Accidents Investigation Branch
Civil Accident Report No EW/A224

ACCIDENTS INVESTIGATION BRANCH
Department of Trade and Industry

# British European Airways Vanguard G–APEC. Report on the accident which occurred at Aarsele, Belgium on 2 October 1971

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| 15/72 | BEA Vanguard G–APEC at Aarsele. Belgium, October 1971 | December 1972 |

Kingdom of Belgium
Ministry of Communications
Civil Aeronautics Administration.

# REPORT ON

# THE ACCIDENT TO BEA VANGUARD G-APEC

# ON 2 OCTOBER 1971

# AARSELE (BELGIUM)

Brussels, august 1972.

| | |
|---|---|
| Aircraft | : Vickers Vanguard 951, G-APEC. |
| Engines | : Four Rolls-Royce Tyne, Type 506, Turbo-propeller. |
| Owner and Operator | : British European Airways Corporation Ltd.<br>Bealine House, Ruislip, Middlesex, United Kingdom. |
| Crew | : Commander - Captain E.T.Probert - Killed.<br>Co-pilot - Mr. J.M. Davies - Killed.<br>Third pilot - Mr. B.J.S. Barnes - Killed.<br>Supernumerary - Captain G. Partridge - Killed.<br>Cabin staff - Four - Killed. |
| Passengers | : 55, killed. |
| Place of accident | : Aarsele, West Flanders, Belgium.<br>(50°59'32" N - 03°26'26" E). |
| Date and time | : 2 October 1971 at 1010 hrs.<br>All times in this report are GMT. |


## SUMMARY.

Whilst in level flight at normal cruising speed at flight level (FL) 190, G-APEC suffered a major rupture in the rear pressure bulkhead. This failure caused the tailplanes to become pressurised. The resultant loss of the major portion of both horizontal tail surfaces caused the aircraft to enter a steep dive from which it was not possible to recover.

The aircraft was destroyed by ground impact and post crash fire.

There were no survivors from the 8 crew and 55 passengers.

# 1. INVESTIGATION.

## 1.1. History of the flight.

G-APEC was operating a British European Airways (BEA) scheduled passenger service flight number BE 706 from London Heathrow to Salzburg on 2 October 1971. At 0934 hrs the aircraft took off from runway 28 L at Heathrow with a crew of 8 and 55 passengers on board.

After take-off the aircraft was routed via Epsom NDB, Biggin and Detling VOR's in accordance with a "Dover One" standard instrument departure clearance. After a period of radar vectoring the pilot reported over the Dover VOR at 0954 hrs climbing through 14,200 feet. At a point on airway Green One (G.1) approximately in mid-channel, control of G-APEC was handed over to Brussels ATC at 1001 hrs.

Satisfactory two way communications were established on 131.1MHz. The pilot reported passing over the Wulpen VOR at 1004 hrs with the aircraft level at FL 190. Just over five minutes later at 1009 hrs 46 secs, with no prior warning, G-APEC transmitted "we are going down, 706, we're going down" immediately followed by a MAYDAY call repeated several times, by two voices.

Fragmentary and garbled transmissions continued containing the phrases "We're going down vertically" and "out of control". This transmission continued for 54 seconds, accompanied by a significant increase in propeller and aerodynamic noises, ceasing abruptly at 1010 hrs 40 secs at about the time of ground impact.

Up to the time of the emergency call there had been no indication of any abnormality in the flight. The major part of both horizontal tail surfaces with their associated elevators became detached from the airframe in flight. The aircraft entered a steep dive, which continued until it struck the ground on open farmland.

At impact, the longitudinal attitude was between 20° and 30° over the vertical. The aircraft was rotating slowly in a clockwise direction about its longitudinal axis at a high forward speed.

The aircraft was completely destroyed by ground impact and subsequent fire.

There were no survivors from the 8 crew and 55 passengers on board.

1.2. Injuries to persons.

| Injuries | Crew | Passengers | Others. |
|---|---|---|---|
| Fatal | 8 | 55 | -- |
| Non fatal | - | - | 1 |
| None | - | - | |

1.3. Damage to aircraft.

The aircraft was completely destroyed by ground impact and subsequent fire.

1.4. Other damage.

The accident made a large crater in a grass field damaging fencing and some trees.

A passing car was struck by flying wreckage and one of the occupants suffered slight injuries.

1.5. Crew.

1.5.1. Commander.

Captain E.T. Probert, aged 40 years, held a valid British airline transport pilot's licence and instrument rating, endorsed for Vanguard aircraft in command.

At the time of the accident he had accumulated a total of 9,260 hours experience as a pilot, 1,927 hours being in Vanguard aircraft. In the 28 days preceding the accident he had flown 44 hours, and 8 hours within the previous 3 days.

1.5.2. Co-pilot.

Mr. J.M. Davies, aged 38 years, held a valid British airline transport pilot's licence and instrument rating endorsed for Vanguard aircraft in command.

At the time of the accident he had accumulated a total of 3,386 hours experience as a pilot, 764 hours being on Vanguard aircraft. In the 28 days preceding the accident he had flown 44 hours, 8 hours within the previous 3 days.

1.5.3. Third pilot.

Mr. B.J.S. Barnes, aged 27 years, held a valid British airline transport pilot's licence and instrument rating endorsed for Vanguard aircraft in command.

At the time of the accident he had accumulated a total of 2,237 hours experience as a pilot, 1,903 hours being on Vanguard aircraft. In the 28 days preceding the accident he had flown 48 hours, 8 hours within the previous 3 days.

1.5.4. Supernumerary pilot.

Captain G. Partridge was a qualified BEA Viscount pilot who was aboard G-APEC solely for the purpose of obtaining experience of ATC procedures in the Salzburg area. He was in no way associated with the operation of the aircraft.

1.6. Aircraft information.

1.6.1. Construction history.

Vanguard type 951, G-APEC, constructors number 706 was built by Vickers Armstrongs (Aircraft) Ltd at Weybridge. It was fitted with four Rolls-Royce Tyne, Type 506, turbo-propeller engines.

G-APEC first flew on 17 October 1959 but remained with the manufacturers until 1961 during which time it flew a total of 89 hours. It was delivered to BEA on 14 January 1961, and remained in their service until the accident.

1.6.2. Certificate of Airworthiness.

A Certificate of Airworthiness, n° A 6129, valid in the Transport Category (Passenger) was first issued for Vanguard G-APEC on 11 January 1961.

The certificate was initially valid for the period 11 January 1961 to 10 March 1961, but was subsequently validated annually until 10 January 1971.

On 11 January 1971, it was re-validated for a three year period expiring on 10 January 1974.

1.6.3. Aircraft flying hours.

The aircraft had flown a total of 21,683 hours 51 minutes up to the time of take-off on the accident flight on 2 October 1971. The total number of landings during that period was 17,261. It had flown at a total of 3,143 hours 54 minutes since the last major check (M 1) on 9 June 1970, 153 hours 23 minutes since the last check I inspection, which took place on 9 September 1971, and 10 hours 28 minutes since the last check A inspection.

1.6.4. Aircraft loading.

The Loadsheet and Balance Chart showed that the aircraft had been below the maximun total weight authorised on departure from London and that the centre of gravity had been within the specified limits.

1.6.5. Record of cabin differential pressure.

An examination of the maximum cabin differential pressure recorded on the Captains Technical Report (completed after each flight) for the 29 flights prior to the accident revealed that the highest pressure recorded was 5.6 lb/sq.in. Calculations based on these data show that for the altitude attained on the accident flight the highest cabin differential pressure achieved would probably have been about 5.75 lb/sq.in.

1.6.6. Power unit histories.

1.6.6.1. Engines.

The aircraft was fitted with four Rolls-Royce Tyne,Type 506, turbo-propeller engines constructed by Rolls-Royce Ltd.

| Engine position | Serial n° | Manufactured in | Last Overhaul | Overhaul life(Hrs) | Hours since Overhaul. |
|---|---|---|---|---|---|
| 1 | 3107 | 1961 | 1970 | 5000 | 2479 |
| 2 | 3115 | 1961 | 1969 | 6000 | 5662 |
| 3 | 3097 | 1961 | 1970 | 5000 | 3491 |
| 4 | 3080 | 1961 | 1968 | 5110 | 5007 |

1.6.6.2. Propellers.

The engines of the aircraft were each fitted with a type PD 223/466/3, four bladed propeller manufactured by De Havilland Propellers Ltd.

The propellers each had an overhaul life of 4500 hours.

| Propeller position. | Serial n° | Hours since overhaul. |
|---|---|---|
| 1 | 424031 | 2806 |
| 2 | 424253 | 1177 |
| 3 | 424214 | 2988 |
| 4 | 424029 | 795 |

1.6.7. Maintenance and check cycles.

The aircraft had been maintained in accordance with an Approved Maintenance Schedule. Under this Schedule the following check cycle periods were called for:

Pre-departure Check - Before every flight.

- Service 'A' - To be carried out within 72 hours elapsed time since the last Check 'A' (or re-issue of Certificate of Maintenance)

- Checks 1A, 1B, 1C, 1D, 1E and 1F.

  - These checks to be carried out in sequence at intervals not exceeding 400 hours flying, or 80 days whichever is the sooner. After each Check M1 or M2, a Check 1A will be carried out to commence the sequence.

- Check S1 and S2.

  - Each check to be repeated at intervals not exceeding 1,800 hours flying.

- Check S3 - This check to be repeated at intervals not exceeding 2,100 hours flying.

- Checks M1, M2.

  - These checks to be completed in sequence and at least one Check M1 or M2 must be completed within 9,000 hours, or 4 years, whichever expires the sooner.

The Schedule contained a number of Appendices in which the requirements for inspections additional of the above Checks were laid down as follows:

- Appendix 1 : Airframe components and accessories overhaul periods.
- Appendix 3 : Time controlled inspections.
- Appendix 8 : Radiographic structure inspections.
- Appendix 9 : Fuselage sampling - structure inspections.
- Appendix 10 : Structural inspections (on routine basis).

The above check cycle periods has been progressively extended by maintenance schedule amendment during the service life of the aircraft. At the time the aircraft entered service with British European Airways in 1961 the Check I period was 145 hours and the Check II period (discontinued in 1966) was 500 hours.

The aircraft was given its most recent major maintenance check between 4 May and 9 June 1970. This constituted an M1 check and was recorded serially as M1-093. Since this major check the records show that three S checks (S1, S2 and S3) and eight Check I (serial n°s 094-101) had been completed. The last Check I (check 1B-101) was completed on 9 September 1971 and on that date the most recent Certificate of Maintenance was issued. This was valid for a period of 80 days or the completion of 400 flying hours. The most recent Service 'A' check was completed and certified on 30 September 1971 and the records indicate that the last pre-departure check was completed and certified on 2 October 1971.

1.6.8. <u>General maintenance history</u>.

An examination of the maintenance documents shows that, throughout the aircraft's service life, a number of events and defects occurred. The frequency and nature of most of the defects are not considered, however, to be untypical of the type.

Detailed examination of the maintenance documents of G-APEC has been carried out including and subsequent to the last major inspection (M1-093). The most repetitive defect in the recent life of the aircraft was a restriction of the elevator control system.

This occurred periodically, during low temperature conditions, between 12 November 1970 and 14 February 1971. The presence of moisture in the general area of the tail unit, including the tailplanes, appeared to accompany this defect. However the cause was believed to have been associated with faulty operation of the port elevator trimmer screw jack under low temperature conditions. This was rectified by replacement of the screw jack and its mounting. Special attention was also given to those events in the recent life of the aircraft which could possibly have had a bearing on the accident.

These fell mainly into the following separate areas :

(1) Corrosive influences at or near the rear pressure bulkhead.

(2) Malfunctions of the cabin pressure control system.

(3) Damage to fuselage which may have had some bearing on the stress conditions of the rear pressure bulkhead and adjacent structure.

(4) Recorded modifications and defects relating to the tailplanes and elevators.

1.6.9. Corrosive influences near the rear pressure bulkhead.

The records provide evidence that fluids were present in the area of the tail cone during the more recent service life of the aircraft. Since the last major check, eight entries, extending over the period 29 December 1970 to 8 September 1971, were made in the maintenance documents indicating the presence of water, ice, and/or hydraulic fluid in the tail cone area and the need to rectify the seal of the tail cone access panel. On 8 December 1970 an entry in the maintenance documents indicated the presence of fluid in the area of the rear toilet. No leak was found.

On 15 April 1971, a further entry was made relating to a leak in the rear toilet container. The rear toilet container was drained, put out of use and replaced two days later.

1.6.10. Malfunctions of the cabin pressure control system.

The records reveal that certain malfunctions of the cabin pressure control system occurred during the service life of the aircraft. The most recent occasions on which these are shown took place from 19 September 1970 to 30 July 1971. During this period difficulties arose in maintaining correct control of the cabin pressure and there were a number of instances of pressure surging.

The attempts to rectify these defects involved the replacement of a number of system components at various times during this period including the left and right Spill Valves, the Mass Flow Controller, the Air Altitude Controller, the Pressure Controller and one Discharge Valve.

The cabin was last pressure tested on 18 November 1970.

The aircraft flew more than 470 hours after 30 July 1971 with no recorded problems concerning cabin pressurisation.

1.6.11. Damage to fuselage.

The records show that during the service life of the aircraft the fuselage suffered minor damage in service on four occasions. On three of these occasions the damage occurred at points remote from the rear pressure bulkhead. On the fourth occasion, on 14 May 1968, the underside of the fuselage was damaged when it came into contact with the runway on landing. The incident mainly involved damage to the fuselage skin over an area covering two fuselage frames. No damage was sustained to the frames, however, and as the rear-most point of skin damage occurred approximately eight feet forward of the rear pressure bulkhead there was no evidence that significant reaction loads were transmitted ot the bulkhead at the time of runway contact.

1.6.12. Modifications to tailplanes and elevators.

There was no outstanding mandatory modification applicable to the tailplanes at the time of the accident.

At the time delivery of G-APEC to BEA, the tailplanes fitted incorporated the modification L 40. This modification, introduced by the manufacturer in 1959 increased the size of the inner rivets of the cleats securing the tailplanes stringers to the ribs and chordal members. The modification was neither mandatory nor retrospective.

In 1962 G-APEC underwent an extensive modification program. During this program the original tailplanes and elevators were removed and replaced by items (pre-mod. L 40) incorporating steel weights attached to the upper and lower surfaces. These weights were introduced as an attempt to reduce the level of vibration throughout the aircraft.

As service experience indicated that no improvement in cabin vibration level was achieved, these weights were removed in October 1965.

Some minor repairs to the tailplanes were carried out at the time of removal of the weights. These repairs were located at stations 143 and 276 on each tailplane and were associated with the difficulties of weights removal.

Subsequent work relating to the tailplanes included the carrying out of crack repairs to the rear spar upper and lower boom angles at the elevator outboard hinge position on the right tailplane and to the rear spar lower boom angle at the elevator outboard hinge position on the port tailplane. Further repairs to the above areas were carried out on 9 June 1970 on the occasion of the last M1 check when a detailed structural inspection took place and in addition a crack located at station 147 on the right tailplane forward spar lower boom was repaired. Some minor rivet repairs were carried out at the same time.

The elevators fitted to G-APEC at the time of the accident were installed on the aircraft in May 1970 during the last major check. The left elevator had been overhauled by BEA in November 1968 and the right elevator had been overhauled by BEA in February 1970. The elevators had not been flown between the time of overhaul and their installation to G-APEC.

1.6.13. Inspections relevant to rear pressure bulkhead before 2 October 1971.

The inspections relevant to the rear pressure bulkhead and adjacent areas, laid down in the maintenance schedules and in force at the time of the accident to G-APEC, can be summarised briefly as follows:

Every 400 hours flying time - All Checks I and Major Checks:

a. Item 37.

This item calls for a visual inspection for satisfactory condition of the rear fuselage structure between stations 750 and 1223.

The front face of the bulkhead below floor level and the lower fuselage skin forward of the bulkhead are covered with soundproofing, so that this inspection permits only the underside of the floor structure, the crowns of the frames and the toilet servicing duct to be seen; this should reveal gross spillage.

b. Item 41.

This item calls for a visual inspection for satisfactory condition of the rear fuselage structure between stations 1223 and 1462, including the rear pressure bulkhead. This item permits the inspection of the rear face only.

Inspection capability at the lower periphery is limited by the convergence of bulkhead plating and the lower fuselage skin to about two inches away from the heel line.

Visual inspection is also limited by the presence of the thiokol bead and a watershed wedge (See figure 6 ).

Every 1,200 hours flying time - Checks 1C, 1F and Major Checks, Item 41:

This item calls for a check on fuselage water drains behind rear pressure bulkhead at base of frames, for obstruction.

Every 4,500 hours flying time - Checks M1 and M2, Item 5309:

This item requires a check for satisfactory condition and cleanliness of rear fuselage lower structure and requires the removal of soundproofing in the lower fuselage (i.e.below floor level between the aft end of the rear freight bay and the rear pressure bulkhead).

In the event of corrosion or damage being found, adjacent wall soundproofing must be removed for further inspection.

NOTE: Both major checks require removal of toilet benches, doors and toilet bulkheads.

Every 10,500 hours flying time - Appendix 9 - Item 5153.

This item is to check for satisfactory condition of the rear pressure bulkhead and fuselage structure aft of the rear freight hold.

It requires the removal of all soundproofing in this below floor area. This inspection started in a preliminary form in June 1967 as part of a sampling programme. Two aircraft that had been in BEA service for about 6 1/2 years and had achieved about 14,000 hours each were inspected. As their examination proved satisfactory, all other aircraft were inspected to this requirement between February 1969 and October 1971, after periods of service of between seven and ten years and at lives of between 15,464 and 20,974 hours.

This item was carried out on G-APEC at the last major check (M1-093) in May/June 1970. No corrosion was reported.

Every two years - Appendix 10 - Item 53-00-79.

This item, introduced in April 1970, requires radiographic examination of the rear pressure bulkhead lap joint below floor from stringer 35 left to 35 right for gross corrosion and general condition.

(This inspection was introduced in the maintenance shedules by BEA because it was not possible to examine the joint adequately by visual means).

G-APEC was given this examination on 8 May 1970. BEA did not detect any signs of gross corrosion from their examination.

Subsequent to the accident,examination of the five radiographic plates involved showed that one exhibited a severe lack of definition. This plate was of such poor quality that the purpose of the inspection could not have been fulfilled.

No repeat radiograph had been made of this area, which included the region of stringer 46 right, where severe corrosion was found after the accident.

1.7. Meterological information.

A large anti-cyclone was centered over Europe with a ridge extending North West across the Low Countries and Southern England. Some smoke haze was present near the surface over the area with visibility locally falling to 4,000 metres or less. The top of the haze layer was reported as being 3,000 feet.

No low or medium cloud was reported but bands of cirrus cloud existed between 25,000 and 30,000 feet, thickening towards the Nort West. No turbulence was forecast and none was reported over the route flown by G-APEC.

The wind structure in the crash area was estimated as:

surface: very light, south easterly.
5,000 ft (850 mb) : 160°, 05 knots.
10,000 ft (700 mb) : 200°, 10 knots.
19,000 ft (500 mb) : 230°, 22 knots.

The accident occurred in conditions of bright sun light.

1.8. Aids to navigation.

The navigational aids available on airway Green 1 to the pilot of G-APEC were the Wulpen VOR and NDB to the west and the Mackel NDB and Fan Marker to the east. All these facilities were serviceable and radiating normally at the time of the accident.

1.9. Communications.

As was seen from the transcripts of ATC radio tape recordings, satisfactory two way communications were established by the aircraft on all the R/T frequencies used.

Analysis of the recording of the last minute of the flight indicated that the aircraft was out of control and that two separate voices were transmitting at the same time. The indications are that two microphones in the aircraft were live probably until ground impact. During the period, in addition to the fragmentary messages passed by the pilots, there was a significant increase in the background propeller and aerodynamic noise levels. (See appendix A)

1.10. Aedrome and ground facilities.

Not applicable to this accident.

1.11. Flight recorder.

1.11.1. The recorder system.

The aircraft was equipped with a Plessey-Davall Type PV 710 flight data recording system. This system operates on the electro-magnetic recording principle and uses pulse code modulation to provide digital data on stainless steel wire.

Six parameters were recorded sequentially against a common time base: Pressure Height, Indicated Air Speed, Magnetic Heading, Normal Acceleration, Pitch Attitude and Roll Attitude.

In addition event markers were introduced for Autopilot elevator and aileron channelsengagement.

A crash protected 300 hours duration recording cassette together with its drive unit was fitted to the aft face of the tailplane main spar in the tail cone.

The system was serviceable when the cassette was last changed on 10 September 1971. The cassette installed at the time of the accident, was fitted to the aircraft on 11 September 1971 and had run a total of approximately 139 hours up to the time of take-off on the accident flight.

1.11.2. Recovery and examination of recorder cassette.

The flight recorder cassette was recovered from the main wreckage site.

Although the outer case had suffered some impact damage it had not been exposed to fire. The internal mechanism had been disrupted and the recording wire broken. However after dismantling the cassette assembly the wire was rejoined in such a way that only 0.3 seconds of recorded data were lost. This point was 3.5 seconds before the end of the recording.

1.11.3. Replay of recorded data.

A satisfactory printout of the data of the entire flight was produced. Although some discrepancies were present in the line by line printout, due to a play back system deficiency, these were limited in number and did not affect the overall accuracy of the data. The record showed that the aircraft had followed the desired flight path after take-off and had conformed to ATC instructions promptly. It showed that G-APEC had levelled out at a pressure altitude of about 19,000 feet some 6 1/4 minutes before the recorder stopped. During this period at cruise flight the IAS had increased from 210 knots to 250 knots at which speed it remained throughout the last minute of recording. No abnormalities of pitch or roll angles, nor of normal acceleration levels were evident during this time. The aircraft was established on a magnetic heading of 110 degrees and the aileron and elevator channels of the auto pilot were indicated as having been engaged throughout the cruise period. The recording terminated whilst the aircraft was in a steady cruise condition at an altitude of 18,930 ft (1,013.25 mb datum).

1.11.4. Last portion of recorded data.

Examination of the last half second of the recording showed that the frequency and amplitude characteristiecs of the wave form were highly abnormal. A detailed analysis however revealed that valid data had been recorded although they were made difficult to detect due to wave form distortions. It was found that the underlying parameters showed no unusual characteristics or indications of a significant diversion from the previously established flight path. The autopilot elevator and aileron channels were still indicating engaged at the end of their recording sequence.

A number of tests were made in an attempt to establish the reasons for and the precise nature of the signal decay which occurred. It was conclusively proved that signal deterioration could only occur in the same manner as shown on G-APEC if the power and data supplies from the processing unit to the recorder unit were interrupted in a given sequence.

This required firstly the separation of the servo supply to the cassette drive unit followed by that of 115 V power supply and it was also necessary that during these separations the two wires transmitting data should remain intact.

The cable loom carrying these supplies passed through an area of the rear pressure bulkhead which became separated during the bulkhead failure sequence.

Examination of the cable loom indicated that separation of these wires had occurred in a manner not inconsistent with the sequence required.

1.11.5. Determination of ground track.

The recorded data of the flight after lift-off lasted for approximately 35 minutes 12 seconds.

To produce a plot of the aircraft's ground track the recorded magnetic heading and IAS data were used as basic parameters. TAS,position and static error corrections were applied to the velocity data but no transducer calibration corrections were applied because the most recent calibration was close to nominal. No corrections were required for the magnetic heading data. Given wind information for various altitude bands was used to convert the derived air track to the ground track. (See figures n° 1 and 2 ). The plot indicates that the flight recorder stopped when the aircraft was approximately three kilometers west of the crash site.

1.12. Wreckage.

1.12.1. Wreckage area.

The aircraft had crashed in a flat grass field with soft clay subsoil adjacent to a drainage ditch bordered by a line of trees. The aircraft was in a steep diving attitude at impact. It had passed beyond the vertical so that the fore and aft axis of the fuselage was at an angle of about 30 degrees beyond the vertical on a heading of 030 degrees magnetic. There was a small angle of bank so that the left mainplane, entered the ground first. A crater some 6 metres deep was formed in which were embedded the remains of the mainplanes, engines, and a large part of the fuselage, all in a disintegrated state. (Figure n° 3)

Scattered round the impact crater up to a radius of about 300 metres were fragments of disintegrated structure mainly from the fuselage and empennages. There were about 11,600 kgs of aviation kerosene fuel on board and fire broke out following impact, giving rise to severe burning within the crater and localised patches of splash burning in the scattered wreckage.

The landing gear and flaps were fully retracted at impact. The outer two thirds of both tailplanes and left elevator, together with the whole of the right elevator were missing from the aircraft when it struck the ground. These components were found, broken into fragments, scattered down wind from the line of flight forming a trail north-west of the main wreckage. Both from their position on the ground and the nature of their damage it was apparent that in-flight separation of these items had occurred.

1.12.2. Wreckage trail.

Major portions of both left and right tailplanes and elevators were found several kilometers from the main wreckage area. The distribution on the ground was in conformity with the aircraft flying on the airway heading 109 degrees and the wind structure which varied in direction and strength from 160°/05 Kts at 5,000 ft. to 230°/22 Kts at 19,000 ft.

The heavier pieces were adjacent to the side of the flight track up to a distance of 3 Kms, whereas lighter pieces extended North and East down wind to a distance of 7,6 kms.(See figure n° 4)

A cross sectional wind drift plot was constructed from the ground positions of the separated pieces and the wind data, with the object of estimating the height at which separation of the tailplanes and elevators had occurred. This plot indicated that separation had probably occurred at a height of not less than 18,000 feet.

1.12.3. Fuselage.

The fuselage, including the flight deck and passenger cabin, was almost totally destroyed by fragmentation on impact with the ground. Such portions as survived were mainly from the rear end and included a portion of lower fuselage structure from the aft end of the rear freight bay up to and including the lower portion of frame 1223 to which the rear pressure bulkhead was attached.

Following preliminary examination at the accident site, a reconstruction and detailed examination of the rear fuselage and empennage was carried out at the Administration de l'Aéronautique establishment at Haren. The examination showed that the damage in this region on ground impact was consistent with the near vertical attitude of the aircraft; the fin and rudder had been grossly crushed and broken up together with the dorsal fuselage structure. Frame 1223 had been broken into three main portions and the rear pressure bulkhead crushed and torn into many pieces. The tail cone with its access panel was attached and in position at ground impact.

Reconstruction of the passenger cabin and flight deck was not praticable due to the degree of fragmentation that had taken place. Portions of equipment and structure from the flight deck were identified including the remains of the centre control pedestal but no useful evidence as to control position or operating procedures could be determined. Parts of all doors and detachable panels in the pressure hull were identified and their presence on the aircraft at ground impact confirmed.

No evidence was found to indicate that any bomb explosion had taken place in the fuselage prior to ground impact; the remains of the rear toilet compartment which is located just forward of the rear pressure bulkhead on the right side were identified and bore no evidence of this nature.

1.12.4. Rear pressure bulkhead.

1.12.4.1. Construction.

The fuselage structure at frame 1223 comprises a fuselage skin plating joint with doubler, the rear pressure bulkhead itself with a doubler plate bonded to its periphery, and frame 1223 ( See figure n° 5 ). The complete joint therefore involves six layers of metal which are rivetted together by a double row of rivets. The assembly is sealed by application of a polysulphide sealant (thiokol) (See figure n° 6 ).

The pressure bulkhead extends reaward in the form of a dome and is a built up structure of 22 swg (0,711 mm) aluminium alloy sheet with doubler plates at the joints. The outer ring is made of eleven sections with the joints disposed radially.

The lower section carries the seals and pressure glands which pass the flying controls and electrical services through the bulkhead; this lower section is made in two portions with a joint and doubler plate running laterally between the two radial joints adjacent respectively to the stringers 34 right and 38 left positions. The central portion of the bulkhead is made in three sections with a peripheral joint and three radial joints. Seven radial bracing members attach to a central hub fitting and to points on frame 1223 but are not otherwise connected to the bulkhead. The whole of the frame joint at station 1223 is liberally coated with polysuphide sealant on top of the finishing paint leaving no untreated edges. This coating is not normally extended to cover the edge of the doubler plating joint.

In the Vanguard 952 and 953 series, the plating thickness was increased from 22 swg to 19 swg (1,016 mm). The increased thickness of the plating was the result of a customer request for the 952, which was then continued as standard on all subsequent aircraft. The 951 design meets all airworthiness requirements for static strength and was tested for fatigue to 72,000 flight cycles.

1.12.4.2. Examination.

A reconstruction of the bulkhead was made and the following pattern of pre-impact damage was established.

Corrosion was found at the lower part of the rear pressure bulkhead. Corrosion attack had taken place over a distance of 48 cms., roughly about the centre line, underneath the double curvature peripheral doubler plate which is bonded to the forward face of the bulkhead; the bond was completely delaminated over this distance and bulkhead material corroded away (See figure n° 7).

From the end of the corroded area at each side, a tear ran upwards and outwards to a rivet line in the lower edge of the joint in the bottom section of the outer bulkhead ring. There was some evidence of nicotine tar staining on the edge of the corroded area (See figure n° 8). On the tear between the corroded area and the rivet line on the left side were a series of "step" marks across the fracture faces where the torn edges had been in mutual contact. The distance between these marks increased progressively and fourteen such "steps" could be identified over a distance of 76 mm. (See figure n° 9). When the tear had extended to this length i.e. approximately 60 cm., it must be assumed that the critical crack length had been exceeded because the tears on both side became continuous running up into the rivet line and turning outboard from the centre line.

The tears then ran along the edge of the joint plate and through the radial joints located respectively at stringers 34 right and 38 left. Passing round the end of the horizontal joint plate the tears then ran upwardsthrough the next outer bulkhead ring sections towards the radial joints located near the stringer 27 positions (See figure n° 10). On the right side this portion of the bulkhead carried the re-inforced cut out supporting the gland for the cable loom supplying the flight recorder; the tear ran upwards through the rivets holes round the lower edge of this cut out. The tears continued on both sides along the lower edges of the radial joints near the stringer 27 position (i.a. at 4 o'clock and 8 o'clock), across the circumferential joint and then ran into the center bulkhead panels. The failures terminated under rivet lines adjacent to the central hub fitting leaving about 15 cms between the two end points. Thus the lower quarter of the bulkhead, with the glands and seals carrying the electrical services and flying controls through it was separated from the rest of the structure, before ground impact,except for approximately 15 cms. at the centre. (See figure n° 11).

1.12.5. Rear fuselage area.

A second area of corrosion was found when the remains of the bulkhead were disassembled from frame 1223. This was located on and beneath the bracket attaching a radial bracing member to frame 1223 and the fuselage structure at stringer 46 position on the lower right side. The corrosion attack had not progressed to the point where any crack had appeared in the bulkhead or frame structure and it had played no part in the failure of the bulkhead. (See figure n° 12)

No other area of corrosion was found either on the bulkhead surface or in the frame 1223 joint nor, superficially, was there any evidence of contaminating liquids or substances. On the fuselage frame immediately behind station 1223 were a series of "tide marks" suggesting that liquid had been trapped between the rear of the bulkhead and this frame to a depth of several inches on at least twelve occasions.

The region aft of the pressure bulkhead is drained by pipes leading to atmosphere; the drain located immediately aft of the bulkhead and adjacent to the "tide marks" on the frame previously described was blocked by dried mud similar in nature to the mud in the crater from which this piece of wreckage was retrieved. Its pre-impact condition could not therefore be determined. Forward of the bulkhead there was no positive evidence of free liquid. The frame drain hole in frame 1223 located at the lower centre line was found blocked with polysuphide sealant, which had been painted on the forward face. An area of surface corrosion of some 4 sq.cm. was found on the rear face of frame 1223, at 15 cm. from the blocked drain hole.(See figure n° 13)

1.12.6. Flying controls.

Examination of the flying control circuits in the fuselage aft of the rear freight bay provided no evidence of any in-flight defect or malfunction.

The elevator, rudder, and control lock systems in this region consist of push pull rods running aft along the lower centre line which are passed trough the rear pressure bulkhead by means of a seal box attached to the cabin floor frame immediately forward of the bulkhead.

The pressure seal box is attached to a tunnel through the bulkhead by means of a reinforced rubber sleeve clamped at each end. The control systems run into the box via lever assemblies from which push pull rods continue the systems rearwards. The lower left side of the rear pressure bulkhead carries a gland through which slide the steel cables operating the elevator and rudder trim systems.

During the examination of the flying control systems in the rear fuselage, the possible effects of displacement of the bulkhead in flight had to be taken into account because of the nature of the bulkhead failure previously described.

The rudder, elevator and control lock circuits together with the seal box, flexible joint and bulkhead aperture had all been separated and broken up on ground impact. The relevant parts were all recovered and identified with the exception of a portion of elevator rod aft of the seal, the clamp securing the forward end of the flexible joint to the seal box and portions of the control lock circuit immediately aft of the bulkhead. No evidence was found that any interference had occurred between the bulkhead and the control rods. Examination of the aft end of the rudder and elevator control circuits and the servo tab actuating mechanism revealed no evidence of overtravel. No evidence was found to suggest any displacement of the cables operating rudder and elevator trim circuits.

### 1.12.7. Tailplanes and elevators.

Both right and left tailplanes and elevators had become separated from the aircraft and broken up in a closely symmetrical manner; the tailplane structure on each side had separated from chordwise failures through station 89 at the rear to station 125 at the front. Each upper skin was completely separated in major sections torn chordwise through the region station 125/143. The front spars had broken at stations 125 and 197 allowing the two outer leading edge sections on each side to detach with part of the lower skin. Further separations of lower skin and centre spar structure had taken place.(See figure n° 14 )

Break up and detachment of the elevators had taken place with separation of hinge beams and chordwise failures in tension and bending through the structure indicating tip rearward movement consistent with the movement of the tailplanes.

The inner portion of right elevator together with its inner hinge beam at station 89 had remained attached to the main wreckage; this was because the rear spar on the right side had broken just outboard of station 89, whereas on the left side the rear spar had broken just inboard of station 89 thus allowing the inner left elevator to separate from the torque tube attachement. All hinge beams other than the inner right beam at station 89 bore evidence of an over rotation downwards of the elevator which had produced damage where the elevator hinge cut-outs had been in contact with the beams.

The left elevator travel stop had been broken by this over rotation in a manner consistent with the damage to the hinge beams; the right elevator travel stop, mounted on the portions of tailplane and elevator which remained attached to the main wreckage was undamaged showing that this portion of elevator had not been subjected to over rotation.

Hinge beams on both right and left tailplanes bore impressions of the profile of the leading edges of the elevators produced by lateral movement during the break up sequence. These marks indicate that both elevators were at that time in a near neutral position. (See figure n° 15 ).

The over rotation observed on all detached portions of elevators must have occurred subsequently to the separation of the tailplanes and elevators and could therefore have played no part in the initiation of the separation sequence.

Examination of the skin, rib, and spar structures of both tailplanes showed a mode of separation which could not be attribued to any externally applied loading. Both upper skins had been lifted and detached over the region stations 125-276 between rear and front spars by separation of the stringer/rib cleat rivets and the pulling through of the countersunk rivet heads attaching skins to spars and ribs. (See figure n° 16 ).

The separation of the top skin appears to have originated at the rear spar where rivets impressions in the skin provided evidence that relative movement of the skin occurred before any distortion of the spar took place. Similar evidence was found on the under surface of the top skin in the region of the centre spar.
Inboard of station 125, towards the tailplane roots, the upper skin sheets had been peeled and torn off the structure.

The lower skins, in general, had remained attached to the rib and spar structure but broken up by a pattern of tensile and tearing failures which on each side had originated at a point coincident with the separation of the front spar at station 197. A chordwise tensile separation ran back towards the centre spar before turning through 90 degrees and running spanwise outboard; further development of the split ran spanwise inboard on both sides to the tailplane roots. Bending failures in the front spars at stations 197 and 125 indicated tip rearward and downward movement. The overall sequence of separation of the tailplanes and elevators appears therefore to have originated with the detachment of the top skin as previously described; this was followed by the rearward and downward separation of the front spar sections outboard of stations 197 and 125 accompagnied by the breakup of the lower skin and rear spar leading to the detachment of the elevators in sections. The appearance of the upper skins from both tailplanes suggested strongly that internal pressure had been responsible for their separation and accordingly tests were carried out to determine behaviour of the tailplanes structure when internally pressurized. During examination of the tailplane it was noted that modification L 40, which increases the size of the inner rivet securing stringers to cleats from 0.125 to 0.15625 ins, had not been embodied. All these rivets were found to be 0.125 ins in diameter.

On the right tailplane front spar top flange at station 198 a small fatigue crack was found emanating from a rivet hole adjacent to a captive nut. This extended over about two cms and some fretting of the local mating surfaces was observed. It was concluded that this crack had been exposed by the failure of the spar at this point and that its presence had not played any significant part in the failure. The left tailplane front spar had failed at the same point with no fatigue crack present.

1.12.8. Powerplants.

No evidence was found of inflight failure of any of the engines and propellers.

The engines were determined to have been rotating under some degree of power at impact with the propeller blades set at angles within the normal operating range.

1.13. Fire.

The aircraft caught fire after impact with the ground.

The aviation kerosene fuel continued to burn until extinguished by the local fire brigade.

1.14. Survival aspects.

This was not a survivable accident.

1.15. Tests and research.

1.15.1. Pressurisation tets on vanguard tailplanes.

A series 952 Vanguard was suitably modified to test the effect of a simulated rear pressure bulkhead rupture on the tailplanes at a high cabin differential pressure.

A metal petal valve was fitted to the bulkhead with a cross sectional area of 685 sq in. A multi-channel ultra-violet trace recorder was connected to a number of pressure transducers located in the tailcone, fin, left and right tailplanes. Cabin ambient temperature was also recorded.

High speed (400 frames per second) cine films were taken of the right tailplane, upper and lower surfaces.

In addition, two low speed (16 frames per second) films were taken of the aft end of the aircraft.

The right hand tailplane was replaced with a pre-modification L 40 tailplane of approximately the same age and flying time of those fitted to G-APEC.

It had been deduced that the cabin differential pressure existing at the time of breaking had been about 5.75 lb/sq in (see par. 1.6.5.). In an attempt to approximate the loads that would be acting on the tailplanes in flight it was decided that a cabin differential pressure of 6.25 lb/sq in would be used in the tests. The elevators and rudder were not fitted to the test specimen but suitable blanks were used to ensure that realistic leak rates were maintained.

Calibration shows that the maximum pressures achieved in the tailcone were in close agreement with the calculated values, although the rates of change of pressure were higher than expected. Calculations showed that for all practical purposes the maximum tailcone pressures were directly proportional to the initial cabin differential pressure and virtually independent of altitude.

The definitive test involved increasing the cabin differential pressure to 6.25 lb/sq in before opening the petal valve to simulate a rear pressure bulkhead failure at an altitude of 19,000 feet. The rear tailcone reached a maximum of 5.5 lb/sq in after 0.12 seconds. Some 0.03 seconds later there was a sudden pressure fluctuation in the right outboard tailplane when the pressure there was 4.12 lb/sq in.

This test produced severe distortion of the right hand tailplane upper surface skins between tailplane stations 143 and 276. The worst damage was along the chord at the elevator hinge rib at station 213 where rivet heads had pulled through the skin. On the right hand side of the fin the skin was distorted between the centre and rear spars. Rivet heads had pulled through the skin at fin stations 117.8 and 154.1.

Internally, there were extensive failures of cleat to stringer rivets in the right tailplane.

A study of the film record in conjunction with the pressure traces showed that the disruption of the tailplane started in the region of station 234 spreading outboard and inboard.

1.15.2. Metallurgical examination.

A metallurgical investigation was carried out to ascertain the chemical and physical properties of the rear pressure bulkhead plating. The material specification is BS-L 72, thickness 22 swg (0.711 mm).

Specimens were taken from the lower centre sheet on which corrosion was found. The chemical analysis revealed that the metal composition was within the limits specified for the L-72 alloy. Tensile test specimens were cut along two perpendicular directions, radial and circumferential, corresponding approximately to the longitudinal and the long transverse directions of the sheet. All specimens showed homogeneity and properties in accordance with the specification.

A metallographic examination was made on several samples cut from the corroded area as well as from the sound metal. These showed that for the uncorroded specimens the metal structure and the cladding were in accordance with the specification.

Specimens taken out of the corroded area revealed extremely severe intergranular corrosion extending from the front face through the sheet. In that area, the front cladding had fragmented completely or disappeared. Multiple intergranular cracks were present. (Fig. 17). A fractographic examination was carried out using a scanning electron microscope on some samples cut along the initial tears. Neither in the heavily corroded area nor along the uncorroded tears, could characteristic fatigue propagation marks be found. However corrosion could mask fatigue marks. In the area where the tears come out of the corroded zone, some marks of mating or friction between the two edges of the tears are present.

From the metallurgical investigation, it is concluded that the metal was sound and conformed to the specification. No evidence could be found of any material defect which could have been a contributory factor in increasing the corrosion susceptibility of the sheet.

1.15.3. Inspection for corrosion of BEA Vanguard Fleet.

When evidence of gross corrosion came to light in the examination of the wreckage, BEA introduced a special inspection calling for visual examination and pressure testing of the 18 Vanguard aircraft in their fleet.

One aircraft failed to pass the pressure test but there was visual evidence of only slight corrosion along the edge of the peripheral doubler. A more searching examination of this corroded section including extensive dismantling of the bulkhead fuselage skin joint, revealed an area of gross corrosion in the heel of the plating which had resulted in a crack about 45 mm. long. A detailed metallurgical examination was made and it was concluded that the corrosion had occurred mainly at the redux joint interface between the rear of the doubler and the front face of the bulkhead plating. The crack had formed by intergranular and stress corrosion with some contribution by fatigue. The small amount of corrosion found on the rear face of the bulkhead was considered to have penetrated from the front face. A further special inspection was made using alternative techniques to check for evidence of disbonding and separation between the doubler and the bulkhead plating and for any corrosion on the front face of the bulkhead plating below floor level; eight aircraft were found to be affected.

One of these aircraft had, during a previous major inspection in February 1969, shown signs of some slight corrosion at the edge of the doubler. BEA had devised a repair scheme under their own design authority. The manufacturer was not informed of the problem at the time. Subsequent to the accident the same aircraft was found to show signs of further slight corrosion in the previously repaired area.

# 2. ANALYSIS AND CONCLUSIONS.

## 2.1. Analysis.

### 2.1.1. Flightpath.

From the evidence of the R/T recordings and the flight recorder readout it is clear that the flight had proceeded normally and without incident from take off at Heathrow up to the point where the flight recorder ceased to function. The aircraft had followed the expected flightpath and the pilots had responded promptly to ATC instructions en route.

The flight recorder stopped in level flight at cruising altitude. There is reasonable agreement between the last position plotted from the flight recorder data and the wind drift plot of the wreckage. There is no reason, therefore, to doubt that the flight recorder stopped because of the rupture of the rear pressure bulkhead and immediately before the separation of the tailplanes and elevators.

### 2.1.2. Structure.

Detailed study of the wreckage together with calculations and physical tests made subsequent to the accident conclusively show that the failure of the rear pressure bulkhead started the sequence of structural failures leading to the accident. The rapid inflation of the tailcone and empennages imposed a high differential pressure across the tailplanes skins causing the upper panels to become detached from the main structure. The existing flight loads then caused a rapid break-up and separation of both tailplanes and elevators. The loss of the aerodynamic download normally provided by the horizontal tail surfaces in cruising flight caused the aircraft to pitch rapidly nose down with no possibility of recovery from the ensuing dive.

The criteria upon which the design of the tailplanes was based did not take into account the possibility that a substantial differential pressure could exist in the tail structure other than that caused by aerodynamic loads. Nor in the light of experience and knowledge available prior to this accident would it have been reasonable to envisage that internal pressures could exist in the tail structure.

The modification L 40, which increased certain rivet sizes in the tailplanes was not mandatory and it is not possible to state conclusively whether or not the increased pressure in the empennages would have been contained if this modification had been incorporated in G-APEC. However, it may be significant that following the tests carried out in the course of the investigation, it was found that the left tailplane of the specimen, which was modified to the later standard, showed no signs of distress or incipient failure. Considerations should be given by the Airworthiness Authorities concerned as to whether tailplanes which do not incorporate modification L 40 should be kept in service.

2.1.3. Pressurisation.

An examination of the pressurisation histories of G-APEC and subsequent calculations made show that the volume of air passing through the pre-existing crack in the rear pressure bulkhead was not large enough to prevent the cabin pressurisation control system from maintaining the desired cabin differential pressure.

2.1.4. Corrosion.

The severe corrosion present at the joint between the fuselage skin and the rear pressure bulkhead had been present unseen for an unknown period of time before the accident. From the conditions of other aircraft of the BEA fleet, it seems likely that the extent and severity of the corrosion found in G-APEC required a relatively long period to develop. This is also supported by the evidence of the nicotine tar staining on G-APEC. It is not possible to quantify this period by examination of the material. The forward face of the bulkhead below floor level is covered by sound proofing which is normally only removed during major checks (at present intervals of 4,500 hours).

A visual inspection of the rear face of the bulkhead is carried out at maximum intervals of 400 hours.

It is doubtful whether the corrosion present in G-APEC could have been seen from the rear because it was concealed within the joint and the convergence of the bulkhead and fuselage structure restricted access. However when the crack progressed into uncorroded material it would have become visible from the rear.

The period of time during which the crack would have been visible before the bulkhead ruptured is unknown but the nature of the progressive tear marks on the fracture surfaces suggests that these correspond to at least fourteen successive pressurisation cycles and that this period was therefore comparatively short.

The corrosion found at the stringer 46 position on station 1223 was close to the rear toilet and therefore in an area where spillage was possible. However there was no positive evidence in the wreckage of either area of corrosion having been associated with toilet liquid spillage.

Although the corrosion around the radial bracing member bracket did not contribute to the accident, there is no doubt that in time it would have significantly affected the structural integrity of the aircraft.

2.1.5. Inspection.

The approved maintenance schedule called for visual inspection of the bulkhead at relatively long intervals. This approach assumed that the bonding paint and sealing schemes remained intact and effective. In fact, delamination accompanied by corrosion can occur between the redux bonded doubler and the front face of the pressure bulkhead. The corrosion attack may be severe before any visual indication is apparent at the edge of the bonded doubler.

The maintenance records show that a radiographic examination of the lower portion of the rear pressure bulkhead lap joint was made prior to the accident. However the radiographic technique used to examine this particular area of the Vanguard aircraft has been demonstrated to be ineffective as a sure means of detecting corrosion. This is because of the difficulty of interpreting the photographic plate details resulting from the complex structure.

With the inspection techniques then in use, the corrosion in G-APEC was not detectable.

The extent of the problem with the bonded joint at station 1223 was not appreciated. As a result no effective technique was devised for inspecting this area. Since the accident, improved inspection techniques together with a modification to the aircraft to improve inspection access have been introduced with the objective of detecting corrosion before the structural integrity of the rear pressure bulkhead is affected.

It is noted that during the life of the Vanguard the periods between check I and major check cycles, in which the majority of inspections for corrosion takesplace, have increased considerably. It must be accepted that where hidden areas exist corrosion is more likely to develop with increased age. it is therefore essential that the techniques employed to inspect such areas effectively detect any corrosion at ist onset.

Evidence from the wreckage and maintenance records shows that appreciable amounts of liquids had been retained at various times in the structure aft of the rear pressure bulkhead. The BEA practice of employing personnel to clean an area before inspection means that the inspector involved will not be aware of the extent of any possible fluid contamination. In the case of toilet spillage in particular it is highly desirable that the inspector should be alerted to the fact.

2.1.6. Tests.

The tests carried out subsequent to the accident substantiated the theoretical appraisal of the mechanics of the tailplanesfailure.

The pattern of failure observed during the tests was similar to that found in the wreckage of G-APEC.

2.1.7. Design Authority.

Under their design authority approval BEA were entirely competent to devise the repair scheme when the first instance of doubler/bulkhead separation and corrosion was discovered. However it is considered highly desirable that airline operators should keep aircraft manufacturers informed when significant defects are discovered in service in order that other operators of similar aircraft can be informed of the problems.

## 2.2. Conclusions.

### 2.2.1. Findings.

(i) The crew was properly licensed and qualified to carry out the flight.

(ii) The documentation of the aircraft was in order.

(iii) The aircraft had been maintained in accordance with an Approval Maintenance Schedule.

(iv) Areas of the rear pressure bulkhead had been affected by by severe corrosion for a unknown period of time prior to the accident.

(v) The inspection techniques used for detecting corrosion in the area of station 1223 were inadequate.

(vi) The rear pressure bulkhead ruptured in cruising flight at FL 190 when the corrosion initiated crack exceeded the critical crack length.

(vii) The tailcone and empennage were exposed to a rapid rise in internal pressure which they were not designed to withstand.

(viii) Structural damage to the upper tailplane skin attachments significantly reduced the strength of both tailplanes allowing existing aerodynamic loads to cause both components to become detached in flight.

(ix) The reduction in the aerodynamic down loads on the horizontal tailplanes caused the aircraft to enter a steep dive from which it was not possible to recover.

### 2.2.2. Cause.

The accident was caused by the rupture of the rear pressure bulkhead, which led to the separation both tailplanes in flight and caused the aircraft to dive into the ground.

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