No. 24

British European Airways Corporation, de Havilland Comet 4B, G-ARCO, accident about 100 miles east of Rhodes, on 12 October 1967. Civil Accident Report No. EW/A/0102, dated April 1968, released by the Board of Trade, United Kingdom, C.A.P. 305

1. - Investigation

1.1 History of the flight

G-ARCO left London (Heathrow) Airport at 2145 hours on 11 October 1967, operating British European Airways (BEA) flight BE 284 to Athens. It carried 38 passengers and 2 154 kg of freight, including 920 kg for Nicosia. The aircraft arrived at Athens at 0111 hours on 12 October and reached its parking area on the apron at about 0115 hours. Six Athens passengers were disembarked. At Athens the flight became Cyprus Airways flight CY 284 for Nicosia. Four passengers and the captain remained on board the aircraft whilst it was refuelled and serviced for the flight to Nicosia. The Captain and the two First Officers continued with the aircraft but the cabin staff was changed, the new staff being those of Cyprus Airways. Twenty-seven passengers joined the aircraft at Athens for the flight to Nicosia.

From the evidence of the BEA and Olympic Airways staff at Athens the aircraft's transit was normal. It was refuelled to a total of approximately 17 000 kg and only one minor defect, relating to the Captain's beam compass, was recorded in the technical log. This defect was dealt with by the ground crew. The baggage for the passengers joining the aircraft for the flight to Nicosia and the freight was placed in holds 1 and 2; the baggage and freight from London to Nicosia remained in holds 4 and 5.

The aircraft taxied out at 0227 hours and was airborne on schedule at 0231 hours; it was cleared by Athens Control to Nicosia on Upper Airway Red 19 to cruise at flight level (FL) 290. After take-off it climbed to 4 000 ft on the 180° radial of Athens VOR and then turned direct to Sounion, which it reported crossing at 0236 hours. At 0246 hours, the aircraft reported that it was crossing R19B at FL 290 and was estimating Rhodes at 0303 hours. At 0258 hours at an estimated position 36°41'N, 27°13'E, the aircraft passed a westbound BEA Comet which was flying at FL 280. Each aircraft saw the other; the Captain of the westbound aircraft has stated that flight conditions were clear and smooth. G-ARCO passed Rhodes at 0304 hours and at 0316 hours reported passing R19C at FL 290 and that it estimated passing abeam of Myrtou, Cyprus, at 0340 hours. This message was not received by Athens direct but was relayed by the westbound aircraft. G-ARCO was then cleared by Athens to change to the Nicosia FIR frequency.

The recording of the R/T communications with Nicosia shows that G-ARCO called them to establish contact; the time of this call was 0318 hours + 9 seconds and it is estimated that the aircraft would then have been at a position 35°51'N, 30°17'E, approximately 15 NM to the east of R19C. Nicosia replied to the aircraft with an instruction to go ahead with its message but no further transmission was heard. Nicosia continued to try to contact the aircraft but without result and overdue action was therefore taken. At 0440 hours R.A.F. Search and Rescue aircraft took off from Akrotiri; at 0625 hours wreckage from G-ARCO was sighted in the vicinity of R19C, the last reported position. The aircraft's estimated track from Athens to the crash position is shown in Fig. 24-1.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	7*	59**	
Non-fatal			
None			

1.3 Damage to aircraft

The aircraft was destroyed.

1.4 Other damage

No other damage.

1.5 Crew information

Captain Gordon Daniel Blackwood, aged 45, qualified as a pilot in the Royal Air Force; he joined British European Airways Corporation in 1946. He held a valid airline transport pilot's licence endorsed in Part I for Comet DH 106 aircraft. His total flying amounted to 14 563 hours, of which 2 637 were on Comets.

First Officer Michael Patrick Thomas, aged 34, qualified as a pilot in the R.A.F.; he joined BEA in 1957. He held a valid airline transport pilot's licence endorsed in Part I for Comet 4B aircraft. His total flying amounted to 6 318 hours, including 2 471 on Comets.

First Officer Denis Esmond Palmer, aged 36, learned to fly in the Cambridge University Air Squadron and served in No. 612 Squadron, Royal Auxiliary Air Force. He joined BEA in 1955 and held a valid airline transport pilot's licence endorsed in Part I for Comet 4B aircraft. His total flying amounted to 5 537 hours, including 2 550 on Comets.

1.6 Aircraft information

The aircraft was constructed in 1961 and delivered to BEA in April of that year. At the time of the accident it had flown 15 470 hours; its certificate of airworthiness was valid until 11 April 1968. The aircraft had been regularly maintained in accordance with an approved maintenance schedule, the last check 1 having been completed on 14 September 1967; since that date the aircraft had flown 243 hours. The four engines had been completely overhauled between 1965 and 1967 and all were well within their overhaul life.

* Includes 4 missing, presumed killed.
** Includes 11 missing, presumed killed.

An overhaul of the aircraft (check 4) was completed in December 1966. During this overhaul a comprehensive inspection was made of the whole aircraft for damage due to corrosion, and repairs were made to all areas where such damage was found. The areas affected were mainly along the belly of the fuselage, and both skinning and stringers were renewed between frames 11-16 and 17-21. A complete overhaul of the flying controls was also made at this time. The aircraft had flown 2 279 hours since this major overhaul.

1.7 Meteorological information

An appreciation of the weather conditions within a 60 NM radius of the crash position made by the meteorological office shows that between 0300 hours and 0330 hours on 12 October 1967 an upper trough with its axis east of the Black Sea to the Nile delta was moving eastwards. There was a north to north-east flow at all levels over Turkey and the eastern Mediterranean, west of Cyprus. An anti-cyclone west of the Black Sea was almost stationary.

It is assessed that the following conditions applied:

0^{o}C isotherm:	9 000 ft
Cloud:	mainly clear. Small probability 2/8 cumulonimbus base 3 000 ft tops 30 000 ft
Icing:	severe in cumulonimbus from 9 000 ft to 25 000 ft
Weather:	fine. Small probability decreasing with time of isolated thunderstorms.

Winds and temperatures

Layer	Mean wind
Surface - 5 000 ft	360^{o}/10 kt
5 000 - 10 000 ft	360^{o}/15 kt
10 000 - 15 000 ft	360^{o}/22 kt
15 000 - 20 000 ft	360^{o}/30 kt
20 000 - 25 000 ft	010^{o}/37 kt
25 000 - 30 000 ft	010^{o}/45 kt

The estimated probable errors are about ± 10 degrees and ± 5 kt for all layers.

Height	Temperature Degrees C
5 000 ft	+ 07
10 000 ft	- 04
20 000 ft	- 17
30 000 ft	- 46
40 000 ft	- 53
45 000 ft	- 57 (tropopause)

All heights are pressure altitudes.

Estimated mean sea level pressure at time and place of accident was 1 017 millibars (mb).

Clear air turbulence and mountain waves

It is considered that the conditions were neither especially favourable for the occurrence of clear air turbulence nor for mountain waves near the island of Kastellorizon at the time of the accident. This view is based on the following considerations:

(a) There is no sign of a stable layer, or a layer with marked vertical wind shear near the flight level (29 000 ft), in the radiosonde observations from Ankara, Heraklion or Nicosia at 0000 hours on 12 October 1967, or in the winds from Nicosia at 0600 hours.

(b) The Richardson number deduced from the three radiosonde ascents for the layer 350-300 mb was in each case substantially greater than unity, and values less than this are normally thought to be required for marked turbulence. Even with the higher critical value for Richardson number of three or four postulated by Rakok and Spillane as appropriate in the Colson-Panafsky Index (Quarterly Journal Royal Meteorological Society 91 p. 509), the absence of a stable layer and/or a layer with marked vertical wind shear makes it unlikely that this index would show the peak claimed to be associated with the occurrence of marked turbulence.

(c) Finally, there is no evidence of strong horizontal shear at 300 mb. Measured winds at 300 mb at 0000 hours, were: Ankara 040/56 kt, Nicosia 010/45 kt, Heraklion 400 mb 360/39 kt, 250 mb 360/44 kt (300 mb wind corrupt in message).

(d) As far as mountain waves are concerned, the main requirement that there be a wind component of at least 15 kt normal to the Turkish Plateau, say at 6 000 ft, is not satisfied in the Ankara wind sounding and only just in the Nicosia wind: this latter, however, is not really a true measure of the flow across the plateau. The other requirement i.e. a marked temperature inversion is not satisfied in any of the three radiosonde temperature soundings.

Turbulence

The only other remote possibility is encounter with a thunderstorm top but even this would be unlikely to produce more turbulence than that indicated on the relevant significant weather chart, i.e. severe between 8 000 ft and 25 000 ft. Apart from this assessment, there is the evidence of the Captain of the west-bound Comet flying at flight level 280, which passed G-ARCO just to the west of Rhodes, who reported that conditions in the area were clear and smooth.

1.8 Aids to navigation

In the area of the accident, the Rhodes NDB and VOR were serviceable and operating. It is a normal practice in BEA to use the Rhodes VOR for track guidance from Rhodes to Nicosia and to establish position over R19C by checking against the outline of the Turkish coast with the aircraft's weather radar on 'mapping'.

1.9 Communications

The communications between the aircraft and ground stations were unremarkable, except perhaps for the message at 0316 hours which Athens did not receive direct but by relay from another aircraft; this was not however an abnormal occurrence. The substance of all the radiocommunications was routine information.

1.10 Aerodrome and ground facilities

Not relevant to this accident.

1.11 Flight recorders

A Plessey/Davall flight recorder was fitted but was not recovered. The recorded information from earlier flights with G-ARCO was processed and studied but no significant data were found.

1.12 Wreckage

According to the evidence from the crews of the aircraft and ships, the surface wreckage was confined within a kerosene slick shaped roughly like an ellipse approximately 3 NM long and $1\frac{1}{2}$ NM wide which, when first sighted at 0625 hours was orientated approximately north and south. Debris from the aircraft and bodies were distributed in two main groups, one towards the north and the other towards the south of the area.

To the north, flotsam and bodies were recovered by Turkish ships. The flotsam included part of the forward toilet of the aircraft, life-jackets, some personal belongings and a Graviner fire extinguisher bottle from the starboard centre section and was free of contamination by kerosene. To the south, flotsam and bodies were recovered by German, Greek and United States ships and an R.A.F. rescue launch. The flotsam was mainly cabin furnishings, seat cushions, carpets and parts of the galley; it also included some handbags and other personal belongings, life-jackets and three life cots of the type provided for small children. Some of the life-jackets had inflated, some were uncased but not inflated and some had remained in their containers. In general, the flotsam recovered in the southern area was heavily contaminated by kerosene. All the wreckage recovered was brought back to the United Kingdom for detailed investigation and laboratory examination.

The position of the surface debris, after it had been drifting for approximately four hours, determined by the R.A.F. aircraft from radio bearings from Rhodes and visual bearings on prominent features of the Turkish coast was close to the airway reporting position R19C. Later that day, at 1130 hours, the German ship Astrid fixed the position of two areas containing debris by radar bearings and distance from the Turkish coastline as 35°55'N, 29°52'E and 35°58'N, 29°49.5'E. By this time the area was orientated approximately 313°-153° and had increased to 3.75 NM in length. From the observations of the position of the surface debris and having regard to the probable surface drift, it has been estimated that the approximate position at which the aircraft fell into the sea is 35°55'N, 30°01'E.

Examination of debris recovered from the sea

Life-jackets. The impression was gained by some observers in the R.A.F. search and rescue aircraft that some of the victims of the accident were wearing life-jackets. A similar statement was subsequently made by the captain of one of the ships taking part in the search. Subsequent investigation showed his statement to have been based on a misconception due to the juxtaposition of bodies and life-jackets. Many of the life-jackets recovered from the sea were out of their containers and unfolded and some were inflated; in some cases the tapes were heavily knotted. These knots were haphazard and of far greater complexity than would be expected had they been tied manually and in no case had the tapes been cut. It was concluded that there was no evidence that any life-jacket had been donned in the air.

Fire extinguisher. This was a Graviner triple head automatic extinguisher type 71A; it had been installed in the aircraft on 20 June 1967, at position No. 6 in the centre section near the starboard wing root. The extinguisher could be operated by the pilot to discharge into one of three areas as required, viz. the starboard wing leading edge, No. 3 engine, and No. 4 engine. Alternatively the bottle could be operated by the aircraft's crash inertia switch; in this case all three heads are fired.

Examination of the bottle by the manufacturer and subsequently by the Royal Aircraft Establishment showed that all three fuses and powder charges had fired and all three charge plugs had ejected normally, indicating operation by the inertia switch. All three indicator plungers had ejected but the piston rods had been sheared at their retaining groves. At ports B and C the indicator piston rods remained extended and were severely bent, whilst at port A the piston rod was retracted and the indicator end was visible at the point of fracture of the plunger.

With this extinguisher the pistons remain extended while the discharge of the bottle is in progress and then return to seal off the bottle to prevent entry of the discharge from another bottle. Therefore, extension of the pistons at ports B and C could mean impact with the water had occurred during the discharge. However, a more likely alternative is that the inertia switch was operated by inertia loading during downward detachment of the forward fuselage from the aircraft in flight.

Seat cushions. Initial examination of the seat cushions showed one to have sustained damage of a type which might be expected from involvement in an explosion. The cushions were therefore sent to the Royal Armament Research and Development Establishment for laboratory examination. Exhaustive investigation and tests by the RARDE provided conclusive evidence that two of these cushions, which were among those recovered from the southern end of the wreckage area and which had come from the tourist cabin of the aircraft, had been damaged by an explosive device detonated within the cabin. (see 1.15).

Passenger wrist watches. 10 wrist watches, recovered from the bodies of passengers, were sent to Farnborough for examination. The watches had stopped because of damaged hands and dials, displaced pinions and/or ingress of water. In all cases it was possible, by detailed examination, to determine the time indicated on each watch when it stopped. The times indicated were as follows:

4-24-30.	5-25-30.	5.25.	4.25.	5-20.	10-12-30.	5-25.
10-5-10.	6-29.	5-22.30.				

It was concluded that the time of impact of the wearers of the watches with the sea, and hence, the approximate time the aircraft struck the sea, was about 0325 hours.

During the examination, it was found that two of the watches were dry, inside, but that the other eight contained traces of kerosene.

Examination of fuel drop tank. On 30 October, some three weeks after the accident, an aircraft fuel drop tank was picked up from the sea north-west of Rhodes. Because of damage it had sustained and some red paint markings, it was thought by the Greek authorities that it might have a connexion with the Comet accident, perhaps providing evidence of a collision. The tank was therefore returned to the United Kingdom for detailed examination. This showed that the damage to the tank was consistent with what would be caused by impact with the sea. The attachment lugs showed that the tank had been dropped through normal release and that it had not been wrenched off the aircraft to which it had been attached. The red paint on the crumpled nose of the tank appeared visually to be of a different colour from that which is used in the BEA colour scheme. This, together with indications that the paint had been wet when applied, measurement of the physical characteristics and chemical analysis show clearly that the smear of red paint on the drop-tank differs significantly in composition from the BEA Comet paint and that the smear is not the result of violent impact with a red painted object.

The origin of the tank, which was identified as coming from an F.100 aircraft, was investigated by the United States authorities. This revealed that the tank was one of a batch which had been supplied to the United States Air Force and that the tank was probably one which had been dropped from a United States F.100 about three months before the accident.

Trajectory calculations. The Royal Aircraft Establishment assisted in the wreckage examination by undertaking an analysis of the evidence provided by the flotsam distribution on the surface of the sea and making consequent trajectory calculations.

Although no airframe wreckage was recovered from the sea, sufficient material was found in the form of carpets, furnishings, seat cushions, passengers, etc., to give guidance as to the likely locations of the major parts of the fuselage in the sea. The natural division of all this material by state, recovery area, and identity, into two groups, indicated that the forward fuselage had fallen into the sea in the northern area and the rear fuselage and the wings containing fuel tanks in the southern area. Some seat cushions were found to the south between 1 to 1½ miles from the southern area. It is considered that separation of the fuselage, into at least two major portions, must have occurred before the aircraft struck the sea, to account for the distribution and state of the flotsam and bodies.

The examination of the flotsam suggested that the division of the fuselage, in the fore and aft sense, could have occurred at about the transverse datum position (centre-section front spar). The design firm indicated that this would be a likely separation point under an ultimate loading condition. Trajectory calculations were accordingly made on the premise that a fuselage separation occurred in the air at the front spar position.

Fig. 24-2 shows the results of the calculations. Plots were first made from a specific point at 29 000 ft altitude, and the resulting scatter of flotsam and bodies, at sea level, noted. This distribution was too large to be reconciled with that seen by the search aircraft. Trajectories were then plotted from sea level upwards, from the general positions for items, as suggested by charts and maps from the search aircraft. A very close interception area of plots was found at about 15 000 ft altitude, but this figure must be regarded only as an approximation and treated with caution owing to the imprecise information of the relative position of the flotsam and bodies at sea level. It was concluded that the aircraft had not broken up at its cruise altitude, but at the lower altitude, to produce the general pattern in the sea of flotsam and bodies, and the damage and injury pattern to bodies. A similar conclusion was reached by the pathologists, basing their argument purely on the medical evidence.

1.13 Fire

There is no evidence from the wreckage or the bodies of the victims which were recovered that there was any fire. The operation of No. 6 fire extinguisher, as explained in 1.12, was probably due to the high inertia loading associated with the break-up of the aircraft in flight.

1.14 Survival

The accident was not survivable.

1.15 Tests and research

Post accident inspection of the Comet fleet

Following the accident a comprehensive engineering review and detailed inspection of the entire fleet of BEA Comets was undertaken by BEA in which the Air Registration Board, Rolls Royce Ltd. and Hawker Siddeley Aviation Ltd. participated. Particular emphasis was laid during these inspections on search for evidence of corrosion of the pressure fuselage; a complete strip down of several aircraft at BEA and another at Hawker Siddeley Aviation Ltd. enabled a thorough assessment to be made. These inspections revealed that although mild corrosion was evident in a number of places none was of a serious nature and there was nothing which could be considered detrimental to the structural integrity of the pressure cabin.

The Avon engines were inspected, and although some defects were discovered none was of a type likely to lead to catastrophic failure.

In addition, a complete and detailed inspection and review of all reported defects and failures affecting G-ARCO since delivery to BEA was carried out. This review did not bring to light any abnormal or outstanding defects or failures and the aircraft's service life is considered to have been average with the remainder of the fleet.

Investigation of explosion aspect

Three small pieces of metal recovered from bodies during the pathological examination, which were identified as specimens of Comet aircraft material in subsequent metallurgical analysis at the Royal Aircraft Establishment, were referred in the first instance to the Royal Armament Research and Development Establishment (RARDE) (E2 Home Office Branch) for examination for possible evidence of explosives. This proved negative, no evidence of explosives being found on the specimens.

Damage to one of the 28 cushions recovered from the sea was recognized as being similar to that which had been seen in cushions used to muffle explosions in cases of safe-breaking which were under investigation in the RARDE laboratories and, consequently, the cushions were sent to the RARDE for examination. It was confirmed by the RARDE that the damaged cushion, which had been identified both visually and chemically as a seat cushion from the tourist cabin, showed marked external characteristics and damage postulating its possible involvement in an explosion. The laboratory investigations were, therefore, concentrated upon this cushion, the primary aim being to establish whether it had, in fact, been involved in an explosion.

It was found that, in addition to the superficial characteristics, there were very many small particles of metal and fibres embedded in the cushion and about twenty holes perforating it from the lower to the upper surface. The appropriate specialist branches of the Establishment carried out intensive physical and chemical examination of the cushion, the metal fragments and the fibres, together with a comprehensive experimental study of the effects of explosions on similar cushions. To confirm their findings, the laboratories carried out practical simulation trials exploding high explosive charges in a mock-up of an aircraft cabin with complete seat assemblies.

As a result the following conclusive evidence was obtained, indicating that this seat cushion (whilst it was in its normal position on a seat) had been subjected to the effects from a detonation of a high explosive.

(a) The physical damage to the cushion included blackening of the surfaces, superficial damage and perforations (Fig. 24-3). Microscopic examination, X-ray and electron diffraction and fluorescence confirmed that the blackening was substantially due to amorphous carbon and identical to that produced by a high explosive. All these characteristics were reproduced in laboratory trials on similar cushions using a military high explosive. There was no evidence of fire.

(b) Several hundred very small particles of metal, from 10 milligrams in weight down to those of microscopic size were found embedded in the cushion. Laboratory trials were undertaken, projecting small particles at measured velocities and determining their degree of penetration of similar cushions. The results proved that these very small particles must have entered the cushion with velocities of several thousand feet per second. Larger particles would pass through the cushion. The perforations observed in the cushion could have been produced by such larger particles. Similar effects were produced in laboratory trials firing charges of high explosive in a light metal case near a cushion. No process, other than an explosive one, is known which could produce such small fragments of metal with such high velocities.

(c) The embedded particles had entered the lower surface of the cushion, making holes from their points of entry to the points at which they had come to rest. The inside surfaces of many of these holes were blackened. The particles were frequently found to have fused the plastic where they had come to rest. When they were removed small pieces of fused plastic were found adhering to the metal, proving that they were hot when they entered the cushion. Exactly the same effects were produced in laboratory explosion trials.

(d) The microstructure of particles of metal extracted from the cushion was investigated by metallographic techniques. Some of the particles were ferrous and some were of light alloy. They showed characteristics which are found in explosively produced fragments. These include recrystallization at micro-promontories, due to flash heating, Neumann bands and parallel banding associated with rapid stressing by explosive shock.

(e) The surfaces of the particles of metal were examined under an electron microscope and their features compared with those of metal particles produced explosively in the laboratory. It was found that many particles had been produced by a spalling action which is characteristic of the effects of a detonation shock. Most of the particles were cup-shaped with rolled edges, which is a diagnostic feature. All their surfaces showed many other diagnostic features such as the effects of hot gas washing, bombardment by high speed micro-particles and cracking patterns attributable to very high speed deformation. All of these features have been matched in the particles produced in the laboratory.

(f) Cotton and other fibres were found to be attached to some of the metal particles and in the perforations in the cushion. These fibres were found by microscopic examination to be similar to those in several fabrics which normally cover the lower surface of the cushion. Their position and appearance were found to be consistent with the passage of high velocity metal particles through the fabrics and indicate that the event occurred while the covers were still in position on the cushion.

(g) It was shown in laboratory trials that blackening of the surface of the foamed plastic takes place even when the cushion is enveloped in its normal inner and outer fabric covers. The gases from the explosion, which produce the blackening, are forced through the pores of the fabrics, causing blackening of the underlying plastic even where the fabrics are not torn. Hence, the presence of the blackening is not contrary to the thesis that the covers were still in position on the cushion when the event occurred.

(h) The blackening of the lower surface of the cushion shows a pattern indicating that the webbing of the seat masked certain areas. Trials showed that such masking is produced by the rubber webbing. This indicates that the explosion occurred while the cushion was in a normal position on the seat.

(i) There are straight tears in the lower surface of the cushion adjacent to the edges of the lines of webbing suggesting that the cushion was restrained in position, for example, by the weight of a passenger when the explosion occurred. In trials, similar tears were produced when the cushion was restrained by a weight but not when it was unrestrained.

In the exhaustive tests undertaken at RARDE, attention was directed towards ascertaining whether the samples provided any evidence of the position, quantity and nature of the explosive and its container. The following information is pertinent to this aspect.

(a) The trajectories of the larger particles which perforated the cushion and those which produced the major area of damage were explored by the use of wire probes (Fig. 24-4). This suggests an origin of limited volume some 12 in below the seat roughly in the vertical plane to the rear edge of the cushion and about 3 in from the line of the port edge of the cushion. The trajectories delineated by the entry paths of the small particles embedded in the cushion confirm this position.

(b) The light alloy fragments were analysed by electron micro-probe and mass-spectrographic techniques. One fragment was identified by its composition and the presence of a small area of paint adhering to its surface as originating in the side supporting framework of the seat. Its shape and surface features suggested strongly that it was produced by explosive attack and that it was very near the centre of the explosion. All the other fragments differed markedly in composition from the alloys used in the construction of the aircraft and seats. These facts and the absence of any fragments of alloy from the flooring suggest that the explosion did not take place below the floor but took place on or above the floor and near to the side support of a seat.

(c) The above conclusion is strengthened by the fact that no fibres originating from the carpet were found in the cushion.

(d) The parts of the lower surface of the cushion where damage occurred and particles entered are restricted to a clearly delineated area. Other parts of the surface were apparently masked and protected by the various components which form the structure of the seat assembly. The seat assembly itself is asymmetric in respect of the delta-shaped supports at the two ends. The support at the inner, or gangway, ends stands in a vertical plane. That at the outer, or cabin wall, end is tilted under the seat. Consideration of the geometry involved and the trajectories indicate that the explosive was on the floor between the seat support and the port side of the cabin, close to the rear toe of the delta-shaped support.

(e) Similar considerations also define roughly the possible projection area of an explosive charge in the postulated position. Assuming that the charge was approximately cylindrical, the weight of a charge with the required projection area would be 12-16 oz.

(f) The ferrous particles retained in the cushion were found by metallographic examination and microchemical analysis to be of mild steel which had been cold worked. They are definitely different from the several steels of which a few small items in the seat assembly are made. They closely resemble the material of common types of steel tubing or boxes. The fragmentation and surface characteristics of these particles show that they must have been produced from an object or objects in contact with or close to the actual explosive. It seems, therefore, that they were derived from some object which was not part of the Comet structure or furnishings and it is possible that they originated from a container for the explosive, consisting of a mild steel tube or similar object.

(g) Laboratory trials were carried out with explosives cased in thin-walled tubes of mild steel, using similar cushions as targets. It was found that particles of steel of the kind found in the cushion were produced by explosives with the characteristic high velocity of detonation of a military explosive such as RDX or TNT or by the comparatively rare type of industrial explosive, such as blasting gelatine. They could not be produced by the common industrial explosives, such as the gelignites, which have a lower velocity of detonation.

(h) The surfaces of the cushion were examined, using sophisticated and very sensitive techniques for the presence of traces of the explosive or the products of its explosion. The results were inconclusive except in respect of the carbon deposits previously referred to. Effective detonation of a high explosive does not often leave identifiable traces. The chances of finding any would have been greatly reduced by the immersion in sea-water to which the cushion had been subjected. Small amounts of lead and zinc were found on the surfaces. The lead could have come from the dressings on one fabric component of the seat cover but the presence of the two metals cannot be satisfactorily explained. Most conventional explosives produce carbon deposits under some conditions. Consequently, the particular explosive could not be identified.

(i) Careful search was made for any fragments which might have been derived from the ancillary parts of an explosive device. Normally, timing and igniting or detonating equipment is required. Nothing was found which could be identified definitely as such. The light alloy fragments found in the cushion, which were not derived from any part of the aircraft or seats, differed in composition from the metals used in British and known foreign types of detonator. Their characteristics showed that they were from some object close to the explosion. It is possible that they were derived from an unknown foreign detonator or from a component of unknown kind and function in an explosive device.

In order to verify these conclusions, RARDE carried out practical trials. An assembly was built of light alloy sheeting to simulate part of the cabin of the Comet. A new complete seat assembly was placed in position. An explosive charge of the military explosive PE4, encased in a thin-walled mild steel tube and fitted with a detonator, was placed in position, adjacent to the rear toe of the delta support, between the support and the side of the cabin. Targets were arranged to assess damage to adjacent seats, and to persons sitting in them. The results showed conclusively that a charge of about 16 oz of the explosive detonated in the position indicated would produce effects and damage similar in all details to that observed in the cushion from the Comet.

The effects produced on the targets showed that a person sitting on the attacked seat might be expected to receive severe lacerations to the rear upper part of the buttocks and a small amount of peppering by particles passing through the seat cushion. Peppering of the calves and lower back of the legs and ankles by other particles would be expected, but it is less likely that major fractures or lacerations of these parts would occur. Other persons in direct line of sight of the device would be expected to be peppered by flying fragments but the number and position of such people would be very restricted because of the close array of high-backed seats.

The explosion produced a hole in the adjacent side of the simulated cabin of some 3-6 sq.ft. with further tearing of the alloy sheet and considerable outward petalling of the torn edges of the skin. The greater part of this damage was above floor level but some was below floor level. A comparatively small hole with some tearing was produced in the floor itself. The skin of the far side of the simulated cabin was peppered where there was a clear line of sight between it and the explosion, but otherwise suffered little damage.

The remaining 27 seat cushions recovered from the Mediterranean were also carefully examined but only one provided any further evidence (Fig. 24-5). In this, X-ray photographs revealed a number of metal particles similar to those in the first cushion. There were five perforations produced by particles, the trajectories of which suggested that this cushion may have been behind and a little to the right of the explosion. There was slight blackening of the lower surface of this cushion which was partially masked by webbing. In the laboratory trial, similar effects were produced on a cushion placed in the position indicated relative to the site of the explosion.

Part of a torn white terylene/cotton shirt was also examined. This shirt was certified by the pathologists as coming from the unique body described in 1.17. In it were found a few small perforations in the region of the right side front. Similar perforations were produced in trials with similar materials placed a few feet from the explosion. It is not possible however to conclude definitely that these perforations were not produced by some other means.

Subsequently, RARDE received from the pathologist a piece of skin and fatty tissue preserved in saline/formaldehyde solution. In this was found a particle of light alloy of microscopic size. Although it was corroded by the action of the preservation solution, its surface, when examined under the electron microscope, showed characteristics closely resembling those of the particles from the cushion, indicating that it had originated from an explosion.

1.16 Consideration of salvage

The feasibility of salvage of the Comet wreckage was examined with Ministry of Defence and United States Navy salvage experts as soon as the preliminary investigation of the accident was under way. Cabin debris and bodies were found on the surface of the water in an elliptically shaped area about 3 miles (N/S) by 1½ miles (E/W) approximately 3 hours after the accident occurred. Taking account of surface drift, it was estimated that the centre of the debris area at the time of impact was 35°55'N and 30°01'E, although the accuracy of this position is probably not better than ± 2 miles. No effective marking of the position could be made with the available equipment owing to the extreme depth of the sea.

As there was no precise knowledge of the position of the aircraft wreckage, it was necessary to assume that it was lying somewhere within the debris area and that there might have been further dispersal during its descent from the surface to the sea bed due to hydrofoil effect. Thus an initial search area some 7 miles by 5½ miles with further extension to 11 miles by 9½ miles was postulated, centred on a position 35°55'N and 30°01'E, which might be subject to further reconsideration against more precise knowledge of sub-surface currents.

The sea bed in this initial area according to reliable information from Naval sources contains a spot depth of 1 583 fathoms towards the northern end. Other spot depths are 1 122 fathoms at the southern end, 1 452 fathoms on the eastern side and 1 371 and 1 290 fathoms on the western. Any salvage operation, in addition to the extreme depths, would thus have some very considerable slopes to contend with, and although the bottom is believed to be mainly silt and gravel there is a strong possibility of rocky outcrops.

After careful examination the conclusion was reached that although it would be possible to mount a search operation using Ocean Bottom Scanning Sonar, prospects of successful search were low having regard to

(a) lack of precise information on the exact location of the wreckage;

(b) problems of identification of contact; and

(c) the probability that much of the wreckage consisted of relatively small pieces.

Having regard to the apparent circumstances of the accident it appeared highly probable that search for, and location of, the wreckage, if this were successful, would make no contribution towards determination of the cause of the accident unless it enabled salvage to be undertaken.

The United States Navy experience in the salvage of the Palomares H-bomb was available as background information against which to assess the feasibility of any attempt at salvage of the Comet wreckage at a depth more than three times greater. Consideration was given to the use of deep submergence vehicles, such as the Aluminaut, and all other means, but after careful study it was concluded that salvage of the main wreckage or of the flight recorder was impracticable. Fortunately at the time this decision was reached, evidence was beginning to be forthcoming of detonation of a high explosive within the cabin as an explanation of the accident.

1.17 Medical aspects

Of the 51 bodies recovered from the sea, 19 were in the northern part of the wreckage area and were landed at Antalya in Turkey, being subsequently air lifted by Royal Air Force aircraft to Rhodes. The 32 bodies recovered from the southern part of the wreckage area were taken direct to Rhodes by a Greek warship. In accordance with standing arrangements, pathologists from the Royal Air Force Institute of Pathology were included in the United Kingdom investigating team. They undertook post-mortem examination of the bodies of 47 of the victims of the accident in Rhodes Hospital under very difficult conditions and under great pressure to complete their work quickly due to lack of refrigerating facilities. The four other bodies recovered from the sea were removed by relatives or other interested parties before any examination was possible.

The medical investigation was directed mainly towards discovering evidence bearing on the sequence of the accident and, of prime importance, its cause. There were two main groups as judged by the injuries sustained. The first (extreme injury) consisted of 21 persons who had sustained massive head injury combined with other severe injury; the second main group (slightly injured) consisted of 12 persons who showed very little external evidence of violence. Between these two extremes lay a third, less well defined, group of persons showing moderate injury (14 cases). Approximately 32 per cent of the bodies were fully dressed and a further 32 per cent retained few or no clothes.

Detailed consideration has been given to the possibility of some relationship between the degree of injury, the amount of clothing retained, probable aircraft seating position, and the salvage group (i.e. northern or southern). It was apparent that

(a) the clothing/injury pattern is random;

(b) no relationship could be established between the salvage group and the probable aircraft seating position; and

(c) no aircraft seating position/clothing relationship was discernible;

but, as regards injury/seating relationship, it appears, as far as the bodies subjected to post-mortem examination are concerned, that

(d) none of those believed to have been seated in the forward tourist compartment suffered extreme injury; and

(e) all those believed to have been seated in the rear tourist cabin sustained more than slight external injury.

It must be borne in mind, however, that there is no evidence on seating other than the recollections of the London/Athens cabin crew and the BEA Athens traffic officer and that there could have been subsequent changes. The evidence on the absence of clothing must also be regarded with caution since some outer clothing might have been removed by the passengers themselves and some clothing is believed to have been detached during the rescue operation. Previous experiments have shown that falling into water from a height of 1 200 ft may lead to loss of clothing, but that this is not invariably so and the converse cannot be inferred; nor can the effect of explosion blast be excluded. However, the combination of retention of clothing and absence of external injury in a few bodies was regarded as significant by the pathologists and explicable on the basis of some passengers having been retained in a fairly stable part of the aircraft until comparatively low level.

During the post-mortem examinations, the possibility that the accident might possibly have resulted from detonation of an explosive was kept in mind. Three small pieces of metal recovered from bodies were the subject of metallurgical examination at the Royal Aircraft Establishment and all were identified as specimens of Comet aircraft material. Their inclusion in the bodies was consistent with fragments which could have been picked up during the accident and did not provide any evidence of having resulted from an explosion. The pathologists did however unearth medical evidence which, while it was recognized as being significant, could not be interpreted at the time. This evidence, both general and related specifically to one body, was later to provide confirmation of the evidence of detonation of a high explosive device provided by the RARDE investigation, viz.

(a) one of the slightly injured bodies showed froth at the nares; the histological appearances found in the subsequent pathological examination in Rhodes were consistent with blast. In respect of three of the other severely injured passengers, the nature of their injuries was such that, although it is not possible to say with certainty that they were not due to multiple impacts within the aircraft during descent or at water impact, it would be impossible to contradict an assertion that they were due to blast;

(b) one male body showed unique features in that

(i) the upper body was 'peppered' with minute dark specks and the skin colour suggested the possibility of scorching; none of the other passengers showed skin lesions other than those due to immersion in kerosene;

(ii) the trachea appeared to be burnt;

(iii) the shirt showed minute holes comparable to the 'pepper' spots on the thorax;

(iv) there was a curious ante or cum mortem flailing injury of the right forearm.

Histologically, superficial burning in the trachea is confirmed. The lesions in the skin are remarkable and show small punctate wounds with very definite evidence of burning. Because of these unique features, an X-ray of the thorax had been obtained with some difficulty and a subsequent comparison of minute radio opaque fragments seen in the X-ray, and originally misinterpreted as artefact, with those found in the seat cushions and identified as resulting from detonation of a high explosive, indicated that a common origin was probable. This was subsequently confirmed when a metal fragment was recovered from one of the pathologists' specimens and was identified by the RARDE as similar to the light alloy fragments found in the cushion (see 1.15).

2. - Analysis and Conclusions

2.1 Analysis

Against the initial knowledge of the circumstances of the accident, it was clear that there had been some form of structural break-up at altitude since the wreckage was scattered over a wide area some 3 miles by $1\frac{1}{2}$ miles. The absence of the main wreckage and the unlikelihood of effective salvage due to the extreme depth of the water into which the aircraft crashed indicated the need to consider a number of possibilities including

(a) the weather;

(b) the previous history of the aircraft and information available from the previous cassette of the flight recorder;

(c) general information on the aircraft type and the possibility of structural weakness of in-service damage;

(d) control failure causing some out-of-control condition;

(e) the possibility of a collision;

(f) the possibility of accidental or intentional explosion.

As shown earlier in the report, an investigation of the meteorological factors showed the improbability of clear air turbulence or turbulence due to thunderstorm activity. It seemed clear that any turbulence which could have existed would not have formed any basis for structural failure at cruising altitude, nor any ready explanation leading to an out-of-control condition and subsequent structural break-up.

Engineering investigation of the aircraft type was commenced very soon after the occurrence of the accident since it was necessary to follow all possible lines of investigation, having regard to the absence of the aircraft wreckage and because there had clearly been some form of structural break-up. This investigation had only been partially completed with negative results at the time that evidence commenced to be forthcoming of the occurrence of detonation of an explosive device within the aircraft. Although some defects were found these were not abnormal, having regard to the type of engineering investigation being undertaken, and nothing was apparent which could explain the catastrophic nature of the accident. The Comet 4 is fundamentally different both in respect of airworthiness requirements and constructional standards from the Comet 1 so that there was no reason to believe that there could be any read-across from the experience of the accidents with the earlier type. The detailed engineering investigation confirmed that this was so.

The maintenance history of G-ARCO and likewise the flight recorder information available from previous flights were found on detailed investigation to contain nothing indicative of any situation which could lead to a failure. The major repairs previously made to the fuselage to eradicate corrosion deterioration appeared from the records to have been properly carried out. With the type of construction involved, it seems probable that any defect in the repair scheme, had this occurred, would have shown up in a fail safe manner.

The possibility of an out-of-control condition other than one due to extreme turbulence or some form of structural failure was examined and discarded. The alternative hydraulic systems available had been proved to be an adequate safeguard against hydraulic failure. Although in respect of the elevators the servodynes have a common final output, there is no record of a failure in this area which could lead to an out-of-control situation, and the power of the system is such that it should be possible for the live servodyne to overcome any malfunction of the second servodyne. In any case, it appears from the termination of radio transmissions and the wreckage area that the aircraft was in level flight at the time at which it was overtaken by catastrophe. It is not conceivable with the type of control system in the Comet 4 that in the circumstances of level flight an out-of-control situation of the sort which appears to have happened in this case could occur through any control failure. Nor could freezing of the elevator controls, which has been known to occur, introduce the possibility, during cruising flight in non-turbulent conditions, of a loss of control situation.

The possibility of collision as an explanation of the accident was immediately pursued but no evidence was found of any other aircraft which could have been in the area at the time being missing; nor was any wreckage of any other aircraft picked up in the immediate area. The medical evidence derived from an examination of 47 bodies excluded a collision in the region of the passenger compartment. On 30 October, a drop tank from an F.100 was recovered from the sea near the island of Rhodes and it was suggested that damage to it and red paint on it might be consistent with collision with the BEA Comet. Tests carried out (see 1.12) show conclusively that there was no similarity between the paint on the drop tank and the standard BEA red, the probability that the damage had been caused by water impact and that the tank was one of a pair dropped from a United States aircraft some months before the accident to G-ARCO.

The wreckage recovered from the sea in the impact area was collected at Rhodes and flown back to the United Kingdom for inspection. The superficial damage to one seat cushion suggested that it might have been involved in an explosion. Consequently, this cushion and the others recovered were sent to the Royal Armament Research and Development Establishment for laboratory examination; the results of this and of experimental work required by this aspect of the investigation is summarized in paragraph 1.15. The evidence derived from the damage to this cushion and the particles enclosed within it and from a second cushion disclosed that these cushions had been subjected to the effects of the detonation of a high explosive, the origin of the explosion being at floor level, within the cabin on the port side between a seat support and the cabin wall. The cushions were positively identified by visual inspection and chemical analysis as being Comet aircraft tourist cabin seat cushions. When evidence of detonation of a high explosive had been found, the pathological findings were reappraised in the light of the new information. Only 51 bodies had been recovered from 66 persons on board at the time of the accident, and it had been impossible to carry out a complete pathological examination of all the bodies recovered. In addition, the extent of the pathological examination had been limited by the facilities available. Despite this, reconsideration of the medical aspects (see 1.17) provided confirmation of the RARDE findings that a high explosive device had been detonated within the cabin.

The lack of radio warning of disaster and the evidence that none of the victims recovered from the sea was wearing a life-jacket is consistent with there having been no warning of the catastrophe. Owing to the imprecise information on the points at which the various pieces of the cabin debris were recovered and the limitations imposed by the nature of the small amount of material recovered, it was not possible, as can be seen from paragraph 1.12, to determine with accuracy the height of break-up of the aircraft cabin. Lack of information on the point of impact of structural components has made it impossible to establish any sequence of break-up of the aircraft; nor, having regard to the depth of water in the area and the effect of hydrofoil action on the scattering of wreckage, would it have been possible to make any reliable deduction about this if the relative location of the parts of the aircraft on the sea bed could have been determined. Nevertheless, it has been possible to reach the conclusion, from the distribution of the cabin debris and from the clear demarcation between kerosene contaminated and non-contaminated cabin debris and bodies of victims, that the aircraft probably broke up at a height of about 15 000 ft. A generally similar conclusion was arrived at independently by the medical investigators, having regard to experience drawn from other accidents in which there has been a structural break-up at height.

The RARDE work suggests that the explosive charge used was equivalent to about 16 oz of plastic explosive No. 4 and it is pertinent to consider what effect this would have had on the aircraft. Estimates of blast damage are that overpressures capable of damaging the cabin structure are restricted to a relatively small radius from the explosion. If the dynamic overpressure capable of damaging the structure is taken as 9-10 psi, damage from a charge of the size envisaged would not occur at distance greater than some 10 ft assuming that reflections and obstructions were absent. In an aircraft, the seating provides very effective screening to an explosion on or near the floor.

Hence damage by blast would be expected to occur only quite near to the explosion, and this was borne out by experiment at the RARDE. An explosion of the order suggested by the experimental evidence in this case would be expected to open up a hole in the adjacent side of the aircraft of some 3-6 sq. ft. with further tearing and considerable outward petalling of the skin. The greater part of this damage would be above floor level although a smaller part would be expected below floor level. If, as is believed, the explosive was at floor level the hole produced in the floor would be very much smaller. In the absence of flight recorder data for the accident flight, any conclusions about the resultant manoeuvres of the aircraft are necessarily conjectural. However, it seems probable that the structural damage resulting from the explosion within the cabin did not result in the immediate destruction of the aircraft but created an out-of-control condition. The evidence of the time of the last radiocommunication, the time indicated by the watches recovered from the victims, and the position of the wreckage and its distribution taken together with the medical evidence suggests that after the explosion the aircraft descended, possibly in the general direction of Rhodes, from about 29 000 ft to a lower altitude, perhaps around 15 000 ft, with the fuselage substantially complete, then broke up into at least two major portions which fell into the sea at about 0325 hours nearly seven minutes after the aircraft made its last call to Nicosia.

2.2 Conclusions

(a) Findings

The aircraft was airworthy and its documentation was in order.

The flight crew was properly licensed.

A high explosive device detonated within the cabin while the aircraft was cruising at FL 290.

The explosion severely damaged the aircraft causing an out-of-control condition followed by structural break-up at a lower altitude.

(b) Cause or Probable cause(s)

The aircraft broke up in the air following detonation of a high explosive device within the cabin.

3. - Recommendations

It is recommended that:

(a) development of underwater separation, flotation and location devices which would facilitate recovery of the flight data recorder when an aircraft crashes in the sea should be actively pursued with a view to separation, flotation and location capability being required for future flight data recorders, and

(b) the feasibility of developing means of detecting the presence of explosive devices should be further studied with a view to assisting airlines and aerodrome authorities in their security measures.

ICAO Ref. AR/013/67

Scheduled international
En-route
Explosion in flight
Miscellaneous - detonation of a high explosive device

ACCIDENT TO DE HAVILLAND COMET 4B, G-ARCO, OF BRITISH EUROPEAN AIRWAYS CORPORATION ABOUT 100 MILES EAST OF RHODES, ON 12 OCTOBER 1967

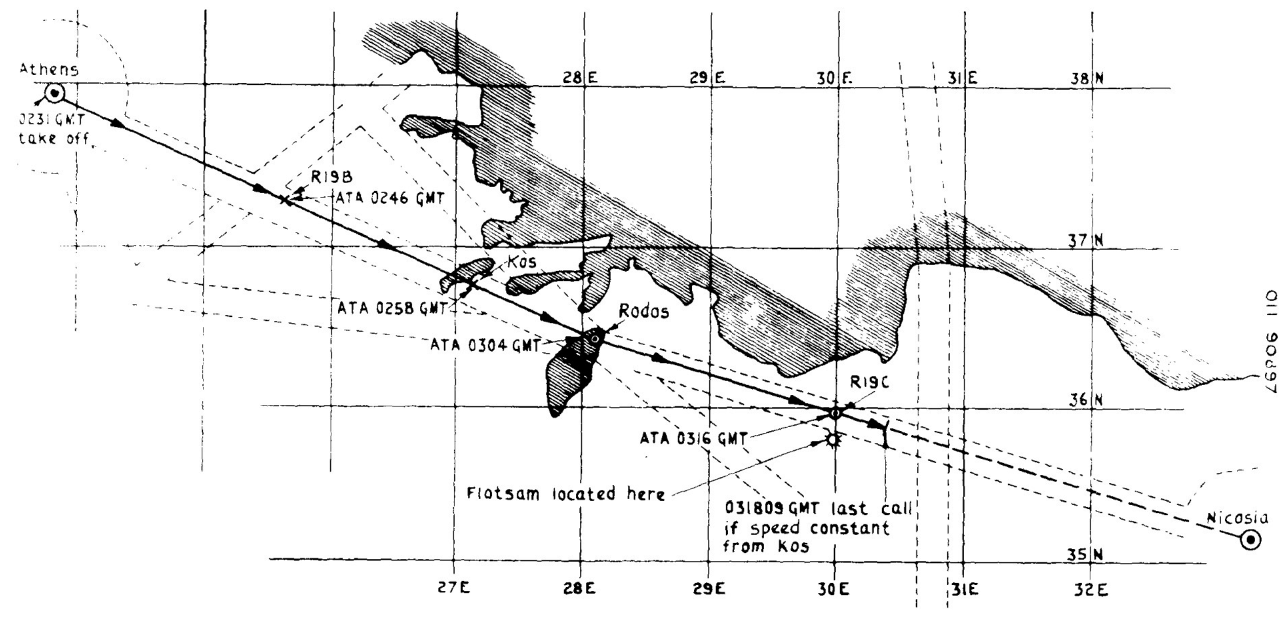


Fig. 24-1 - Times and positions of aircraft along track.

ACCIDENT TO DE HAVILLAND COMET 4B, G-ARCO, OF BRITISH EUROPEAN AIRWAYS CORPORATION ABOUT 100 MILES EAST OF RHODES, ON 12 OCTOBER 1967

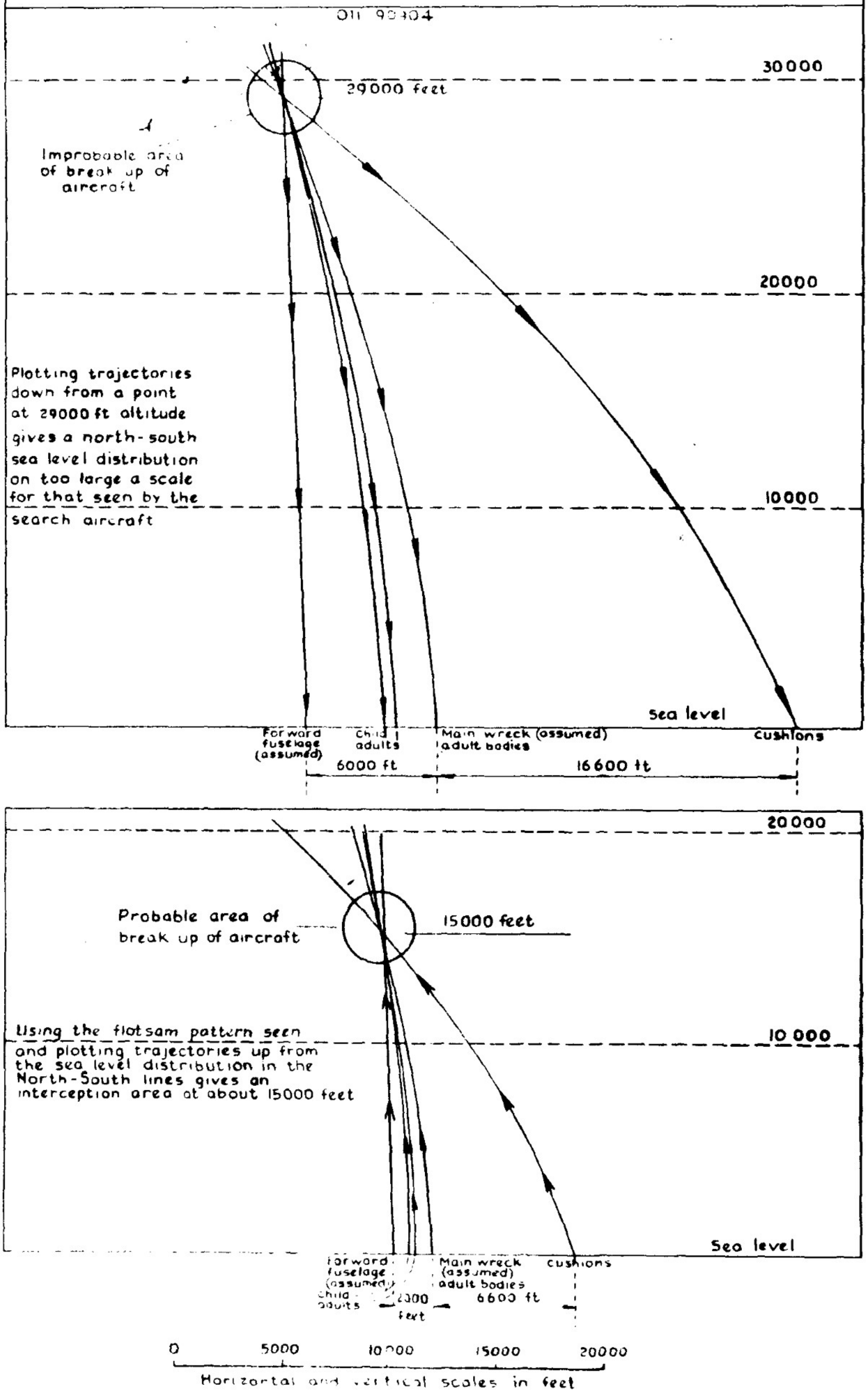


Fig. 24-2 - Trajectory plots.

ACCIDENT TO DE HAVILLAND COMET 4B, G-ARCO, OF BRITISH EUROPEAN AIRWAYS CORPORATION ABOUT 100 MILES EAST OF RHODES, ON 12 OCTOBER 1967

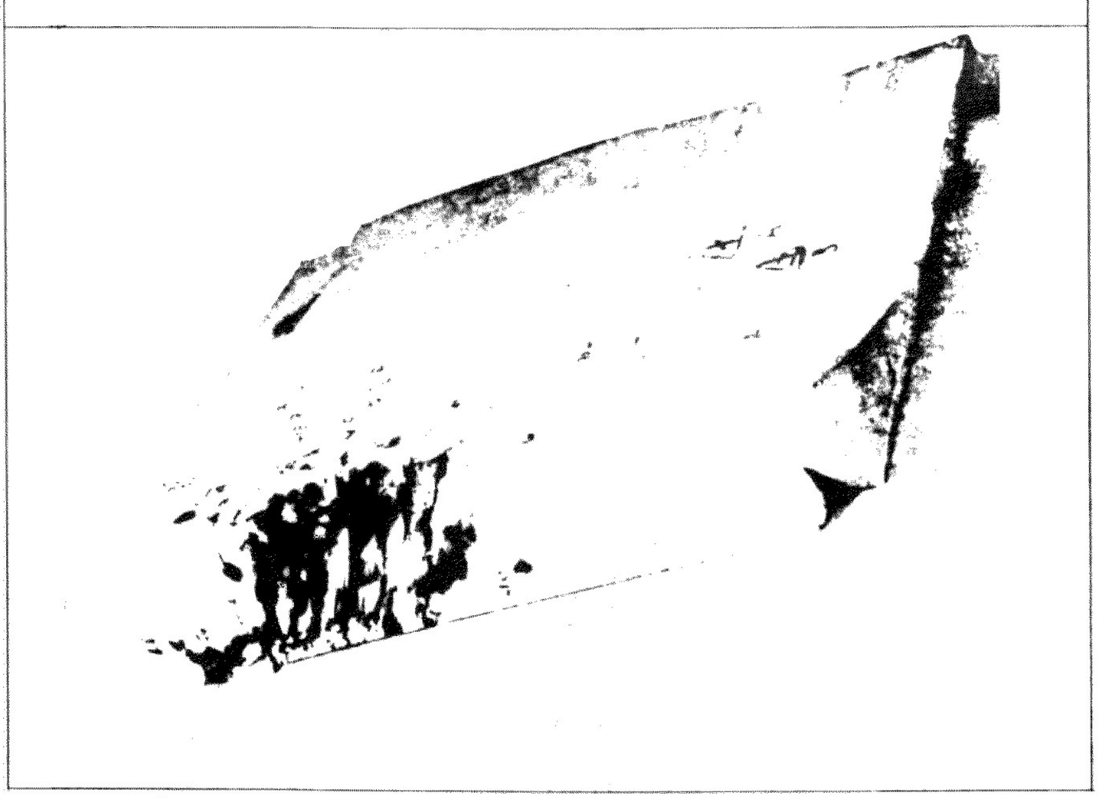
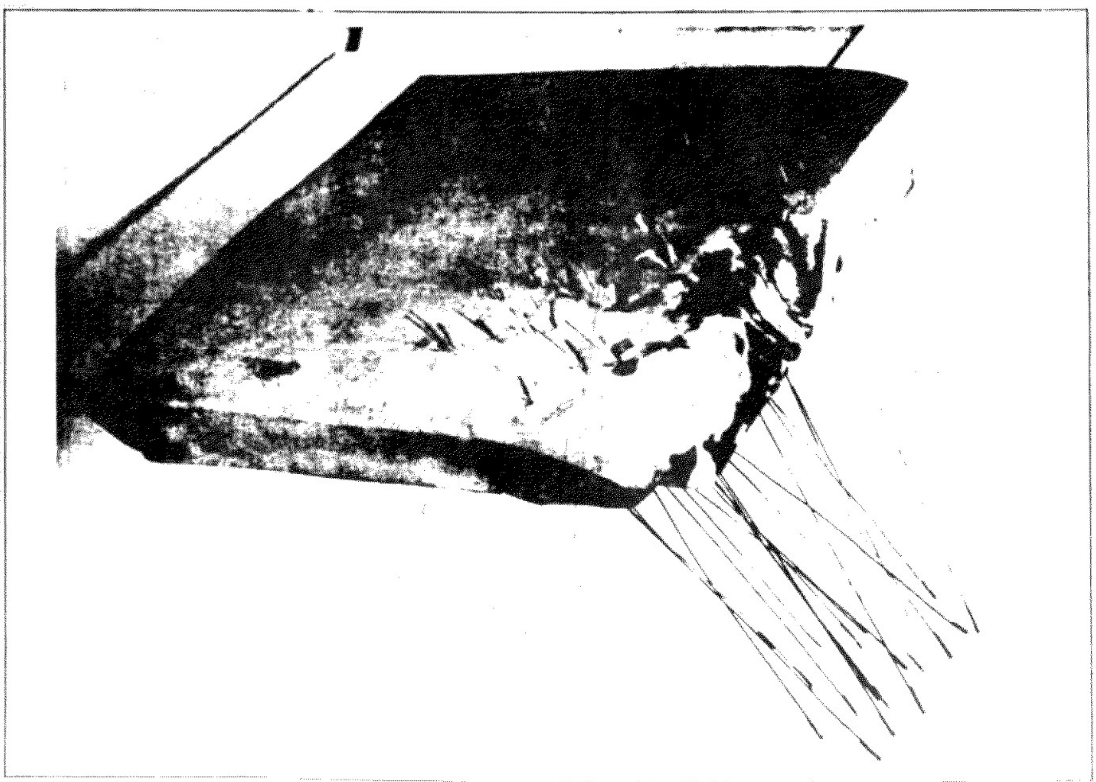


Fig. 24-3 - Damaged seat cushion.



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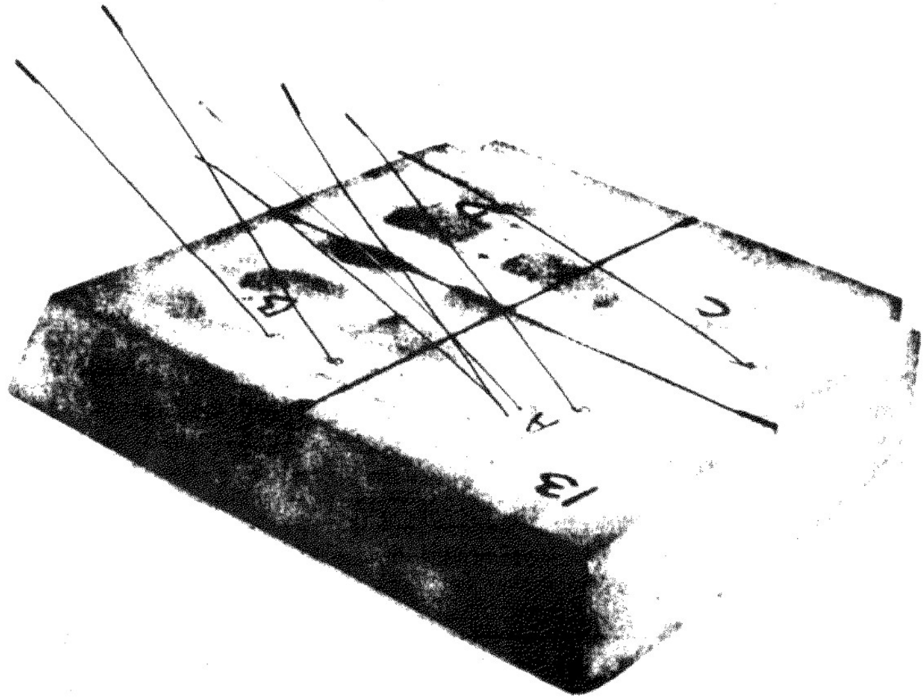

Fig. 24-5 - Second seat cushion with wires showing trajectories.