the duplicated VHF communication equipment for one pilot to be in contact with Fort-de-France while the other is speaking to Piarco, but in the circumstances there is little purpose in doing so. It is more likely that the time recording at one or both ground stations was incorrect, especially when considering that the flight manual performance charts give a time of 12 minutes for climb to flight level 165, while comparison of the take-off time logged at Fort-de-France (1104 hours) with the recorded time the aircraft reported at flight level 165 according to the Piarco log (1109 hours) gives 5 minutes for the climb. ifferences in time to climb to a given altitude are possible with different climb techniques but the large margin of difference apparent in this case is unrealistic.

The Piarco recording shows the descent clearance as being acknowledged at 1113 hours and the recollection of the controller at St. Johns was that the aircraft reported at flight level 115 at 1115 hours and flight level 40 at 1125 hours. The performance charts indicate a normal descent time of 11 minutes or 9 minutes when using the high speed descent technique from flight level 165, and it is considered necessary to allow about 2 minutes for the aircraft to slow down to the landing gear and flap operating speed. Thus, 1124 hours was the earliest time descent would have been completed following a high speed descent. Since a reduction to penetration speed is specified where turbulence is to be expected, it is probable that the descent was made in smooth conditions, that is, in an area clear of cumulonimbus cloud.

Once the deviation from a direct line joining the en-route radio navigation aids had taken place, it was only possible to keep track of the aircraft's position by pilot navigation methods involving dead reckoning calculation, ADF and VOR bearings and such supplementary information as was admissible from the weather radar. Frequent changes of direction, dictated by the need to avoid the worst of the weather, coupled with the aircraft's high speed would reduce the accuracy of the dead reckoning. Static interference originating in the thunderstorms would have reduced the dependability of the ADF indications but the VOR should have remained mostly unaffected. The pilots' relative inexperience of jet aircraft operations may have added to their difficulties in retaining a mental appreciation of the position of the aircraft. The captain had flown a total of 297 hours in Boeing 707 aircraft and the co-pilot and second officer less than this; whilst there is no reason to doubt their competence in handling the aircraft, their substantial experience in navigating piston-engined aircraft in the Caribbean area needed to be modified to take account of the higher speeds and altitudes which compress distance and flight time. In the earlier stages of experience this requires conscious effort, while more experienced pilots are likely to contend with these factors as a matter of course.

2.1.2 Aircraft instrumentation

The possibility has been considered that the pilots were misled in establishing the aircraft's position as a result of RMI compass cards giving erroneous indications. Although each RMI compass card normally derived its information from a separate gyrosyn compass system, the incorrect setting of the sensitivity control of the compass comparator permitted a difference of up to 43° to exist before the instrument warning system functioned. In the light of the recorded RMI malfunctions, the possibility is suggested that there was a discrepancy of up to 43° between the heading indications of the two RMIs without the comparator warning system operating. A characteristic of the recurring fault was that it affected the co-pilot's RMI in such a way that the compass card appeared to stick on any heading flown by the aircraft, usually during the approach to land phase. It was noted, however, that the readouts obtained from the synchro-receiver of the compass comparator (034°M ± 20°) and the 'B' data synchro transmitter of the co-pilot's RMI (031°M) were compatible. At the same time, the general distribution of wreckage at the crash site was assessed as an impact direction of approximately 025°M. In the circumstances, this might be considered to be reasonable correlation of direction information, in which case it is unlikely that the pilots had been misled by faulty heading information.

In spite of the considerable efforts made to recover significant navigation instruments, the No. 1 (captain's) RMI was not found; the positions of the ADF/VOR pointers must, therefore, remain unknown. Operational considerations would suggest that at least one pointer was selected to an ADF receiver tuned to the main NDG at St. John's, SDX radiating on 369 kc/s; at the same time, it is relevant to consider that the No. 1 ADF was probably tuned to the locator ANU on 351 kc/s of lower output. The significance of the pointer on the No. 2 (co-pilot's) RMI, though possibly of secondary importance, is obscure. There is insufficient congruity between the pointer positions and the several alternative omnibearing indicator readouts to conclude that either RMI pointer was selected to VOR and, except for illustrating the magnitude of static interference, no conclusions can be drawn as to which NDBs might have been in use if the RMI pointers were selected to ADF. A plot of the magnetic bearings appropriate to the No. 2 RMI pointer positions deducted from the wreckage gives a position over the sea approximately 15 NM west-south-west of St. Johns, if it is assumed without factual evidence that No. 1 pointer was correctly indicating the bearing of a station at Guadeloupe and No. 2 pointer was indicating a station at Antigua. It is, therefore, considered unrealistic to draw conclusions from the examination of the RMI pointer components.

There is evidence that the No. 1 ADF was operating on a frequency very close to that of the locator beacon at St. Johns. No. 2 ADF was not recovered but the possibility that it had been operating on the frequency of ZDX (369 kc/s), the stronger of the two beacons at St. Johns, should not be disregarded. It is likely that the single VOR receiver recovered had been selected to 115.1 Mc/s, the frequency of the Guadeloupe VOR; it seems probable, therefore, that use had been made of this facility or was being made at the time of the accident. In order to obtain a dependable fix of the aircraft's position when it was well off-track during the descent, the minimum requirement in the weather conditions prevailing was a two-bearing fix using VOR from stations in the equivalent juxtaposition of Guadeloupe to St. Johns. However, this type of position fixing cannot be utilized if the aircraft is near a line joining the two stations and it is preferable that bearing and distance information from the destination should be available from VOR and DME readings. The aircraft was equipped to receive such information but the necessary ground facilities did not exist at St. Johns. As a result, the accuracy of the pilot's position fixing may have been poor. If, in an attempt to supplement the position information, use was made of the weather radar, it is likely that the coastline as such was discernible but the identity

of the island and the proximity of the high ground is likely to have been obscured in the returns from the heavy cloud and rain in the vicinity. The distance to the coastline however would have been evident and it is possible that the amended ETA of 1130 hours in place of 1135 hours was based on this distance, coupled with the assumption that the coastline was that of Antigua.

Consideration of the navigational aspects of the flight may be summarized as follows:

(a) The aircraft deviated from the direct route between Fort-de-France and St. Johns but the absence of reliable data precludes an accurate reconstruction of the flight path.

(b) The possibility that there might have been a faulty presentation of heading information on the co-pilot's instrumentation cannot be ruled out in the light of the history of instrument defects, but examination of the wreckage indicates that such a fault was not present at the time of impact. The accuracy of the captain's compass system remains unknown but there is no history of related defects as in the case of the co-pilot's instrument.

(c) Evidence regarding the positions of the RMI pointers is inconclusive and it is considered unrealistic to draw conclusions from the examination of the RMI pointer components.

(d) Of the two ADF receivers on board, only one was recovered and this was probably tuned to the lower powered of the two NDBs at St. Johns. It is likely that the single VOR receiver recovered was selected to the frequency of Guadeloupe VOR. Both of these settings are consistent with normal navigational practice on this route.

(e) There were no abnormal radio propagation effects which may have degraded or distorted the VOR signals significantly at the relevant time.

There is, therefore, no direct evidence of any faulty presentation of navigational information by those instruments which were recovered but since the examination of some instruments produced inconclusive results and evidence was not available from the unrecovered components, the possibility that the pilots may have been misled by some of them cannot be ruled out with absolute certainty. In this connection, it is possible to develop an hypothesis involving a repetition of the circumstances of the flight on the same route in the subject aircraft on 10 September 1965, when the co-pilot's RMI seized on a heading of 002°M during the descent to Antigua and corrected itself on the final approach to land. If the flight in which the accident occurred had been made by the direct route, the selected course of between 000° and 009° found on the captain's PDI could be accounted for as the course necessary to overfly Pointe-à-Pitre VOR in order to correct for having made a westerly take-off on runway 27 at Fort-de-France. Allowing for an easterly wind of 15 kt at cruising altitude and a track of 356°M after passing the VOR, a compass heading of 002° would seem reasonable to the pilots especially if the No. 2 pointers, which could have been selected to ADF and their receivers tuned to an NDB at Antigua, were pointing generally ahead. The magnetic bearing of the destination would in this event indicate an approximate 'on track' situation, while it is possible that with the co-pilot's RMI seized on 002°M the aircraft was heading well to the west of track. At the same time, the magnetic bearing of the Pointe-à-Pitre VOR would have been misrepresented on the co-pilot's RMI by the amount the real heading of the aircraft differed from the seized heading of

002°M plus any possible error in the No. 1 pointers if they were selected to VOR. It is possible to elaborate on this hypothesis at some length and, in given conditions, pose a situation where the readings of the co-pilot's RMI indicated an aircraft position about 9 miles south-south-west of Antigua when it was in fact in a similar position in relation to Montserrat. However, it does not provide a reason why the captain ignored his own RMI readings and the evidence in its support is tenuous and to some extent circumstantial.

2.1.3 Pertinent observations

The need for a VOR station at Antigua was foreseen as long ago as 1956 and the requirement for a VOR/DME installation was accepted in 1964, but it was not installed because of the cost. Antigua stands at a confluence of air routes from the north, west and south, and the airport at St. Johns is utilized by major international airlines using large jet aircraft fitted with modern navigational equipment. If the complementary installations are not available on the ground, the aircraft equipment is rendered useless. It is considered that the installation of VOR/DME ground facilities at Antigua is overdue and should be implemented to provide a navigational system in the area consistent with the radio navigation aids with which modern civil aircraft are normally equipped.

The absence of a telecommunication log at St. Johns contributed to the ambiguities of the reconstruction of the flight. Annex 10 to the Convention on International Civil Aviation in paragraph 3.5.1 of Part III indicated as a Standard that such a log shall be maintained. It is considered that this Standard should have been complied with and that it is desirable that an automatic recording system relating to all aeronautical telecommunication service RT frequencies at St. Johns should be installed, preferably incorporating an automatic time signal recording.

The problems of presenting to pilots relevant topographical and radio facilities information in sufficient detail and clarity to satisfy the requirements of current high speed jet aircraft operations are complex. The traditional use of a multiplicity of maps for this purpose is inconsistent with the advances made in other fields of navigation and technology and is inappropriate to the conditions existing in the cockpit of a jet aircraft. It is contended that the practice of using one chart containing radio facilities information on which 2½ in of paper represents a sector of 158 NM, while adequate topographical information is only available on a different chart, leads to a tendency to use one to the exclusion of the other. This tendency is accentuated when the cockpit work load is high as, for instance, in bad weather conditions on a short sector flight. It is suggested that research effort is necessary to evolve an improved method of presenting en-route and terminal information, so that pilots have a quick and accurate reference to all necessary data without the need to handle cumbersome maps and charts in the confined space of a cockpit. A device incorporating visual projection and the superimposition of particular types of information in response to the operation of appropriate selectors might be the basis of such improved method.

It is considered that the malfunctions of the co-pilot's RMI recorded in 1965 are of a pattern indicative of an intermittent fault that remained uncorrected. While conceding the difficulty of tracking down an intermittent fault, the RMI must be looked upon as a flight instrument of fundamental importance in a flight instrument arrangement which provides each pilot with a single RMI and no additional means of heading indication except for the stand-by magnetic compass, and the operating efficiency of the co-pilot's instrument is considered to have been less than satisfactory.

The loss of information from the flight recording as a result of the recorder's failure to survive the impact forces and subsequent fire is particularly unfortunate in this case because the recorded information might have provided valuable indications as to whether or not there was an incorrect heading indication. Although the nature of the impact was such that only the highest order of crash protection of the recorder would have been sufficient, a part of the fuselage forward of the tail cone was substantially whole and uncrushed, affording a suitable location with good protection for the recorder. It is a poignant observation that having been carried in the aircraft for thousands of hours, the flight recorder failed to perform its paramount purpose when applied to the specific eventuality with which it was designed to contend. It is understood that the shortcomings of its installation have been drawn to the attention of the appropriate authorities and corrective action is already in hand. It is, therefore, considered unnecessary to make a recommendation to this effect.

2.2 Conclusions

(a) Findings

The documentation of the aircraft was in order.

The crew members were properly licensed and sufficiently experienced to carry out the flight.

Examination of the aircraft and its equipment revealed no evidence of pre-crash failure, except for the desensitization of the compass comparator and the broken yellow lead of the synchro receiver in the same unit.

The aircraft was flown to the west of the direct route from Fort-de-France to St. Johns, either to avoid thunderstorms or as a result of an erroneous heading indication.

An error was made in the navigation of the aircraft which was coupled with the misidentification of the coastline of Montserrat for that of Antigua.

There is no direct evidence that the pilots were misled by erroneous presentation of navigational information. However, since the examination of the relevant equipment was limited by the damage sustained and the loss of some significant components, the possibility of navigational error arising from erroneous instrument indication cannot be dismissed.

The absence of appropriate navigation aids at Antigua contributed to the problem of navigating the aircraft with accuracy during the descent phase.

(b) Cause or
Probable cause(s)

The accident was the result of the aircraft descending below a safe height when its position had not been accurately established.

3. - Recommendations

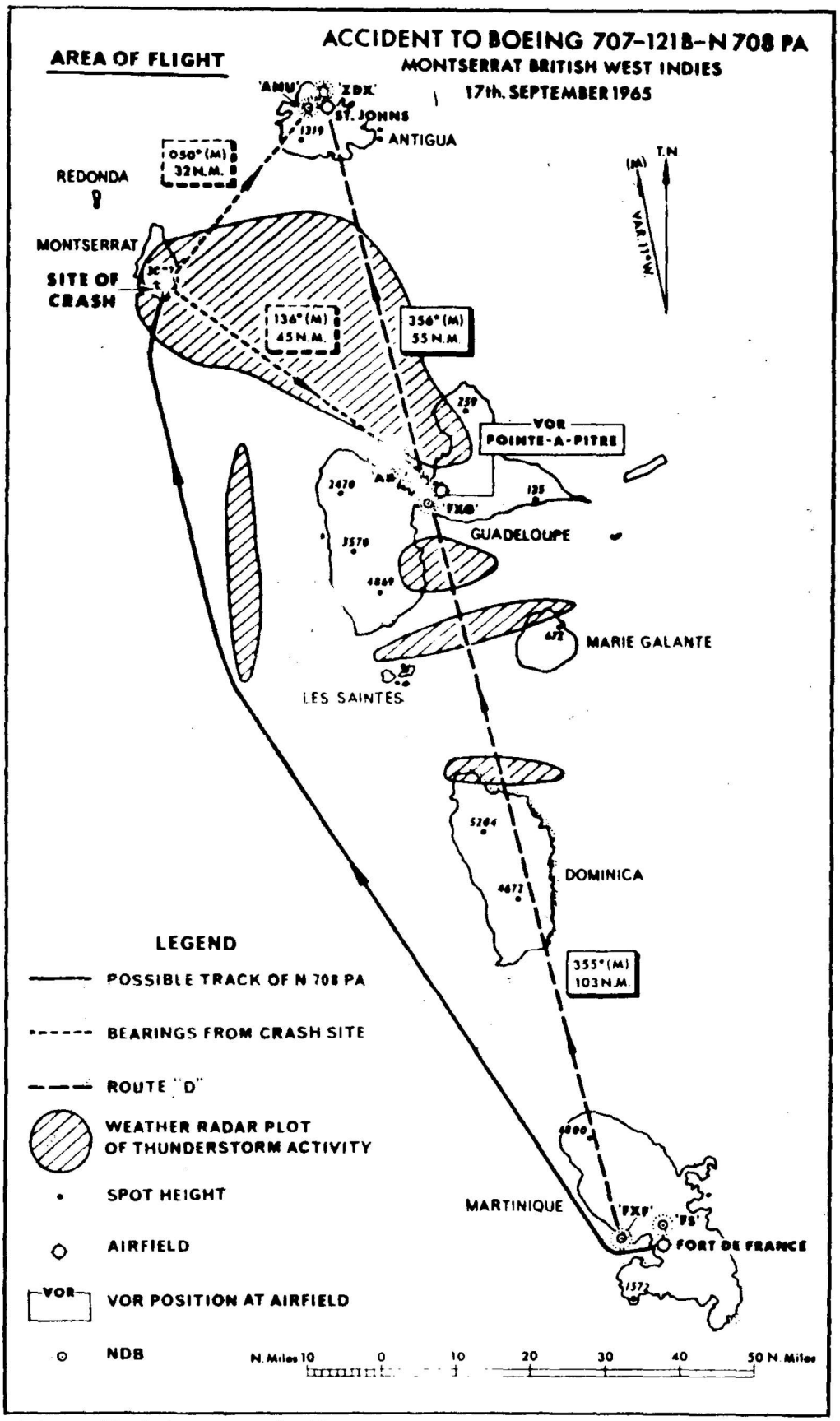
It is recommended that:

(a) VOR/DME facilities be installed at Antigua near St. Johns Airport.

(b) the R/T communications at St. Johns be recorded in accordance with the appropriate ICAO Standard and that an automatic time signal be incorporated in the recordings.

(c) the method used for the presentation of topographical, radio facilities and other relevant information to pilots in the cockpit be the subject of study, with a view to producing a viable solution to the existing problem of handling maps in a confined space under conditions of high work load.

APPENDIX 1



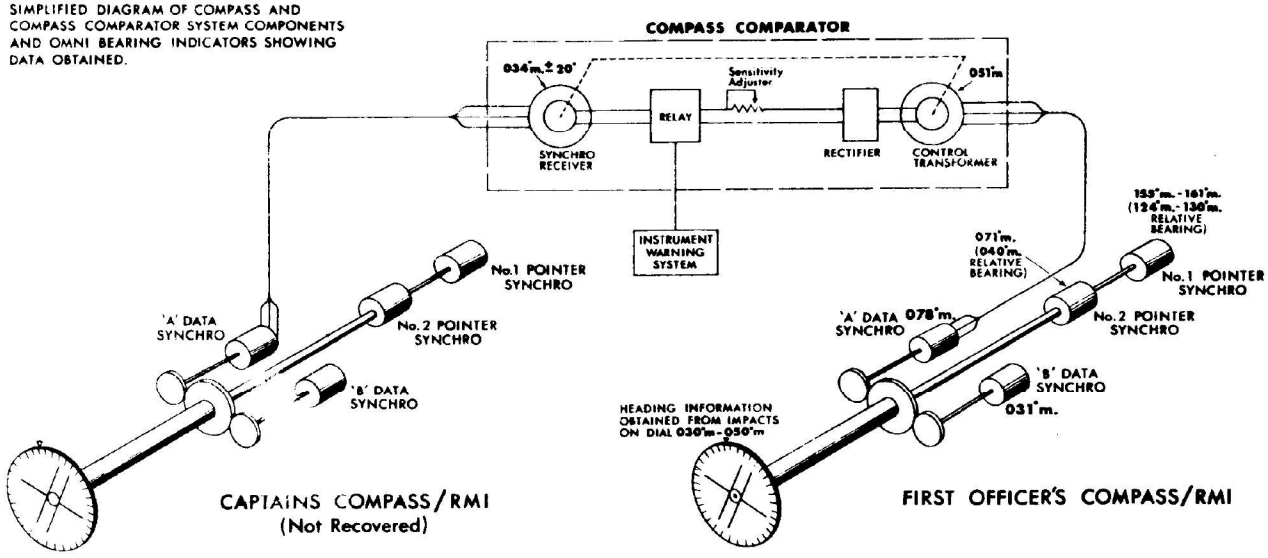
B.O.T.C. A. Dept. C. Ops. 10 D.O. Drg. No. 4947 17-4-67

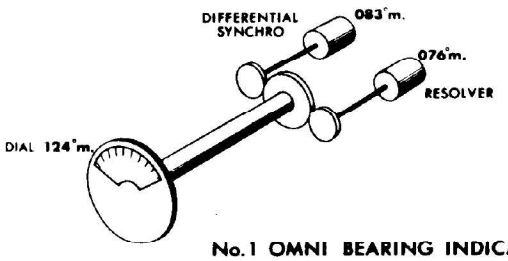
ACCIDENT TO BOEING 707-121B—N708PA

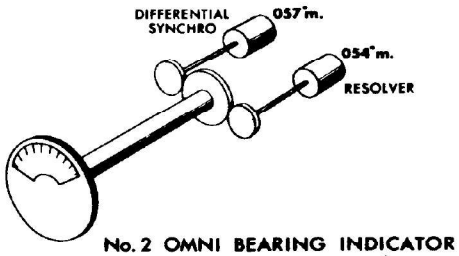
MONTSERRAT BRITISH WEST INDIES

17th Sep. 1965

SIMPLIFIED DIAGRAM OF COMPASS AND COMPASS COMPARATOR SYSTEM COMPONENTS AND OMNI BEARING INDICATORS SHOWING DATA OBTAINED.







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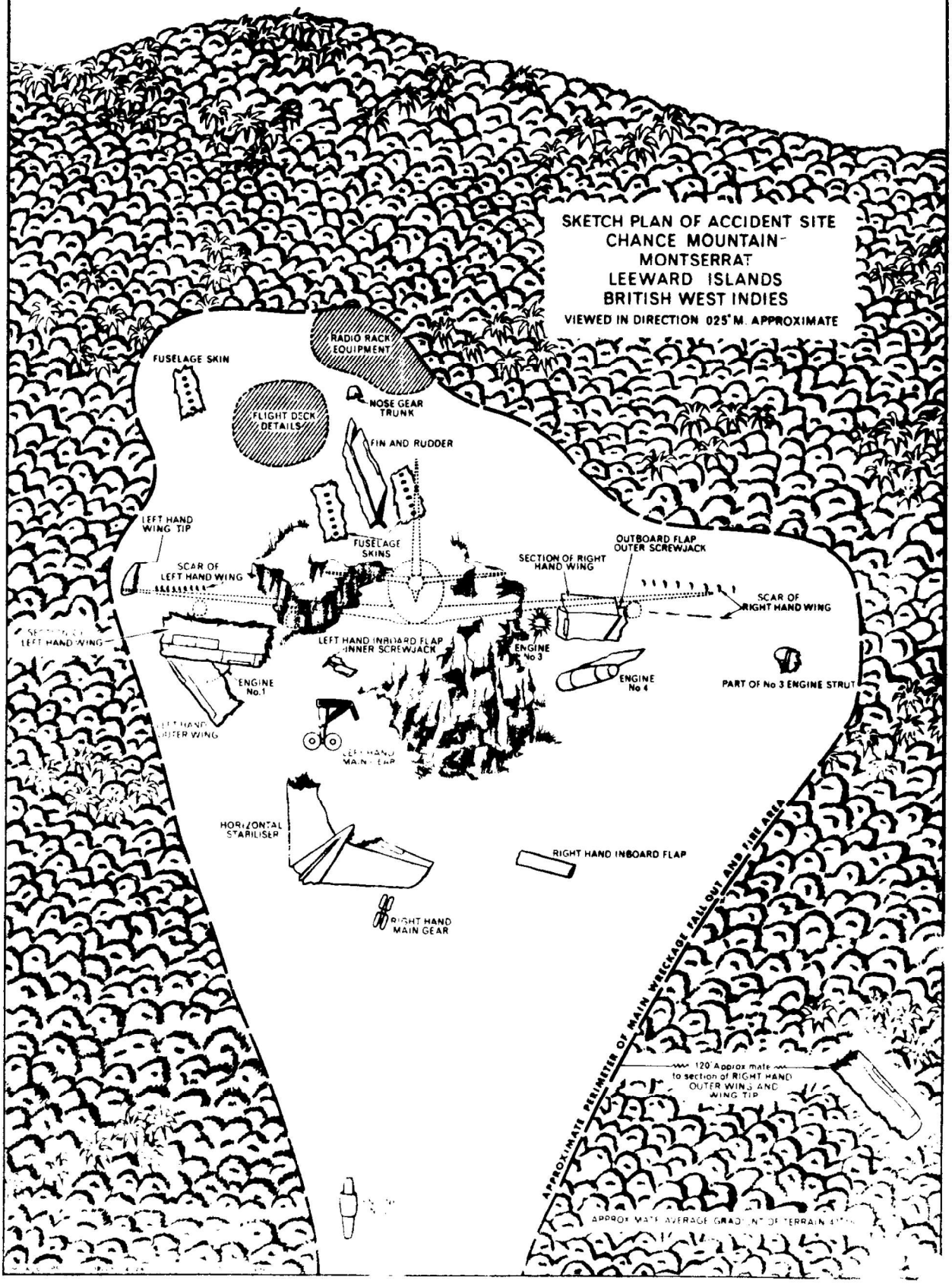
APPENDIX 3

ACCIDENT TO BOEING 707-121B, N 708PA, OF PAN AMERICAN WORLD AIRWAYS INC., ON CHANCE MOUNTAIN, MONTSERRAT, WEST INDIES, ON 17 SEPTEMBER 1965



APPENDIX 4

SUMMARY OF THE REPORT ON THE RADIO PROPAGATION ASPECTS RELATING TO VOR OPERATION DURING THE FLIGHT OF BOEING 707, N708PA, ON 17 SEPTEMBER 1965

For the purpose of this study the radio propagation aspects relating to VOR operation have been considered for a position 45 NM from the Guadeloupe VOR station at an altitude of 2 000 ft.

It has been calculated that, allowing for aerial and feeder losses, the aircraft in this position would have been expected to have received a signal input to the VOR receiver of at least 8 μ V, which should have been adequate to ensure a reliable bearing indication.

A series of laboratory tests have been carried out in which two VOR type signals, derived from separate sources so as to simulate co-channel operating conditions, were fed into a VOR receiver. These tests demonstrated that, over a wide range of wanted signal input levels, the level of the unwanted signal necessary to cause large bearing errors is of the same order as the wanted signal level. To produce bearing errors greater than about 8 degrees, the unwanted signal had to be greater than the wanted signal and under these conditions the bearing indicator behaved in a most erratic manner.

In the Caribbean area there are four VOR stations, in addition to Guadeloupe, which transmit on this same frequency, i.e. 115.1 Mc/s, the nearest of which is of the order of 900 NM from Montserrat. Tests of VHF transmissions in the Pacific area over a similar distance have demonstrated that under conditions of super-refraction, signal levels within a few db of the free space value, i.e. a field of about 100 μ V/m have been recorded. The phenomenon of super-refraction is essentially associated with anticyclonic fine weather and does not normally occur when the atmosphere is well mixed.

However, super-refraction ducts may also be produced by the diverging down draft under a thunderstorm, for about a mile or two, and although there may have been many discrete thunderstorms occurring simultaneously about the time of the accident, it is considered highly improbable that a co-channel signal could have been propagated to the aircraft by a multiplicity of thunderstorm ducts.

The possibility of the existence of any ionospheric mode to support the propagation of 115.1 Mc/s co-channel VOR signals over such great distances has also been investigated. The most likely ionospheric mechanism is by sporadic E reflections. It is known that to produce a bearing error of 4 degrees, necessitates an unwanted signal the order of -8 db with reference to the wanted signal, i.e. an unwanted signal of 25 μ V/m. In order to receive this level of signal over the distance involved, the required sporadic E critical frequency would need to be as high as 28 Mc/s, a figure which has as far as is known never been recorded. To produce a greater bearing error postulates an even higher sporadic frequency.

Other possible ionospheric modes of propagation are Regular F layer reflections and meteoric ionization. The possibility of these modes supporting 115.1 Mc/s signals over a 900-nautical mile path, assuming even optimum conditions, is much less than the possibility of the existence of a suitable sporadic E mechanism.

The solar, geophysical and ionospheric data observed in the Caribbean on the day of the accident have been examined and it has been deduced that the day was 'unremarkable' as far as solar and geophysical events were concerned. Sporadic E ionization was practically non-existent at the time of the accident and the critical frequency never exceeded 5 Mc/s throughout the day.

It is conceivable that a rogue VOR type signal could be radiated at very low level as a result of leakage from VOR ground test equipment: this could cause a bearing error. There are no data available to support such a possibility.

The existence of an unmodulated carrier rogue signal differing in frequency with the wanted carrier by only 30 c/s is considered only a hypothetical case since the stability of either carrier is such that it would be only a momentary condition. Such a rogue signal, but differing in frequency from the wanted carrier by any frequency other than 30 c/s, would simply desensitize the receiver by increased automatic gain control action and would ultimately 'fail safe', indicating this condition by operating the flag indicator.

To simulate the effects of lightning strikes and precipitation static on a typical VOR receiver, some laboratory tests have been carried out in which a VOR type signal was injected into a VOR receiver. Noise, in the form of pulses at a potential of approximately 16 KV was injected into the receiver aerial terminal. With a wanted VOR signal of 5 μ V the effect of either a single pulse or a continuous train of pulses was to cause the bearing indication to oscillate one degree either side of the correct bearing. With a wanted VOR signal of the order 1 μ V, the effect was to cause the bearing indication to oscillate 2 to 4 degrees either side of the correct bearing.