Airframe Structural Fatigue

Past, Present and Future

James Burd

AERONAUTICA

AA&S 2017
Phoenix, Arizona

Airframe Structural Fatigue

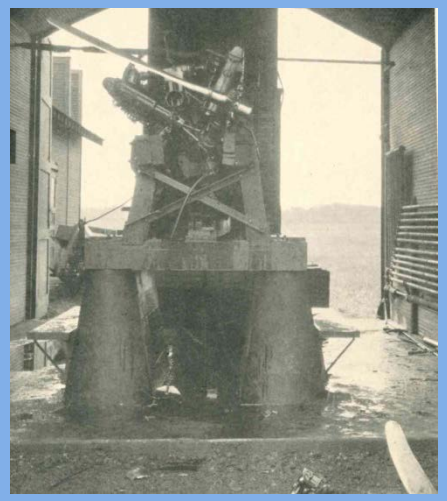
- Fatigue remains a primary concern today for the aviation industry. However, its been a long road with many lessons learned along the way.

"The farther back you can look, the farther forward you are likely to see." Churchill

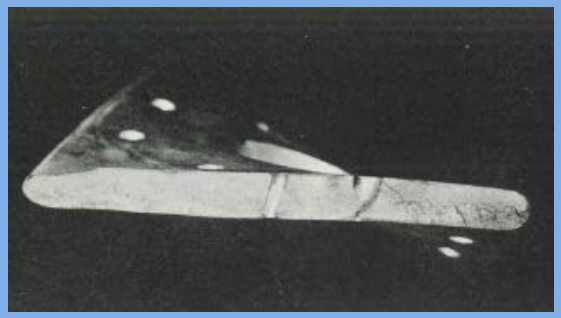
- Discussion:
  - Background
  - Accidents Related to Fatigue
  - Case Studies – Past thru Present
  - Review of Service Difficulties – Then and Now
  - Challenges

Background

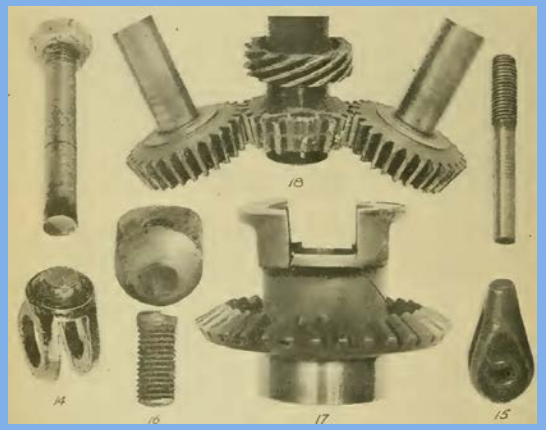
- Initial failures primarily occurred in engine components, flight control cables and propellers but primary structure was also of concern.
- Earliest recorded fatigue testing performed by Advisory Committee for Aeronautics in 1913 on the B.E. 2 wing spars in Great Britain.



Propeller Fatigue Test – McCook Army Airfield 1926



Fatigue Crack in Propeller Blade



Fatigue Failures of Engine Parts and Cable Fittings

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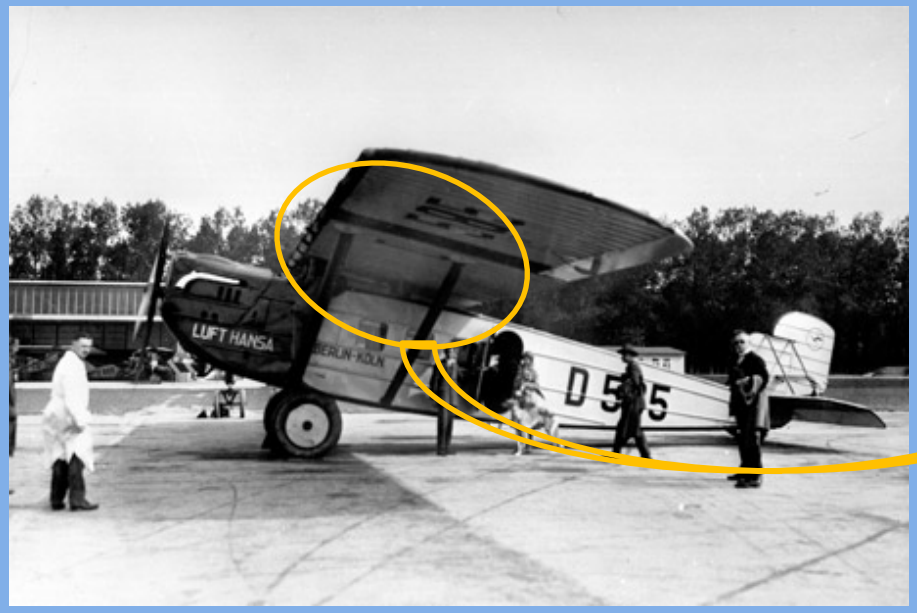
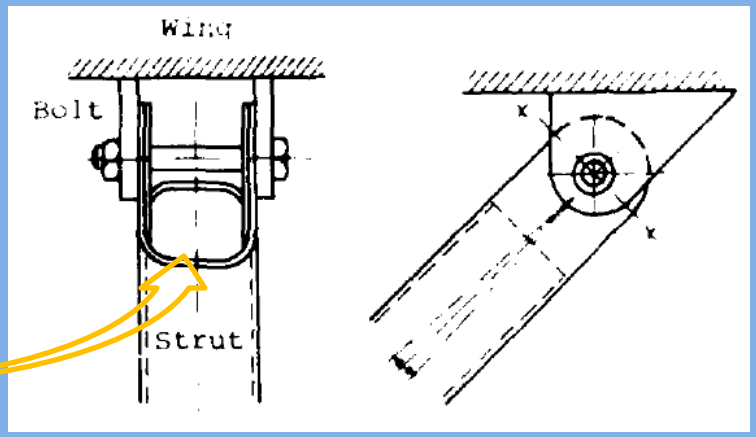
Background

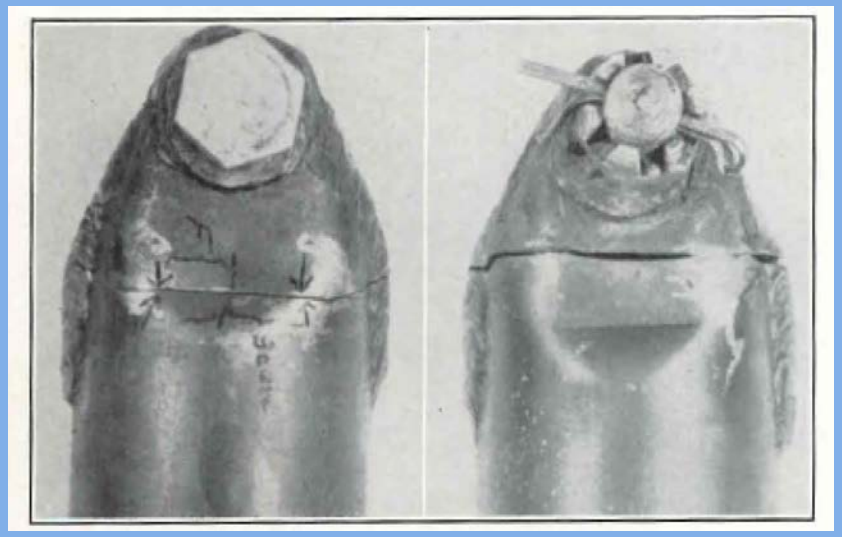
- Earliest publicized aircraft accident due to airframe fatigue occurred on 23 September 1927 when a Dornier Merkur flight from Munich to Berlin crashed due to a wing strut fatigue failure.





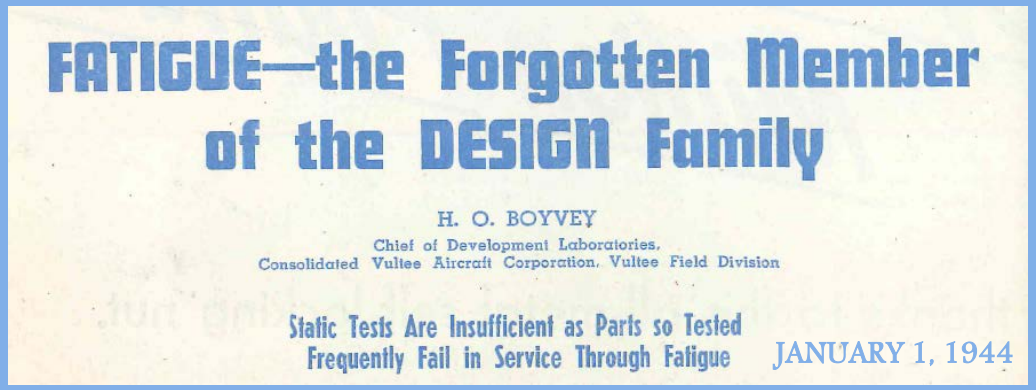
Background

- The earliest documented fatigue failure on a general aviation aircraft operating in the USA occurred on 2 May 1925 when an Alexander Model D-2 crashed due to a wing strut fatigue failure which was investigated by the then Bureau of Standards.



Background

- With the expansion in aviation and the impending global conflict of WW2, the sheer number of aircraft and usage rose exponentially in the later 1930's and early 1940's. With the increase, the issue of airframe fatigue came to the forefront particularly with the armed air forces and manufacturers.
- As a result, a significant increase in the number of incidents and accidents attributed to fatigue rose and so did the interests within the technical community.



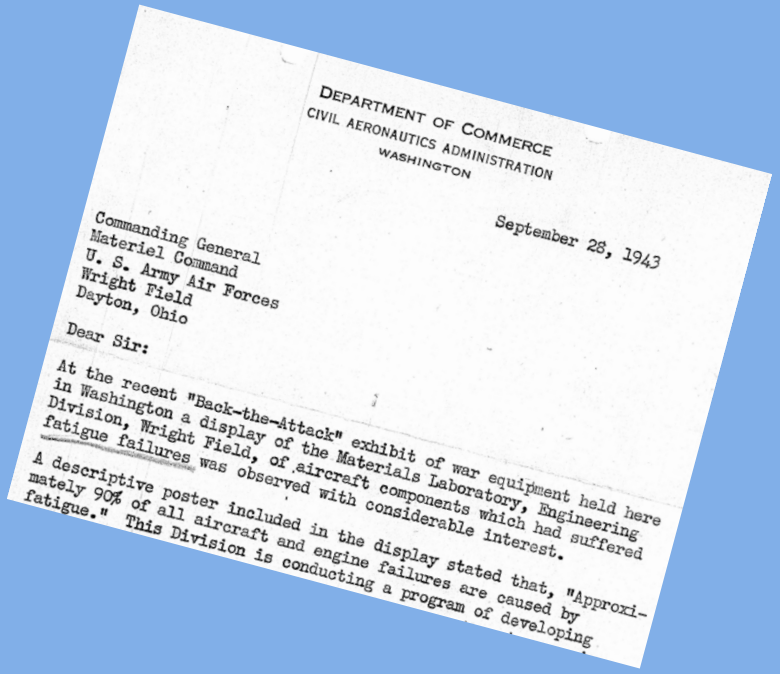
FATIGUE—the Forgotten Member of the DESIGN Family

H. O. BOYVEY

Chief of Development Laboratories,
Consolidated Vultee Aircraft Corporation, Vultee Field Division

Static Tests Are Insufficient as Parts so Tested Frequently Fail in Service Through Fatigue

JANUARY 1, 1944



DEPARTMENT OF COMMERCE
CIVIL AERONAUTICS ADMINISTRATION
WASHINGTON

September 28, 1943

Commanding General
Materiel Command
U. S. Army Air Forces
Wright Field
Dayton, Ohio

Dear Sir:

At the recent "Back-the-Attack" exhibit of war equipment held here in Washington a display of the Materials Laboratory, Engineering Division, Wright Field, of aircraft components which had suffered fatigue failures was observed with considerable interest.

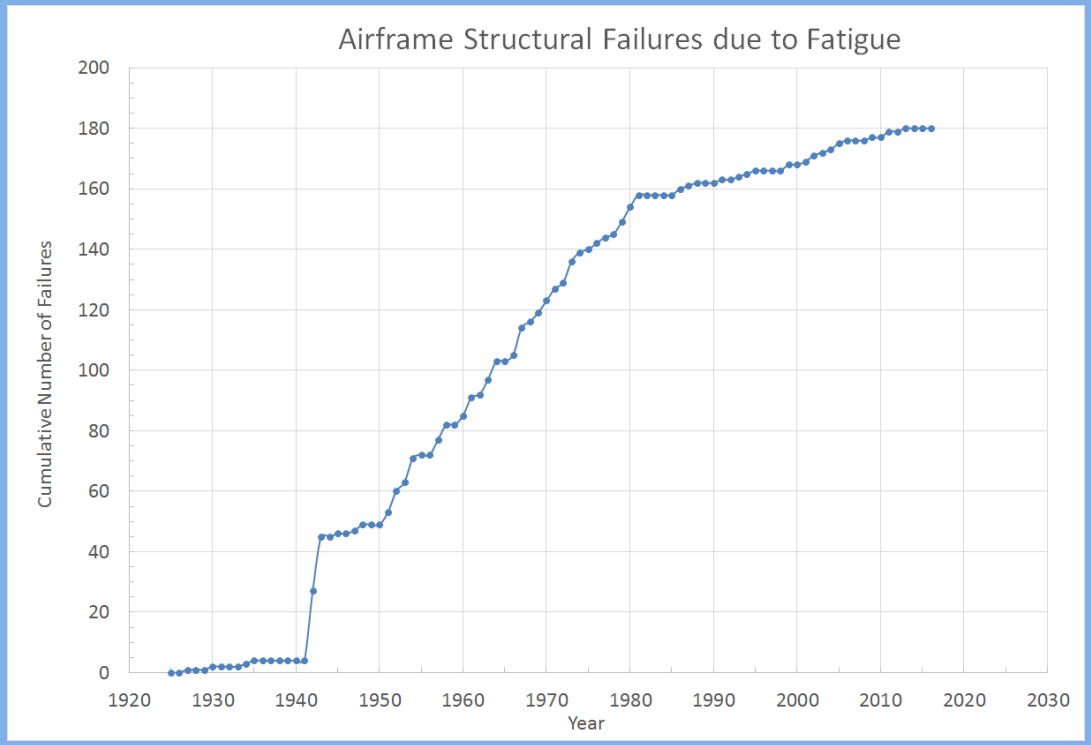
A descriptive poster included in the display stated that, "Approximately 90% of all aircraft and engine failures are caused by fatigue." This Division is conducting a program of developing

Accidents & Incidents

- Early accidents due to fatigue prior to 1940 were isolated occurrences.
- WW2 brought enormous increase in aircraft production and utilization.
- Large numbers of aircraft utilized for training pilots during WW2 logged considerable flight hours bringing metal fatigue to the fore front.
- Post WW2 expansion in technology and travel expanded the aviation industry further.
- Following charts depict major accidents and/or incidents attributed to fatigue from 1920 to present.
- Trend demonstrates that major accidents due to fatigue have leveled off since the implementation by industry of fatigue and fracture controls in both production and service

Accidents & Incidents - Summary

- Historical trends show a rapid rise in fatal crashes due to fatigue post WW2 and then a distinct drop in crashes due to fatigue after around 1980 (industry actively addressing the issues)



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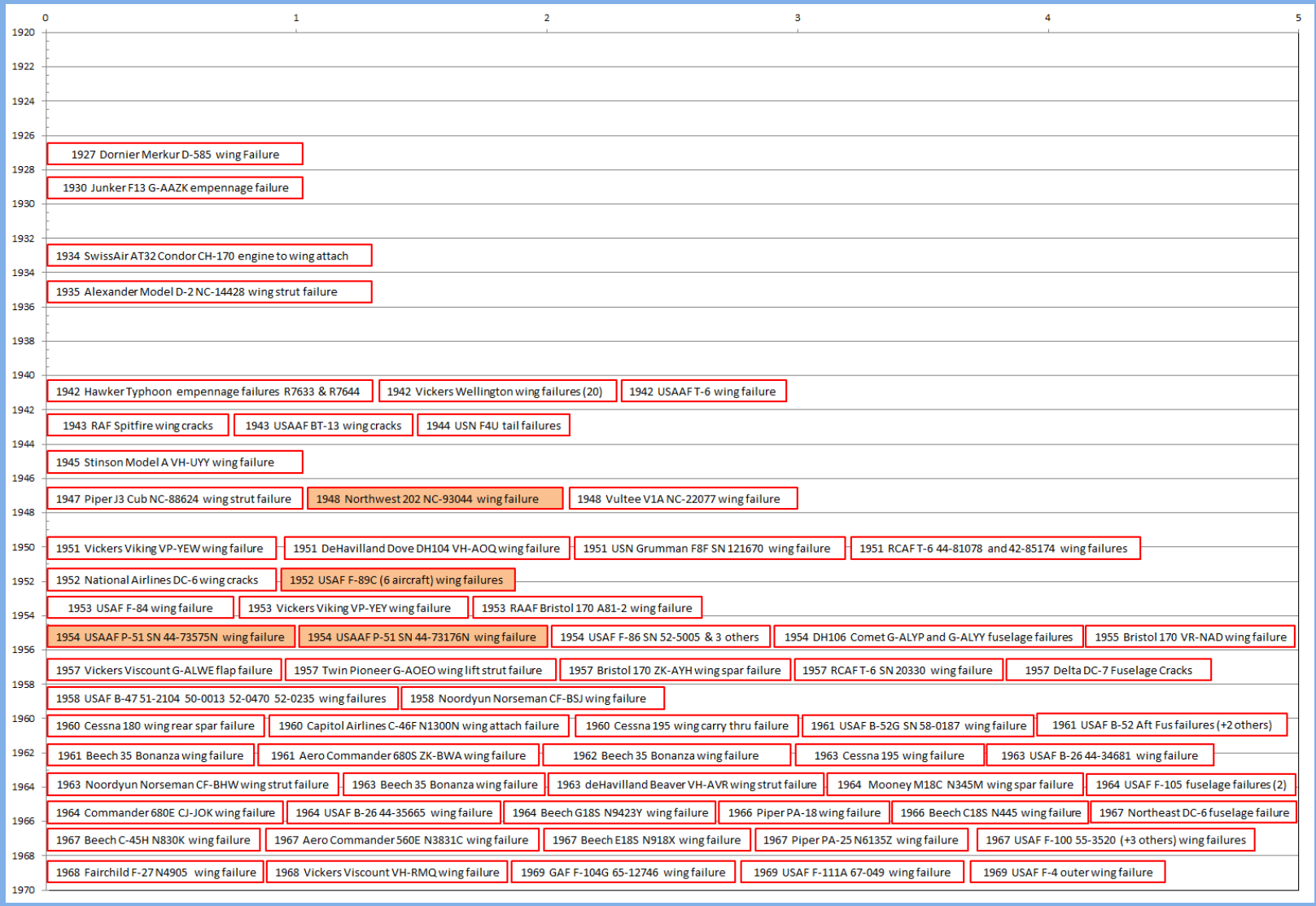
Accidents & Incidents 1920-1970



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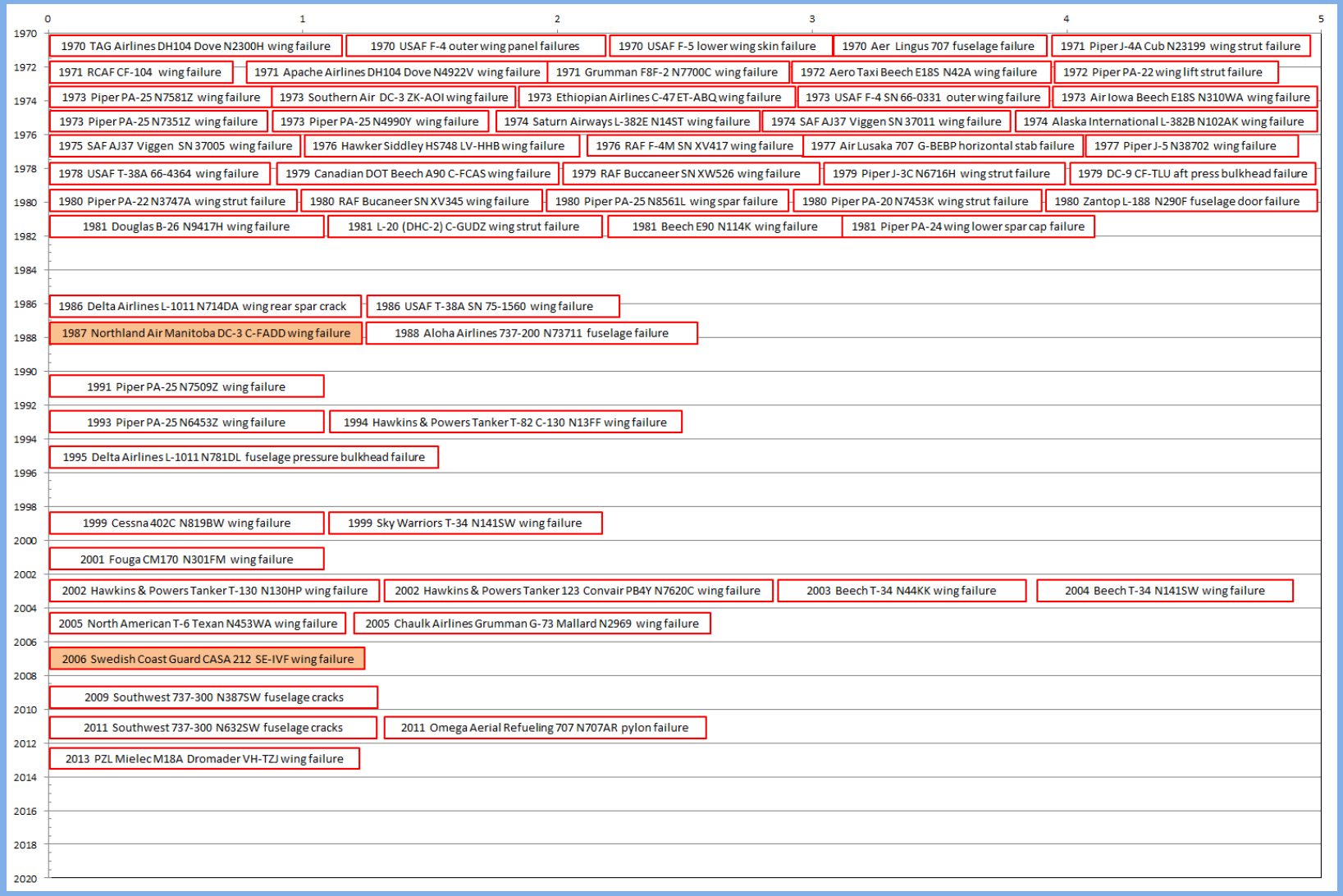
Accidents & Incidents 1970-Present



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Accidents & Incidents

Northwest Airlines Flight 421 Chicago to Minneapolis- Martin 202, NC93044 – 29 Aug 1948

8/29/48	Nr. Winona, Minnesota	Northwest	Martin 202	37	4 - - -	33 - - -	Destroyed	

During flight through a thunderstorm area, a structural failure originating in the wing panel attachment fitting occurred. The aircraft then broke apart in the air resulting in fatal injury to all on board.

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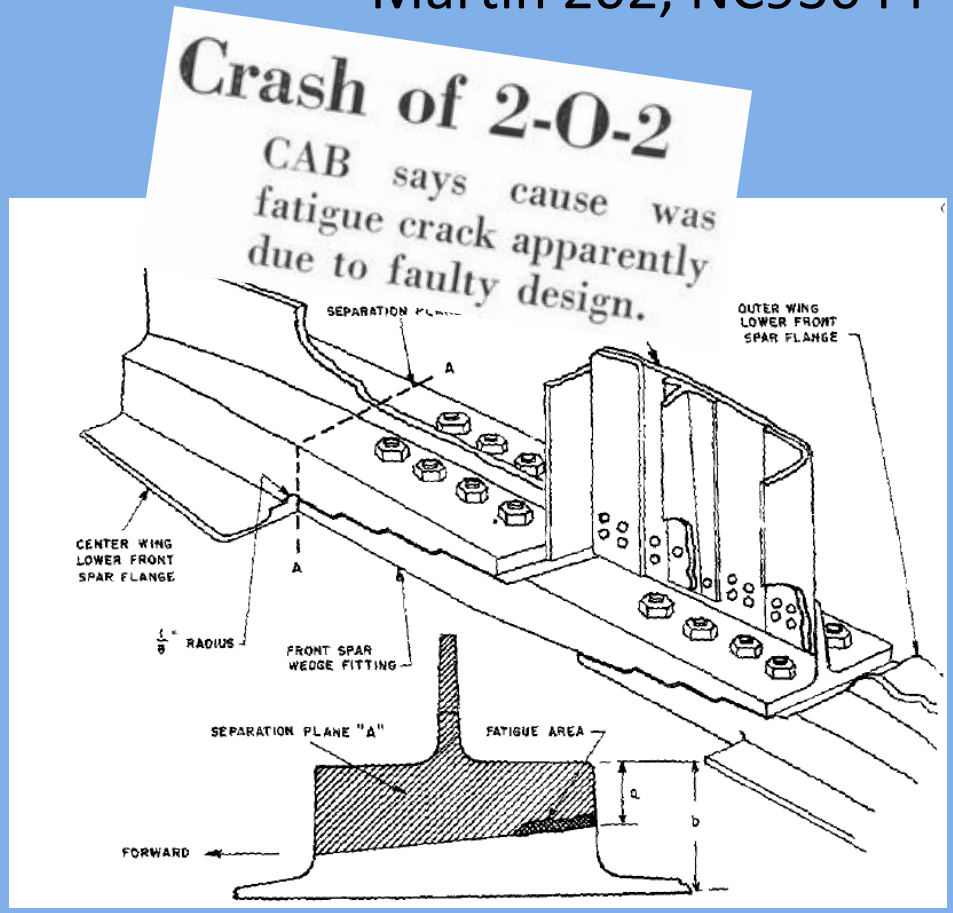
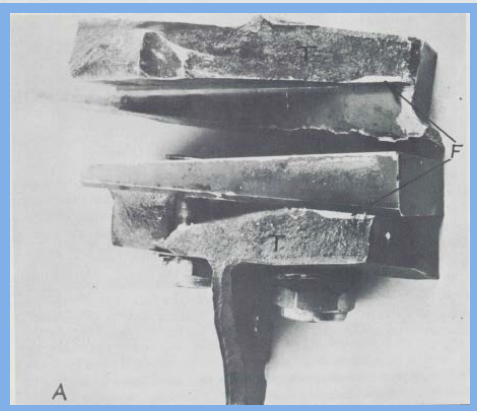
Accidents & Incidents

Northwest Airlines Flight 421 Chicago to Minneapolis-
Martin 202, NC93044 – 29 Aug 1948





Wing Joint at WS187 Failure – Spar Cap and Fitting are 75ST Material

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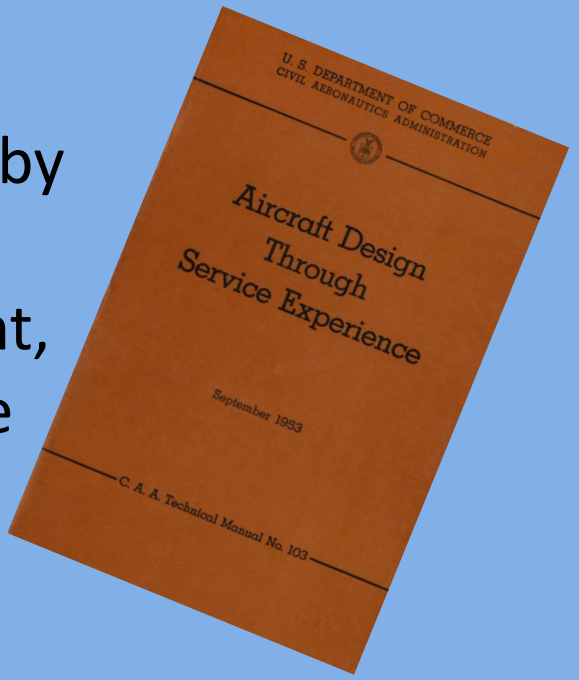
Accidents & Incidents

Northwest Airlines Flight 421 Chicago to Minneapolis-
Martin 202, NC93044 – 29 Aug 1948

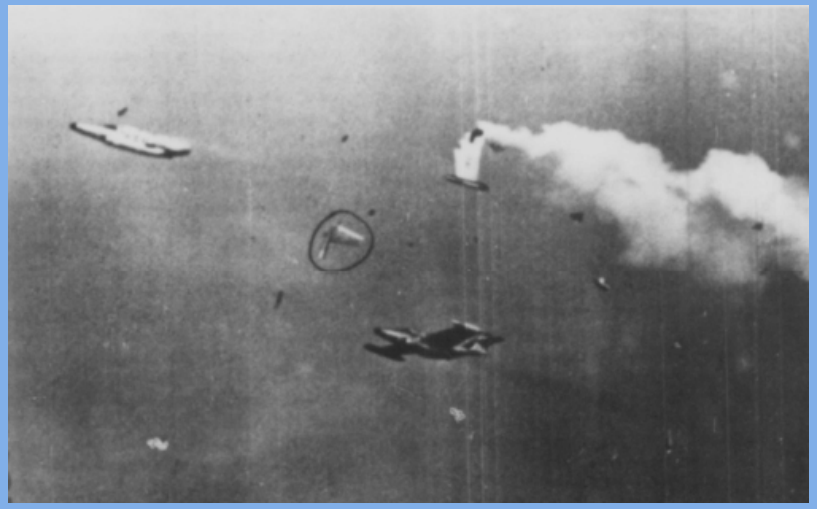
- Investigation discovered high stress concentrations caused fatigue failure
- Full scale fatigue testing was conducted by Martin. Did not find any cracking during visual inspections. Following the accident, a more detailed inspection found fatigue cracks at the joint.
- CAA mandated inspections & mod.
- CAA published as example in TM 103
- Accident was impetus for CAR 4b.270 *new fatigue rule

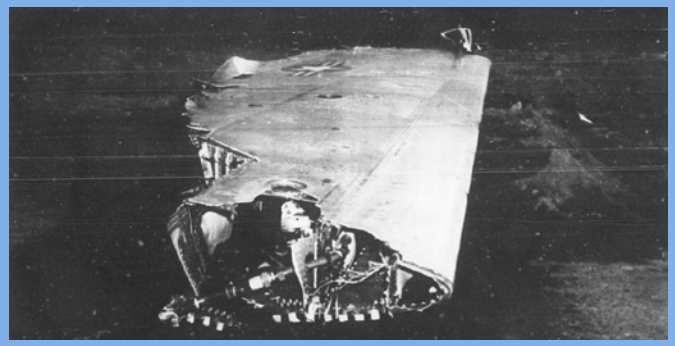


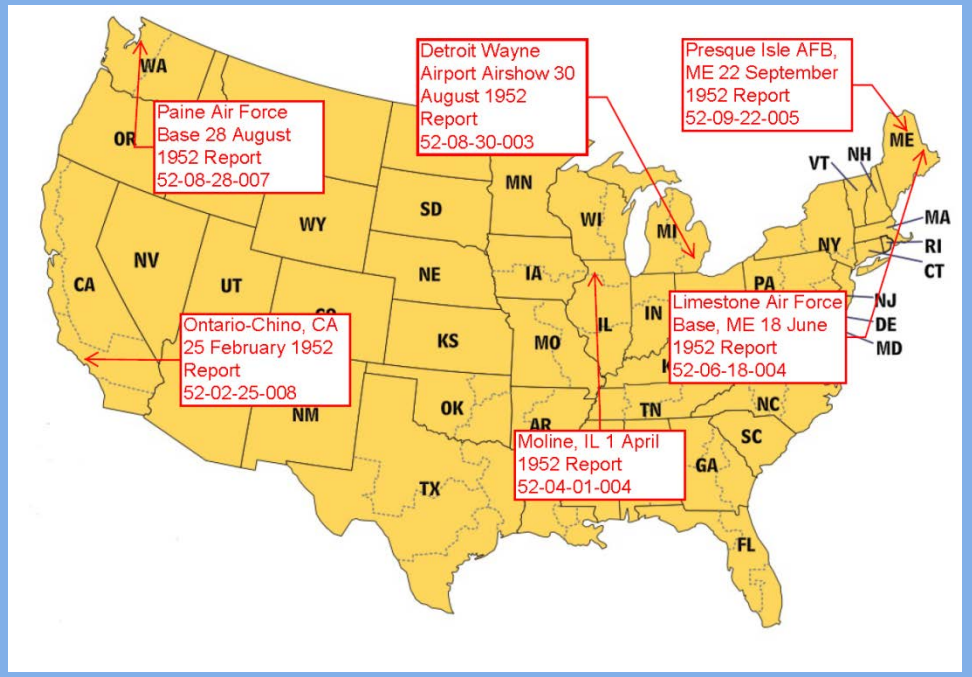
ISSUE: HIGH STRESS CONCENTRATION

Accidents & Incidents

USAF F-89C, 25 Aug. 1952, SN 51-5781 Detroit Airshow



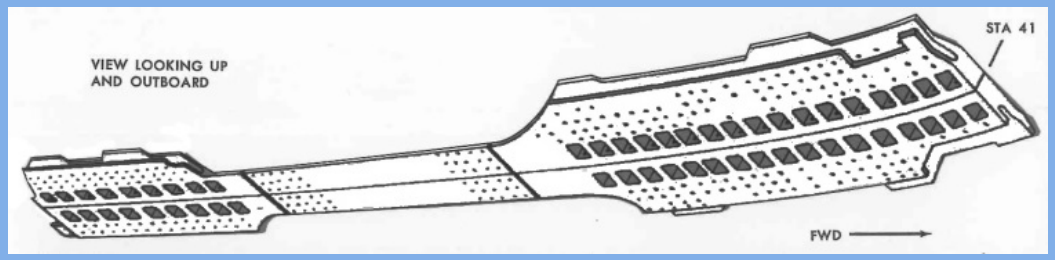


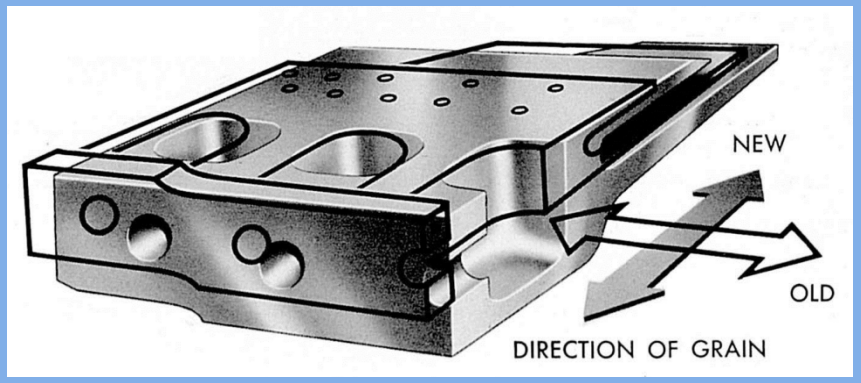


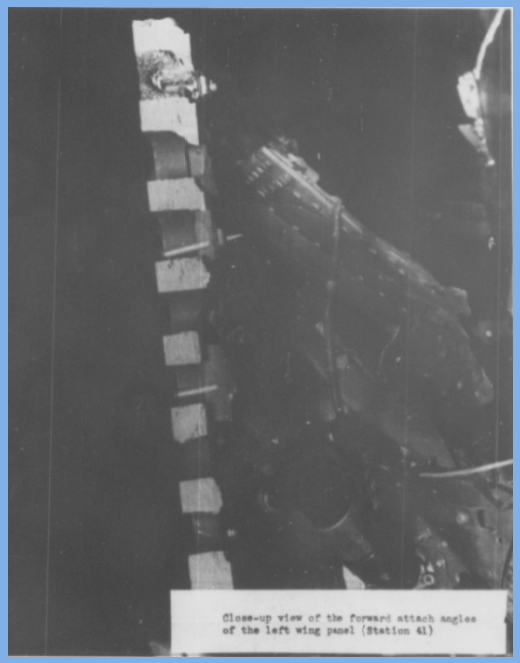
A total of 6 wing failures occurred in 1952 in little over a 6 month period

Accidents & Incidents

USAF F-89C, 25 Aug. 1952, SN 51-5781 Detroit Airshow






Close-up view of the forward attach angles of the left wing panel (Station 41)

The fitting was redesigned to be heavier and also align the material grain orientation to be parallel with the applied fatigue loads

It was fatigue failure of these extruded fittings that is now credited with causing the series of Scorpion crashes that resulted in USAF grounding of all F-89s last September.

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Accidents & Incidents

USAF F-89C, 25 Aug. 1952, SN 51-5781 Detroit Airshow

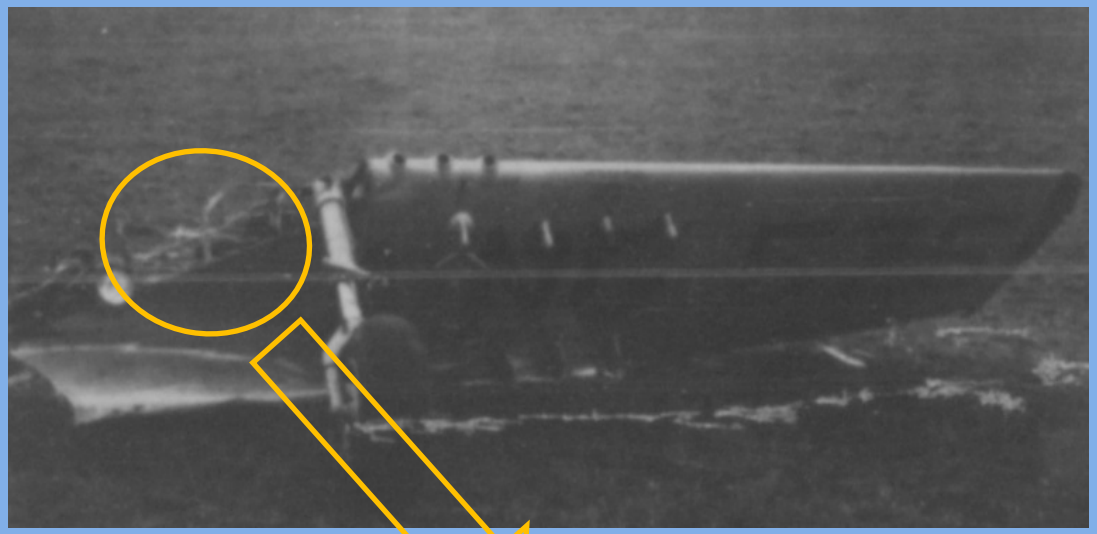
- Initial accidents attributed to pilot error
- Accident investigation found:
  - F-89C experienced higher external outer wing loads than engineering predicted
  - High stresses at wing attach
  - Poor material grain orientation (75ST)
- USAF mandated fatigue testing
- USAF ordered fleet modification

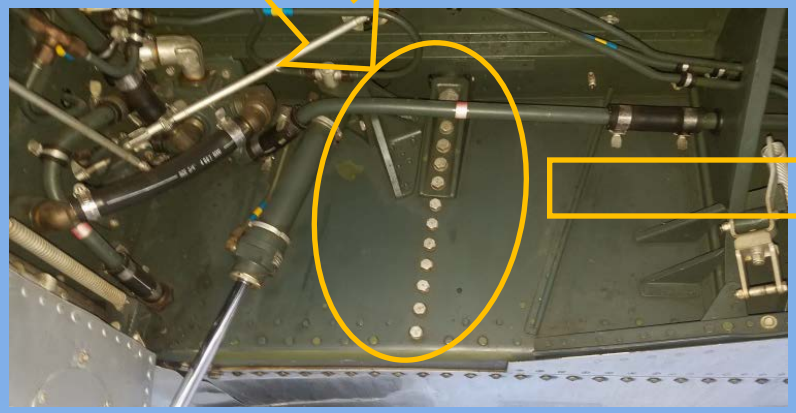
AF Plans $15-Million F-89 Fix

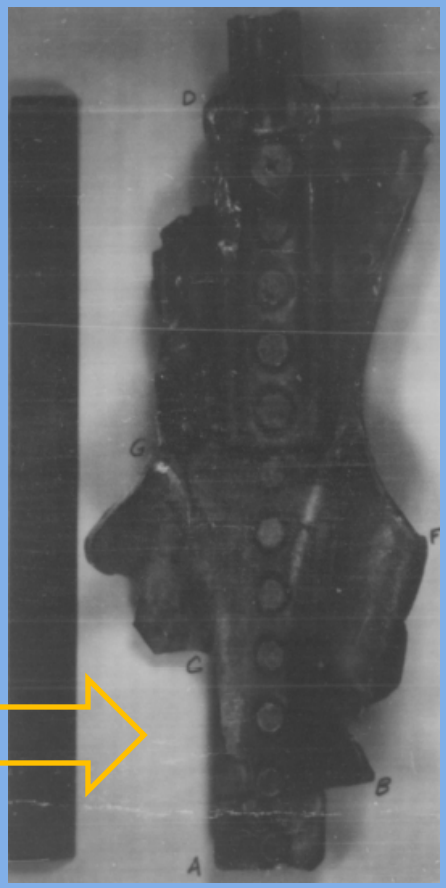
ISSUE: POOR GRAIN ORIENTATION & HIGH LOADS

Accidents & Incidents

USAF F-51D, 9 Nov. 1954 SN 44-73575



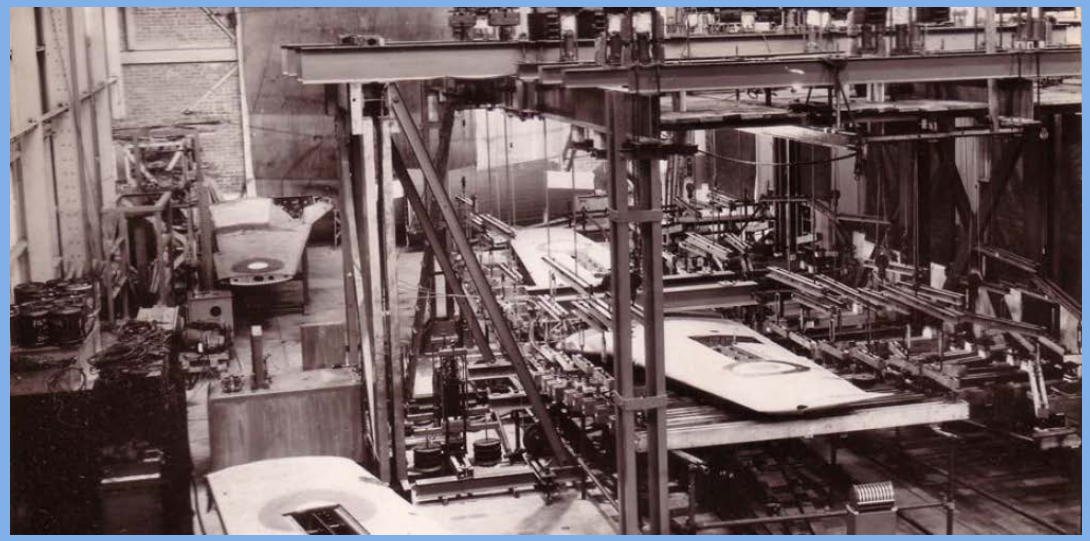


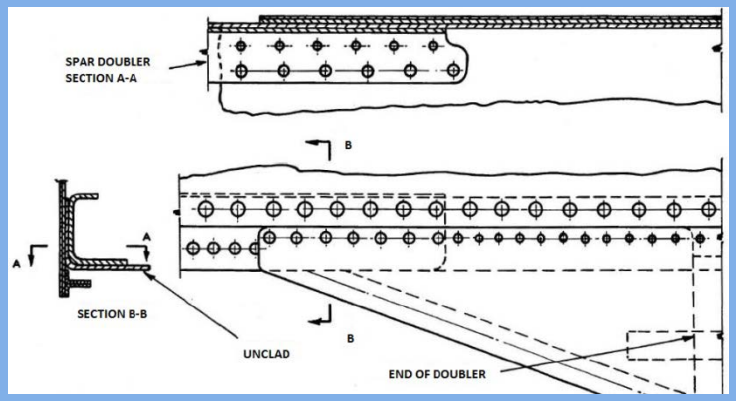


WS17 Wing to Fus Attach

Accidents & Incidents

USAF F-51D, 9 Nov. 1954 SN 44-73575





ARL Tests: 1950-1964:

Over 100 P-51 wings fatigue tested

Multiple Failures in Wing

Material = 24ST

WS 17.5 to 28

Wing Spar Fatigue Failure at Attachment WS 17.5 (same as in-service failure location)

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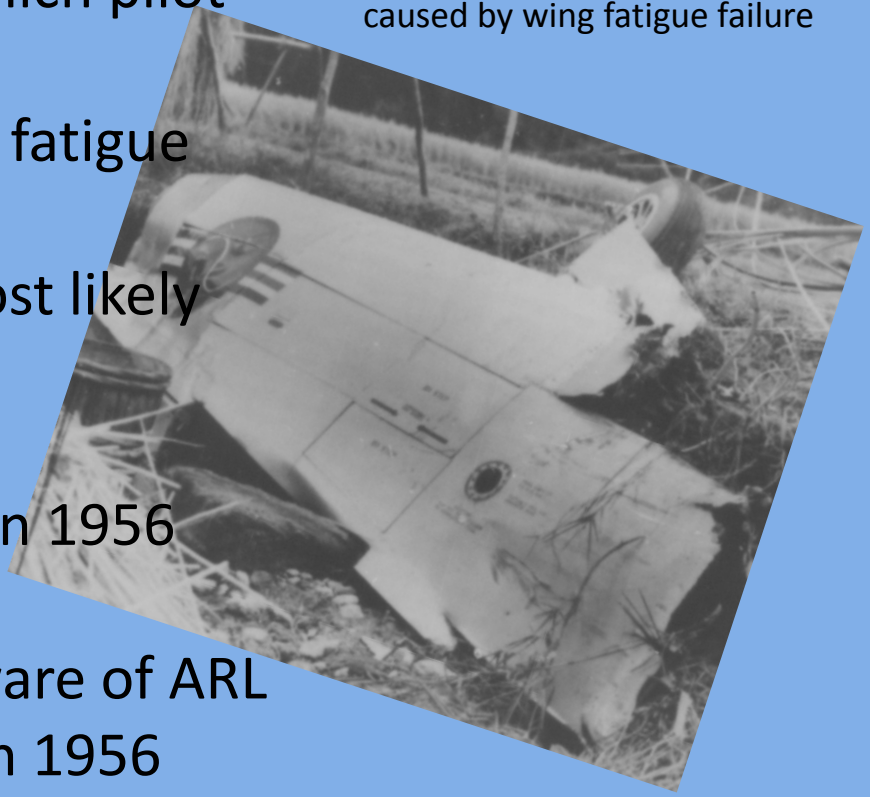
Accidents & Incidents

USAF F-51D, 9 Nov. 1954 SN 44-73575

- Initial accidents attributed to pilot error
- SN 44-73575 sole accident in which pilot survived to testify
- Material examination identified fatigue cracks at WS 17 joint
- Other previous wing failures most likely were due to fatigue
- USAF issued alert to squadrons
- USAF retired F-51 from service in 1956 due to aging fleet issues
- USAF seems to have been unaware of ARL testing which NACA published in 1956

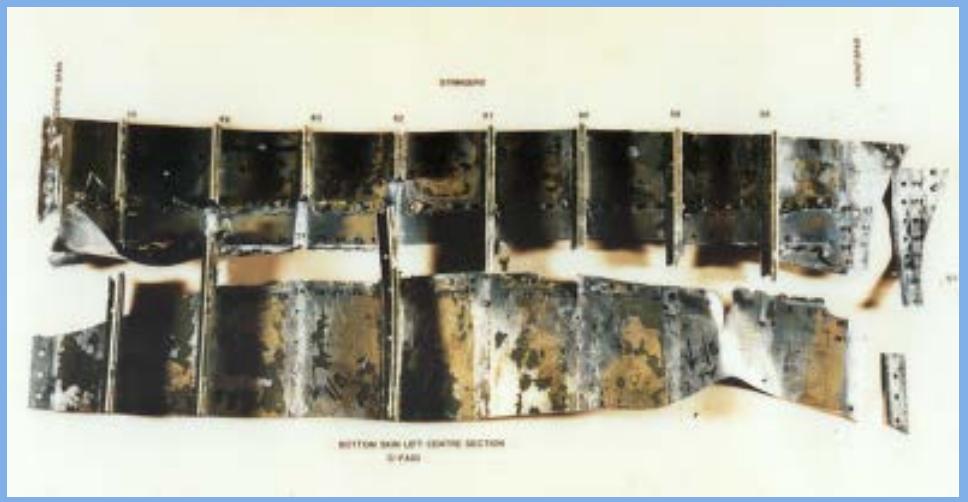
Another F-51 accident revisited and believed to be caused by wing fatigue failure



ISSUE: AGING FLEET – UNKNOWN FATIGUE STATE

Accidents & Incidents

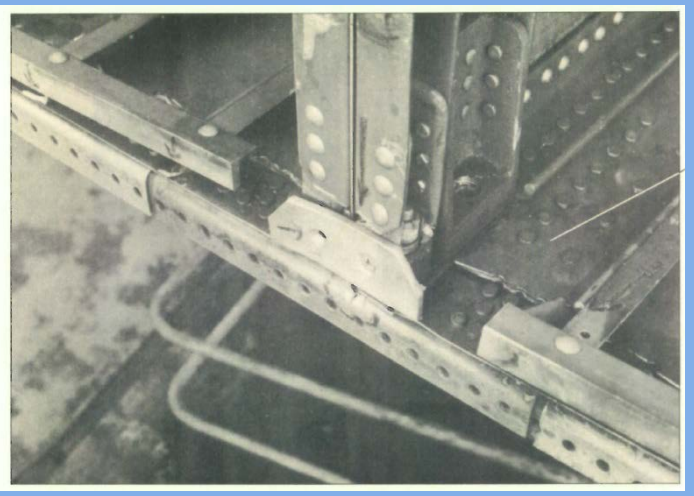
1987 NORTHLAND AIR MANITOBA DC-3 C-FADD



The left wing failed, under normal flight loads, as a result of a fatigue crack in the centre section lower wing skin. Anomalies in the radiographs taken during mandatory non-destructive testing inspections were not correctly interpreted.

Accidents & Incidents

1987 NORTHLAND AIR MANITOBA DC-3 C-FADD



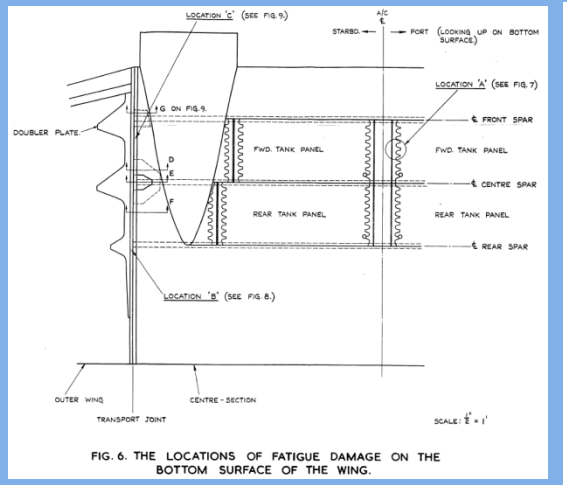
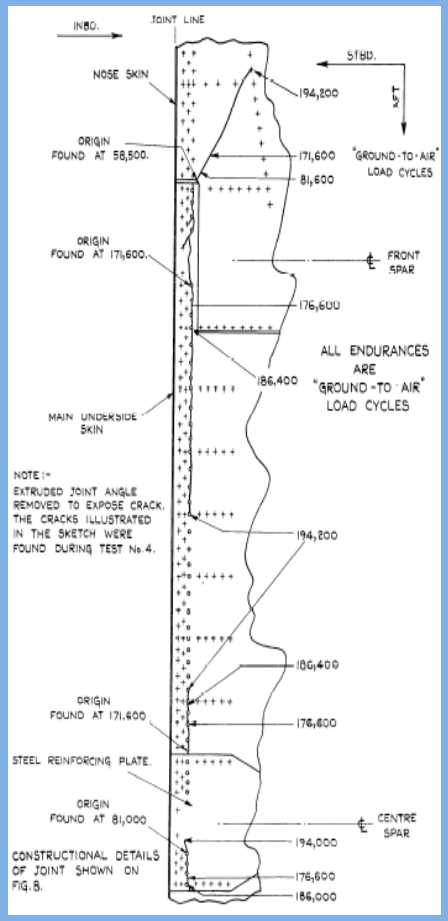


FIG. 6. THE LOCATIONS OF FATIGUE DAMAGE ON THE BOTTOM SURFACE OF THE WING.

- RAE Full Scale Fatigue Tests in 1960
- Results indicated multiple fatigue crack sites near wing joint



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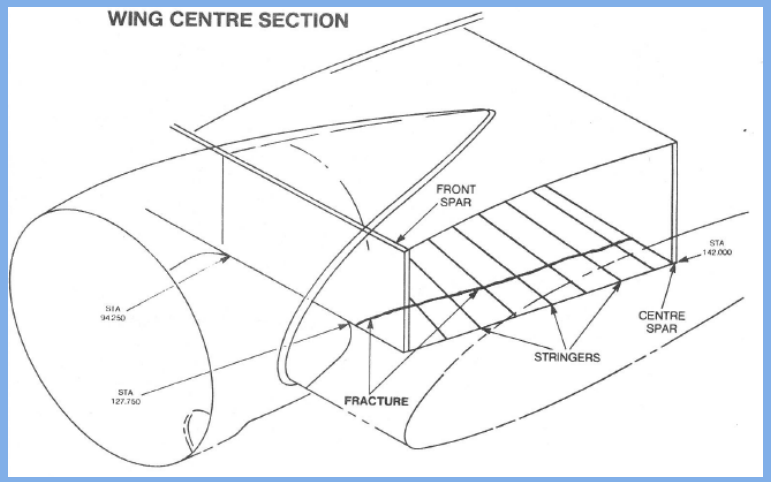
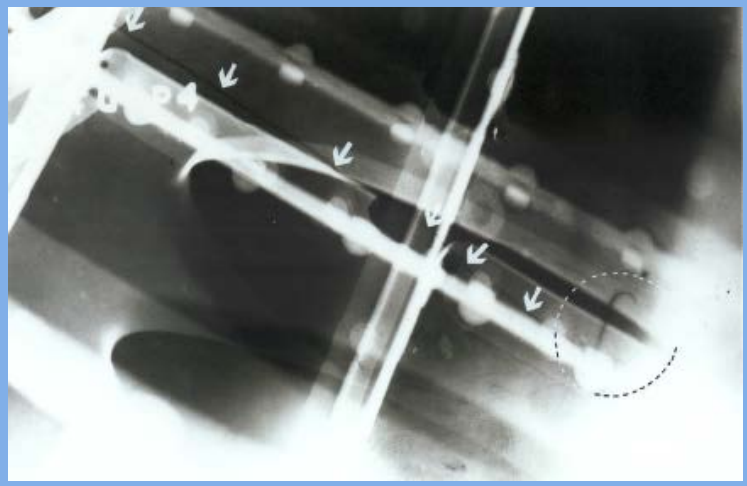
Accidents & Incidents

1987 NORTHLAND AIR MANITOBA DC-3 C-FADD





- Two key issues identified at that time by the accident investigation:
  - *"A 15-inch fatigue crack was visible in radiographs taken at the normal inspection cycle, 297.8 hours of flight time before the accident, but was not interpreted by the radiographer"*
  - *"There are no aviation regulatory standards applicable to radiographic work performed on aircraft"*
- Transport Canada issued an emergency AD to audit all radiographics for this inspection and a mandatory modification.

ISSUE: UNRELIABLE INSPECTION METHOD

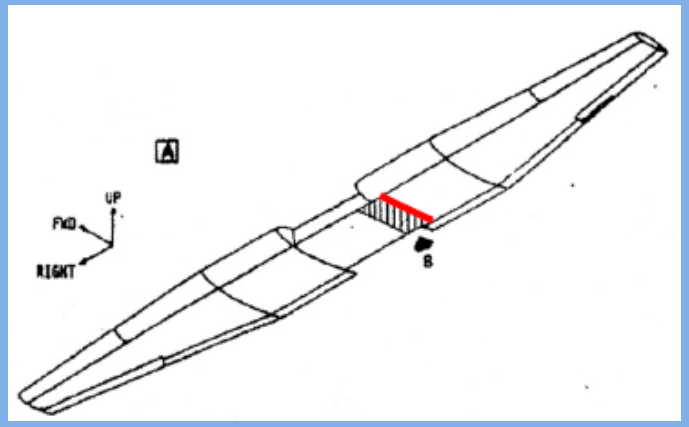
Accidents & Incidents

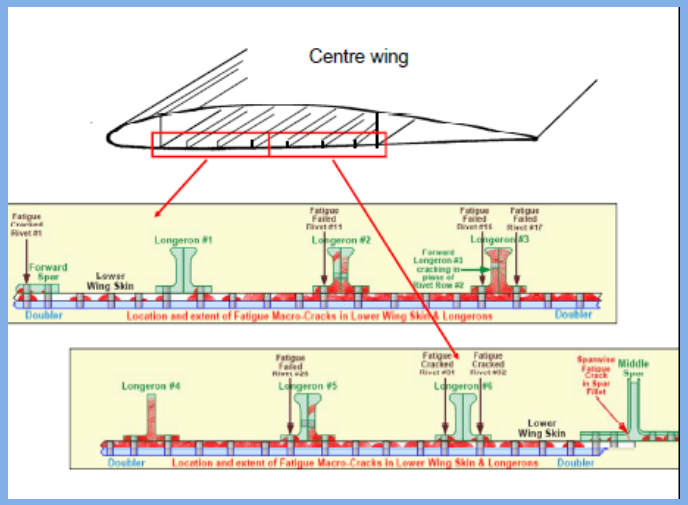
2006 SWEDISH COAST GUARD CASA 212 SE-IVF

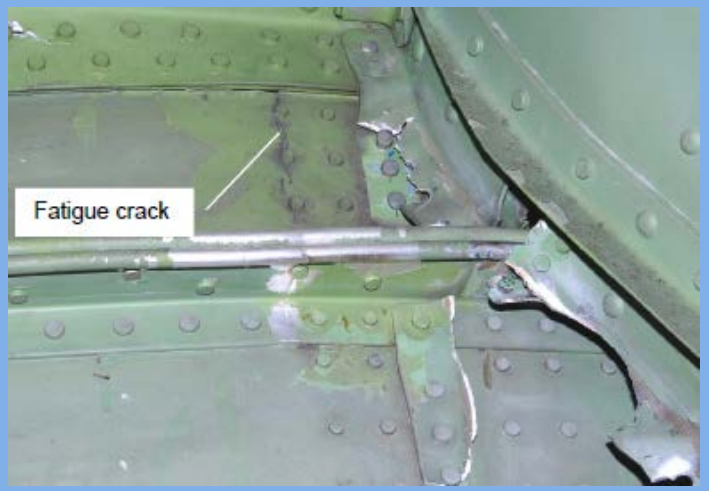
- On 26 October 2006, a Swedish Coast Guard aircraft with call sign KBV585 crashed due to an in-flight wing failure
- The aircraft was a CASA 212 also registered as SE-IVF and under the EASA jurisdiction.

Accidents & Incidents

2006 SWEDISH COAST GUARD CASA 212 SE-IVF





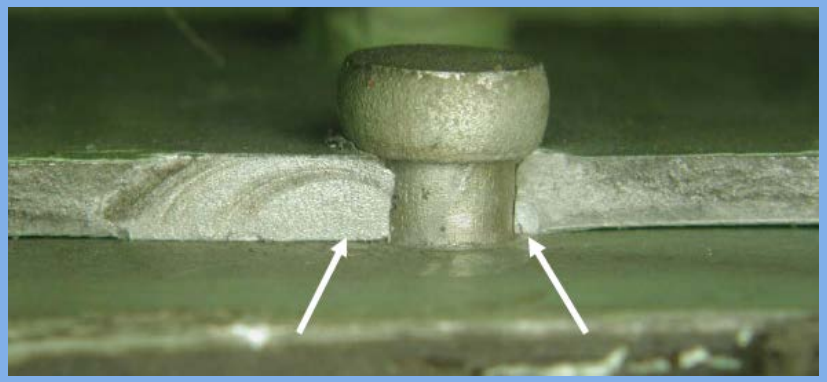


Accidents & Incidents

2006 SWEDISH COAST GUARD CASA 212 SE-IVF

- The accident investigation had several findings:

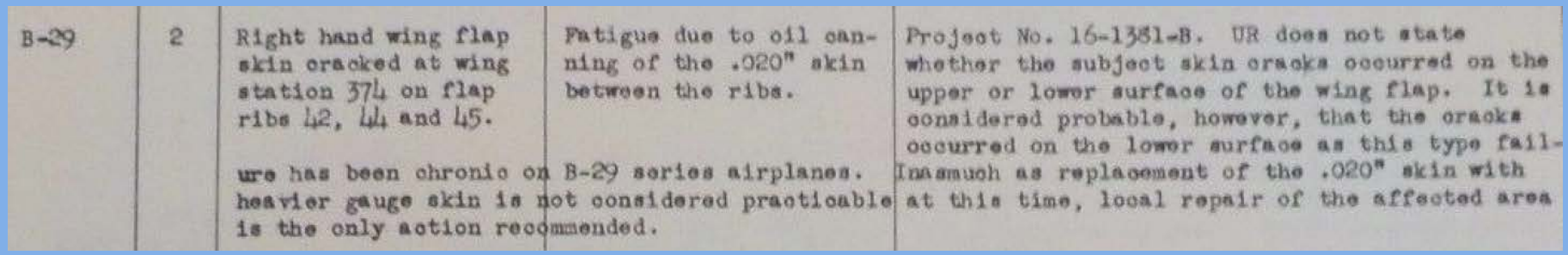
- *The strength of the left wing was considerably reduced as the result of an extensive fatigue crack*
- *The crack was characteristic of Multiple Side Damage (MSD) which had developed over a long period of time.*
- *There were signs that the accident aircraft had been operated with an unfavorable load spectrum.*
- *No inspection threshold reduction for SID due to special mission utilization*
- *Manufacturing defects in the wing were found.*
- *The wing to fuselage fairings transferred wing loads to the skin due to improper installation*
- *It would have been possible to detect the cracks visually with suitable instructions had they been performed.*



ISSUE: WFD AND SPECIAL MISSION UTILIZATION

Service Difficulties

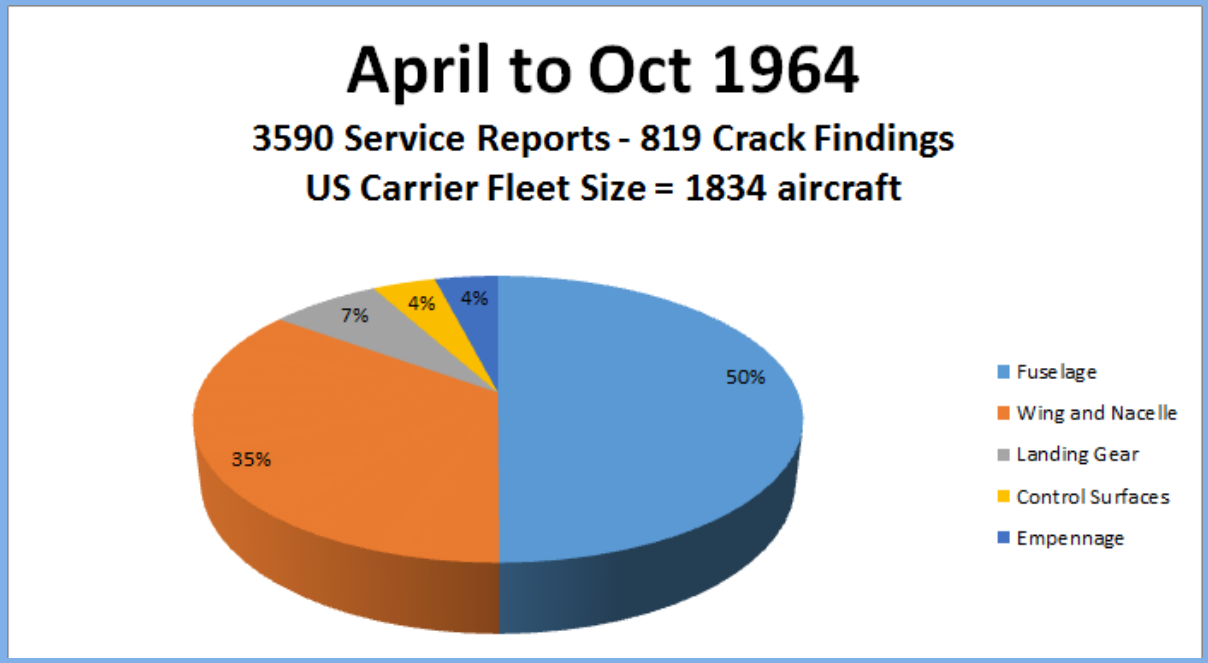
- In-service issues related to fatigue have been an on-going concern for a long time and was recognized as early as WW2.
- Unsatisfactory Reports (UR) were issued by the USAAF during WW2 for all aircraft related issues which required attention. These reports included issues related to fatigue but the USAAF did not specifically deal with them as a whole.



B-29	2	Right hand wing flap skin cracked at wing station 374 on flap ribs 42, 44 and 45.	Fatigue due to oil canning of the .020" skin between the ribs.	Project No. 16-1381-B. UR does not state whether the subject skin cracks occurred on the upper or lower surface of the wing flap. It is considered probable, however, that the cracks occurred on the lower surface as this type failure has been chronic on B-29 series airplanes. Inasmuch as replacement of the .020" skin with heavier gauge skin is not considered practicable at this time, local repair of the affected area is the only action recommended.

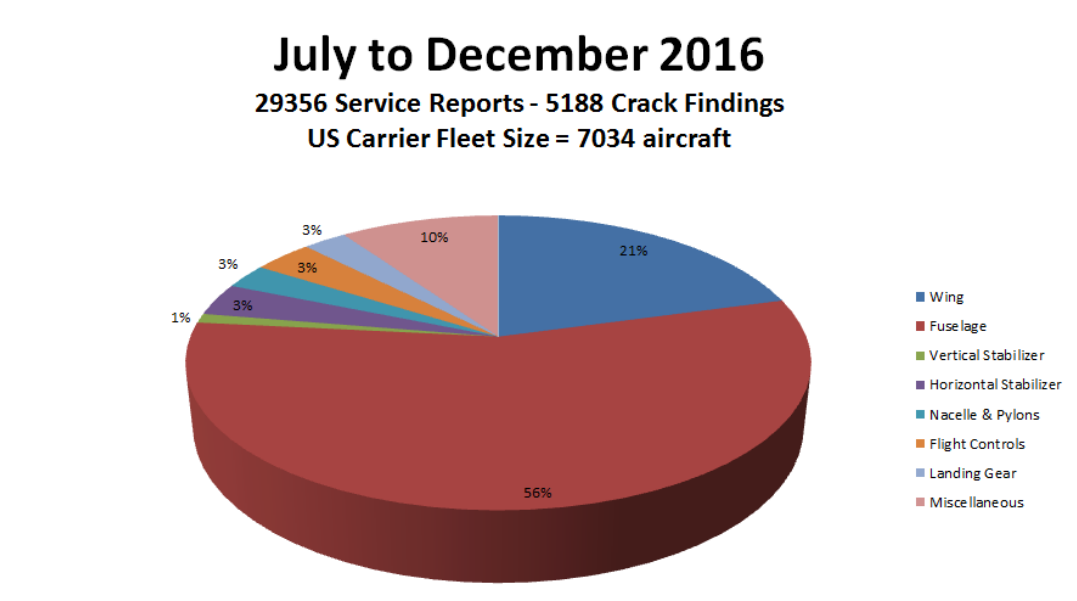
Service Difficulties

- More attention to fatigue related service issues was given as continued airworthiness concerns rose in the late 1950's. At the 1965 ICAF, Mr. Dougherty of the FAA Flight Standards Service presented some interesting service statistics related to airframe fatigue.



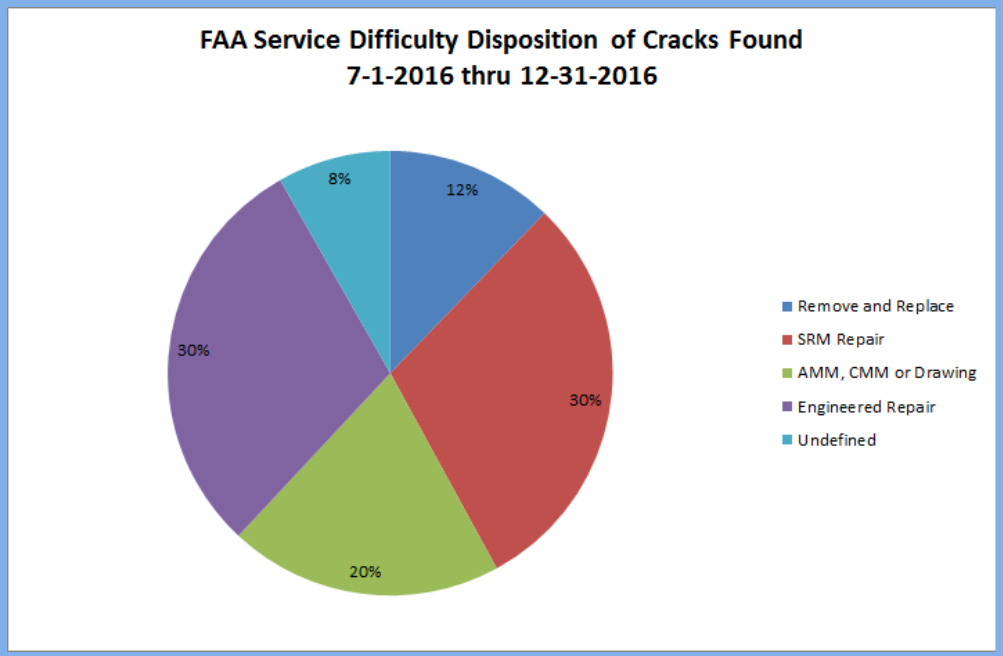
Service Difficulties

- For comparison, the FAA SDR database was queried and a sample of fatigue related services issues was obtained for an equivalent six month period from 2016.
- Over time, the number of service issues related to fatigue seem to have increased. This could be in part due to the fleet size but also due to increasing safety related inspections.



Service Difficulties

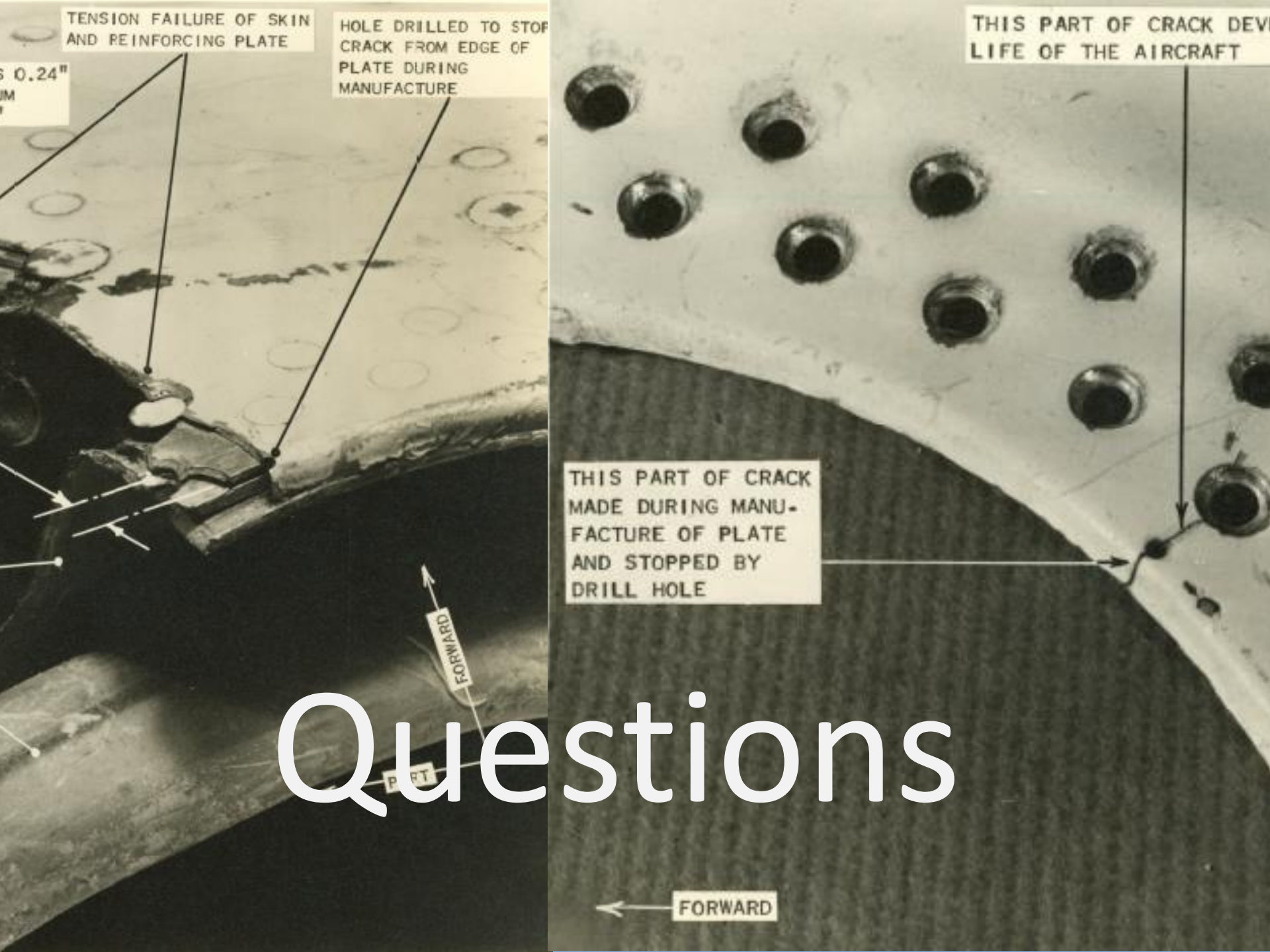
- The industry trend is positive. Fatal accidents have been reduced and in-service inspections are finding cracks prior to creating a safety issue.
- Increased inspections has resulted in increased findings which require disposition and can have impact to fleet.



- Over 60% of all findings are being handled thru the use of OEM data and result in expedited dispositions.
- Approximately 30% of findings however require specialized engineering disposition and can result in delays and sometimes in AOG conditions.

Challenges

- Many lessons continue to be learned from service accidents and incidents:
  - Design
  - Material behavior
  - Manufacturing Quality
  - Loads
  - Usage/Environment/Aging Fleet
  - Inspection Methods
- Major Accidents and Incidents have been greatly reduced due to incorporation of both design and inspection changes. However, special mission aircraft continue to pose a problem due to operation outside normal standards. Case in point, the 2006 CASA 212 accident.
- Increased in-service Inspections have enabled industry to catch damage before it becomes critical. However, increased findings tax industry resources. Improvements in maintainability are needed to alleviate this.


TENSION FAILURE OF SKIN AND REINFORCING PLATE
HOLE DRILLED TO STOP CRACK FROM EDGE OF PLATE DURING MANUFACTURE
THIS PART OF CRACK DEV
LIFE OF THE AIRCRAFT
THIS PART OF CRACK MADE DURING MANU-FACTURE OF PLATE AND STOPPED BY DRILL HOLE
FORWARD
FORWARD

Questions