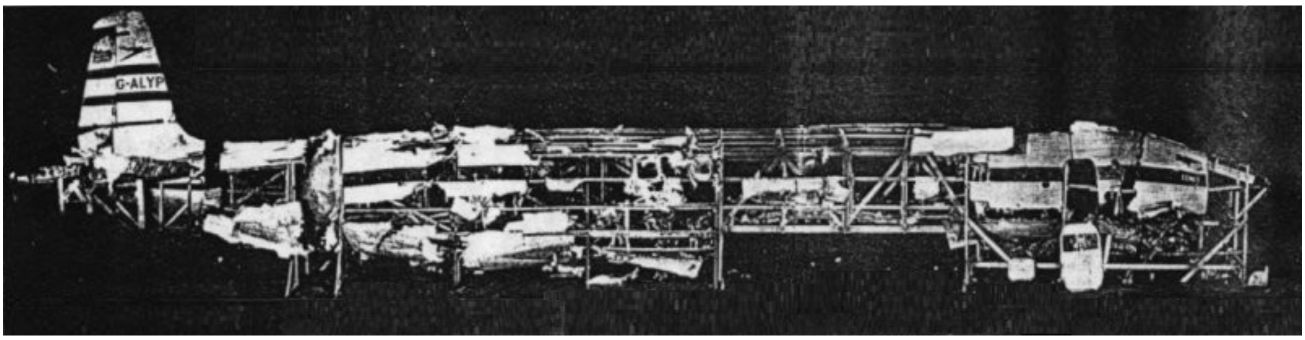
16 January, 2018
The Real Story of the Comet
Dr. Paul Withey

The presenter was a metallurgist with academic and industrial backgrounds. He promised a broad lecture and presented the topic in depth by combining historical, technical and forensic elements. His overall aim was to stress the lessons learned in the aftermath of the usually coined 'Comet Disasters'.

The DH106 Comet contrasted with post-war piston-engine airliners of the early 50s. First flown on 27 July 1949, the aircraft entered service on 2 May 1952. On account of its four 4,450lb thrust DH Goblin engines, it was designed to cruise faster and fly higher than any previous airliner, attaining 490mph at 35,000ft, and offering 1,750st.m. range. Maximum take-off weight was 107,000lb and seating capacity was 44. BOAC, the aircraft's first user, reduced seating to 36 passengers in order to improve comfort and cabin service facilities.

The aircraft was fully pressurised, and compared to contemporary piston-engine airliners (which flew slower and lower) had an 8.25psi pressure differential cabin to assure 8,000ft equivalent cabin altitude in the cruise. The fuselage design had a circular cross-section and was constructed of aluminium-alloy - specification DTD 596 that was 22swg (0.71mm thick) and had 20swg (0.91mm) thick reinforcements near pressure-shell cut-outs. This material was well understood to be fatigue critical, and designed to criteria that as presented were reassuringly justifiable, e.g.: the peak expected stress loads of 190MPa was well below the material's ultimate tensile stress (UTS) value of 450MPa.

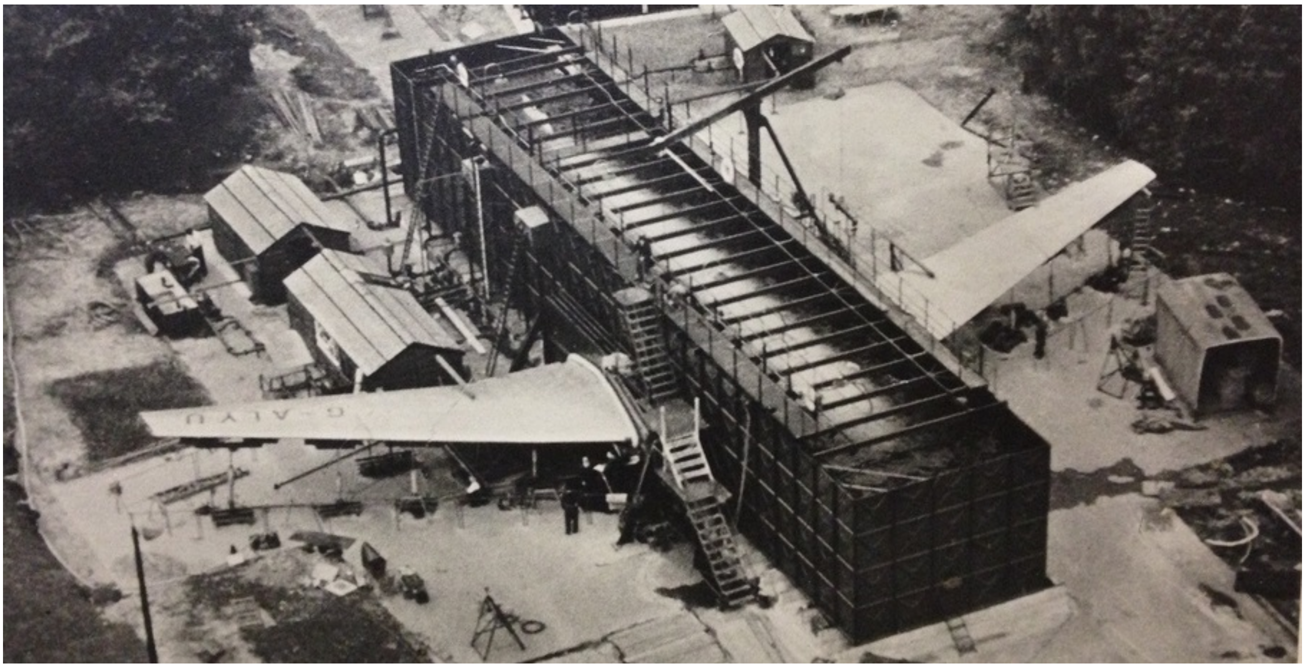
It was stressed that fatigue was a well-understood issue, and the speaker explained how seriously de Havilland addressed the topic. Established certification requirements stipulated a lower margin between 'proof' (maximum likely) and 'ultimate' (maximum acceptable) stress levels than those adopted by de Havilland: so in all respects the airframe was designed to exceed as much as comply with statutory safety requirements. The company was required to produce stress test results based on a 15,000 cycle trial to show that the major airframe components complied with the statutory certification requirements. They constructed an airframe fatigue test-rig, and by July 1953 the rig had simulated 16,000 flight cycles without any significant failures. Given the test programme was well ahead of any aircraft in service, and fatigue performance was being addressed so seriously, the results provided confidence in the company and its design.



Comet G-ALYP wreckage reconstructed for investigation

On entry to service on 2 May 1952, BOAC aircraft G-ALYP departed London (Heathrow) for Rome (Ciampino) - the world's first scheduled jet airliner operation. The flight was the first stage of a series that would reach Johannesburg in South Africa in considerably less time than slower predecessors which had to make over-night stops. The airline also opened services to Singapore, and from there to Tokyo in the months that followed. And de Havilland were delivering aircraft to BOAC and other airlines, including Air France and Canadian Pacific, but it was not long before accidents began to mar the aircraft's standing:

- **26 Oct 1952:** BOAC G-ALYZ crashed after rotation on take-off at Rome – two passengers were injured and the aircraft was written off. The cause of the accident was attributed to inappropriate crew action (due to inadequate understanding of limitations).
- **3 Mar 1953** : Canadian Pacific CF-CUN crashed identically at Karachi – this happened at night and resulted in the loss of all 11 people on-board. It had been a delivery flight and the speaker suggested that although the cause was the same as at Rome, the crew were tired, and investigation suggested that they should have known not to press on.
- **2 May 1953** : BOAC G-ALYV crashed soon after departing Calcutta with the loss of all 43 people on board. This occurred in storm conditions and investigation revealed a tail surface spar failure caused by control inputs: configuration changes were applied to all aircraft in service and production.
- **10 Jan 1954**: BOAC G-ALYP broke up in mid-air 20 minutes after departing Ciampino and crashed into the Mediterranean near Elba, with the loss of all 35 on board. There were no witnesses and only partial radio transmissions, so no obvious reason for the crash could be deduced, but fatigue could be inferred. BOAC grounded its Comet fleet pending the accident investigation, but were able to resume services on 20 March.
- **8 Apr 1954** : BOAC G-ALYY also broke up in mid-air after departing Ciampino this time flying south and it crashed into the sea near Naples. All 21 people on board were lost and by now fatigue failure was widely expected to prove to the cause of both accidents.

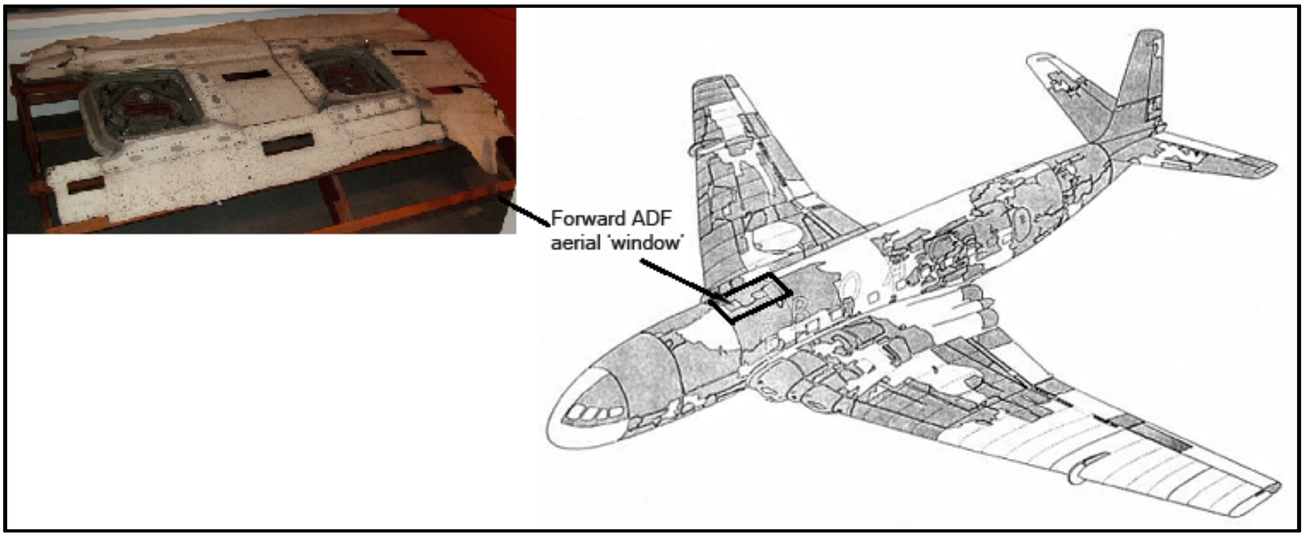


G-ALYU in the fatigue test-rig at RAE Farnborough

The aircraft certificate of airworthiness was withdrawn on 12 April 1954 and production of the aircraft at Hatfield was suspended. The circumstances of the two accidents in the Mediterranean were very similar, and a large proportion of the wreckage of ‘YP was being recovered. Similarly, the wreckage of ‘YY too, and a public inquiry was announced. Associated to this RAE Farnborough were donated a Comet 1 airframe from the BOAC Fleet, G-ALYU, which had accumulated 3,057 cycles. The fuselage was enclosed in a 281,000 gallon water tank and the wings were subjected to bending forces by actuators that modelled flight loadings in synchronisation with water pressure loading of the fuselage. In these controlled conditions cycles are accumulated faster than in the air, and it was after 1,826 test cycles in the rig (by then 4,883 airframe cycles total) that the fuselage suffered a catastrophic structural failure. This was considerably earlier than had been expected, but it was similar – but lower - to the cycle time of the two BOAC aircraft already lost in service.

There were signs from the wreckage coming in from the crash scenes that were indicating a probable metal fatigue failure in the fuselage. There was a portion of carpet from the passenger cabin that had been ejected and entangled in a wing spar, and on one wing there was an imprint of the BOAC blue cheat-line showing that the fuselage had ruptured and a skin section impacted the wing’s upper surface with considerable force. The speaker showed a simple sketch showing how the centre fuselage had split, roughly, along the crown and, without the rigidity of the centre-section, the nose and tail sections fell away from the rest of the aircraft. The wings folder upwards and fuselage skins impacted the wing upper surfaces. This happened quicker than it can be expressed in a write-up; it was a very sudden and unpleasant event.

The test specimen confirmed that the square apertures in the pressurised shell, which did not have rounded corners, were where the catastrophic failures were occurring. The initial crack propagated slowly, but after reaching a critical crack length it extended rapidly along the local stress orientation. The re-assembled wreckage of ‘YP showed that a crack started adjacent to the ADF (radio) aerial in the crown of the centre-section window, whereas the test specimen started by a fuselage window.



The ADF antenna installation and location – starting point of the ‘YP failure

The speaker’s knowledge of metallurgy enabled him to understand the evidence he had described. He showed the well-known (in aviation circles) photographs of how cracks had propagated, and pointed out how small cracks visible during production had been competently dealt with by drilled ‘stoppers.’ Photographs showed how a crack started to spiral out, and as it aligned to the direction of greatest stress it propagated linearly until, on reaching the critical crack length, the panel would rupture. The cracks that caused the known failures were revealed to have been so small that they were under the chamfer of flush rivets and would have been unseen in visual inspections. He reconciled the evidence shown with theoretical work that was established in the early 60s (the "Paris-Ergodan Law") to illustrate what was learned overall from the accidents. I believe his own words, from a published seminar paper, serve much better than my scribblings from the presentation to describe the analysis[1]

"The fatigue crack was associated with the stress concentrations of the rather square rear ADF window cutout (stress of 315 MPa at edge of window), and with a bolt hole around the window (although the stress at the bolt position was only 70 MPa).

"The Chief Designer at De Havilland had wanted to glue the windows in position, but the tooling for the square shape was too difficult to make. A lower stress concentration shape would have been easier to manufacture.

"The manufacturer had performed fatigue tests of the forward cabin area at about 10 psi (with cracking occurring at 18,000 cycles), but these were carried out after static tests of to up to 16.5 psi (twice operating pressure) had previously been applied. Cracks were also known to be present after manufacture, and the remedy was to drill 1.6 mm holes at the crack tip to 'arrest' them (such an arrested crack was present near the rear ADF window, which had not propagated until the final failure).

"Modifications were made to the design of the aircraft and the Comet 4 re-entered service in October 1958 on the trans-Atlantic route with 80 passengers."

The seminar notes also provide a succinct summary:

Technological Outcomes:

- Full-scale testing of aircraft structures utilised in future aircraft.
- Better understanding of fatigue testing achieved, i.e. match service and test loads (no previous over-pressurisation cycles first).
- Attention drawn to detectability/critical size issues for fatigue cracks in aircraft structures.
- Concept of 'one-bay' crack tolerance in fuselage probably formulated.

Causes:

1. New technology introducing new load cases (high altitude flight for turbojet engines requiring cabin pressurisation).
2. Mis-match between service loads and fatigue test procedure.
3. Possible contribution from out-of-plane bending loads (bi-axial stresses).

Design Failures:

- Improperly understood failure mode assessment procedures necessitated by implementation of new technology.
- Poor configuration due to wing root engine placement (very few other aircraft have had engines in this position), affecting uprating potential, fire hazard, and structural integrity in the event of engine disintegration.

He made one announcement that tells every budding engineer what is often seemingly so good: but being 'good' too often can have a 'bad' inference. The testing by de Havilland on the airframe used at Farnborough (it had completed 1,121 cycles in service with and been used for 10 pressurisation tests at Hatfield before reaching BOAC) had applied more that the necessary test pressure in the pre-delivery tests and with hindsight was believed to have weakened the fuselage. This would explain why the RAE trial achieving so few cycles (1,826 on rig – 4,883 total) before it failed in test-

[1] https://www.fose1.plymouth.ac.uk/fatiguefracture/tutorials/FailureCases/sf2.html

ing. There is no doubt that what was done was done in good faith, but the outcome was a salutary and very punishing lesson.

The Comet was redesigned with rounded windows, a longer fuselage and a larger wing that accommodated four Rolls-Royce Avon engines. The Comet 4A became the first trans-Atlantic jet airliner in 1958. It was followed by variants: the 4B (medium range) and 4C (longer range). By then larger and more economical aircraft such as the Boeing 707 and Douglas DC-8 were available, and production was curtailed. A total of 114 examples were delivered to 17 countries in addition to the UK. A further 51 airframes were supplied to the Royal Air Force. The 'Nimrod' had a modified wing to accommodation Rolls-Royce Spey engines, and a bulky under-belly 'weapons pannier' which demanded a modified tail with greater area. It served as Britain's maritime-reconnaissance aircraft until withdrawn in 2011.

The first DH106 Comet 4 (up to 81 passenger capacity) reached BOAC in September 1958

The presentation was packed with information, conveyed a complex tale in a seamless manner, and whilst it addressed a topic that has been well publicised elsewhere (and many of those attending might have thought they understood well already), was presented in a style that met the needs of all manner of attendees. The vote of thanks from Tony Irwin, who flew the Comet 4 when he was on the BOAC aircrew rosters, expressed strong personal thanks for the insight provided by the speaker, and the 160 or so audience had no hesitation in adding their own round of applause.

Lecture notes by Mike Hirst