Airframe Structural Fatigue

Past, Present and Future

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James Burd



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

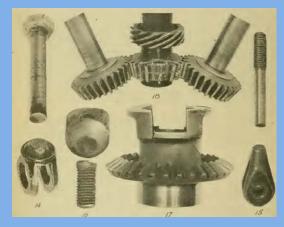
- Discussion:
 - Background
 - Accidents Related to Fatigue
 - Case Studies Past thru Present
 - Review of Service Difficulties Then and Now
 - Challenges



- 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.







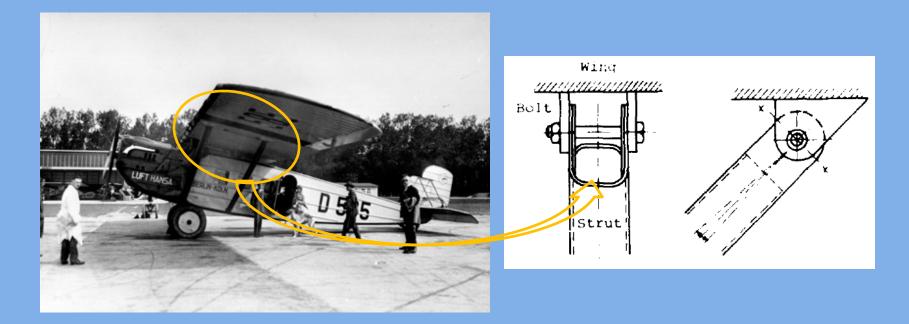
Propeller Fatigue Test – McCook Army Airfield 1926



Fatigue Crack in Propeller Blade

AA&S 2017 Phoenix, Arizona Fatigue Failures of Engine Parts and Cable Fittings

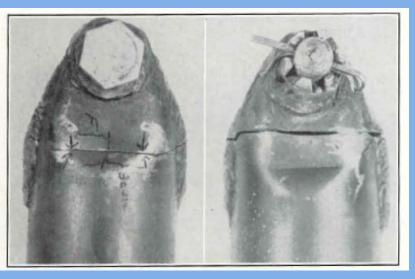
• Earliest publicized aircraft accident due to airframe fatigue occurred on 23 September 1927 when a Dornier Merkur flight from Munich to Berlin crashed due to a wing strut fatigue failure.





 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.







- 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.

IANUARY 1, 1944

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 DEPARTMENT OF COMMENCE CULL AREXONATION COMMENCE WARMINGTON DEPARTMENT OF COMMENCE WARMINGTON DEPARTMENT OF COMMENCE WARMINGTON DEPARTMENT OF COMMENCE DEPARTMENT DEPARTMEN

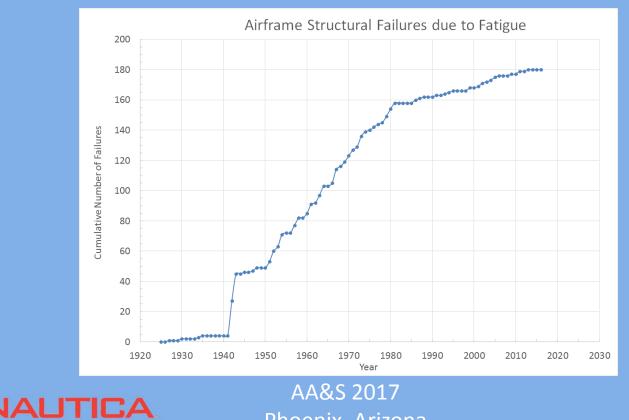


- Early accidents due to fatigue prior to 1940 were isolated occurrences.
- WW2 brought enormous increase in aircraft production and utilization.
- Large numbers of aircraft utilized for training pilots during WW2 logged considerable flight hours bringing metal fatigue to the fore front.
- Post WW2 expansion 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)



Accidents & Incidents 1920-1970

(
1920 -	
1922 -	
1924 -	
1926 -	
1928 -	1927 Dornier Merkur D-585 wing Failure
1930 -	1930 Junker F13 G-AAZK empennage failure
1932 -	1934 SwissAir AT32 Condor CH-170 engine to wing attach
1934 -	1935 Alexander Model D-2 NC-14428 wing strut failure
1936 -	
1938 -	
1940 -	
1942 -	1942 Hawker Typhoon empennage failures R7633 & R7644 1942 Vickers Wellington wing failures (20) 1942 USAAF T-6 wing failure
1942 -	1943 RAF Spitfire wing cracks 1943 USAAF BT-13 wing cracks 1944 USN F4U tail failures
1944 -	1945 Stinson Model A VH-UYY wing failure
1946 -	
1948 -	1947 Piper J3 Cub NC-88624 wing strut failure 1948 Northwest 202 NC-93044 wing failure 1948 Vultee V1A NC-22077 wing failure
1950 -	1951 Vickers Viking VP-YEW wing failure 1951 DeHavilland Dove DH104 VH-AOQ wing failure 1951 USN Grumman F8F SN 121670 wing failure 1951 RCAFT-6 44-81078 and 42-85174 wing failures
1952 -	1952 National Airlines DC-6 wing cracks 1952 USAF F-89C (6 aircraft) wing failures
1954 -	1953 USAF F-84 wing failure 1953 Vickers Viking VP-YEY wing failure 1953 RAAF Bristol 170 A81-2 wing failure
	1954 USAAF P-51 SN 44-73575N wing failure 1954 USAAF P-51 SN 44-73176N wing failure 1954 USAF F-86 SN 52-5005 & 3 others 1954 DH106 Comet G-ALYP and G-ALYP fuselage failures 1955 Bristol 170 VR-NAD wing failure
1956 -	1957 Vickers Viscount G-ALWE flap failure 1957 Twin Pioneer G-AOEO wing lift strut failure 1957 Bristol 170 ZK-AYH wing spar failure 1957 RCAF T-6 SN 20330 wing failure 1957 Delta DC-7 Fuselage Cracks
1958 -	1958 USAF B-47 51-2104 50-0013 52-0470 52-0235 wing failures 1958 Noordyun Norseman CF-BSJ wing failure
1960 -	1960 Cessna 180 wing rear spar failure 1960 Capitol Airlines C-46F N1300N wing attach failure 1960 Cessna 195 wing carry thru failure 1961 USAF B-52G SN 58-0187 wing failure 1961 USAF B-52 Aft Fus failures (+2 others)
1962 -	1961 Beech 35 Bonanza wing failure 1961 Aero Commander 680S ZK-BWA wing failure 1962 Beech 35 Bonanza wing failure 1963 Cessna 195 wing failure 1963 USAF B-26 44-34681 wing failure
1964 -	1963 Noordyun Norseman CF-BHW wing strut failure 1963 Beech 35 Bonanza wing failure 1963 deHavilland Beaver VH-AVR wing strut failure 1964 Mooney M18C N345M wing spar failure 1964 USAF F-105 fuselage failures (2)
1966 -	1964 Commander 680E CJ-JOK wing failure 1964 USAF B-26 44-35665 wing failure 1964 Beech G18S N9423Y wing failure 1966 Piper PA-18 wing failure 1966 Beech C18S N445 wing failure 1967 Northeast DC-6 fuse lage failure
	1967 Beech C-45H N830K wing failure 1967 Aero Commander 560E N3831C wing failure 1967 Beech E18S N918X wing failure 1967 Piper PA-25 N6135Z wing failure 1967 USAF F-100 55-3520 (+3 others) wing failures
1968 -	1968 Fairchild F-27 N4905 wingfailure 1968 Vickers Viscount VH-RMQ wing failure 1969 GAF F-104G 65-12746 wing failure 1969 USAF F-111A 67-049 wing failure 1969 USAF F-4 outer wing failure
1970 -	

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Accidents & Incidents 1970-Present

0) 1 2 3 4 5					
1970 -	1970 TAG Airlines DH104 Dove N2300H wing failure 1970 USAF F-4 outer wing panel failures 1970 USAF F-5 lower wing skin failure 1970 Aer Lingus 707 fuselage failure 1971 Piper J-4A Cub N23199 wing strut failure					
1972 -	1971 RCAF CF-104 wing failure 1971 Apache Airlines DH104 Dove N4922V wing failure 1971 Grumman F8F-2 N7700C wing failure 1972 Aero Taxi Beech E18S N42A wing failure 1972 Piper PA-22 wing lift strut failure					
1974 -	1973 Piper PA-25 N7581Z wing failure 1973 Southern Air DC-3 ZK-AOI wing failure 1973 Ethiopian Airlines C-47 ET-ABQ wing failure 1973 USAF F-4 SN 66-0331 outer wing failure 1973 Air Iowa Beech E18S N310WA wing failure					
1976 -	1973 Piper PA-25 N7351Z wing failure 1973 Piper PA-25 N4990Y wing failure 1974 Saturn Airways L-382E N14ST wing failure 1974 SAF AJ37 Viggen SN 37011 wing failure 1974 Alaska International L-382B N102AK wing failure					
15/10	1975 SAF AJ37 Viggen SN 37005 wingfailure 1976 Hawker Siddley HS748 LV-HHB wingfailure 1976 RAF F-4M SN XV417 wingfailure 1977 Air Lusaka 707 G-BEBP horizontal stab failure 1977 Piper J-5 N38702 wingfailure					
1978 -	1978 USAF T-38A 66-4364 wing failure 1979 Canadian DOT Beech A90 C-FCAS wing failure 1979 RAF Buccaneer SN XW526 wing failure 1979 Piper J-3C N6716H wing strut failure 1979 DC-9 CF-TLU aft press bulkhead failure					
1980 -	1980 Piper PA-22 N3747A wing strut failure 1980 RAF Bucaneer SN XV345 wing failure 1980 Piper PA-25 N8561L wing spar failure 1980 Piper PA-20 N7453K wing strut failure 1980 Zantop L-188 N290F fuselage door failure					
1982 -	1981 Douglas B-26 N9417H wing failure 1981 L-20 (DHC-2) C-GUDZ wing strut failure 1981 Beech E90 N114K wing failure 1981 Piper PA-24 wing lower sparcap failure					
1984 -						
1504						
1986 -	1986 Delta Airlines L-1011 N714DA wing rear spar crack 1986 USAF T-38A SN 75-1560 wing failure					
1988 -	1987 Northland Air Manitoba DC-3 C-FADD wing failure 1988 Aloha Airlines 737-200 N73711 fuselage failure					
1990 -						
4000	1991 Piper PA-25 N7509Z wing failure					
1992 -	1993 Piper PA-25 N6453Z wing failure 1994 Hawkins & Powers Tanker T-82 C-130 N13FF wing failure					
1994 -	1995 Delta Airlines L-1011 N781DL fuselage pressure bulkhead failure					
1996 -						
1998 -						
2000	1999 Cessna 402C N819BW wing failure 1999 Sky Warriors T-34 N141SW wing failure					
2000 -	2001 Fouga CM170 N301FM wing failure					
2002 -	2002 Hawkins & Powers Tanker T-130 N130HP wing failure 2002 Hawkins & Powers Tanker 123 Convair PB4Y N7620C wing failure 2003 Beech T-34 N44KK wing failure 2004 Beech T-34 N141SW wing failure					
2004 -	2005 North American T-6 Texan N453WA wing failure 2005 Chaulk Airlines Grumman G-73 Mallard N2969 wing failure					
2006 -						
2008 -	2006 Swedish Coast Guard CASA 212 SE-IVF wing failure					
2010 -	2009 Southwest 737-300 N387SW fuselage cracks					
2010	2011 Southwest 737-300 N632SW fuselage cracks 2011 Omega Aerial Refueling 707 N707AR pylon failure					
2012 -	2013 PZL Mielec M18A Dromader VH-TZJ wing failure					
2014 -						
2016 -						
2018 -						
2020 -						



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

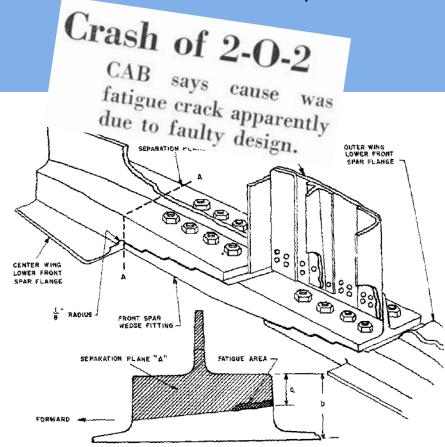


8/29/48 Nr. Hinona, Minnesota Northwest Martin 202 37 4 - - 33 - - Destroyed

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.



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

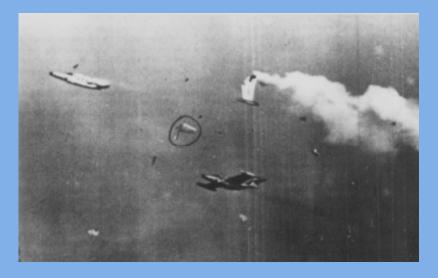


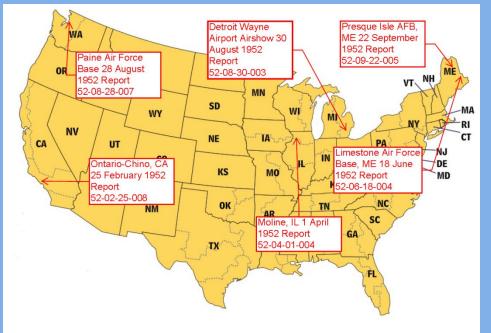
Northwest Airlines Flight 421 Chicago to Minneapolis-Martin 202, NC93044 – 29 Aug 1948

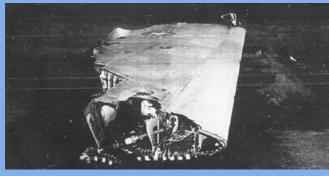
- Investigation discovered high stress concentrations caused fatigue failure
- Full scale fatigue testing was conducted by Martin. Did not find any cracking during visual inspections. Following the accident, a more detailed inspection found fatigue cracks at the joint.
- CAA mandated inspections & mod.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

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



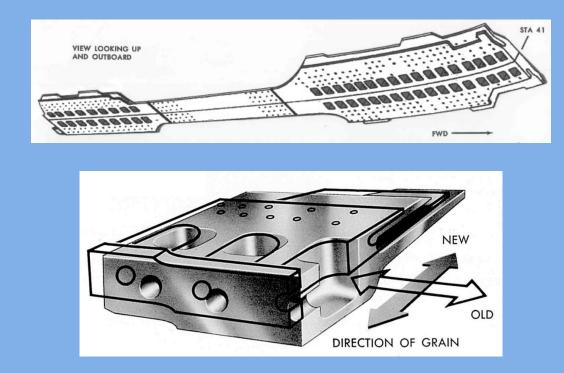


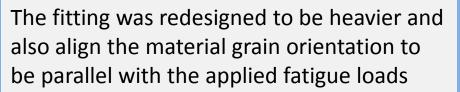


A total of 6 wing failures occurred in 1952 in little over a 6 month period



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







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.



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

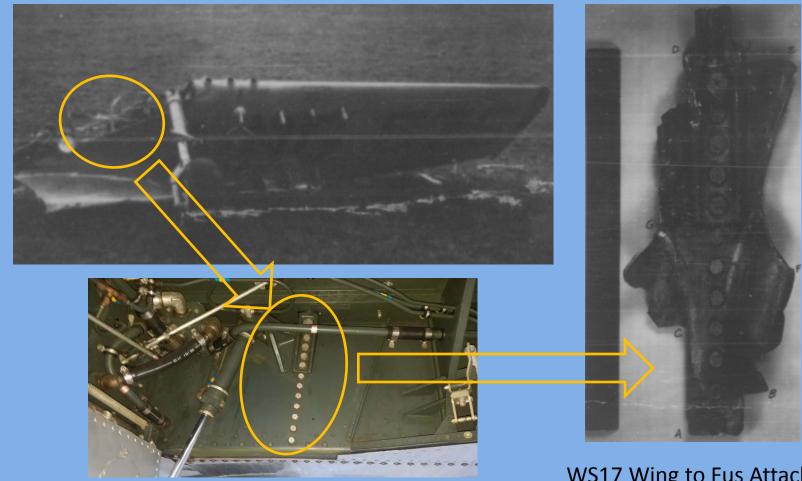
AF Plans \$15-Million F-89 Fix



ISSUE: POOR GRAIN ORIENTATION & HIGH LOADS



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

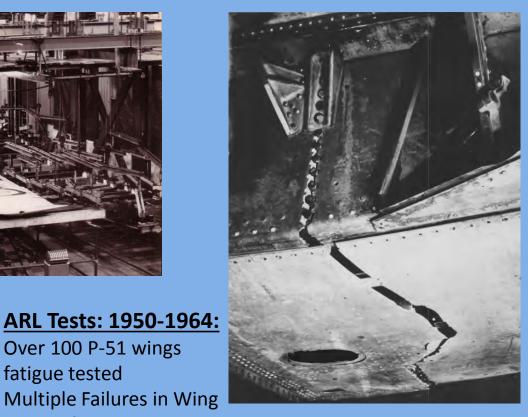




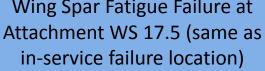
AA&S 2017 Phoenix, Arizona WS17 Wing to Fus Attach

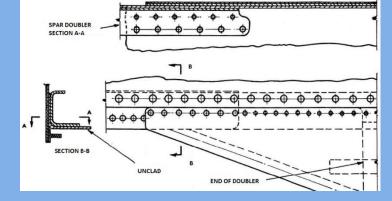
USAF F-51D, 9 Nov. 1954 SN 44-73575





Wing Spar Fatigue Failure at in-service failure location)







AA&S 2017 Phoenix, Arizona

Over 100 P-51 wings

fatigue tested

Material = 24ST

WS 17.5 to 28

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 ISSUE: AGING FLEET – UNKNOWN FATIGUE STATE



AA&S 2017 <u>Phoenix, Arizona</u> Another F-51 accident revisited and believed to be caused by wing fatigue failure

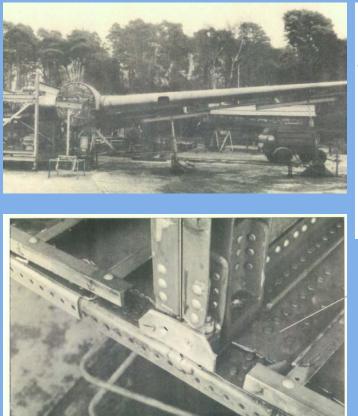
Accidents & Incidents 1987 NORTHLAND AIR MANITOBA DC-3 C-FADD

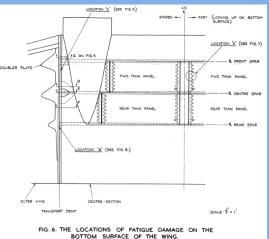


The left wing failed, under normal flight loads, as a result of a fatigue crack in the centre section lower wing skin. Anomalies in the radiographs taken during mandatory non-destructive testing inspections were not correctly interpreted.

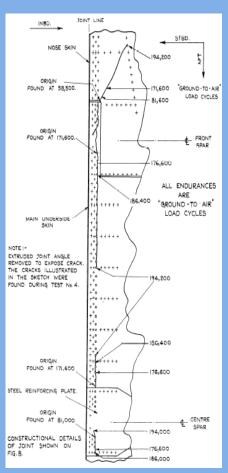


Accidents & Incidents 1987 NORTHLAND AIR MANITOBA DC-3 C-FADD



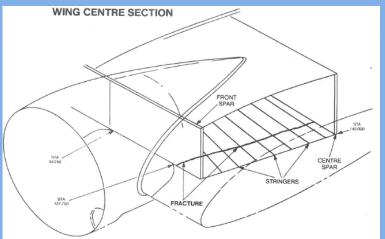


- RAE Full Scale Fatigue Tests in 1960
- Results indicated multiple fatigue crack sites near wing joint





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



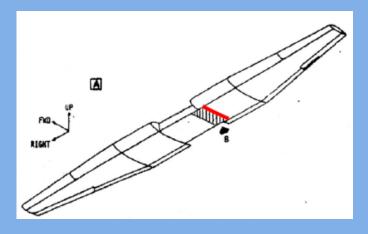


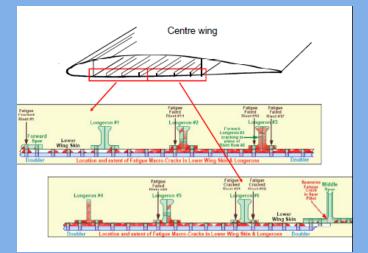


- On 26 October 2006, a Swedish Coast Guard aircraft with call sign KBV585 crashed due to an in-flight wing failure
- The aircraft was a CASA 212 also registered as SE-IVF and under the EASA jurisdiction.



2006 SWEDISH COAST GUARD CASA 212 SE-IVF





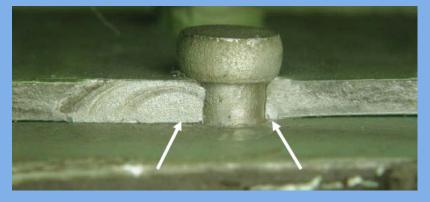
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2006 SWEDISH COAST GUARD CASA 212 SE-IVF

- 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

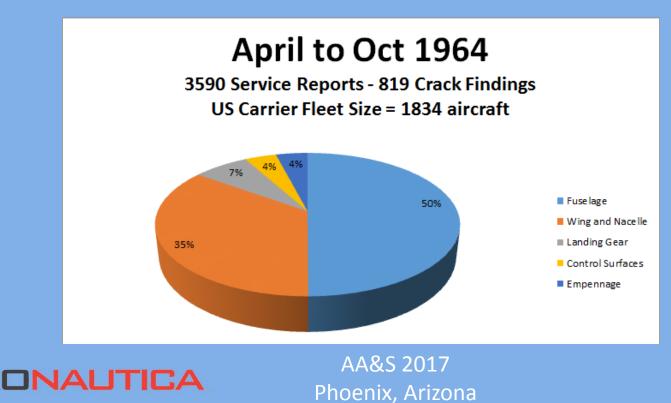


- In-service issues related to fatigue have been an on-going concern for a long time and was recognized as early as WW2.
- Unsatisfactory Reports (UR) were issued by the USAAF during WW2 for all aircraft related issues which required attention. These reports included issues related to fatigue but the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

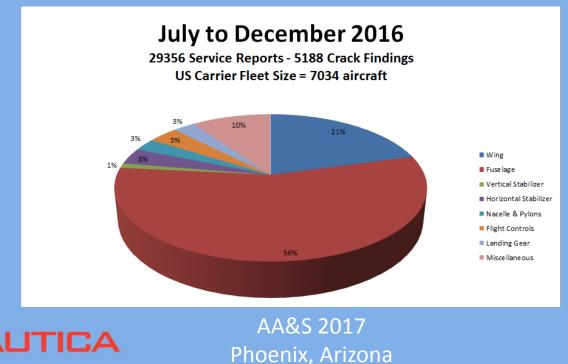
B-29	2	Right hand wing flap skin cracked at wing station 374 on flap ribs 42, 44 and 45. Fatigue due to oil can- ning of the .020" skin between the ribs.	Project No. 15-1351-B. UR does not state whether the subject skin cracks occurred on the upper or lower surface of the wing flap. It is considered probable, however, that the cracks occurred on the lower surface as this type fail-
			Inasmuch as replacement of the .020" skin with at this time, local repair of the affected area



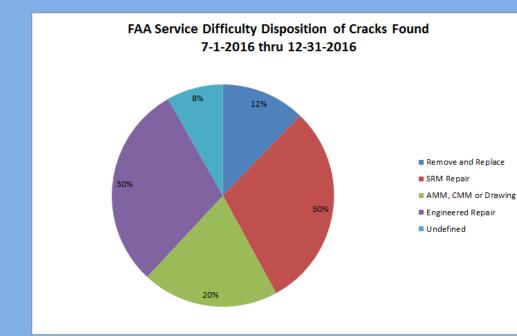
 More attention to fatigue related service issues was given as continued airworthiness concerns rose in the late 1950's. At the 1965 ICAF, Mr. Dougherty of the FAA Flight Standards Service presented some interesting service statistics related to airframe fatigue.



- 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.



- 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
- Loads
- Usage/Environment/Aging Fleet
- Manufacturing Quality
- 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

6 0.24"

M

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

Questions