Mid-air Explosion of Comet I over the Mediterranean Sea

Jan. 10th, 1954, Over the Mediterranean Sea (near Rome)

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(Summary)

On January 10th, 1954, the Comet G-ALYP, the first jet air transport with a pressurized cabin in the world, exploded in mid-air as a result of fatigue failure of the fuselage structure at an altitude of 8,000m near Elba over the Mediterranean Sea, after taking-off from Rome. All thirty-five people on board were killed in this accident.

1. Component

Fuselage

2. Event

The Comet was developed right after World War II at de Haviland Aircraft Company in UK, and it started service operation in May of 1952. The first Comet, G-ALPY operated by BOAC, exploded in mid-air at an altitude of 8,000m over the Mediterranean Sea near Elba after the take-off from Champino airport, Rome. All thirty-five on board (6 crew and 26 passengers) were killed in this accident.

Figure 1 shows the Comet 1 air transport. Figure 2 shows the parts of the aircraft that were retrieved from the Mediterranean Sea by the salvage operation.

3. Course

The aircraft crashed after only 1,290 flight cycles (3,600 flight hours). This was only about one-tenth of expected design life. Following this accident, all flights of the Comet air transports were canceled, and the entire fleet was carefully inspected. 60 structural items that were thought to be suspect were reinforced. In March, the British Aviation Authority issued permission for resumption of the operation, and BOAC recommenced the flights.

However, a similar accident occurred again on April 8th, 1954 over the Mediterranean Sea near Naples involving an improved Comet air transport, G-ALYY. All twenty-one persons onboard were killed this time.

After a large-scale and exhaustive investigation, the direct cause of the accident was found to be fatigue cracks emanated from the corners of the ADF window at the ceiling of the fuselage and the windows in the passenger cabin that were caused by the pressurization cycles.

The fuselage structure of an aircraft having a pressurized cabin is subjected to pressurization fatigue cycles caused by the pressure difference between the cabin and the atmosphere outside. Generally, cabin pressure is maintained at around 0.8 atm, while the atmosphere pressure outside the aircraft is about 0.2

atm when cruising at an altitude of 12,000m in the stratosphere. Therefore, the fuselage structure is subjected to a 0.6 atm pressure difference each flight.

In the fatigue design of the Comet, the effect of this pressurization cycle was taken into consideration to some extent. During the development of the air transport, an internal pressure cycle test was conducted on the fuselage structure.

Fatigue cracks were first detected after 18,000 pressurization cycles, and therefore the fatigue design life was determined to be more than 10,000 flight cycles.

However, the accident occurred after far fewer flight cycles than this design life. The pressure pattern applied for the fatigue test using the actual fuselage structure is shown in Fig. 1. In the fatigue test, the pressure difference inside and outside of the cabin was assumed to be 0.56 atm. However, in the fatigue test conducted on the ground, a proof pressure load corresponding to 1.12 atm, that is twice that of actual pressure difference, was applied every 1,000 pressure cycles for safety purposes. As a result of this test, the fatigue crack initiation life was determined to be 18,000 pressure cycles.

The effect of proof pressure test that was not conducted on actual aircraft for service was examined during the accident investigation study. A fatigue test was conducted on an aircraft that had experienced 1,230 service flights after applying a proof pressure test of 0.75 atm. In that test, fatigue cracks were detected after 1,830 pressure cycles. The total of 3060 cycles is about one-sixth of the 18,000 cycles obtained by the fatigue tests with the higher proof pressure loads. This fact implied that the fatigue cycle might approach 1,290 or 900 cycles of accident aircraft provided that proof pressure test was not conducted. It was made clear that the proof pressure test conducted during fatigue test extended the fatigue life, and as the result, proof pressure test during fatigue test could not give the safety side prediction of the fatigue life.

4. Cause

The following causal factors contributed to the occurrence of the accidents after a considerably smaller number of flight cycles than the guaranteed fatigue life of 18,000 flight cycles.

(1) Following the regulations of the British Aviation Bureau, a periodical proof pressure test with a pressure load twice that of normal cabin pressure was conducted during the internal pressure fatigue test. Crack initiation was observed after 18,000 pressurizing cycles in that test. However, tensile plastic deformation was induced at the corners of the windows by the proof pressure load. The plastically deformed zone formed a compressive residual stress field when the proof-pressure was removed, which resulted in longer fatigue life, because a compressive residual stress field has the same effect as reduced mean stress conditions (See Fig. 2).

(2) Instead of the full-scale fuselage structure, only a part of the cylindrical fuselage fixed at the rigid steel wall was provided for the internal pressurization fatigue test. This test condition resulted in an under-estimate of the deformation and strain compared with those of the actual aircraft structures.

(3) Unlike the oval shaped windows in aircraft today, the windows were almost rectangular, with small radius at each corner. Consequently, the stress concentration factor was high, and fatigue cracks initiated readily.

5. Immediate Action

BOAC stopped operation of all Comet aircraft immediately, and the British Aviation Authority suspended the type certificate of the aircraft. The British government ordered the Royal Aircraft Establishment to conduct a thorough investigation into the cause of the accidents.

Many fragments of the aircraft were retrieved from the sea at a depth of 180m by salvage and were reconstructed on the ground. In parallel to these operations, a pressurizing fatigue test for the full-scale fuselage structure was conducted by immersing it in a huge water chamber.

6. Countermeasure

Thorough revisions were made to the fatigue test methodology for full-scale structures and fatigue design concept. The major revisions are as follows:

(1) For the development of new aircraft, two full-scale structures must be provided for testing: one is for the static load test, and the other is for the fatigue test including the pressurization test.

(2) In conducting the full-scale fatigue tests, in addition to the effect of the magnitude and number of fatigue loads, the effect of the load sequence must be taken into consideration.

(3) Stress concentration factors of cutouts and notches must be correctly evaluated, and they must be minimized in the design of the structure as much as possible.

7. Knowledge

(1) Effect of proof pressure test: Proof pressure loading is beneficial for the safety assurance of most of pressure vessels when they are provided for service. However, in the case of aircraft, proof pressure load is not applied to the actual fuselage structure. In such a case, the fatigue life will be much shorter than that with proof loading beforehand.

(2) Effect of load sequence on fatigue life: In the event of the fatigue life evaluation of structures subjected to random fatigue loads, the application order of very high overload that might appear only a few times during entire life significantly affects the total life estimate. When a large tensile overload is applied in earlier stages of the fatigue test, the total fatigue life becomes longer, which gives us an unsafe estimation of the actual fatigue life. This effect must be taken into account for testing and evaluation.

(3) Notch effects on fatigue life: Stress concentrated by notches often causes fatigue cracks to occur. The crack initiation time becomes shorter as the stress concentration becomes higher. Therefore, the stress concentration at notch corners should be reduced by giving the notch corner a larger radius.

8. Background

One year before the accident, on May 2nd, 1953, an accident on Comet occurred at Calcutta, the cause of which is now believed to be the same as above-mentioned in that accident, forty-eight people on board were killed in the crash that occurred eight minutes after the take-off. At that time, the cause was thought to be either a pilot error, a sandstorm or a whirlwind. However, the method for investigating the cause of aircraft accidents was not established yet then, and no further examination was conducted.

9. Sequel

At the time of the accident investigation, the effect of pressure overloads on fatigue life had not been correctly recognized. Today, however, the effect of overloads on extension of fatigue life is considered as follows:

Figure 6 shows the relationship between the crack length (a) and number of fatigue cycles (N) for a constant amplitude fatigue test with periodical overload cycles as given in the Figure. The fatigue life for case C is four times longer than that for case A as a result of the residual compressive stress induced by the tensile overload. The mechanism for this effect is explained by (a) and (b) in the same Figure. It can also be explained by the concept of crack closure and plastic wake model.

As described above, the extension of fatigue life by the periodical application of tensile overload has been verified by theory and experiment.

10. On the Side

While the UK was involved in the investigation of the accident cause and the development of new safety measures during which time the type certificate of the de Haviland Comet was suspended, Boeing succeeded in developing the B-707 jet air transport aircraft.

By the time that de Haviland had overcome all of the troubles and finished the development of the new Comet-Ⅳ, the entire international market of jet aircraft had shifted to the US.

11. Social Impact

This accident gave many people the impression that the commercialization of the jet aircraft with pressurized cabin at that time may be premature. In particular, people became uneasy about its reliability and safety.

12. Information Source

(1) ICAO Aircraft Accident Digest Vol. 6-2(1956) pp.16-45.

13. Primary Scenario

01. Ignorance
02. Insufficient Knowledge
03. Error of Evaluation/Test Method
04. Insufficient Analysis or Research
05. Insufficient Prior Research
06. Ignorance of Residual Compressive Stress Effect
07. Insufficient Analysis or Research
08. Insufficient Environment Study
09. Under-Estimation of Stress/Strain
10. Planning and Design

11. Poor Planning
12. Non-avoidance of Stress Concentration
13. Usage
14. Operation/Use
15. Operation of aircraft
16. Failure
17. Fracture/Damage
18. Fatigue Failure
19. Failure
20. Large-Scale Damage
21. Mid-air Explosion
22. Crash
23. Loss to Organization
24. Economic Loss
25. Loss of International Market
26. Damage to Society
27. Change in Perception
28. Increase of Distrust to Jet Air Transport

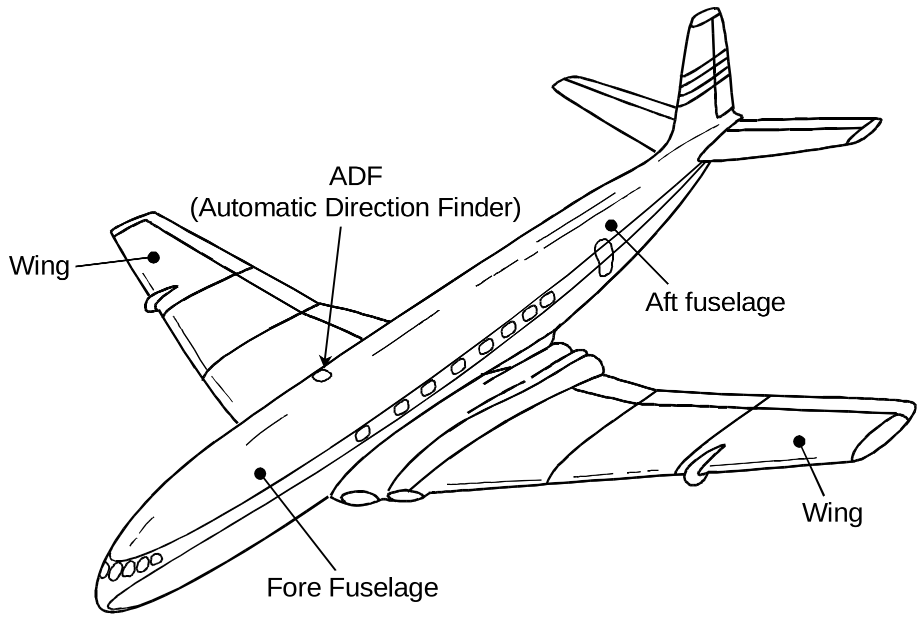

Fig. 1 Comet-1 (G-ALYP).

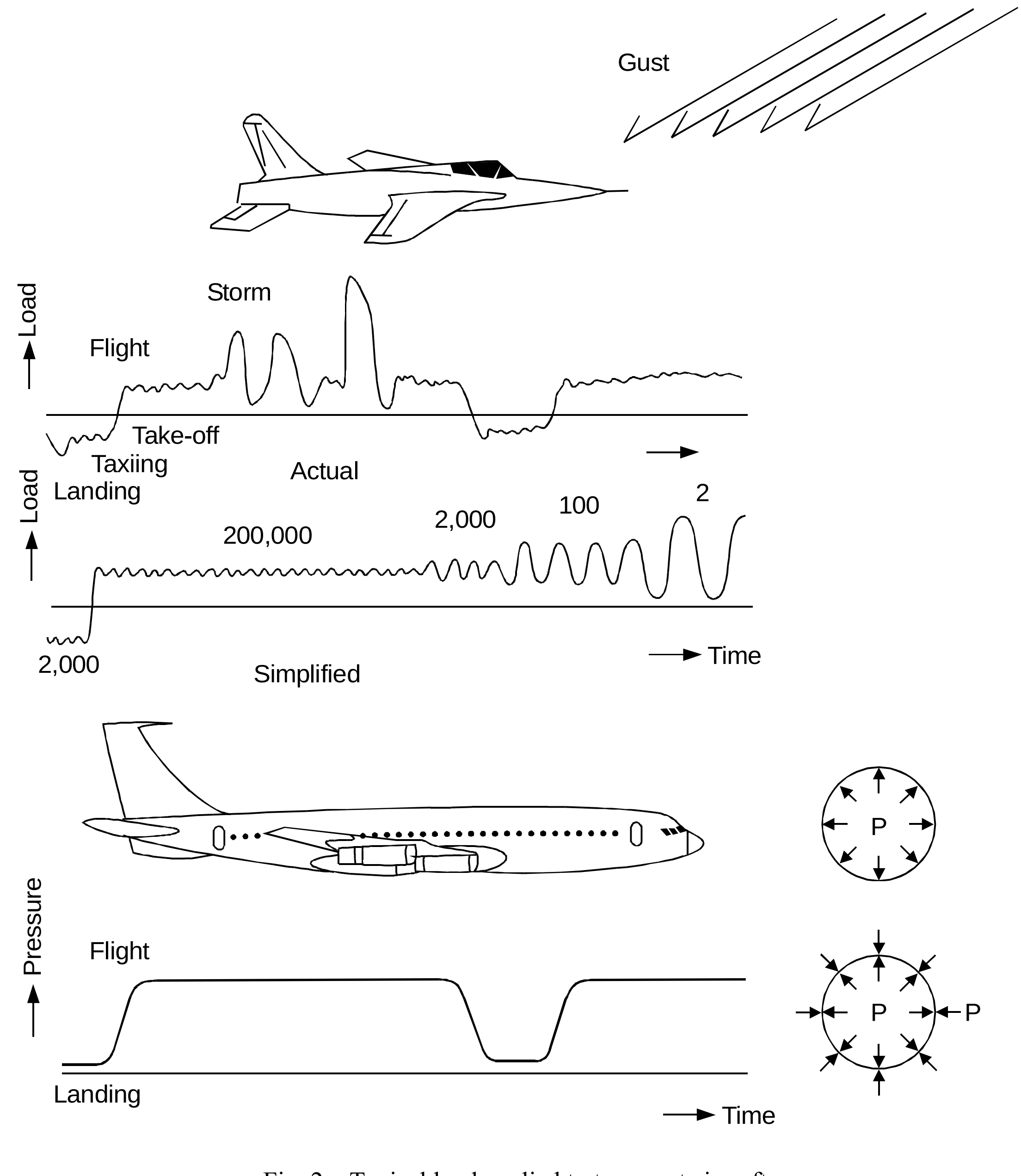

Fig. 2 Typical load applied to transport aircraft.

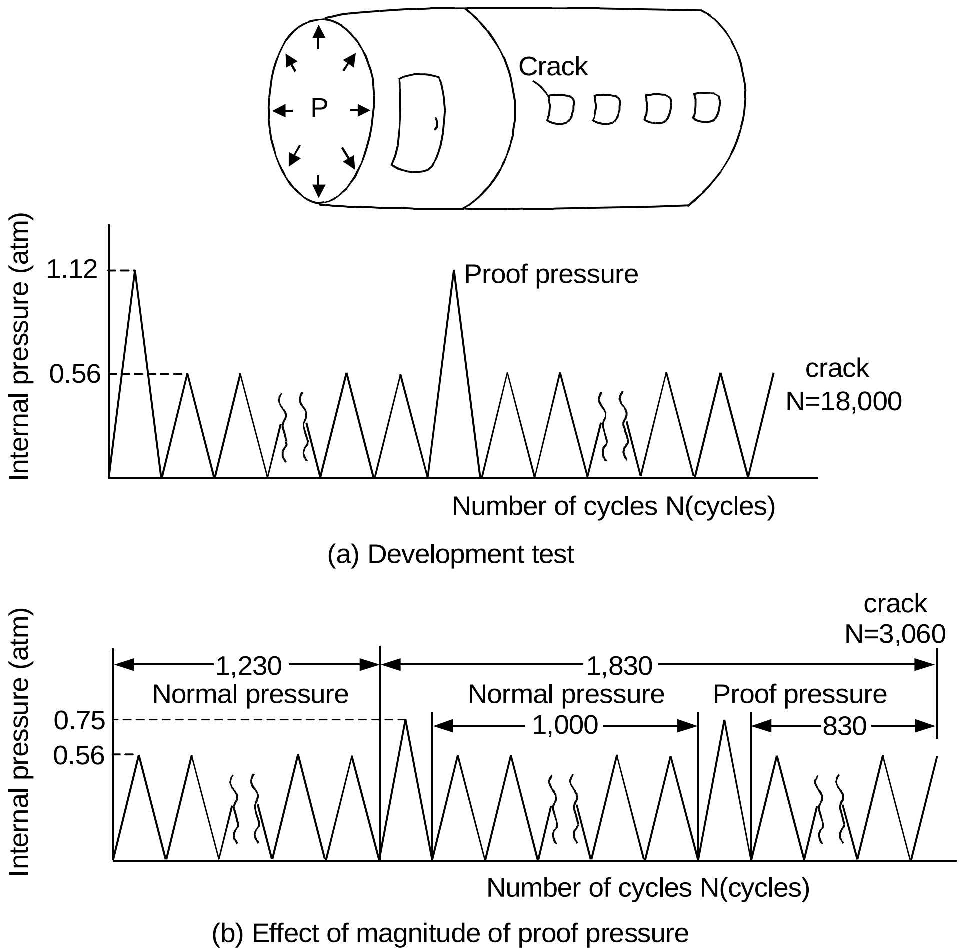

Fig. 3 Pressurizing Pattern of Comet Ⅰ

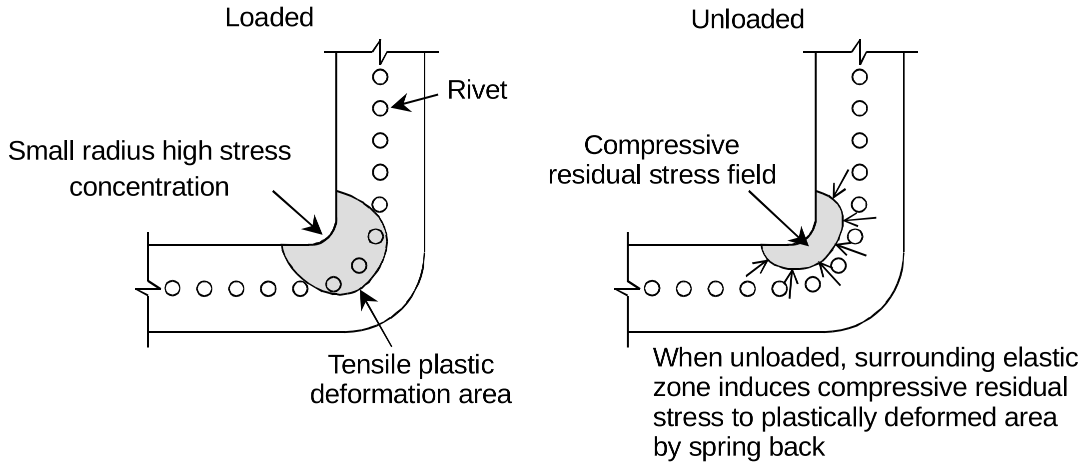

Fig. 4 Deformation at Window Corner by Loading and Unloading of Overload.

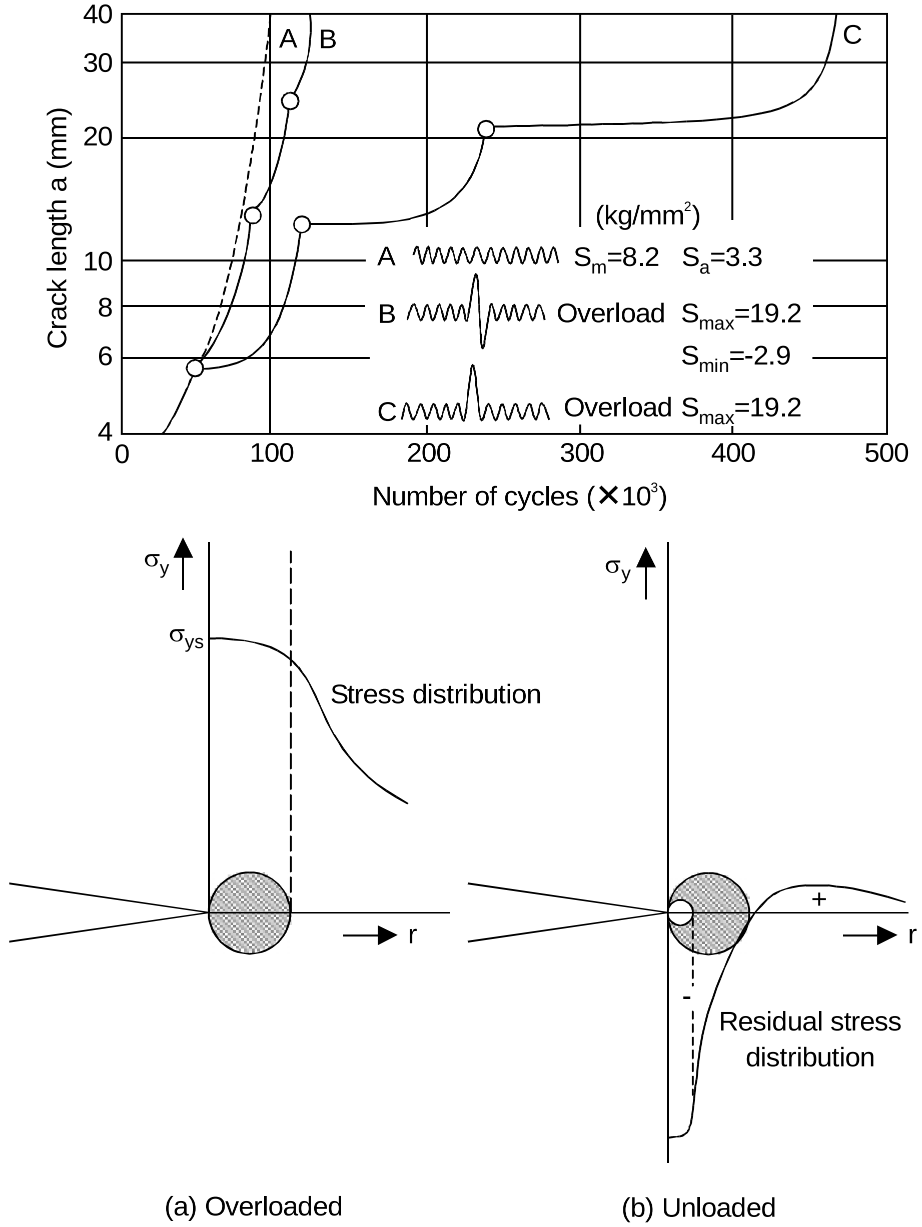

Fig. 5 Relation Between Crack Length and Fatigue Cycles Under Periodical Overloads.