Rolls-Royce Plc

Lessons in Airframe Design from the deHavilland Comet

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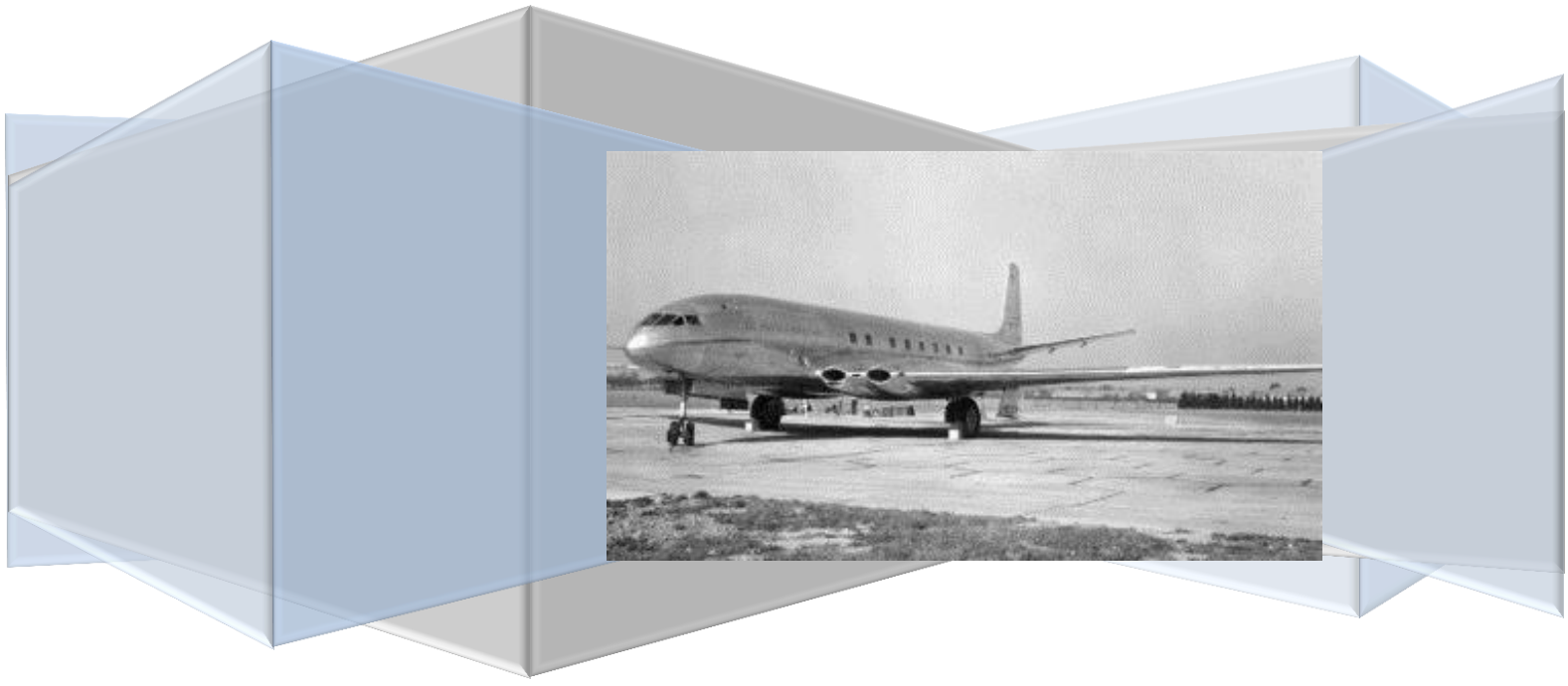


Introduction

The deHavilland Comet was famous for a number of reasons – it was designed to be a roaring revolution in air travel, but ultimately became known because of its catastrophic failures and some of the lessons that it taught the aviation world. In this report we will look closely at the rise and fall of the revolutionary Comet, the fatal accidents which ultimately led to its commercial failure and the legacy it left behind. Some of its design mistakes are well known, for instance the shape of its windows, however there was a much bigger impact on both engineering design and the investigation of aviation accidents. This report will uncover those vital lessons, and also highlight the short but varied lifespan of the Comet and its variants.

Contents

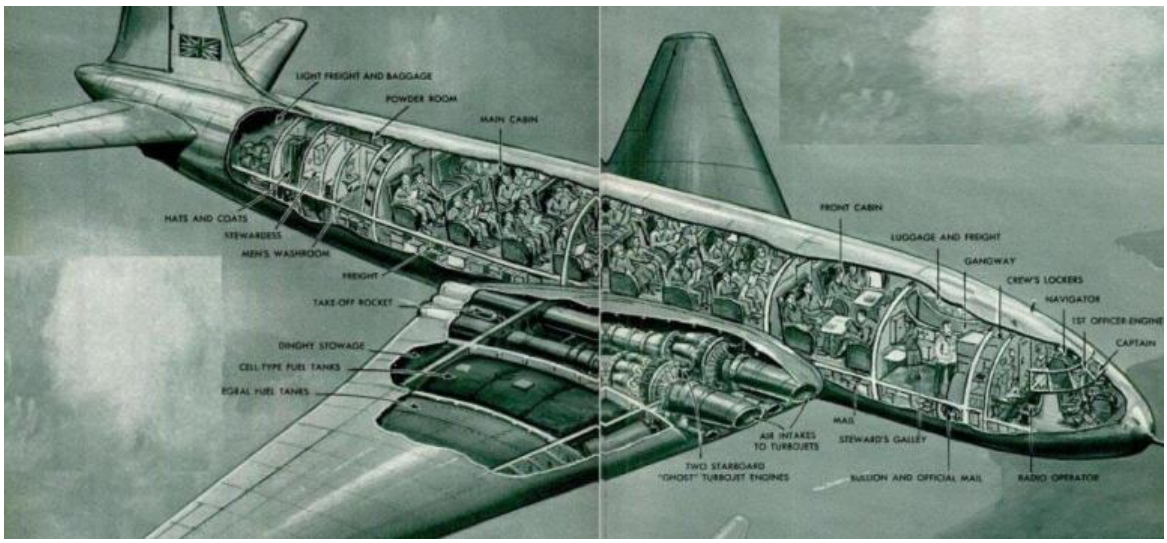
1. The revolution of the Comet

The deHavilland Comet was the first commercial aircraft to feature modern turbojet engines – previous aircraft had featured propellers or piston engines as their means of power. This alternate means of power meant that it could fly higher and further than its competitors, its main advantage being that a plane equipped with turbojets could fly above weather systems, reducing turbulence and noise. This massive step-up in technology came about at a time when air travel was becoming accessible to the general public rather than exclusive to wealthy travellers; and many commercial planes were not purpose-built but converted from freight and military planes used in Wold War 2. These planes were low flying, noisy and unpressurised, and so the sleek and shiny Comet was incredibly modern and attractive by comparison.

The Comet was introduced on May 2nd 1952 having undergone its first test flight in July 1949. (Aerospace Engineering, 2012) It had a range of new features which were necessary for the new type of flight it provided, these included:

- Pressurised Cabin
- Backwards swept wings
- Integral fuel tanks in the wings
- 4 wheel bogie landing gear

  Below is an advertisement from the period showing the internal structure of the aircraft: the main cabin seated about 40 passengers and was split into 2 main areas; First class (at the front) and standard class (main cabin). As was standard at the time, luggage was carried in the cabin also, and the hold used only for mail or cargo. The Comet featured large square windows to offer views that the majority of the public had never seen before from the aircraft as it ascended to cruise height (Hollingham, 2017). The jet engines were built into the wings, originally intended to be Halford H2 Ghosts, were replaced by DeHavilland Ghosts before the Comet entered service. This more streamlined design contributed to the 'futuristic' aesthetic, along with the chrome skin which covered the whole aircraft.



Images: (IggyDang, 2018)

As a piece of British engineering, they were mostly popular with British based airlines including British Overseas Airways Corporation (BOAC, which would later go on to become British Airways along with a few smaller subsidiaries), Dan-Air, British European Airways and also the RAF. However there were orders placed from airlines around the world, including Air India, Japan Airlines, and American carriers such as Pan Am Pacific (Anon., n.d.).

There was an extensive advertising campaign prior to the launch of the Comet, they were considered the ultimate way to travel and were the flagship of the BOAC fleet.

2. Failure and investigation

After launching to the public in May 1952, the first write-off or 'hull loss' incident occurred less than six months later when a BOAC flight leaving Rome failed to become airborne during take-off and ran off the end of the runway. There were no injuries but the plane, which was just a month into service, was damaged beyond repair.

All pre-flight checks showed the equipment to be normal and functioning, however during take-off, the engines did not create enough thrust. This caused the plane to buffet and almost stall, before bouncing on its landing gear as the pilot attempted to lift off. The pilot abandoned the take-off manoeuvre and let off the engine throttles, but it was too late to avoid a crash into a mound of earth at the end of the runway, and slid almost 300 yards across the ground, causing extensive damage to the underside of the aircraft and spilling fuel. The crash was blamed on pilot error – it is believed he did not adequately allow for the 'nose up' positioning of the plane as it approached the end of the runway. However, this incident was not good for the reputation of the Comet and would be the first of several high profile crashes. (Aviation Safety Network, 2018)


BBC

DAILY EXPRESS

TUESDAY MARCH 3 1953 — LORD BEAVERBROOK

REFUGEES — FOG: — QUEEN MARY — APPEAL

COMET CRASHES: 11 DIE

Disaster at take-off

FIRST FATAL MISHAP TO WORLD'S No. 1 PLANE

AIR EXPERTS KILLED ON EMPIRE FLIGHT

KARACHI, Tuesday.

A COMET jet airliner crashed at Karachi Airport early today—killing six British technicians and the Canadian crew of five. There were no survivors.

The crash came at the end of the runway during take-off, and the plane was totally burned.

This is the first fatal crash of a Comet, Britain's world-leading jet passenger plane.

LEE MENG APPEAL VERDICT HELD BACK

THE SILENT GUNMAN

POCKET CARTOON

QUEEN MARY KEPT IN BED

The Comet's first fatal accident happened on March 3rd 1953 – still within the first year of the Comet's service. The 2 month old

aircraft involved was being operated by Canadian Pacific Airlines on a delivery flight from Karachi in Pakistan to Sydney, Australia – there were no passengers on board, only crew with limited experience of operating the new turbo jet systems, and the take-off would be their first at night. Once again the plane failed to produce enough thrust to lift the main wheels off the runway, as the pilot attempted to take off with the nose too high. Despite a late attempt to correct this, the plane could not gain enough speed and crashed off the end of the runway into a dry drainage canal at more than 138mph, colliding with a 40 foot embankment and killing all 11 people on board. (Aviation Safety Network, 2018)

In response to this incident, Canadian pacific Airlines cancelled their remaining order of 1 further Comet and refused to use the model in commercial service.

In the space of 12 months between May 1953 and April 1954 there would be three further fatal crashes. However, these would come under specific scrutiny due to the nature in which the aircraft were lost: each aircraft was lost in mid-air shortly after take-off, with no survivors and each plane almost totally reduced to debris. (Hollingham, 2017)

The first of the 3 incidents was on 2nd may 1953. This incident seemed relatively straight forward; a Comet on a flight leaving Calcutta Airport in India took off successfully but encountered severe weather as it climbed to cruising altitude, damaging the plane and causing structural problems. The plane was not destroyed initially but the pilots could not get it back under control and it crashed and killed all passengers and crew on board. (Anon., 1953)

The second incident was scheduled on BOAC Flight 781 from Rome to London Heathrow. It was lost under unexplained circumstances on January 10th 1954, 20 minutes after take-off. The flight had been ascending to cruising altitude and lost communication part way through a message and did not sent out any distress signals, the aircraft fell into the sea. (Aviation Safety Network, 2018)

After this accident BOAC voluntarily grounds its fleet, which contains the majority of Comets in service. DeHavilland engineers inspected each of the planes and come up with a list of 60 modifications which would address any possible design flaw they identified. (AeroAssurance, 2017)

An investigation by the Abell Committee Court of Inquiry was launched after this incident. There were several lines of inquiry, including sabotage which the media speculated heavily about, as well as structural failure due to high load, failure of flight controls, fire or engine problems, as well as others. The Navy conducted recovery of the crashed aircraft, searching until September 1954, where they recovered 70% of the main structure, as well as 80% of the power systems and about half of the control systems and equipment. The Abell Committee reported that they had found no serious fault with the aircraft and concluded that fire was probably the cause of the accident. A number of changes were made to the wings and engines to protect them from a similar disaster. (Contributor, n.d.)

Finally, On April 8, 1954, South African Airways Flight 201 from Rome, broke apart within 30 minutes of take-off showing the same characteristics as the previous crash. It had been checked and modified as a result of the previous incidents, as well as undergoing extra testing and declared safe but still failed during flight, killing all passengers and crew. The entire Comet fleet was immediately grounded and an investigation board set up by the Royal Aircraft Establishment at Farnborough. The

Comet 1's Certificate of Airworthiness was revoked, meaning it was not legally allowed to fly, and the production line at the deHavilland manufacturing facility in Hatfield was suspended (Swopes, 2018).

What followed would be the most extensive and intense aircraft accident investigation in the history of aviation at the time. Experts at the establishment used a wide range of new investigation techniques, setting a benchmark which is still used in modern inquiries.

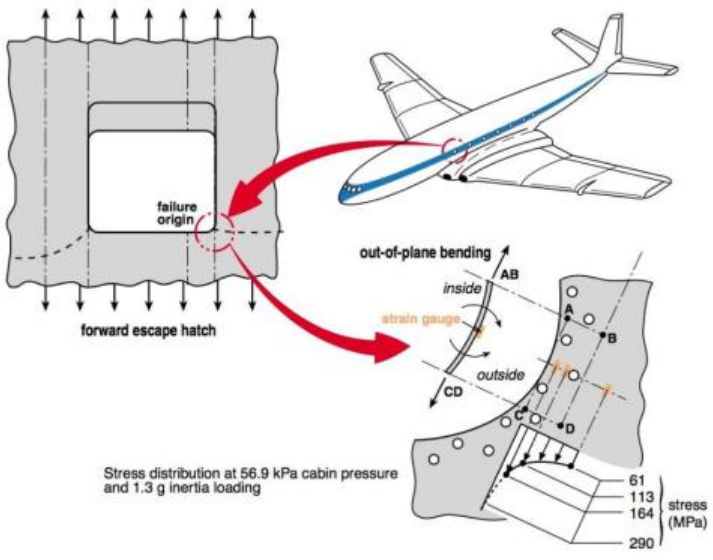
One of the key testing methods involving building a large pool in a hanger and filling it with water. (AeroAssurance, 2017)

BOAC donated a number of air frames to the investigation for testing and one of these aircraft was submerged and subjected to cycles of de-pressurisation and re-pressurization in the pool. This method allowed investigators to detect pressure escaping from the sealed airliner and find the weak spots without the aircraft breaking apart as it had done in the air during previous accidents.

The aircraft which underwent this procedure had accumulated 1221 internal pressurisation cycles in service and after a further 1836 test cycles, when the cabin ripped open, simulating what would be explosive decompression at altitude, as the air from inside the aircraft (held at high pressure to allow passengers to breathe) forced its way outside into the atmosphere where the air was under less pressure. (Image: (IggyDang, 2018)

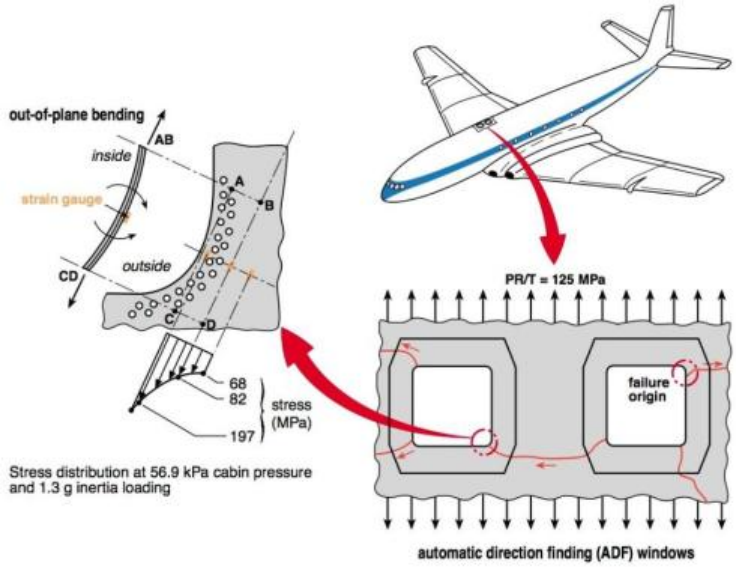
Fatigue cracking was found that originated from the rear lower corner of the forward escape hatch, and also from the right-hand aft corner of windows. In tests on another Comet aircraft, investigators had found that up to 70% of the aircraft's ultimate stress under pressure was concentrated on the corners of the aircraft's square windows. (Withey, 1997)

Both the escape hatch and windows were square, so they feature sharp right hand corners which cause local areas of high stress-concentration - these provide perfect conditions for cracking to happen and worsen under fatigue loading. This fatigue loading would have happened as the aircraft reached cruise altitude, as the pressure inside the aircraft rose and the pressure outside dropped.



Aircraft fuselages, like any cylindrical shape, develop internal membrane stresses to resist the internal pressure loads. These forces induce secondary out-of-plane bending moments trying to "straighten-out" the curve.

The stress concentration around the escape hatch and window cut outs was exacerbated by countersunk bolt holes creating a "knife-edge" in both skins.



- It has been has argued that the shell structure would have had enough residual strength to sustain large cracks *if* they had grown **midway** between two window cutouts. However, cracks grew across a bay from one cutout to the next, resulting in the aircraft skin failing, and explosive decompression. This could have been the final in a series of failures which led to the downing of the Comets.

Ultimately, the planes came down because they depressurised so fast that they broke apart, thanks to weak spots in the sharp corners of the windows and the escape hatch (Images and content: (Aerospace Engineering, 2012))

3. Later development and successes

DeHavilland decided to redesign the Comet and have it recertified and entered back into service. However, it took four years for this to take place. In the meantime, Boeing had released its 707 passenger jet, which could carry almost twice as many passengers, at similar speed and comfort. Sales of the Comet would never fully recover, a total of 114 were built against 865 707s. (Glancey, 2014)

However this did not prevent the Comet from having a wide range of variants and uses. (Contributor, n.d.)

- **Comet 1A** - Higher-allowed take-off weight, greater fuel capacity, and water-methanol injection; 10 were produced. All failed accident testing and were scrapped.
- **Comet 1X** – Two Royal Canadian Air Force Comet 1As rebuilt with heavier-gauge skins to match Comet 2 standard for the fuselage
- **Comet 1XB**: Four Comet 1As were upgraded with a reinforced fuselage structure and oval windows. Both 1X series were limited in number of pressurisation cycles.
- The **DH 111 Comet Bomber**, a nuclear bomb carrying variant developed to Air Ministry specification, and submitted May 1948. It had been originally proposed in 1948 as a photo reconnaissance craft for use during the Cold War. It featured different Ghost engines, narrowed fuselage, radar, and range of 3,350 miles (5,390 km). It was abandoned due to weapons storage issues and the incoming V-bomber having the same capabilities.
- **Comet 2 -** Larger, higher fuel capacity, more powerful Rolls-Royce Avon engines, to make the aircraft more suitable for transatlantic operations. Built with heavier gauge skin and rounded windows, and the Avon engines featuring larger air intakes and outward-curving jet tailpipes. The first production aircraft flew on 27 August 1953. The 2 performed well on test flights, but range was still not suitable for North Atlantic operating airlines. All but four Comet 2s were allocated to the RAF for a range of roles, including VIP transport, carrying medical equipment including iron lungs, specialised signals intelligence and electronic surveillance.
- **Comet 2X**: A single Comet Mk 1 powered by four Rolls-Royce Avon 502 turbojet engines, used as a development aircraft for the Comet 2.
- **Comet 2E**: Two Comet 2s fitted with Avon 504s in the inner nacelles and Avon 524s in the outer ones, used by BOAC for proving flights during 1957–1958.
- **Comet T2 & C2:** Fitted out as crew trainers for the RAF
- **Comet 2R**: Three Comet 2s modified for use in radar and electronic systems development, the 2R series was equipped to monitor Cold War signal traffic
- The **Comet 3:** Flew for the first time on 19 July 1954, based off the Comet 2 but 15 ft 5in longer and powered by Rolls-

Royce Avon M502 engines, with extra fuel tanks added. Never saw commercial service as it did not have a strengthened fuselage required by the accident investigation and couldn't be fully pressurised. Several launched in build, but only 1 was ever completed and went on to have possibly the most varied life of any commercial aircraft; Originally used for promotion and demonstration purposes including at least 1 visit to the Paris Air show and a round the world tour. The demonstrator later became a flying testbed, particularly for landing equipment, before eventually being retired and becoming the mock-up for the Hawker-Siddeley Nimrod after deHavilland was bought out.

- **Comet 4:** Further fuel and capacity improvements, 18 ft 6 in (5.64 m) larger than Comet 1 and seating 74 to 81 passengers. Considered the definitive series, with a longer range, higher cruising speed and higher maximum take-off weight. Its Avon engines had twice the thrust of the original Ghosts. Deliveries to BOAC began on 30 September 1958.

- **Comet 4B**: Developed for Capital Airlines, featured greater capacity through a 2m longer fuselage, and a shorter wingspan; 18 were produced.
- **Comet 4C**: A combination of Comet 4's wings and the 4B's longer fuselage; 23 were produced. 2 were used to build prototypes of the Nimrod anti-submarine military plane.
- A Comet 4C (SA-R-7) was ordered by Saudi Arabian Airlines for the exclusive use of King Saud bin Abdul Aziz. Extensively modified, the aircraft included a VIP front cabin, a bed, special toilets with gold fittings and had a green, gold and white colour scheme with polished wings and lower fuselage that was commissioned from aviation artist John Stroud. This went on to be described as "the world's first executive jet".
- **Comet 5 Proposal:** Featured wider fuselage with five-abreast seating, a wing with greater sweep and podded Rolls-Royce Conway engines. Without support from the Ministry of Transport, the proposal was never realised.

Legacy

The Comet left a large spanning legacy covering a range of areas in aviation.

Windows are no longer designed square, instead they have smooth curving edges to prevent the build-up of stress in any one given point.

Airframes now have specially designed crack stoppers between the windows to prevent any cracks from spreading along the length of the aircraft, from weak spot to weak spot. These placed between each window frame-cutout to prevent the crack from growing from one window to the next.

One of the most important lessons from this series of incidents is a change in design philosophy. Most people have heard of making something 'Fail safe' – in that, if something goes wrong or becomes damaged, the object in question can continue to function safely up to a critical level of damage. Before the Comet investigation, products were designed using the 'safe-life' theory – they were designed to be used without any prior damage and only then expected to sustain the required fatigue lifespan. Fail-safe replaced 'safe-life' as a design standard in the aftermath of the comet disasters and is still used across the board in modern design engineering.

During in-service inspections, engineers are now required to carry out a series of calculations on any cracks or damage they come across which can predict their strength and guarantee whether it will deteriorate to a critical level before the next inspection. The aircraft can be kept in service longer with light damage or sent for immediate repair when necessary based off this data.

Structures are now designed to be tolerant of damage with multiple 'belt and braces' type measures including load paths, creating residual strength so that it can sustain damage in service without total failure. These in-built redundancies makes them damage tolerant so they can continue to operate safely in the event damage is sustained during flight.

Air Crash Investigation Practices first established in the wake of the Comet disasters, such as large scale recreation of the conditions under which the aircraft crashed, are still in practice today, 70 years on.

As well as these ground breaking changes to design and safety attitudes, the Comet made waves in the world of aviation and international travel before the accidents. The Comet was the first Turbo Jet powered aircraft and as a result introduced the concept of affordable travel and the significant improvement in travelling conditions to the public for the first time.

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