

= De Havilland Comet =

The de Havilland DH 106 Comet was the world's first production commercial jetliner. Developed and manufactured by de Havilland at its Hatfield Aerodrome, Hertfordshire, United Kingdom headquarters, the Comet 1 prototype first flew on 27 July 1949. It featured an aerodynamically clean design with four de Havilland Ghost turbojet engines buried in the wings, a pressurised fuselage, and large square windows. For the era, it offered a relatively quiet, comfortable passenger cabin and showed signs of being a commercial success at its 1952 debut.

A year after entering commercial service, the Comets began suffering problems, with three of them breaking up during mid-flight in well publicised accidents. These were later found to be due to catastrophic metal fatigue in the airframes, not well understood at the time. The Comet was withdrawn from service and extensively tested to discover the cause; the first incident had been incorrectly blamed on adverse weather. Design flaws, including dangerous stresses at the corners of the square windows and installation methods, were ultimately identified. As a result, the Comet was extensively redesigned with oval windows, structural reinforcement, and other changes. Rival manufacturers meanwhile heeded the lessons learned from the Comet while developing their own aircraft.

Although sales never fully recovered, the improved Comet 2 and the prototype Comet 3 culminated in the redesigned Comet 4 series which debuted in 1958 and had a productive career of over 30 years. The Comet was adapted for a variety of military roles such as VIP, medical and passenger transport, as well as surveillance. The most extensive modification resulted in a specialised maritime patrol aircraft variant, the Hawker Siddeley Nimrod. Nimrod remained in service with the Royal Air Force (RAF) until June 2011, over 60 years after the Comet's first flight.

= Development =

= Origins =

On 11 March 1943, the Cabinet of the United Kingdom formed the Brabazon Committee to determine the UK's airliner needs after the conclusion of the Second World War. One of its recommendations was for a pressurised, transatlantic mailplane that could carry non-stop, one long ton (1,000 t) of payload at a cruising speed of 400 mph (640 km/h). De Havilland chose to challenge the widely held scepticism of jet engines as too fuel-hungry and unreliable. So committee member Sir Geoffrey de Havilland, head of the de Havilland company, used his personal influence and his company's expertise to champion the development of a jet propelled aircraft; and proposed a specification for a pure turbojet-powered design. The committee accepted the proposal, calling it the "Type IV" (of five designs), and awarded a development and production contract to de Havilland under the designation Type 106 in February 1945. The type and design were to be so advanced that De Havilland had to undertake the design and development of both, the airframe, and the engines. This was because in 1945 no turbojet engine manufacturer in the world was drawing up a design specification for an engine with the thrust and specific fuel consumption, that could power an aircraft at the proposed cruising altitude (40 thousand feet), speed, and transatlantic range as was called for by the Type 106. First phase development of the DH 106 focused on short and intermediate range mailplanes with a small passenger compartment and as few as six seats, before being redefined as a long-range airliner with a capacity of 24 seats. Out of all the Brabazon designs, the DH 106 was seen as the riskiest both in terms of introducing untried design elements and for the financial commitment involved. Nevertheless, the British Overseas Airways Corporation (BOAC) found the Type IV's specifications attractive, and initially proposed a purchase of 25 aircraft; in December 1945, when a firm contract was laid out, the order total was revised to 10.

A design team was formed in 1946 under the leadership of chief designer Ronald Bishop, who had been responsible for the Mosquito fighter-bomber. A number of unorthodox configurations

were considered , ranging from canard to tailless designs ; all were subsequently rejected . The Ministry of Supply was , however , interested in the most radical of the proposed designs and ordered two experimental tailless DH 108s to serve as proof of concept aircraft for testing swept @-@ wing configurations in both low @-@ speed and high @-@ speed flight . During flight tests , the DH 108 gained a reputation for being accident @-@ prone and unstable , leading de Havilland and BOAC to gravitate to conventional configurations and , necessarily , designs with less technical risk . The DH 108s were later modified to test the DH 106 's power controls .

In September 1946 , prior to the completion of the DH 108s , BOAC requests necessitated a redesign of the DH 106 from its previous 24 @-@ seat configuration to a larger 36 @-@ seat version . With no time to develop the technology necessary for a proposed tailless configuration , Bishop opted for a more conventional 20 @-@ degree swept @-@ wing design with unswept tail surfaces , married to an enlarged fuselage accommodating 36 passengers in a four @-@ abreast arrangement with a central aisle . Replacing previously specified Halford H.1 Goblin engines , four new , more powerful Rolls @-@ Royce Avons were to be incorporated in pairs buried in the wing roots ; Halford H.2 Ghost engines were eventually applied as an interim solution while the Avons cleared certification . The redesigned aircraft was named the DH 106 Comet in December 1947 . Revised first orders from BOAC and British South American Airways totalled 14 aircraft with delivery projected for 1952 .

= = = Testing and prototypes = = =

As the Comet represented a new category of passenger aircraft , more rigorous testing was a development priority . From 1947 to 1948 , de Havilland conducted an extensive research and development phase , including the use of several stress test rigs at Hatfield for small components and large assemblies alike . Sections of pressurised fuselage were subjected to high @-@ altitude flight conditions via a large decompression chamber on @-@ site , and tested to failure . However , tracing fuselage failure points proved difficult with this method , and de Havilland ultimately switched to conducting structural tests with a water tank that could be safely configured to increase pressures gradually . The entire forward fuselage section was tested for metal fatigue by repeatedly pressurising to 2 @. 75 pounds per square inch (19 @. 0 kPa) overpressure and depressurising through more than 16 @, 000 cycles , equivalent to about 40 @, 000 hours of airline service . The windows were also tested under a pressure of 12 psi (83 kPa) , 4 @. 75 psi (32 @. 8 kPa) above expected pressures at the normal service ceiling of 36 @, 000 ft (11 @, 000 m) . One window frame survived 100 psi (690 kPa) , about 1 @, 250 percent over the maximum pressure it was expected to encounter in service .

The first prototype DH 106 Comet (carrying Class B markings G @-@ 5 @-@ 1) was completed in 1949 , and was initially used to conduct ground tests and brief early flights . The prototype 's maiden flight took place on 27 July 1949 out of Hatfield Aerodrome and lasted 31 minutes . At the controls was de Havilland chief test pilot John Cunningham , a famous night @-@ fighter pilot of the Second World War , along with co @-@ pilot Harold " Tubby " Waters , engineers John Wilson (electrics) and Frank Reynolds (hydraulics) , and flight test observer Tony Fairbrother .

The prototype was registered G @-@ ALVG just before it was publicly displayed at the 1949 Farnborough Airshow prior to the start of flight trials . A year later , the second prototype G @-@ 5 @-@ 2 made its maiden flight . The second prototype was registered G @-@ ALZK in July 1950 and it was used by the BOAC Comet Unit at Hurn from April 1951 to carry out 500 flying hours of crew training and route proving . Australian airline Qantas also sent its own technical experts to observe the performance of the prototypes , seeking to quell internal uncertainty about its prospective Comet purchase . Both prototypes could be externally distinguished from later Comets by the large single @-@ wheeled main landing gear , which was replaced on production models starting with G @-@ ALYP by four @-@ wheeled bogies .

= = Design = =

== Overview ==

The Comet was an all metal low wing cantilever monoplane powered by four jet engines ; it had a four place cockpit occupied by two pilots , a flight engineer , and a navigator . The clean , low drag design of the aircraft featured many design elements that were fairly uncommon at the time , including a swept wing leading edge , integral wing fuel tanks , and four wheel bogie main undercarriage units designed by de Havilland . Two pairs of turbojet engines (on the Comet 1s , Halford H.2 Ghosts , subsequently known as de Havilland Ghost 50 Mk1s) were buried into the wings .

The original Comet was approximately the length of the later Boeing 737 100 , but carried fewer people in a significantly more spacious environment . BOAC installed 36 reclining " slumberseats " with 45 inch (1143 mm) centres on its first Comets , allowing for greater leg room in front and behind ; Air France had 11 rows of seats with four seats to a row installed on its Comets . Large picture window views and table seating accommodations for a row of passengers afforded a " feel of comfort and luxury " atypical of transportation of the period . Amenities included a galley that could serve hot and cold food and drinks , a bar , and separate men 's and women 's toilets . Provisions for emergency situations included several life rafts stored in the wings near the engines , and individual life vests were stowed under each seat .

One of the most striking aspects of Comet travel was the quiet , " vibration free flying " as touted by BOAC . For passengers used to propeller driven airliners , smooth and quiet jet flight was a novel experience .

== Avionics and systems ==

For ease of training and fleet conversion , de Havilland designed the Comet 's flight deck layout with a degree of similarity to the Lockheed Constellation , an aircraft that was popular at the time with key customers such as BOAC . The cockpit included full dual controls for the captain and first officer , while a flight engineer controlled various key systems , including fuel , air conditioning , and electrical systems . The navigator occupied a dedicated station with a table across from the flight engineer .

Several of the Comet 's avionics systems were new to civil aviation . One such feature was irreversible powered flight controls , which increased the pilot 's ease of control and the safety of the aircraft by preventing aerodynamic forces from changing the directed positions and placement of the aircraft 's control surfaces . Additionally , a large number of the control surfaces , such as the elevators , were equipped with a complex gearing system as a safeguard against accidentally over stressing the surfaces or airframe at higher speed ranges .

The Comet had a total of four hydraulic systems , two primaries , one secondary , and a final emergency system for basic functions such as lowering the undercarriage . The undercarriage could also be lowered by a combination of gravity and a hand pump . Power was syphoned from all four engines for the hydraulics , cabin air conditioning , and the de icing system ; these systems had operational redundancy in that they could keep working even if only a single engine was active . The majority of hydraulic components were centred in a single avionics bay . A pressurised refuelling system , developed by Flight Refuelling Ltd , allowed the Comet 's fuel tanks to be refuelled at a far greater rate than other methods .

The cockpit was significantly altered for the Comet 4 's introduction , on which an improved layout focusing on the onboard navigational suite was introduced . An EKCO E160 radar unit was installed in the Comet 4 's nose cone , providing search functions as well as ground and cloud mapping capabilities , and a radar interface was built into the Comet 4 cockpit along with redesigned instruments .

Sud Est 's design bureau , while working on the Sud Aviation Caravelle in 1953 , licensed several design features from de Havilland , building on previous collaborations on earlier licensed designs , including the DH 100 Vampire ; the nose and cockpit layout of the Comet 1 was grafted

onto the Caravelle . In 1969 , when the Comet 4 's design was modified by Hawker Siddeley to become the basis for the Nimrod , the cockpit layout was completely redesigned and bore little resemblance to its predecessors except for the control yoke .

== Fuselage ==

Diverse geographic destinations and cabin pressurisation alike on the Comet demanded the use of a high proportion of alloys , plastics , and other materials new to civil aviation across the aircraft in order to meet certification requirements . The Comet 's high cabin pressure and fast operating speeds were unprecedented in commercial aviation , making its fuselage design an experimental process . At its introduction , Comet airframes would be subjected to an intense , high @-@ speed operating schedule which included simultaneous extreme heat from desert airfields and frosty cold from the kerosene @-@ filled fuel tanks .

The Comet 's thin metal skin was composed of advanced new alloys and was both riveted and chemically bonded , which saved weight and reduced the risk of fatigue cracks spreading from the rivets . The chemical bonding process was accomplished using a new adhesive , Redux , which was liberally used in the construction of the wings and the fuselage of the Comet ; it also had the advantage of simplifying the manufacturing process .

When several of the fuselage alloys were discovered to be vulnerable to weakening via metal fatigue , a detailed routine inspection process was introduced . As well as thorough visual inspections of the outer skin , mandatory structural sampling was routinely conducted by both civil and military Comet operators . The need to inspect areas not easily viewable by the naked eye led to the introduction of widespread radiography examination in aviation ; this also had the advantage of detecting cracks and flaws too small to be seen otherwise .

Operationally , the design of the cargo holds led to considerable difficulty for the ground crew , especially baggage handlers at the airports . The cargo hold had its doors located directly underneath the aircraft , so each item of baggage or cargo had to be loaded vertically upwards from the top of the baggage truck , then slid along the hold floor to be stacked inside . The individual pieces of luggage and cargo also had to be retrieved in a similarly slow manner at the arriving airport .

== Propulsion ==

The Comet was powered by two pairs of turbojet engines buried in the wings close to the fuselage . Chief designer Bishop chose the Comet 's embedded @-@ engine configuration because it avoided the drag of podded engines and allowed for a smaller fin and rudder , since the hazards of asymmetric thrust were reduced . The engines were outfitted with baffles to reduce noise emissions , and extensive soundproofing was also implemented to improve passenger conditions .

Placing the engines within the wings had the advantage of a reduction in the risk of foreign object damage , which could seriously damage jet engines . The low @-@ mounted engines and good placement of service panels also made aircraft maintenance easier to perform . However , the Comet 's buried engine configuration increased its structural weight and complexity . Armour had to be placed around the engine cells to contain debris from any serious engine failures ; also , placing the engines inside the wing required a more complicated wing structure .

The Comet 1 featured 5 @, @ 050 lbf (22 @. @ 5 kN) de Havilland Ghost 50 Mk1 turbojet engines . Two hydrogen peroxide @-@ powered de Havilland Sprite booster rockets were originally intended to be installed to boost takeoff under hot and high altitude conditions from airports such as Khartoum and Nairobi . These were tested on 30 flights , but the Ghosts alone were considered powerful enough and some airlines concluded that rocket motors were impractical . Sprite fittings were retained on production aircraft . Comet 1s subsequently received more powerful 5 @, @ 700 lbf (25 kN) Ghost DGT3 series engines .

From the Comet 2 onwards , the Ghost engines were replaced by the newer and more powerful 7 @, @ 000 lbf (31 kN) Rolls @-@ Royce Avon AJ.65 engines . To achieve optimum efficiency with

the new powerplants , the air intakes were enlarged to increase mass air flow . Upgraded Avon engines were introduced on the Comet 3 , and the Avon @-@ powered Comet 4 was highly praised for its takeoff performance from high altitude locations such as Mexico City .

= = Operational history = =

= = = Introduction = = =

The earliest production aircraft , registered G @-@ ALYP (" Yoke Peter ") , first flew on 9 January 1951 and was subsequently lent to BOAC for development flying by its Comet Unit . On 22 January 1952 , the fifth production aircraft , registered G @-@ ALYS , received the first Certificate of Airworthiness awarded to a Comet , six months ahead of schedule . On 2 May 1952 , as part of BOAC 's route @-@ proving trials , G @-@ ALYP took off on the world 's first jetliner flight with fare @-@ paying passengers and inaugurated scheduled service from London to Johannesburg . The final Comet from BOAC 's initial order , registered G @-@ ALYZ , began flying in September 1952 and carried cargo along South American routes while simulating passenger schedules .

The Comet was a hit with passengers including Queen Elizabeth , the Queen Mother and Princess Margaret , who were guests on a special flight on 30 June 1953 hosted by Sir Geoffrey and Lady de Havilland , and thus became the first members of the British Royal Family to fly by jet . Flights on the Comet were about 50 percent faster than on advanced piston @-@ engined aircraft such as the Douglas DC @-@ 6 (490 mph for the Comet compared to the DC @-@ 6 's 315 mph) , and a faster rate of climb further cut flight times . In August 1953 BOAC scheduled nine @-@ stop London to Tokyo flights by Comet for 36 hours , compared to 86 hours and 35 minutes on their Argonaut piston airliner . (Pan Am 's DC @-@ 6B was scheduled for 46 hours 45 minutes .) The five @-@ stop flight from London to Johannesburg was scheduled for 21 hr 20 min .

In their first year Comets carried 30 @,@ 000 passengers . As the aircraft could be profitable with a load factor as low as 43 percent , commercial success was expected . The Ghost engines allowed the Comet to fly above weather competitors had to fly through . They ran smoothly and were less noisy than piston engines , had low maintenance costs , and were fuel @-@ efficient above 30 @,@ 000 ft (9 @,@ 100 m) . In summer 1953 eight BOAC Comets left London each week : three to Johannesburg , two to Tokyo , two to Singapore and one to Colombo .

In 1953 the Comet appeared to have achieved success for de Havilland . In addition to the sales to BOAC , two French airlines , Union Aéromaritime de Transport and Air France , each acquired three Comet 1As , an upgraded variant with greater fuel capacity , for flights to West Africa and the Middle East . A slightly longer version of the Comet 1 with more powerful engines , the Comet 2 , was being developed , and orders were placed by Air India , British Commonwealth Pacific Airlines , Japan Air Lines , Linea Aeropostal Venezolana , and Panair do Brasil . American carriers Capital Airlines , National Airlines , and Pan Am placed orders for the planned Comet 3 , an even larger , longer @-@ range version for transatlantic operations . Qantas was interested in the Comet 1 but concluded that a version with more range and better takeoff performance was needed for the London to Canberra route .

= = = Early hull losses = = =

On 26 October 1952 , the Comet suffered its first hull loss when a BOAC flight departing Rome 's Ciampino airport failed to become airborne and ran into rough ground at the end of the runway . Two passengers sustained minor injuries , and the aircraft , G @-@ ALYZ , was a total loss . On 3 March 1953 , a new Canadian Pacific Airlines Comet 1A , registered CF @-@ CUN and named Empress of Hawaii , failed to become airborne while attempting a night takeoff from Karachi , Pakistan , on a delivery flight to Australia . The aircraft plunged into a dry drainage canal and collided with an embankment , killing all five crew and six passengers on board . The accident was the first fatal jetliner crash , as well as the Comet 's first accident to result in fatalities . In response ,

Canadian Pacific cancelled its remaining order for a second Comet 1A and never operated the type in commercial service .

Both early accidents were originally attributed to pilot error , as over @-@ rotation had led to a loss of lift from the leading edge of the aircraft 's wings . It was later determined that the Comet 's wing profile experienced a loss of lift at a high angle of attack , and its engine inlets also suffered a lack of pressure recovery in the same conditions . As a result , de Havilland re @-@ profiled the wings ' leading edge with a pronounced " droop " , and wing fences were added to control spanwise flow . A fictionalised investigation into the Comet 's takeoff accidents was the subject of the 1959 novel *Cone of Silence* by Arthur David Beaty , a former BOAC captain . *Cone of Silence* was made into a film in 1960 , and Beaty also recounted the story of the Comet 's takeoff accidents in a chapter of his 1984 non @-@ fiction work , *Strange Encounters : Mysteries of the Air* .

The Comet 's second fatal accident occurred on 2 May 1953 , when BOAC Flight 783 , a Comet 1 , registered G @-@ ALYV , crashed in a severe thundersquall six minutes after taking off from Calcutta @-@ Dum Dum (now Netaji Subhash Chandra Bose International Airport) , India , killing all 43 on board . Witnesses observed the wingless Comet on fire plunging into the village of Jagalgori , leading investigators to suspect structural failure .

= = = = India Court of Inquiry = = = =

After the loss of G @-@ ALYV , the Central Government of India convened a court of inquiry to examine the cause of the accident . Professor Natesan Srinivasan joined the inquiry as the main technical expert . A large portion of the aircraft was recovered and reassembled at Farnborough , during which the break @-@ up was found to have begun with a left elevator spar failure in the stabilizer . The inquiry concluded that the aircraft had encountered extreme negative G forces during takeoff ; severe turbulence generated by adverse weather was determined to have induced down @-@ loading , leading to the loss of the wings . Examination of the cockpit controls suggested that the pilot may have inadvertently over @-@ stressed the aircraft when pulling out of a steep dive by over @-@ manipulation of the fully powered flight controls . Investigators did not consider metal fatigue as a contributory cause .

The inquiry 's recommendations revolved around the enforcement of stricter speed limits during turbulence , and two significant design changes also resulted : all Comets were equipped with weather radar and the " Q feel " system was introduced , which ensured that control column forces (invariably called stick forces) would be proportional to control loads . This artificial feel was the first of its kind to be introduced in any aircraft . The Comet 1 and 1A had been criticised for a lack of " feel " in their controls , and investigators suggested that this might have contributed to the pilot 's alleged over @-@ stressing of the aircraft ; Comet chief test pilot John Cunningham contended , however , that the jetliner flew smoothly and was highly responsive in a manner consistent with other de Havilland aircraft .

= = = Comet disasters of 1954 = = =

Rome 's Ciampino airport , the site of the first Comet hull loss , was the origin of more disastrous Comet flights just over a year later . On 10 January 1954 , 20 minutes after taking off from Ciampino , the first production Comet , G @-@ ALYP , broke up in mid @-@ air while operating BOAC Flight 781 and crashed into the Mediterranean off the Italian island of Elba with the loss of all 35 on board . With no witnesses to the disaster and only partial radio transmissions as incomplete evidence , no obvious reason for the crash could be deduced . Engineers at de Havilland immediately recommended 60 modifications aimed at any possible design flaw while the Abell Committee met to determine potential causes of the crash . BOAC also voluntarily grounded its Comet fleet pending investigation into the causes of the accident .

= = = = Abell Committee Court of Inquiry = = = =

Media attention centred on sabotage , while other speculation ranged from clear @-@ air turbulence to an explosion of vapour in an empty fuel tank . The Abell Committee focused on six potential aerodynamic and mechanical causes : control flutter (which had led to the loss of DH 108 prototypes) , structural failure due to high loads or metal fatigue of the wing structure , failure of the powered flight controls , failure of the window panels leading to explosive decompression , or fire and other engine problems . The committee concluded that fire was the most likely cause of the problem , and a number of changes were made to the aircraft to protect the engines and wings from damage that might lead to another fire .

During the investigation , the Royal Navy conducted recovery operations . The first pieces of wreckage were discovered on 12 February 1954 and the search continued until September 1954 , by which time 70 percent by weight of the main structure , 80 percent of the power section , and 50 percent of the aircraft 's systems and equipment had been recovered . The forensic reconstruction effort had just begun when the Abell Committee reported its findings . No apparent fault in the aircraft was found , and the British government decided against opening a further public inquiry into the accident . The prestigious nature of the Comet project , particularly for the British aerospace industry , and the financial impact of the aircraft 's grounding on BOAC 's operations , both served to pressure the inquiry to end without further investigation . Comet flights resumed on 23 March 1954 .

On 8 April 1954 , Comet G @-@ ALYY (" Yoke Yoke ") , on charter to South African Airways , was on a leg from Rome to Cairo (of a longer route , SA Flight 201 from London to Johannesburg) , when it crashed in the Mediterranean near Naples with the loss of all 21 passengers and crew on board . The Comet fleet was immediately grounded once again and a large investigation board was formed under the direction of the Royal Aircraft Establishment (RAE) . Prime Minister Winston Churchill tasked the Royal Navy with helping to locate and retrieve the wreckage so that the cause of the accident could be determined . The Comet 's Certificate of Airworthiness was revoked and Comet 1 line production was suspended at the Hatfield factory while the BOAC fleet was permanently grounded , cocooned and stored .

= = = = Cohen Committee Court of Inquiry = = = =

On 19 October 1954 , the Cohen Committee was established to examine the causes of the Comet crashes . Chaired by Lord Cohen , the committee tasked an investigation team led by Sir Arnold Hall , Director of the RAE at Farnborough , to perform a more detailed investigation . Hall 's team began considering fatigue as the most likely cause of both accidents , and initiated further research into measurable strain on the aircraft 's skin . With the recovery of large sections of G @-@ ALYP from the Elba crash and BOAC 's donation of an identical airframe , G @-@ ALYU , for further examination , an extensive " water torture " test eventually provided conclusive results . This time , the entire fuselage was tested in a dedicated water tank that was built specifically at Farnborough to accommodate its full length . Stress around the window corners was found to be much higher than expected and stresses on the skin were generally more than previously expected or tested . This was due to stress concentration , a consequence of the windows ' square shape , which generated levels of stress two or three times greater than across the rest of the fuselage .

In water tank testing , engineers subjected G @-@ ALYU to repeated re @-@ pressurisation and over @-@ pressurisation , and on 24 June 1954 , after 3 @,@ 057 flight cycles (1 @,@ 221 actual and 1 @,@ 836 simulated) , G @-@ ALYU burst open . Hall , Geoffrey de Havilland and Bishop were immediately called to the scene , where the water tank was drained to reveal that the fuselage had ripped open at a corner of the forward left escape hatch cutout . A further test reproduced the same results . Based on these findings , Comet 1 structural failures could be expected at anywhere from 1 @,@ 000 to 9 @,@ 000 cycles . Before the Elba accident , G @-@ ALYP had made 1 @,@ 290 pressurised flights , while G @-@ ALYY had made 900 pressurised flights before crashing . Dr P.B. Walker , Head of the Structures Department at the RAE , said he was not surprised by this , noting that the difference was about three to one , and previous experience with metal fatigue suggested a total range of nine to one between experiment and outcome in the field could result in failure .

The RAE also reconstructed about two thirds of G ALYP at Farnborough and found fatigue crack growth from a rivet hole at the low drag fibreglass forward aperture around the Automatic Direction Finder , which had caused a catastrophic break up of the aircraft in high altitude flight . The punch rivet construction technique employed in the Comet 's design had exacerbated its structural fatigue problems ; the aircraft 's windows had been engineered to be glued and riveted , but had been punch riveted only . Unlike drill riveting , the imperfect nature of the hole created by punch riveting could cause fatigue cracks to start developing around the rivet . Principal investigator Hall accepted the RAE 's conclusion of design and construction flaws as the likely explanation for G ALYU 's structural failure after 3 , 060 pressurisation cycles . The Cohen inquiry closed on 24 November 1954 , and although the inquiry had " found that the basic design of the Comet was sound " , de Havilland nonetheless began a refit programme to strengthen the fuselage and wing structure , employing thicker gauge skin and replacing all square windows and panels with rounded versions .

= = = Resumption of service = = =

With the discovery of the structural problems of the early series , all remaining Comets were withdrawn from service , while de Havilland launched a major effort to build a new version that would be both larger and stronger . All outstanding orders for the Comet 2 were cancelled by airline customers . The square windows of the Comet 1 were replaced by the oval versions used on the Comet 2 , which first flew in 1953 , and the skin sheeting was thickened slightly . Remaining Comet 1s and 1As were either scrapped or modified with oval windows and rip stop doublers .

All production Comet 2s were also modified to alleviate the fatigue problems (most of these served with the RAF as the Comet C2) , while a programme to produce a Comet 2 with more powerful Avons was delayed . The prototype Comet 3 first flew in July 1954 , and was tested in a non pressurised state pending completion of the Cohen inquiry . Comet commercial flights would not resume until 1958 .

Development flying and route proving with the Comet 3 allowed accelerated certification of what was destined to be the most successful variant of the type , the Comet 4 . All airline customers for the Comet 3 subsequently cancelled their orders and switched to the Comet 4 , which was based on the Comet 3 but with improved fuel capacity . BOAC ordered 19 Comet 4s in March 1955 , while American operator Capital Airlines ordered 14 Comets in July 1956 . Capital 's order included 10 Comet 4As , a variant modified for short range operations with a stretched fuselage and short wings , lacking the pinion (outboard wing) fuel tanks of the Comet 4 . However , because of financial problems and a subsequent takeover by United Airlines , Capital would never operate the Comet .

The Comet 4 first flew on 27 April 1958 and received its Certificate of Airworthiness on 24 September 1958 ; the first was delivered to BOAC the next day . The base price of a new Comet 4 was around £ 1 , 140 , 000 , equivalent to £ 24 , 020 , 000 in today 's pounds . The Comet 4 enabled BOAC to inaugurate the first regular jet powered transatlantic services on 4 October 1958 between London and New York (albeit still requiring a fuel stop at Gander International Airport , Newfoundland , on westward North Atlantic crossings) . While BOAC gained publicity as the first to provide transatlantic jet service , by the end of the month rival Pan American World Airways was flying the Boeing 707 on the same route , and in 1960 the Douglas DC 8 as well . The American jets were larger , faster , longer ranged , and more cost effective than the Comet . After analysing route structures for the Comet , BOAC reluctantly cast about for a successor , and in 1956 entered into an agreement with Boeing to purchase the 707 .

The Comet 4 was ordered by two other airlines : Aerolíneas Argentinas took delivery of six Comet 4s from 1959 to 1960 , using them between Buenos Aires and Santiago , New York and Europe , while East African Airways received three new Comet 4s from 1960 to 1962 and operated them to the United Kingdom and to Kenya , Tanzania , and Uganda . The Comet 4A ordered by Capital Airlines was instead built for BEA as the Comet 4B with a further fuselage stretch of 38 in (97 cm) and seating for 99 passengers . The first Comet 4B flew on 27 June 1959 and BEA began Tel Aviv

to London @-@ Heathrow services on 1 April 1960 . Olympic Airways was the only other customer to order the type . The last Comet 4 variant , the Comet 4C , first flew on 31 October 1959 and entered service with Mexicana in 1960 . The Comet 4C had the Comet 4B 's longer fuselage and the longer wings and extra fuel tanks of the original Comet 4 , which gave it a longer range than the 4B . Ordered by Kuwait Airways , Middle East Airlines , Misrair (later United Arab Airlines) , and Sudan Airways , it was the most popular Comet variant .

= = = Later service = = =

In 1959 BOAC began shifting its Comets from transatlantic routes and released the Comet to associate companies , making the Comet 4 's ascendancy as a premier airliner brief . Besides the 707 and DC @-@ 8 , the introduction of the Vickers VC10 allowed competing aircraft to assume the high @-@ speed , long @-@ range passenger service role pioneered by the Comet . In 1960 , as part of a government @-@ backed consolidation of the British aerospace industry , de Havilland itself was acquired by Hawker Siddeley , within which it became a wholly owned division .

In the 1960s orders declined , with a total of 76 Comet 4s being delivered from 1958 to 1964 . In November 1965 BOAC retired its Comet 4s from revenue service , while other operators continued commercial passenger flights with the Comet until 1981 . Dan @-@ Air played a significant role in the fleet 's later history and , at one time , owned all 49 remaining airworthy civil Comets . On 14 March 1997 a Comet 4C serial XS235 and named Canopus , which had been acquired by the British Ministry of Technology and used for radio , radar and avionics trials , made the last documented production Comet flight .

= = Legacy = =

The Comet is widely regarded jointly as an adventurous step forward and a supreme tragedy ; nevertheless , the aircraft 's legacy does include numerous advances in aircraft design and in accident investigations . The inquiries into the accidents that plagued the Comet 1 were perhaps some of the most extensive and revolutionary that have ever taken place , establishing precedents in accident investigation ; many of the deep @-@ sea salvage and aircraft reconstruction techniques employed have remained in use within the aviation industry . In spite of the Comet being subjected to what was then the most rigorous testing of any contemporary airliner , pressurisation and the dynamic stresses involved were not thoroughly understood at the time of the aircraft 's development , nor was the concept of metal fatigue . While these lessons could be implemented on the drawing board for future aircraft , corrections could only be retroactively applied to the Comet .

According to de Havilland 's chief test pilot John Cunningham , who had flown the prototype 's first flight , representatives from American manufacturers such as Boeing and Douglas privately disclosed that if de Havilland had not experienced the Comet 's pressurisation problems first , it would have happened to them . Cunningham likened the Comet to the later Concorde , and added that he had assumed that the aircraft would change aviation , which it subsequently did . Aviation author Bill Withuhn concluded that the Comet had pushed " ' the state @-@ of @-@ the @-@ art ' beyond its limits . "

Aeronautical engineering firms were quick to respond to the Comet 's commercial advantages and technical flaws alike ; other aircraft manufacturers learned from , and profited by , the hard @-@ earned lessons embodied by de Havilland 's Comet . While the Comet 's buried engines were used on some other early jet airliners , such as the Tupolev Tu @-@ 104 , later aircraft , such as the Boeing 707 and Douglas DC @-@ 8 , would differ by employing podded engines held on pylons beneath the wings . Boeing stated that podded engines were selected for their passenger airliners because buried engines carried a higher risk of catastrophic wing failure in the event of engine fire . In response to the Comet tragedies , manufacturers also developed various means of pressurisation testing , often going so far as to explore rapid depressurisation ; subsequent fuselage skins were of a greater thickness than the skin of the Comet .

= = Variants = =

= = = Comet 1 = = =

The square @-@ windowed Comet 1 was the first model produced , a total of 12 aircraft in service and test . Following closely the design features of the two prototypes , the only noticeable change was the adoption of four @-@ wheel bogie main undercarriage units , replacing the single main wheels . Four Ghost 50 Mk 1 engines were fitted (later replaced by more powerful Ghost DGT3 series engines) . The span was 115 ft (35 @.@ 05 m) , and overall length 93 ft (28 @.@ 35 m) ; the maximum takeoff weight was over 105 @,@ 000 lb (47 @.@ 628 kg) and over 40 passengers could be carried .

An updated Comet 1A was offered with higher @-@ allowed weight , greater fuel capacity , and water @-@ methanol injection ; 10 were produced . In the wake of the 1954 disasters , all Comet 1s and 1As were brought back to Hatfield , first placed in a protective cocoon and retained for testing . All were substantially damaged in stress testing or were scrapped entirely .

Comet 1X : Two RCAF Comet 1As were rebuilt with heavier @-@ gauge skins to a Comet 2 standard for the fuselage , and renamed Comet 1X .

Comet 1XB : Four Comet 1As were upgraded to a 1XB standard 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 B35 / 46 , was submitted to the Air Ministry on 27 May 1948 . It had been originally proposed in 1948 as the " PR Comet " , a high @-@ altitude photo reconnaissance adaptation of the Comet 1 . The Ghost DGT3 @-@ powered airframe featured a narrowed fuselage , a bulbous nose with H2S Mk IX radar , and a four @-@ crewmember pressurised cockpit under a large bubble canopy . Fuel tanks carrying 2 @,@ 400 imperial gallons (11 @,@ 000 L) were added to attain a range of 3 @,@ 350 miles (5 @,@ 390 km) . The proposed DH 111 received a negative evaluation from the Royal Aircraft Establishment over serious concerns regarding weapons storage ; this along with the redundant capability offered by the RAF 's proposed V bomber trio led de Havilland to abandon the project on 22 October 1948 .

= = = Comet 2 = = =

The Comet 2 had a slightly larger wing , higher fuel capacity and more powerful Rolls @-@ Royce Avon engines , which all improved the aircraft 's range and performance ; its fuselage was 3 ft 1 in (0 @.@ 94 m) longer than the Comet 1 's . Design changes had been made to make the aircraft more suitable for transatlantic operations . Following the Comet 1 disasters , these models were rebuilt with heavier gauge skin and rounded windows , and the Avon engines featuring larger air intakes and outward @-@ curving jet tailpipes . A total of 12 of the 44 @-@ seat Comet 2s were ordered by BOAC for the South Atlantic route . The first production aircraft (G @-@ AMXA) flew on 27 August 1953 . Although these aircraft performed well on test flights on the South Atlantic , their range was still not suitable for the North Atlantic . All but four Comet 2s were allocated to the RAF with deliveries beginning in 1955 . Modifications to the interiors allowed the Comet 2s to be used in a number of different roles . For VIP transport , the seating and accommodations were altered while provisions for carrying medical equipment including iron lungs were incorporated . Specialised ELINT and electronic surveillance capability was later added to some airframes .

Comet 2X : Limited to a single Comet Mk 1 powered by four Rolls @-@ Royce Avon 502 turbojet engines and used as a development aircraft for the Comet 2 .

Comet 2E : Two Comet 2 airliners were fitted with Avon 504s in the inner nacelles and Avon 524s in the outer ones . These aircraft were used by BOAC for proving flights during 1957 ? 1958 .

Comet T2 : The first two of 10 Comet 2s for the RAF were fitted out as crew trainers , with the first aircraft (XK669) flying for the first time on 9 December 1955 .

Comet C2 : Eight Comet 2s originally destined for the civil market were completed for the RAF and

assigned to No. 216 Squadron .

Comet 2R : Three Comet 2s were modified for use in radar and electronic systems development , initially assigned to No. 90 Group (later Signals Command) for the RAF . In service with No. 192 and No. 51 Squadrons , the 2R series was equipped to monitor Warsaw Pact signal traffic and operated in this role from 1958 .

== Comet 3 ==

The Comet 3 , which flew for the first time on 19 July 1954 , was a Comet 2 lengthened by 15 ft 5 in (4 @. 70 m) and powered by Avon M502 engines developing 10 @, 000 lbf (44 kN) . The variant added wing pinion tanks , and offered greater capacity and range . The Comet 3 was destined to remain a development series since it did not incorporate the fuselage @-@ strengthening modifications of the later series aircraft , and was not able to be fully pressurised . Only two Comet 3s began construction with G @-@ ANLO , the only airworthy Comet 3 , demonstrated at the Farnborough SBAC Show in September 1954 . The other Comet 3 airframe was not completed to production standard and was used primarily for ground @-@ based structural and technology testing during development of the similarly sized Comet 4 . Nine additional Comet 3 airframes were not completed and their construction was abandoned at Hatfield . In BOAC colours , G @-@ ANLO was flown by John Cunningham in a marathon round @-@ the @-@ world promotional tour in December 1955 . As a flying testbed , it was later modified with Avon RA29 engines fitted , as well as replacing the original long @-@ span wings with reduced span wings as the Comet 3B and demonstrated in British European Airways (BEA) livery at the Farnborough Airshow in September 1958 . Assigned in 1961 to the Blind Landing Experimental Unit (BLEU) at RAE Bedford , the final testbed role played by G ? ANLO was in automatic landing system experiments . When retired in 1973 , the airframe was used for foam arrester trials before the fuselage was salvaged at BAE Woodford , to serve as the mock @-@ up for the Nimrod .

== Comet 4 ==

The Comet 4 was a further improvement on the stretched Comet 3 with even greater fuel capacity . The design had progressed significantly from the original Comet 1 , growing by 18 ft 6 in (5 @. 64 m) and typically seating 74 to 81 passengers compared to the Comet 1 's 36 to 44 (119 passengers could be accommodated in a special charter seating package in the later 4C series) . The Comet 4 was considered the definitive series , having a longer range , higher cruising speed and higher maximum takeoff weight . These improvements were possible largely because of Avon engines with twice the thrust of the Comet 1 's Ghosts . Deliveries to BOAC began on 30 September 1958 with two 48 @-@ seat aircraft , which were used to initiate the first scheduled transatlantic services .

Comet 4B : Originally developed for Capital Airlines as the 4A , the 4B featured greater capacity through a 2m longer fuselage , and a shorter wingspan ; 18 were produced .

Comet 4C : This variant featured the Comet 4 's wings and the 4B 's longer fuselage ; 23 were produced .

The last two Comet 4C fuselages were used to build prototypes of the Hawker Siddeley Nimrod maritime patrol aircraft . A Comet 4C (SA @-@ R @-@ 7) was ordered by Saudi Arabian Airlines with eventual disposition to the Saudi Royal Flight for the exclusive use of King Saud bin Abdul Aziz . Extensively modified at the factory , the aircraft included a VIP front cabin , a bed , special toilets with gold fittings and was distinguished by a green , gold and white colour scheme with polished wings and lower fuselage that was commissioned from aviation artist John Stroud . Following its first flight , the special order Comet 4C was described as " the world 's first executive jet . "

== Comet 5 proposal ==

The Comet 5 was proposed as an improvement over previous models , including a 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 languished as a hypothetical aircraft and was never realised .

= = = Hawker Siddeley Nimrod = = =

The last two Comet 4C aircraft produced were modified as prototypes (XV148 & XV147) to meet a British requirement for a maritime patrol aircraft for the Royal Air Force ; initially named " Maritime Comet " , the design was designated Type HS 801 . This variant became the Hawker Siddeley Nimrod and production aircraft were built at the Hawker Siddeley factory at Woodford Aerodrome . Entering service in 1969 , five Nimrod variants were produced . The final Nimrod aircraft were retired in June 2011 .

= = Operators = =

The original operators of the early Comet 1 and the Comet 1A were BOAC , Union Aériomarine de Transport , and Air France . All early Comets were withdrawn from service for accident inquiries , during which orders from British Commonwealth Pacific Airlines , Japan Air Lines , Linea Aeropostal Venezolana , National Airlines , Pan American World Airways , and Panair do Brasil were cancelled . When the redesigned Comet 4 entered service , it was flown by customers BOAC , Aerolíneas Argentinas , and East African Airways , while the Comet 4B variant was operated by customers BEA and Olympic Airways , and the Comet 4C model was flown by customers Kuwait Airways , Mexicana , Middle East Airlines , Misrair Airlines , and Sudan Airways .

Other operators used the Comet either through leasing arrangements or through second @-@ hand acquisitions . BOAC 's Comet 4s were leased out to Air Ceylon , Air India , AREA Ecuador , Central African Airways , and Qantas Empire Airways ; after 1965 they were sold to AREA Ecuador , Dan @-@ Air , Mexicana , Malaysian Airways , and the Ministry of Defence . BEA 's Comet 4Bs were chartered by Cyprus Airways , Malta Airways , and Transportes Aéreos Portugueses . Channel Airways obtained five Comet 4Bs from BEA in 1970 for inclusive tour charters . Dan @-@ Air bought all of the surviving flyable Comet 4s from the late 1960s into the 1970s ; some were for spares reclamation but most were operated on the carrier 's inclusive tour charters ; a total of 48 Comets of all marks were acquired by the airline .

In military service , the United Kingdom 's Royal Air Force was the largest operator , with the 51 Squadron (1958 ? 1975 ; Comet C2 , 2R) , 192 Squadron (1957 ? 1958 ; Comet C2 , 2R) , 216 Squadron (1956 ? 1975 ; Comet C2 and C4) , and the Royal Aircraft Establishment using the aircraft . The Royal Canadian Air Force also operated Comet 1As (later retrofitted to 1XB) through its 412 Squadron from 1953 to 1963 .

= = Accidents and incidents = =

The Comet was involved in 26 hull @-@ loss accidents , including 13 fatal crashes which resulted in 426 fatalities . Pilot error was blamed for the type 's first fatal accident , which occurred during takeoff at Karachi , Pakistan on 3 March 1953 and involved a Canadian Pacific Airlines Comet 1A . Three fatal Comet 1 crashes due to structural problems , specifically BOAC Flight 783 / 057 on 2 May 1953 , BOAC Flight 781 on 10 January 1954 , and South African Airways Flight 201 on 8 April 1954 , led to the grounding of the entire Comet fleet . After design modifications were implemented , Comet services resumed in 1958 .

Pilot error resulting in controlled flight into terrain was blamed for five fatal Comet 4 accidents : an Aerolíneas Argentinas crash near Asunción , Paraguay on 27 August 1959 , Aerolíneas Argentinas Flight 322 at Campinas near São Paulo , Brazil on 23 November 1961 , United Arab Airlines Flight 869 in Thailand 's Khao Yai mountains on 19 July 1962 , a Saudi Arabian Government crash in the Italian Alps on 20 March 1963 , and United Arab Airlines Flight 844 in Tripoli , Libya on 2 January 1971 . The Dan @-@ Air de Havilland Comet crash in Spain 's Montseny range on 3 July 1970 was

attributed to navigational errors by air traffic control and pilots . Other fatal Comet 4 accidents include a British European Airways crash in Ankara , Turkey following instrument failure on 21 December 1961 , United Arab Airlines Flight 869 during inclement weather near Bombay , India on 28 July 1963 , and the terrorist bombing of Cyprus Airways Flight 284 off the Turkish coast on 12 October 1967 .

Nine Comets , including Comet 1s operated by BOAC and Union Aeromaritime de Transport and Comet 4s flown by Aerolíneas Argentinas , Dan @-@ Air , Malaysian Airlines , and United Arab Airlines , were irreparably damaged during takeoff or landing accidents that were survived by all on board . A hangar fire damaged a No. 192 Squadron RAF Comet 2R beyond repair on 13 September 1957 , and three Middle East Airlines Comet 4Cs were destroyed by Israeli troops at Beirut , Lebanon on 28 December 1968 .

= = Aircraft on display = =

Since retirement , three early @-@ generation Comet airframes have survived in museum collections . The only complete remaining Comet 1 , a Comet 1XB with the registration G @-@ APAS , is displayed at the RAF Museum Cosford . While painted in BOAC colours , it never flew for the airline , having been first delivered to Air France and then to the Ministry of Supply after conversion to 1XB standard ; this aircraft also served with the RAF as XM823 . The sole surviving Comet fuselage with the original square @-@ shaped windows , part of a Comet 1A registered F @-@ BGNX , has undergone restoration and is on display at the de Havilland Aircraft Museum in Hertfordshire , England . A Comet C2 Sagittarius with serial XK699 , later maintenance serial 7971M , has been on display at the gate of RAF Lyneham in Wiltshire , England since 1987 . In 2012 , with the planned closure of RAF Lyneham , the aircraft was slated to be dismantled and shipped to the RAF Museum Cosford where it will be re @-@ assembled for display .

Seven complete Comet 4s are housed in museum collections . The Imperial War Museum Duxford has a Comet 4 (G @-@ APDB) , originally in Dan @-@ Air colours as part of its Flight Line Display , and later in BOAC livery at its AirSpace building . A Comet 4B (G @-@ APYD) is stored in a facility at the Science Museum at Wroughton in Wiltshire , England . Comet 4Cs are exhibited at the Flugausstellung Leo Junior at Hermeskeil , Germany (G @-@ BDIW) , the Museum of Flight near Seattle , Washington (N888WA) , the National Museum of Flight near Edinburgh , Scotland (G @-@ BDIX) , and the Parque Zoológico Irapuato in Guanajuato , Mexico (N777WA) .

The last Comet to fly , Comet 4C Canopus (XS235) , is kept in running condition at Bruntingthorpe Aerodrome , where fast taxi runs are regularly conducted . Since the 2000s , various parties have proposed restoring Canopus , which is maintained by a staff of volunteers , to airworthy , fully flight @-@ capable condition . The Bruntingthorpe Aerodrome also displays a related Hawker Siddeley Nimrod MR2 aircraft .

= = Specifications = =

Sources : Jane 's All The World 's Aircraft 1965 ? 66 , De Havilland Aircraft since 1909 , and Flight International .

= = Popular culture = =