# Failure Investigation of WB-57 Aircraft Engine Cowling

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The NASA Johnson Space Center (JSC) in Houston, Texas is the home of the NASA WB-57 High Altitude Research Program. Three fully operational WB-57 aircraft are based near JSC at Ellington Field. The aircraft have been flying research missions since the early 1960's, and continue to be an asset to the scientific community with professional, reliable, customer-oriented service designed to meet all scientific objectives.

The NASA WB-57 Program provides unique, high-altitude airborne platforms to US Government agencies, academic institutions, and commercial customers in order to support scientific research and advanced technology development and testing at locations around the world. Mission examples include atmospheric and earth science, ground mapping, cosmic dust collection, rocket launch support, and test bed operations for future airborne or spaceborne systems[1].

During the return from a 6 hour flight, at 30,000 feet, in the clean configuration, traveling at 175 knots indicated airspeed, in un-accelerated flight with the auto pilot engaged, in calm air, the 2-man crew heard a mechanical bang and felt a slight shudder followed by a few seconds of high frequency vibration. The crew did not notice any other abnormalities leading up to, or for the remaining 1 hour of flight and made an uneventful landing. Upon taxi into the chocks, the recovery ground crew noticed the high frequency long wire antenna had become disconnected from the vertical stabilizer and was trailing over the left inboard wing, and that the left engine upper center removable cowling panel was missing, with noticeable damage to the left engine inboard cowling fixed structure. The missing cowling panel was never recovered.

Each engine cowling panel is attached to the engine nacelle using six bushings made of 17-4 PH steel. The cylinder portions of four of the six bushings were found still attached to the aircraft (Fig 1). The other two bushings were lost with the panel. The other four bushings exhibited ratchet marks (multiple fatigue origins) which initiated in the sharp radius of the flange/cylinder fillet and were observed 300 degrees around the flange perimeter (Fig 2-3). Low stress, high cycle fatigue (HCF) was observed on the fracture surfaces of all four bushings[2] (Fig 4).

To improve the cowling panel joint design and enable return to flight, new cowling bushings with thicker flanges and a larger machined flange/cylinder fillet radius were installed on all cowling panels. In addition, a spacer was added to the joint to achieve the proper stack tolerance. Finally, a time change requirement for all cowling bushings was instituted.

**References:**

[1] http://jsc-aircraft-ops.jsc.nasa.gov/wb57/
[2] ASM Handbook, Vol 11, pp 102-135

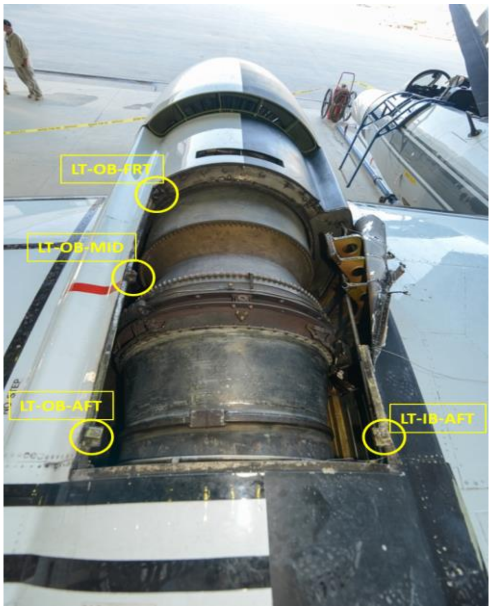


**Fig 1.** WB-57 Aircraft Left Engine w/Missing Cowling. Location of four remaining bushings circled in yellow.

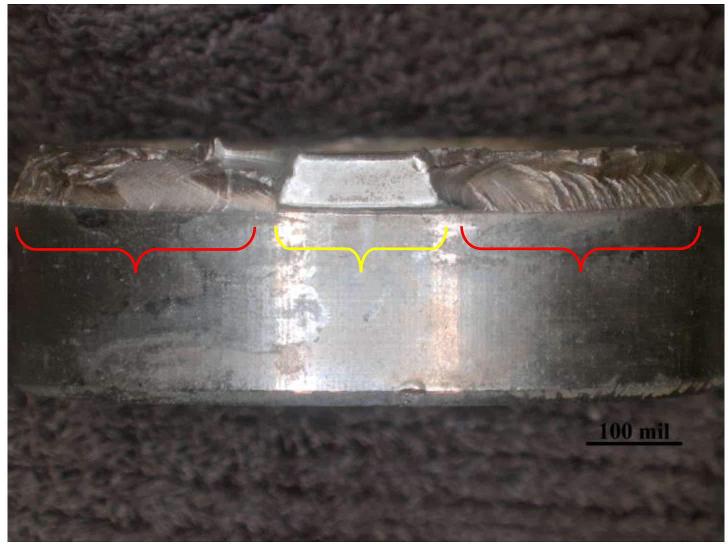


**Fig 2.** Photo of Failed Engine Cowling Bushing. Fatigue fracture zone in red, unfractured zone in yellow.

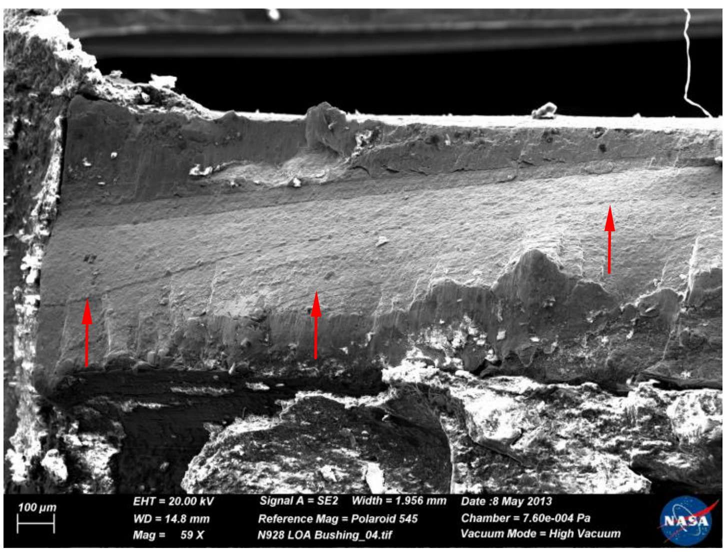


**Fig 3.** SEM of Failed Engine Cowling Bushing (ratchet marks at red arrows)

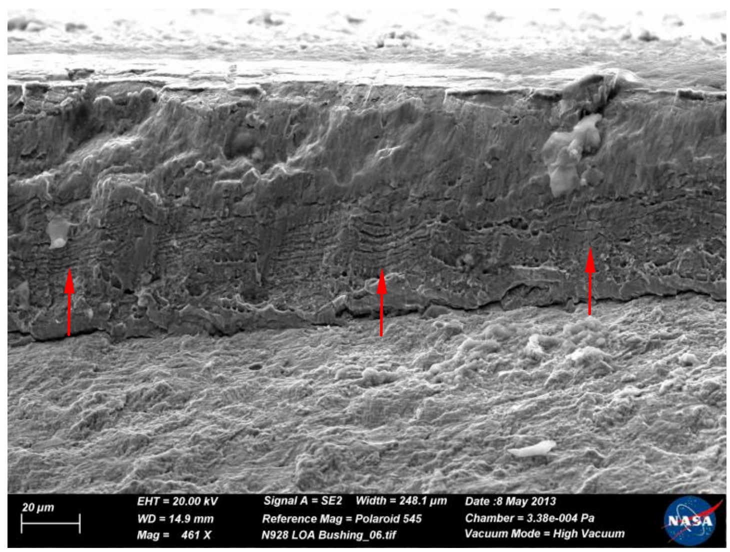


**Fig 4.** SEM Image of HCF Striations (red arrows)

## Microscopy & Microanalysis 2014

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# Presentation Overview

- History & Evolution of WB-57
- WB-57 Mission
- Flight Conditions Summary
- Failure Analysis
- Conclusions
- Corrective Actions

# History/Evolution of WB-57

1949: British designed English Electric Canberra.

1953: USAF purchases license and contracts Glenn L. Martin Company to build 403 each Martin B-57 Canberra tactical bomber and reconnaissance aircraft.
21 aircraft modified with longer wings to “F” model.

1972: USAF transfers first WB57F to NASA.

1983: USAF retires fleet.

NASA currently owns only three remaining flightworthy WB-57F in world.

# WB-57 Mission

- JSC is the home of the NASA WB-57 High Altitude Research Program.
- Three fully operational WB-57 @ Ellington Field.
- Research missions since the early 1960s.
- Provides unique, high-altitude airborne platforms to support scientific research and advanced technology development and testing at locations around the world :
  - U.S. Government agencies.
  - Academic institutions.
  - Commercial customers.
- Missions:
  - Atmospheric and earth science.
  - Ground mapping.
  - Cosmic dust collection.
  - Rocket launch support.
  - Test bed operations for future airborne or space-borne systems.

# Mishap Information:

- Flight Conditions:
  - Returning from a 6 hour flight.
  - Altitude: 30,000 feet.
  - Configuration: Clean.
  - Airspeed: Un-accelerated, auto-pilot engaged, indicated 175 knots.
  - Environmental Conditions: Calm air.
- Crew Observations:
  - 2-man crew heard a mechanical bang.
  - Felt a slight shudder followed by a few seconds of high frequency vibration.
  - No other abnormalities leading up to, or for the remaining 1 hour of flight.
  - Made an uneventful landing.
  - Upon taxi into the chocks, the recovery ground crew noticed the high frequency long wire antenna had become disconnected from the vertical stabilizer and was trailing over the left inboard wing.
  - The left engine upper center removable cowling panel was missing.
  - Noticeable damage to the left engine inboard cowling fixed structure.
  - The missing cowling panel was never recovered.

# Aircraft Photo:

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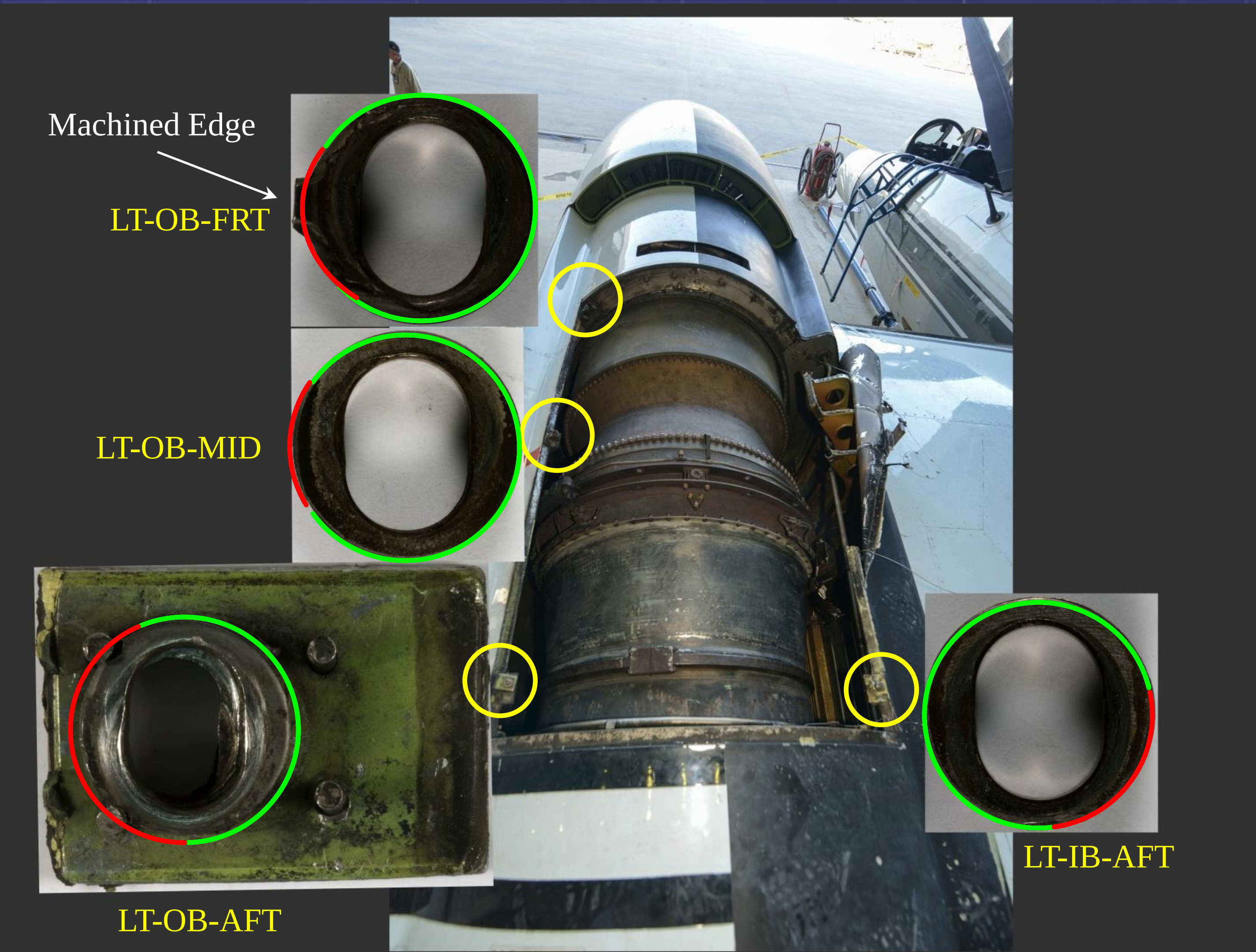


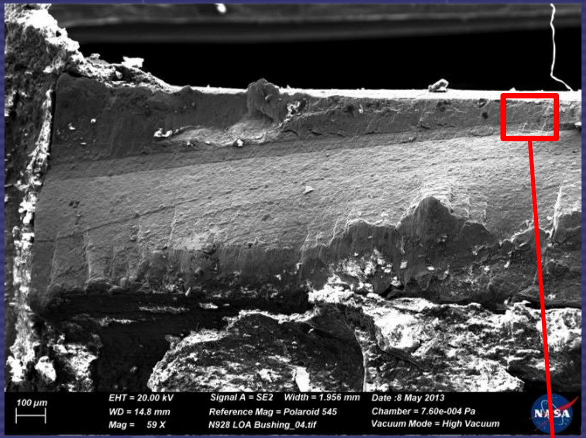

High cycle fatigue
Multiple initiation points

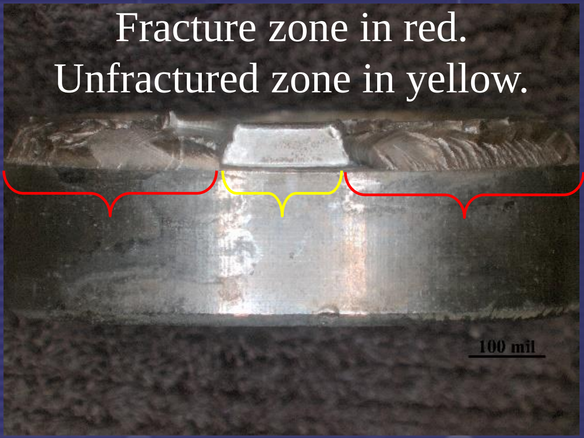
Overload fracture

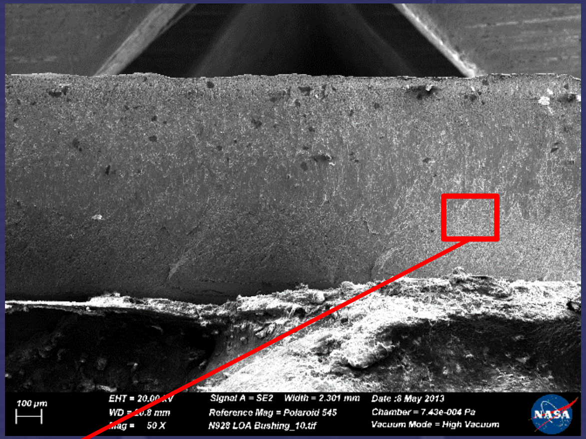
*Note: Mapping of crack type on bushing on PT-OB-FRT and PT-OB-AFT known due to noted bushing features. Mapping assumed for PT-OB-MID and PT-IB-AFT*

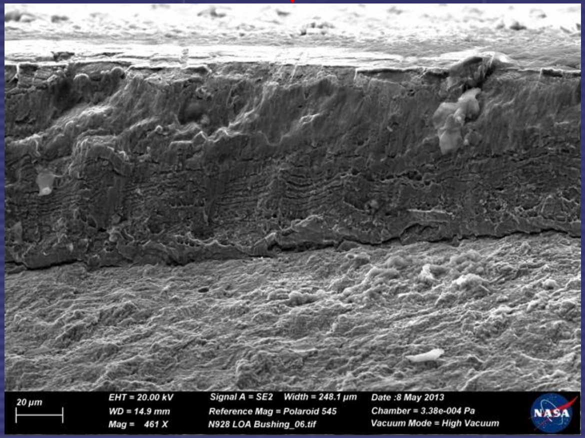
Remaining 2 attachment fittings (PT-IB-MID, PT-IB-FRT) missing from aircraft.

# SEM Fatigue Micrograph - Port Outboard Front Bushing

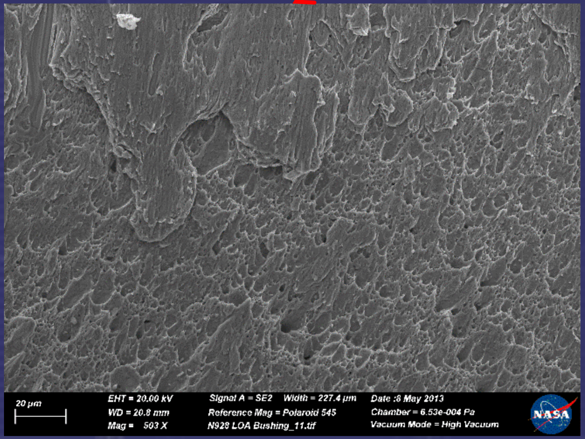




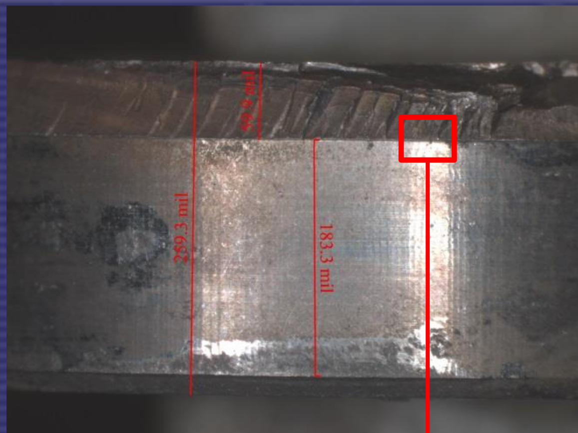


Fatigue Zone

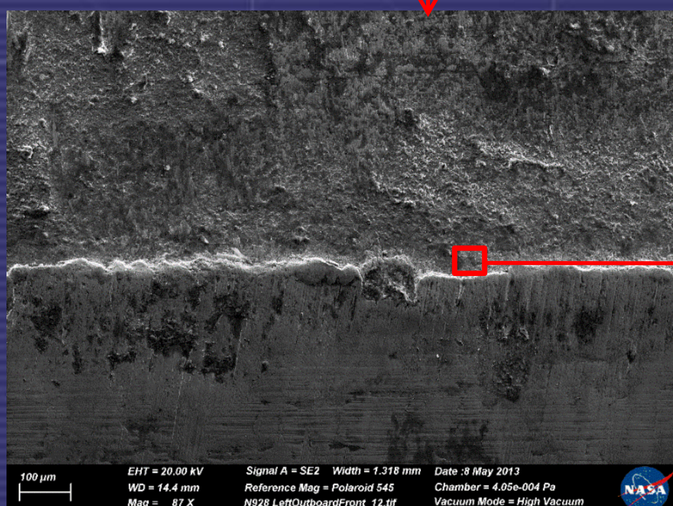


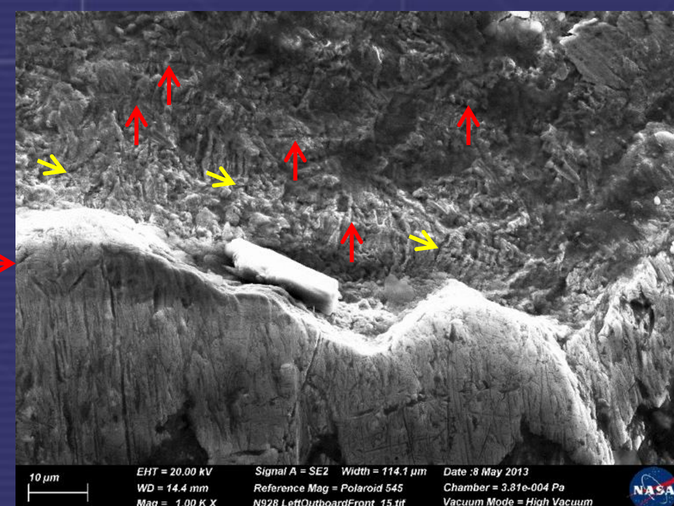
Overload Zone

# SEM Fatigue Micrograph - Port Outboard Front Bushing




Multiple origin fatigue initiated on the flange to cylinder radius. SEM micrographs of the fracture reveal striations (red arrows) and tear ridges (yellow arrows). All of the N928 bushings failed in a similar manner by low stress, high-cycle fatigue (HCF).

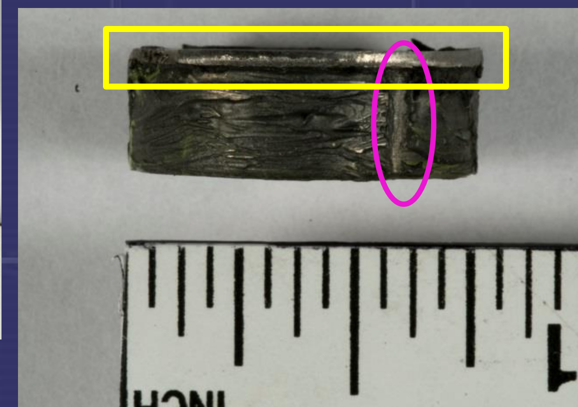


# Left Outboard Aft Spacer



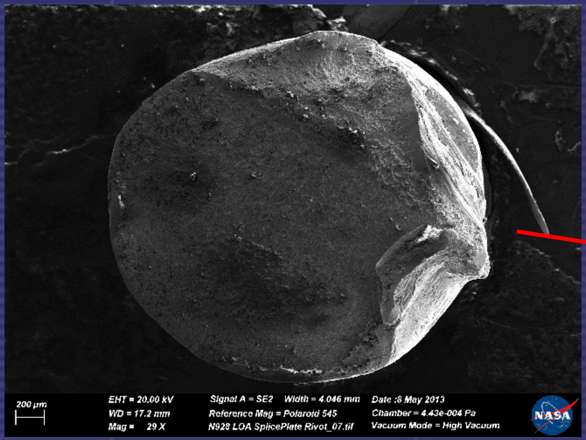
outboard



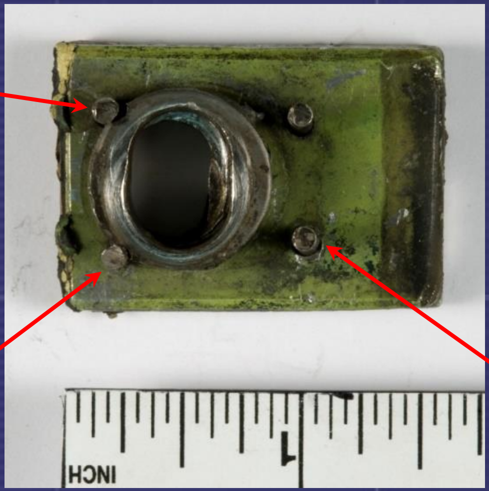

- Drilled holes are shown at the red arrows.  The rivets on the right perfectly fit into the drilled holes.
- Fracture on bushing is shown at right photo in yellow box.
- The bushing was fractured from the flange. There is wear on top-side of bushing (green arrow), which is consistent with wear from the bolt head.
- The witness mark on the bushing (pink arrow and oval) resulted from contact with the top right rivet of center image when cowling was departing the aircraft.

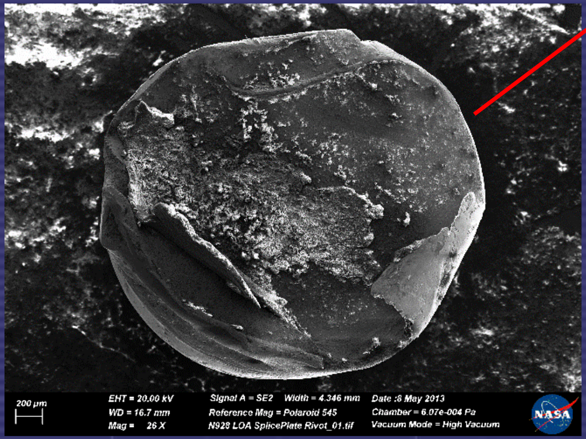
# Spacer/Flange/Cowling Rivet Fracture Surface

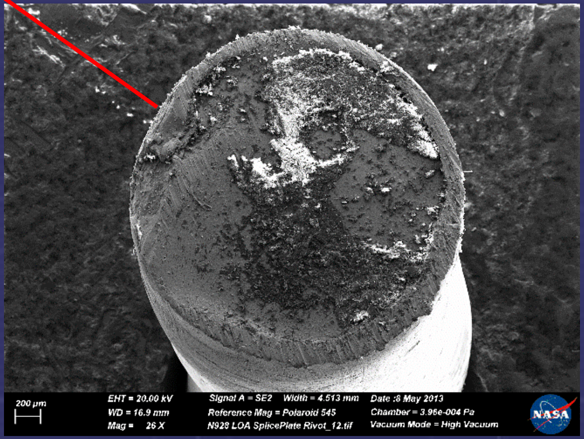
- Monel 405 rivets
- Ductile failure fracture surface
- No evidence of fatigue
- Consistent with single overload event




Outboard



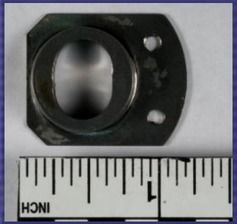



# Examination of Aircraft N928 (Incident A/C) RT Side (non-incident panel) Aft Cowling Bushings

Fwd Inboard

Mid Inboard



Aft Inboard

Six each right side (non-incident side) aft cowling bushings from WB-57 N928 were inspected.

Mag-particle non-destructive inspection at EFD and on-site was performed.  No cracks were observed.

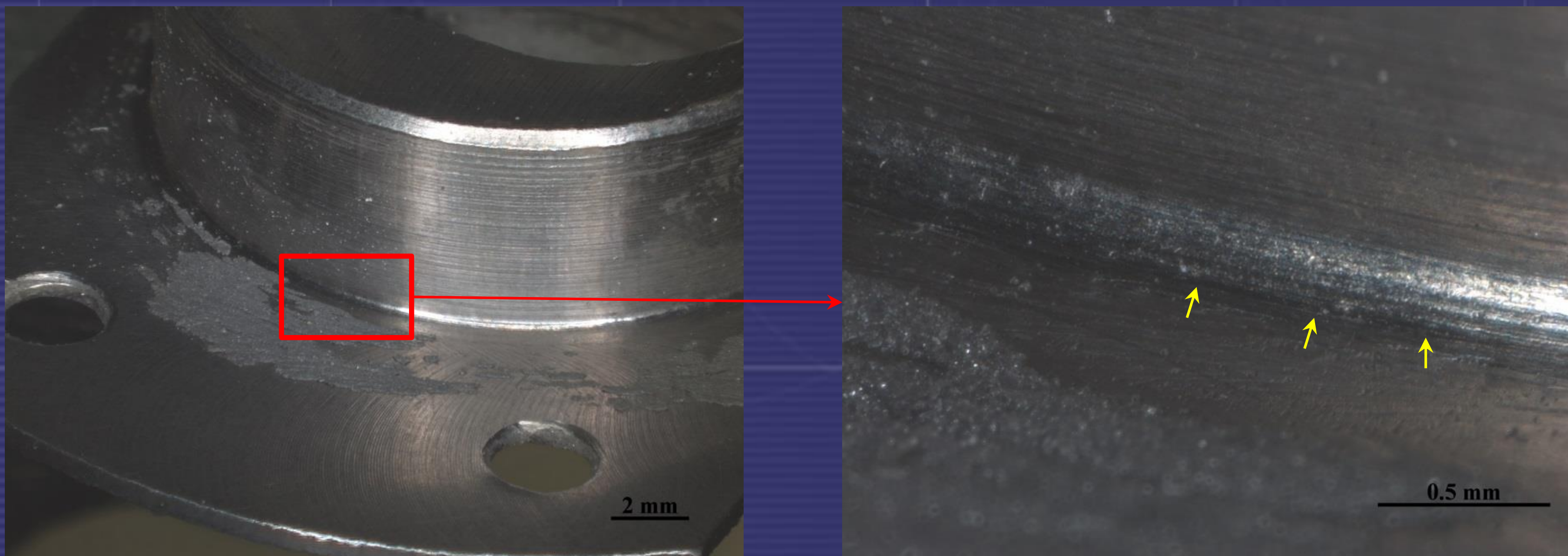
Stereoscopic inspection of the six bushings found: aft outboard, fwd outboard, and aft inboard bushings contained several small, crack-like features at the fillet.  The mid outboard bushing was received with one of its base plate corners bent.  Numerous cracks were observed at the fillet where the base plate was bent.


Aft Outboard


Mid Outboard

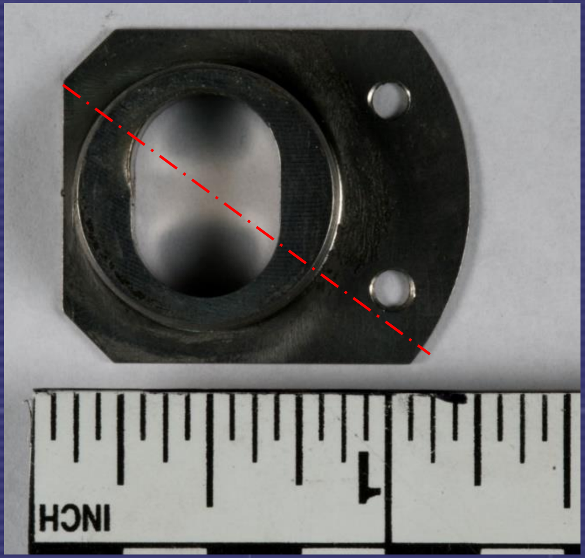

Fwd Outboard

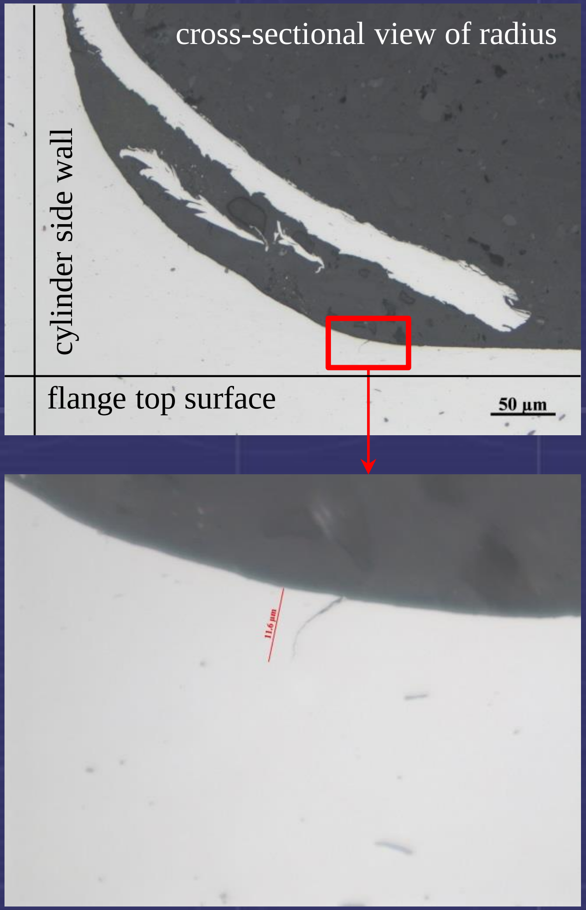
# Stereomicroscope Images of A/C N928 RT Aft Outboard Bushing




Aft Outboard bushing contained wear
and several crack-like features (yellow arrows) at the fillet.

# Metallography of A/C N928 (Incident A/C)
# RT Side (Non-Incident Side) Aft Outboard Bushings






Aft Outboard bushing was cross-sectioned to determine the depth of the crack-like features at the flange-to-cylinder radius. The feature was measured to have a depth of 12 microns (0.0005”).

The shape of the crack is consistent with a fatigue crack emanating at a 45 degree angle down from the surface of the flange-to-cylinder radius and then changing direction to grow perpindicular to the flange top surface, propagating through the thickness of the flange.

# Bushing Fatigue Life

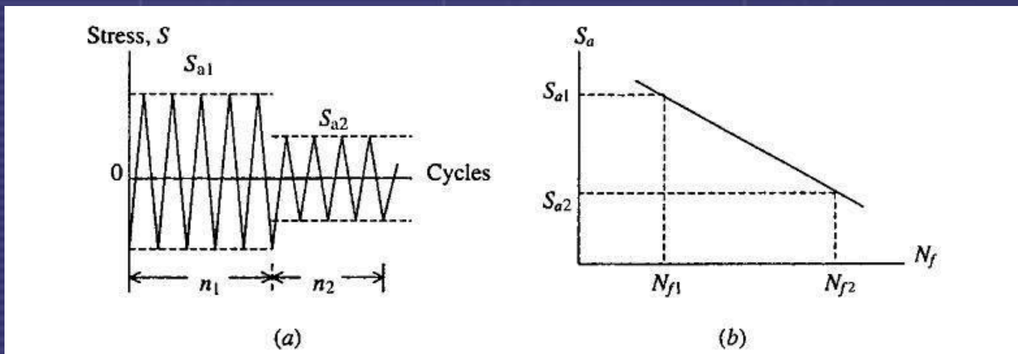
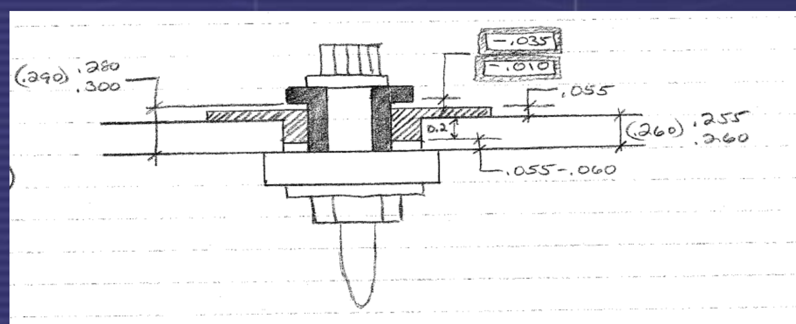



**Figure 9.3** Constant amplitude stress blocks and $S$–$N$ curve. ($a$) Constant amplitude stress blocks. ($b$) $S$–$N$ curve.

**Cycles to failure is greatly influenced by stress in part**

(where N = # of cycles to failure is plotted on *log scale*)




**Bushing stress induced by cowling panel fit and joint stack up which varies panel-to-panel, joint-to-joint**

# Conclusions – Incident Panel

**Left (Incident) Side Cowling Panel Bushing Analysis**

- **All four LT side cowling bushings submitted from N928 exhibited low stress, high-cycle fatigue.**
  - The multiple-origin fatigue initiated in the sharp radius of the flange/cylinder fillet and progressed across the flange thickness.
  - Both the LT-OB-FRT and LT-OB-MID bushing exhibited ratchet marks (multiple fatigue origins) exceeding 300 degrees around the flange/cylinder fillet. Failure of the cowling door probably initiated at one of these two significantly fatigue cracked bushings.
  - LT-OB-AFT bushing repair (6061-T6 spacer with 4 Monel 405 rivets) did not initiate the cowling door failure. However, with the spacer in place, the accompanying bolt was not long enough to achieve proper thread engagement.
- **The 4 failed bushings exhibited significant variations in bushing height and flange thicknesses.**
- **The bushings are 17-4 PH stainless steel. The hardness could be the result of any of the following heat treats: H1050, H1075, H1100 or H1150.**

# Conclusions – Non-Incident Panel

**Right (non-incident) Side Cowling Panel Bushing Analysis**

- Five RT side cowling panel bushings were received intact. One bushing was damaged upon removal from panel.
- Bushings were NDE'd at EFD and on-site. No cracks were found.
- Upon viewing intact bushings under optical microscope, some bushings had crack-like features but source could not be determined non-destructively.
- Aft Outboard bushing was cross-sectioned and polished to view under Scanning Electron Microscope which revealed a 0.0005" long fatigue crack (well below NDE detection threshold).

***Fatigue cracks were observed on both the left side incident cowling panel and the right side non-incident panel. Fatigue cracks on the incident side were much more extensive, likely due to differences in bushing stress caused by variations in panel fit and joint stack up.***

# Corrective Actions:

- To improve the cowling panel joint design and enable return to flight, new cowling bushings with thicker flanges and a larger machined flange/cylinder fillet radius were installed on all cowling panels.
- In addition, a spacer was added to the joint to achieve the proper stack tolerance.
- Finally, a time change requirement for all cowling bushings was instituted.