Air Force Life Cycle Management Center

U.S. AIR FORCE

A-10
Forward Nacelle Hanger Frame Material Substitution

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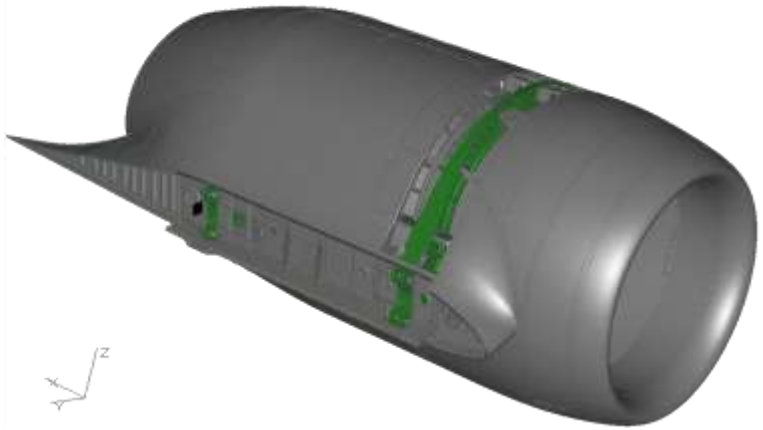
Background

- New Nacelle Center Sections are required to replace worn out items.

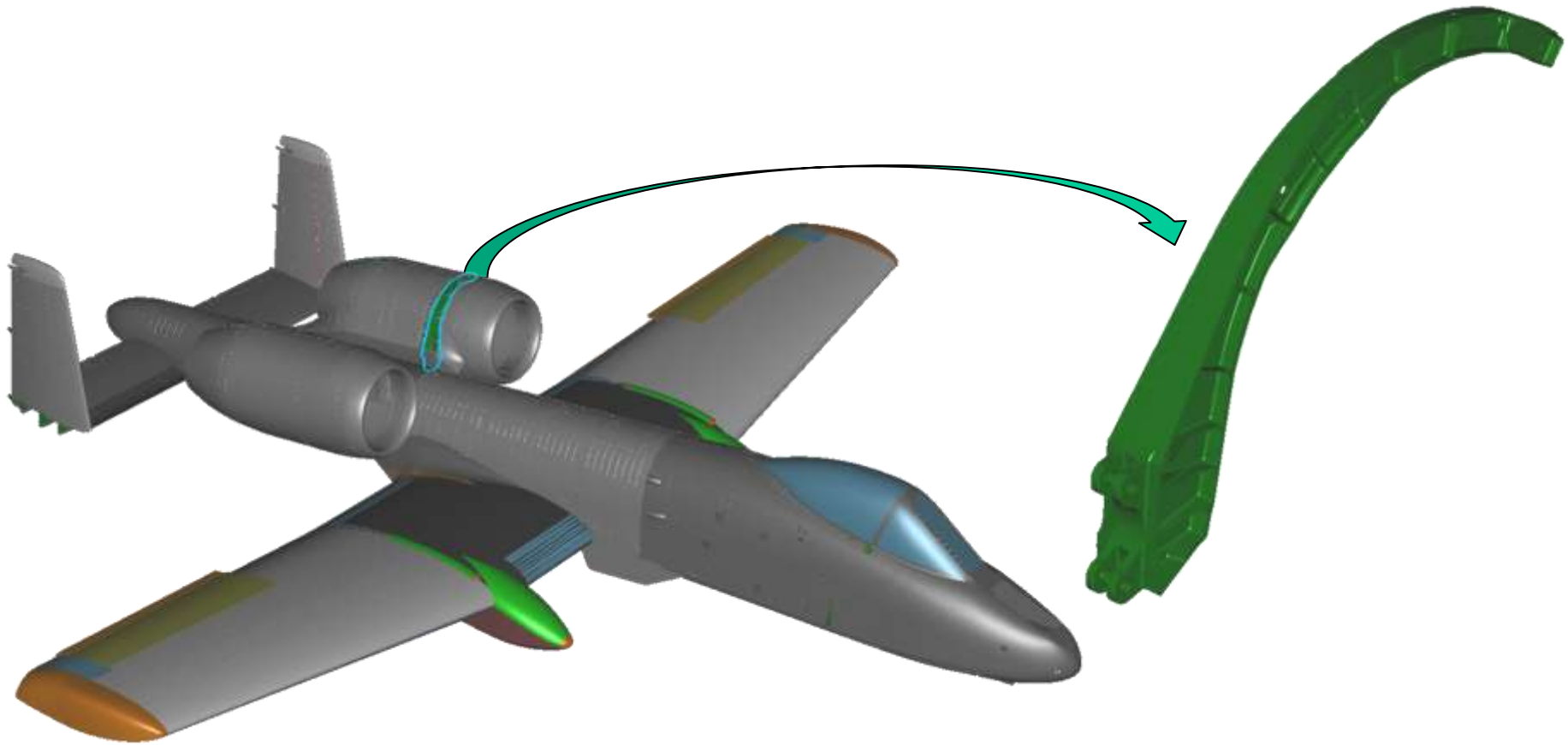


- Decided to use 7050-T7451 instead of 7175-T736 (T74) forgings for new center sections.

- New Nacelle Center Sections are in high demand.

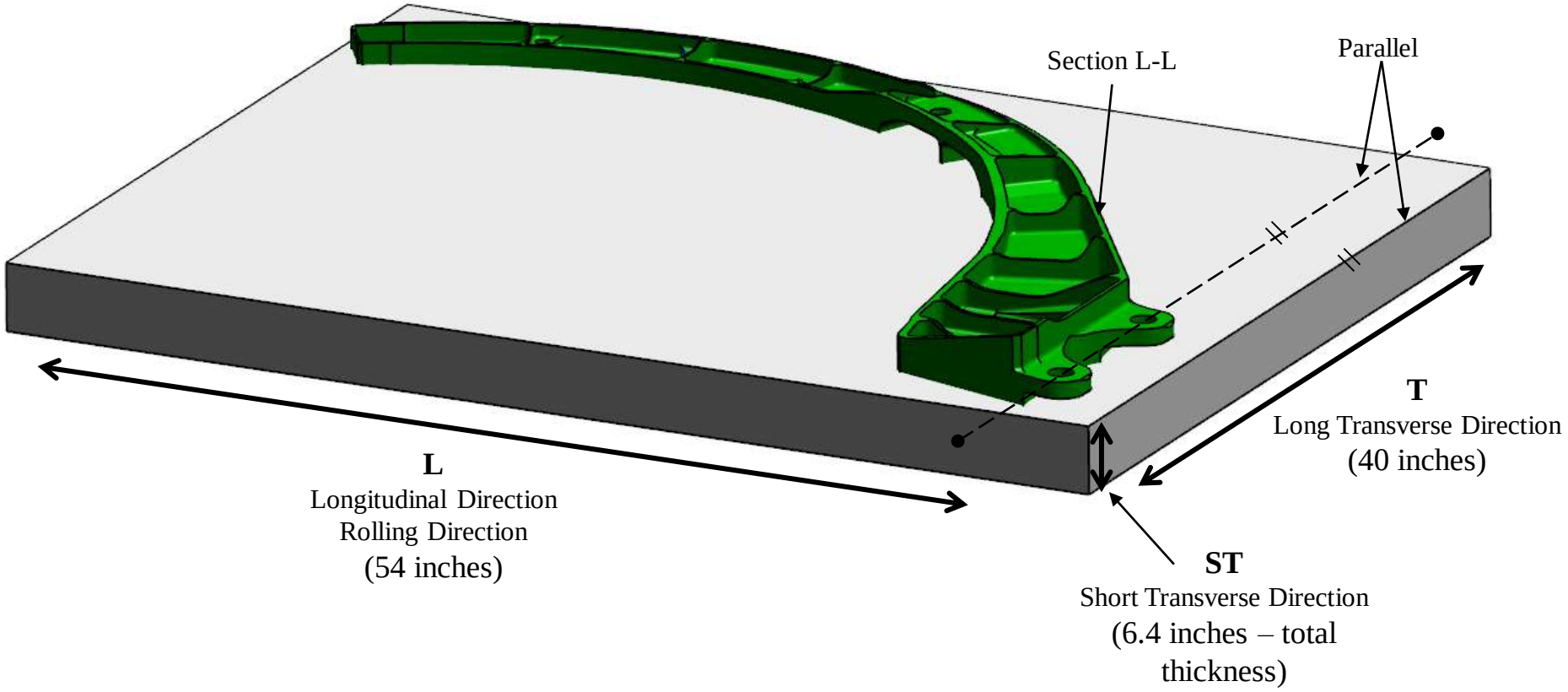
Background

- **Purpose:** Transmit Inertial loads (Aero and Weight) of the Nacelle / engine to the fuselage. Does not react thrust loads.
- **Fracture Criticality:** F&FC 1A



Description of Change

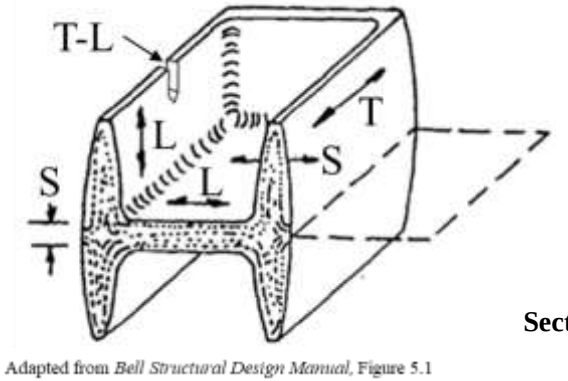
- **Description:** Material Product form change for the Fwd Hanger frame from a 7175-T736 (T74) forging to a 7050-T7451 plate.



Description of Change

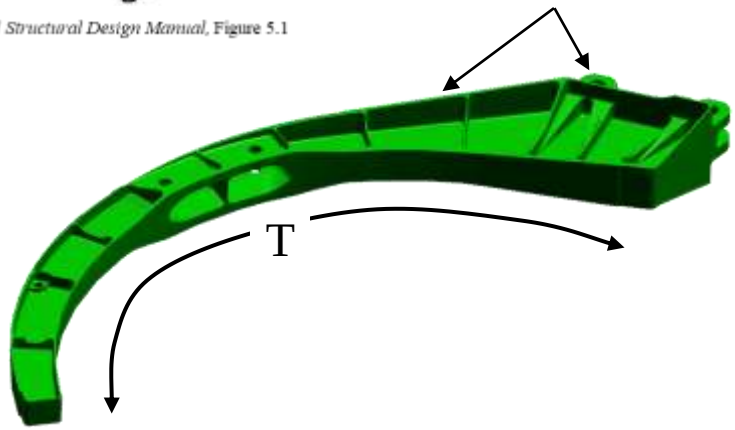
The grain direction will not be the same between the 7175-T736 (T74) forging and the 7050-T7451 plate. The possible difference in range is somewhere between L-T and S-T. For example: what was T-L in the forged flanges will now be L-S in the machined flanges.

Grain Orientation Change

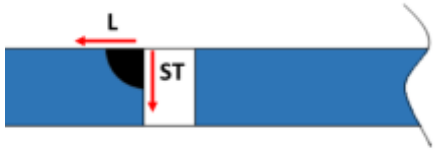


Adapted from *Bell Structural Design Manual*, Figure 5.1

Analysis Locations:
Section L-L and Upper Lugs.



Forging Grain Direction



Forging Grain Direction in flanges
(Section L-L)

In between LT and L

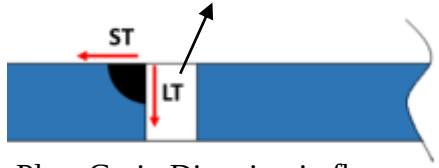


Plate Grain Direction in flanges
(Section L-L)

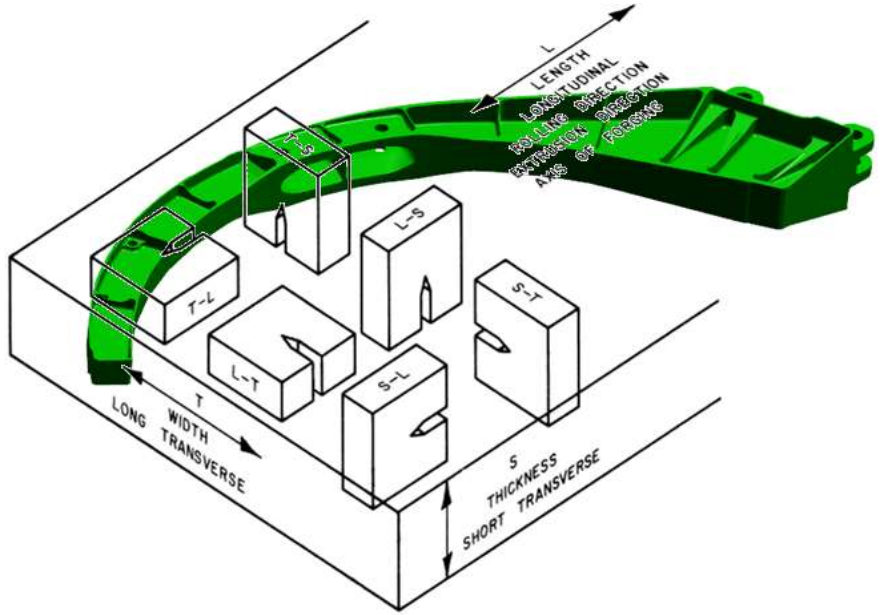
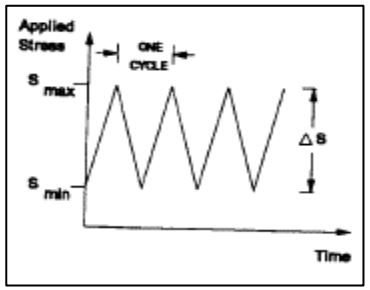
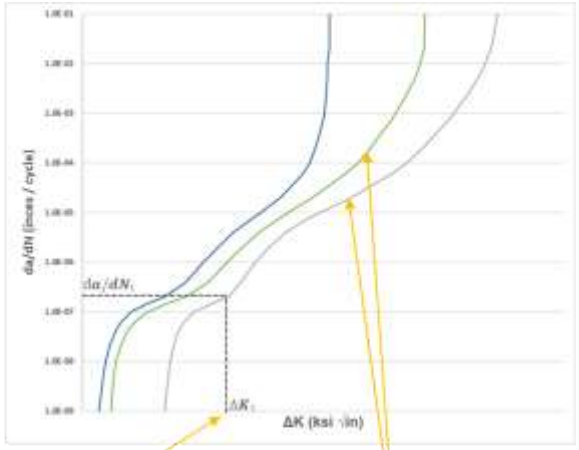


Plate Grain Direction

Review of Spectra and Retardation



REF: USAF damage tolerant design handbook

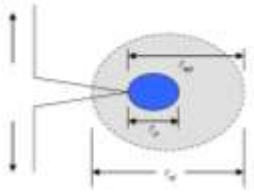


$$\Delta K = \Delta\sigma\beta\sqrt{\pi a}$$

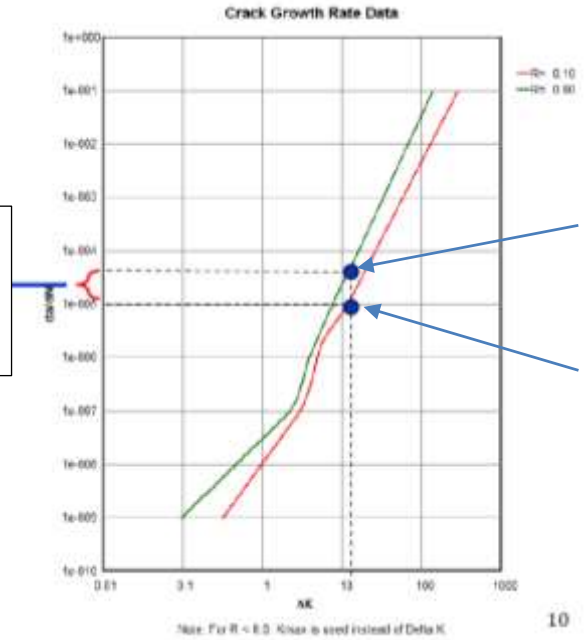
$$R = \frac{\sigma_{min}}{\sigma_{max}}$$

$$\Delta\sigma = \sigma_{max} - \sigma_{min}$$

Spectra and Material Rate Curves



The change in crack growth rate due to the reduction of the stress ratio.



Curve used with no SOLR

Curve used with SOLR

Retardation (Willenborg) and Material Rate Curves

Material Property Comparison – USAF Rate Data -- 7050 (L-T) vs 7175 (L-T)

Basic Material Data

7175-T736 is the older version of 7175-T74

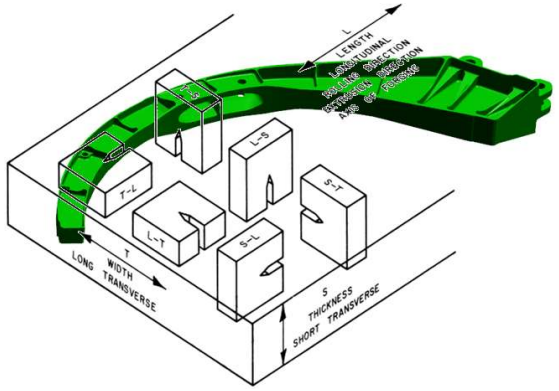
	7050-T7451 (L-T)	7175-T74 (L-T)
E	10300 ksi	10200 ksi
v	0.33	0.33
KC	50 ksi√in	50 ksi√in
KIC	30 ksi√in	30 ksi√in
Fty	59 ksi	66 ksi

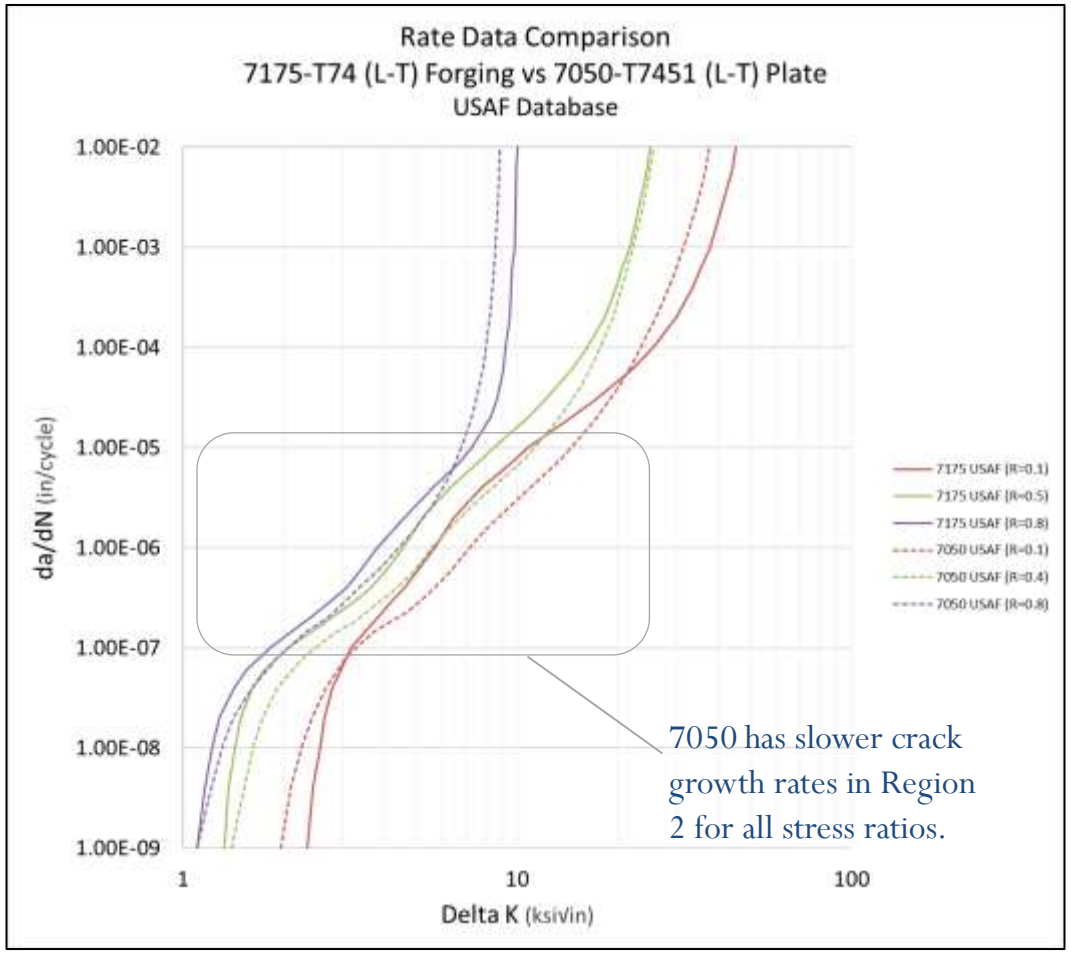
Note: 7175-T74 was re-curve fit to be consistent with 7050-T7451.

Harter T Method was used.

Original SOLR for Fwd Hanger Frame Lug was 1.8.

SOLR for new fit is 2.2.





Da/dN v Delta K

In comparing da/dN vs Delta K curves, they are fairly similar, except for in Region 2 area where the majority of crack growth occurs. In those cases 7050 is more benign. Therefore, based on a look at the rate data, 7050 will have improved or similar crack growth to 7175.

Material Property Comparison – USAF Rate Data -- 7050 (S-T) vs 7175 (L-T)

Basic Material Data

	7050-T7451 (S-T)	7175-T74 (L-T)
E	10300 ksi	10200 ksi
v	0.33	0.33
KC	50 ksi√in [1]	50 ksi√in
KIC	24 ksi√in [2]	30 ksi√in
Fty	56 ksi	66 ksi

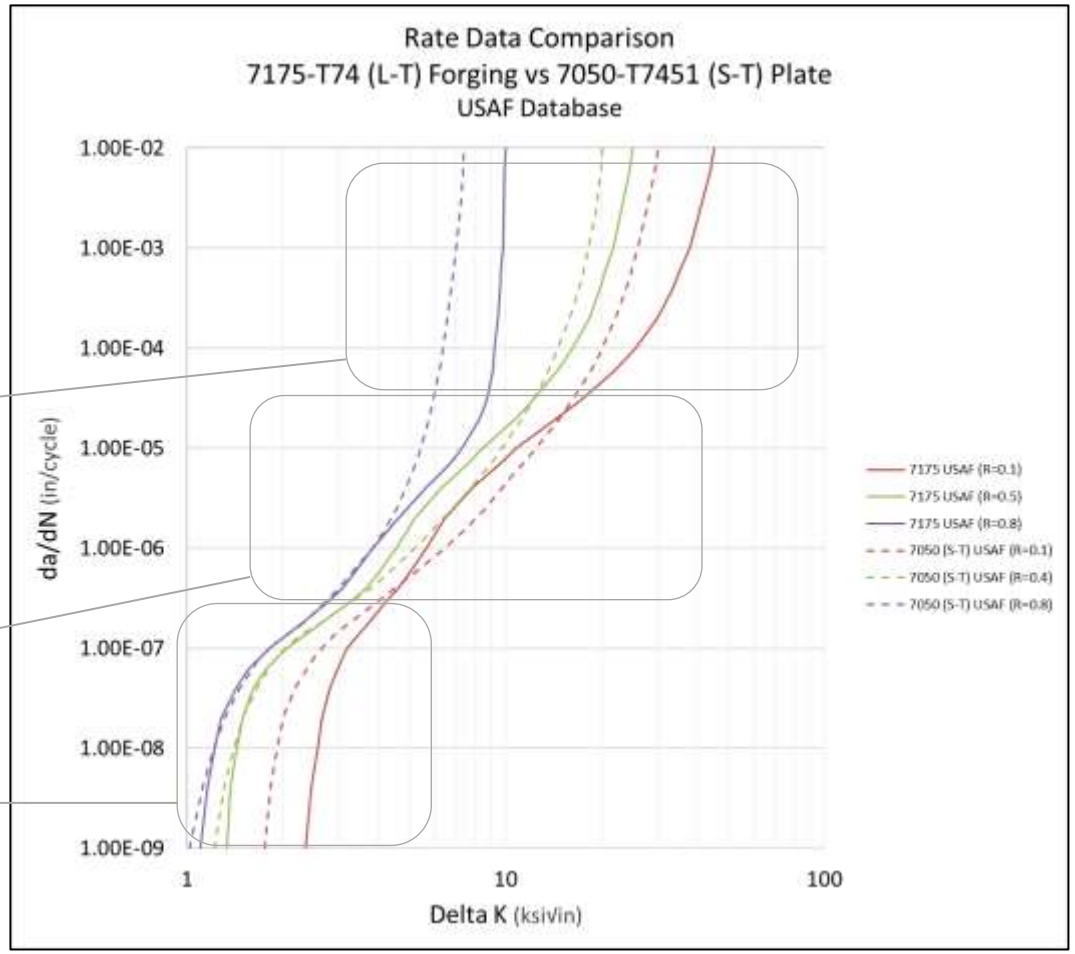
[1] Note: Is an assumed value. See next page

[2] Note: MMPDS S-L Data is used. See next page

7175 has slower crack growth in Region 3 (fast fracture) at all stress ratios

7050 has approximately slower crack growth in Region 2 (stable growth) at stress ratios (R) of 0.1 and 0.4

7175 has slower crack growth in Region 1 (short crack) at all stress ratios



Da/dN v Delta K

It is possible that there are locations which were L-T, in the 7175 forging, are now S-T in the 7050 machining. Because of this a check of the S-T to L-T is necessary. For higher stress ratios the difference are closer than at lower stress ratios. However, in most cases the 7050 S-T material is better or similar to in region 2 than 7175 L-T. For Region 1 and Region 3, 7175 L-T is better than 7050 S-T. Therefore, just a comparison of the da/dN curve cannot really give a feel for which will be better.

Material Property Comparison – USAF Rate Data -- 7050 (S-T) vs 7175 (L-T)

Once the crack grows to become a through crack it will be growing in the S-L directions. Therefore, in reality, the K_{IC} and K_C values should be lower than the 30 ksi√in and 50 ksi√in originally in the material lookup files. MMPDS provides a K_{IC} of 24 ksi√in, there it is used.

A sensitivity study was performed with K_{IC} to see if it changed, how different would the crack growth life be. The results were small, but enough that it was decided to use the lower value then was originally in the lookup file.

A study was performed for K_C, and the resulting lives had insignificant differences. So, the original value was used.

Adjusted Look Up file parameters

Original Look Up file parameters

	7050-T7451 (S-T)	7050-T7451 (S-T)
E	10300 ksi	10300 ksi
v	0.33	0.33
KC	50 ksi√in [1]	50 ksi√in
KIC	24 ksi√in [2]	30 ksi√in
Fty	56 ksi	61 ksi

Plate Grain Direction in flanges (Section L-L)

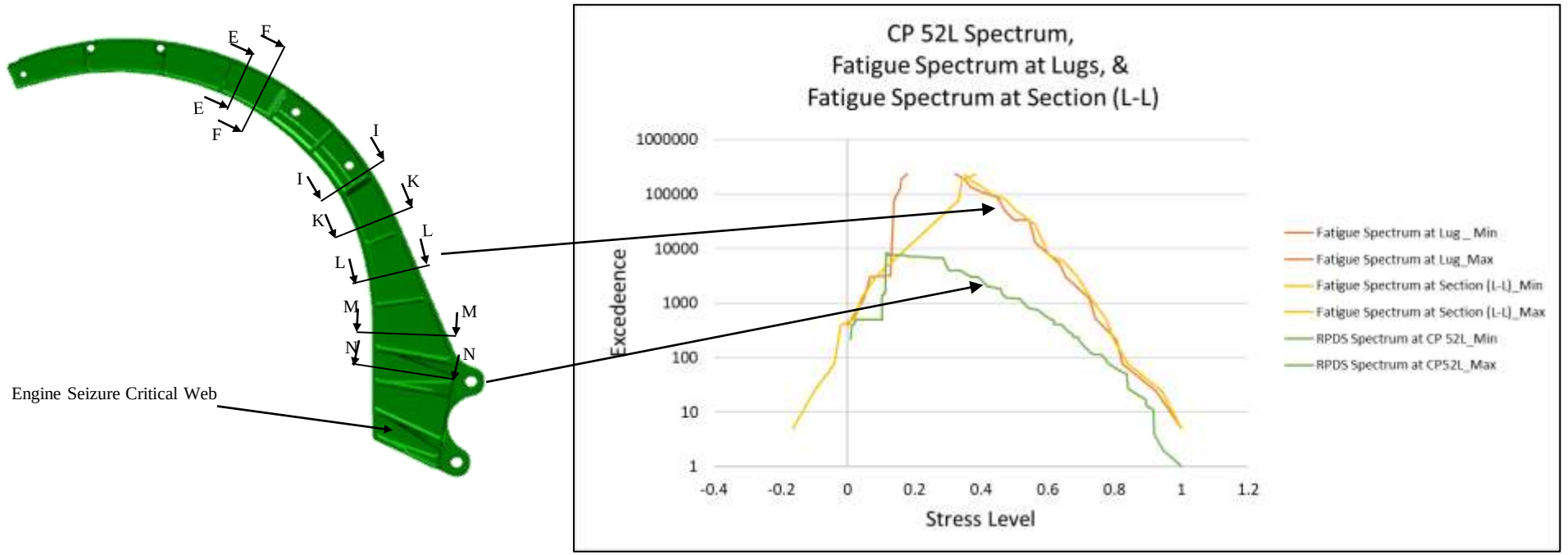
Forging Grain Direction in flanges (Section L-L)

Thickness = 0.327”

Review of Spectra

Original Fatigue Spectrum at Section L-L and Lugs used to understand difference in severity between the lugs and Section L-L.

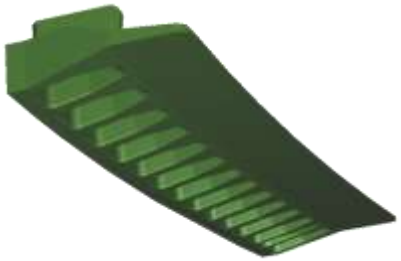
RPDS spectrum at the Lugs were used in final analysis for comparison of lives between 7175 and 7050 material (both locations).



A comparison between the three spectrum show that the fatigue spectrum (6,000 hour spectra) has more max stress events then RPDS, which is what would be expected. It also shows that there is similar number of max peaks events for the fatigue spectrum of lug as compared to Section L-L.

DTA Analysis for Lugs

Severity of Stress spectrum of WS 110 location is similar to Hanger Frame Upper Lug.
-Only thing different between the two models is the spectra (CP 27 vs CP 52)



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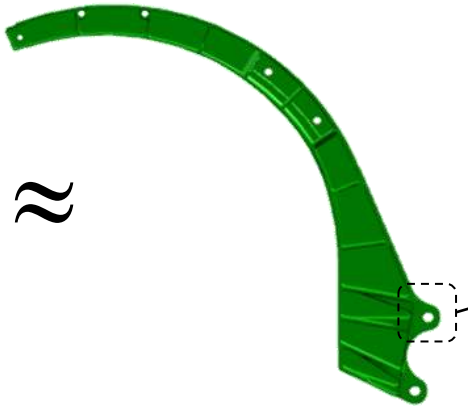
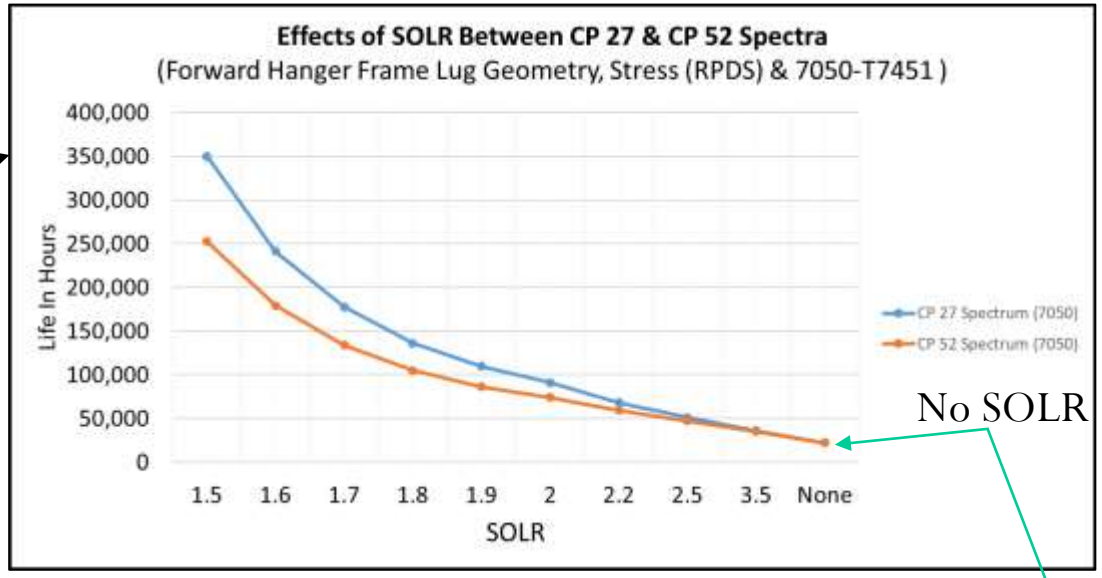
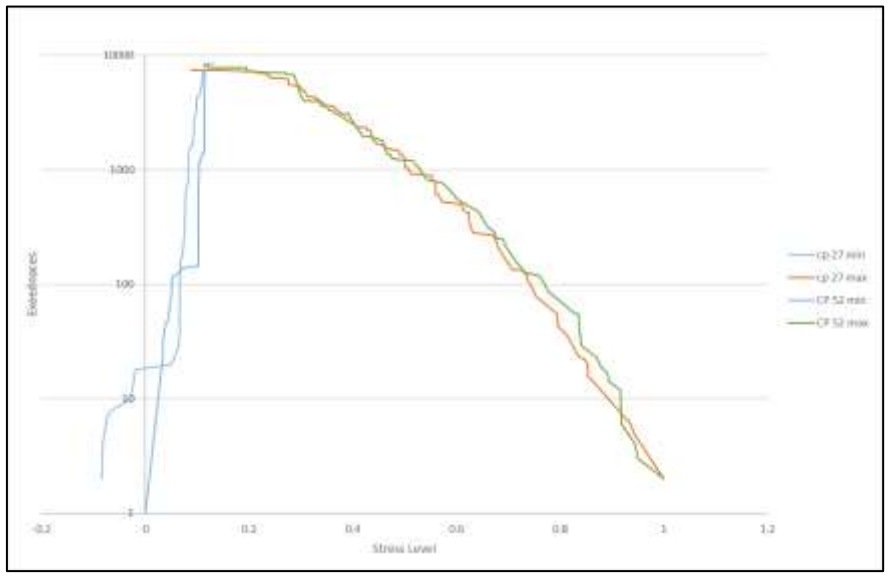






SOLR	1.5	1.6	1.7	1.8	1.9	2	2.2	2.5	3.5	None
Percent Difference	-32%	-29%	-28%	-26%	-24%	-20%	-14%	-8%	-3%	0%

No SOLR provides a straight comparison of the severity of two spectra
A Range SOLR shows the influence of SOLR on the spectra

Note: spectrum coupon testing was performed for WS 110 splice fitting spectrum for 7050-T7451.
Resulted in an SOLR of 2.5

DTA Analysis for Lugs

A general pattern that has been seen from testing is:

1) the greater the thickness the lower the SOLR value (more retardation).
2) The greater the maximum stress the lower the SOLR value (more retardation).

Both Analyses used:

1) Fwd Hanger Frame Lug Geometry
2) Fwd Hanger Frame Lug Stress (RPDS)
3) 7050-T7451 Material
4) Only the spectrum varied

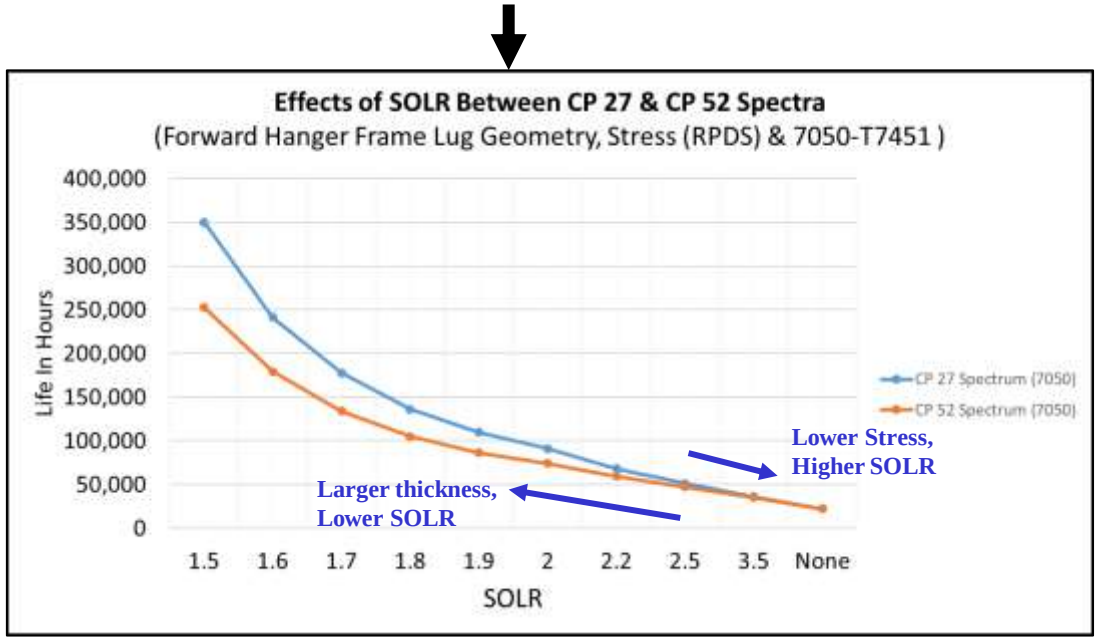
INFO:

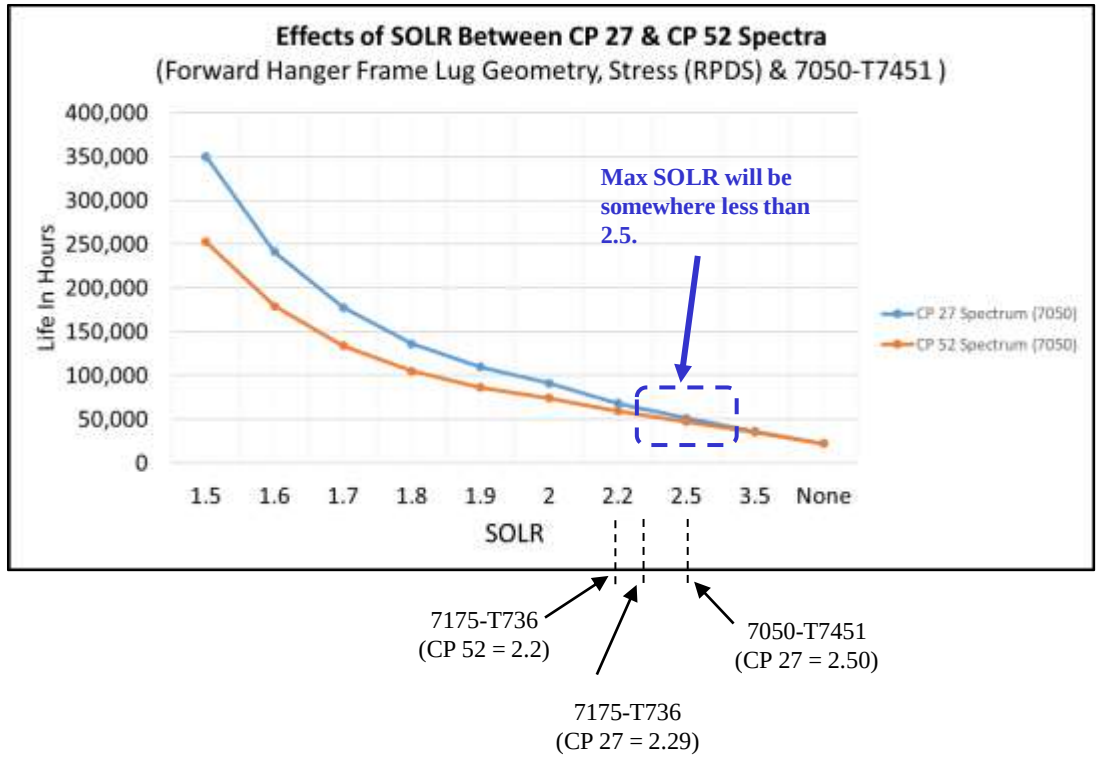
Tension Stress Level – CP 27 = 21.625 ksi, Hanger Frame Lug = 19.23 ksi

*Note: Bearing Stress for the lug is 24.60 ksi. A_{br} = 0.93in^2, A_t = 1.19in^2, --- 24.60 (0.93/1.19) = 19.23 ksi

Geometry –

Thickness – CP 27 = 0.455 inches, Upper Lug = 0.78 inches





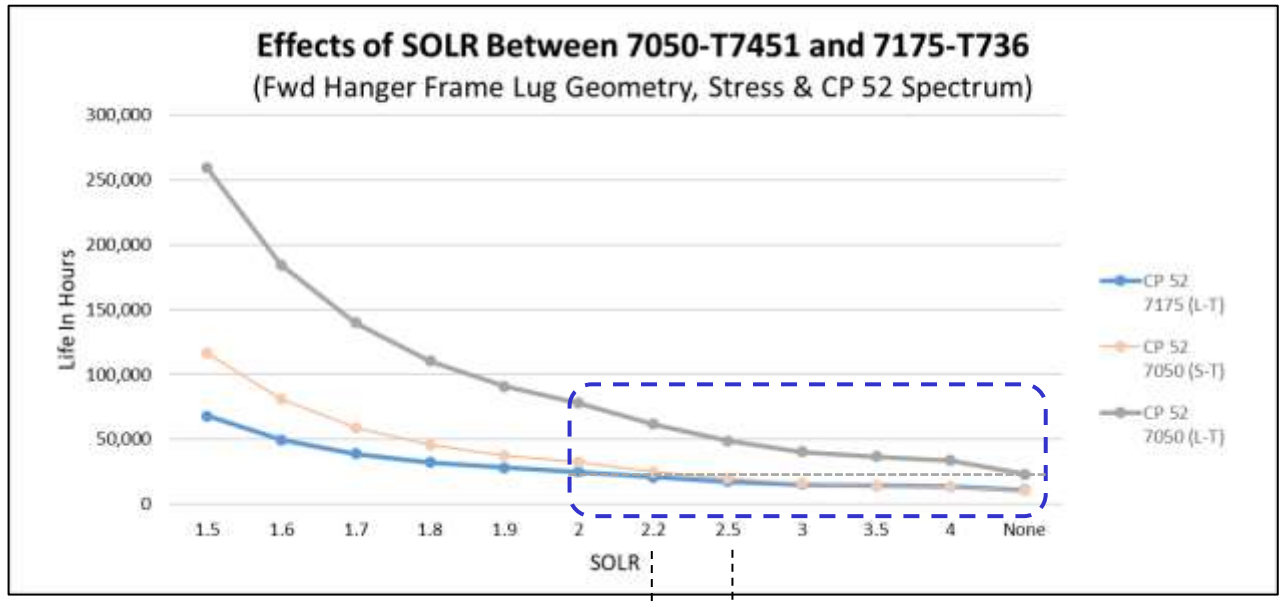
*Note: CP 27 SOLR was re-correlated, and present for reference

DTA Analysis for Lugs

Comparison in Crack Growth lives between 7175 (L-T) and 7050 (L-T)

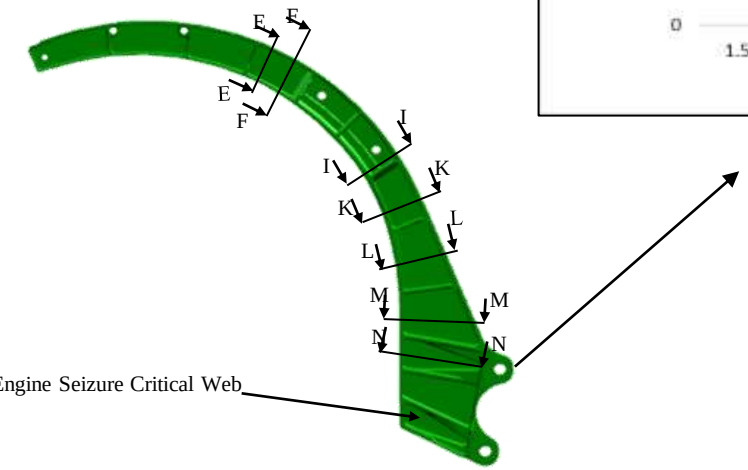
All Analyses used:

1) Fwd Hanger Frame Lug Geometry
2) Fwd Hanger Frame Lug Stress (RPDS)
3) CP 52 Spectrum
4) Only material differed



7175-T736
(CP 52 = 2.2)

7050-T7451
(CP 27 = 2.50)



The Difference in life for 7050 at no SOLR to 7175 at an SOLR of 2 is -8%

Since we do not have an SOLR developed for 7050 for the hanger frame structure, we ran crack growth lives at a series of SOLR values to understand the trend.

For the expected range of SOLR values, the difference in life, at section L-L, between 7050-T7451 (S-T) and 7175-T736 (L-T) is similar.

For the expected range of SOLR values, the difference in life, at the Lugs, between 7050-T7451 (L-T) and 7175-T736 (L-T) is similar.

Note: the Lugs are the critical location on the hanger frame.

DTA Analysis for Section L-L

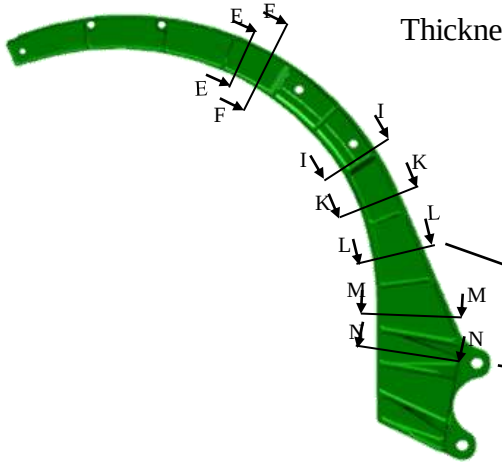
Comparison in Crack Growth lives between 7175 (L-T) and 7050 (S-T)

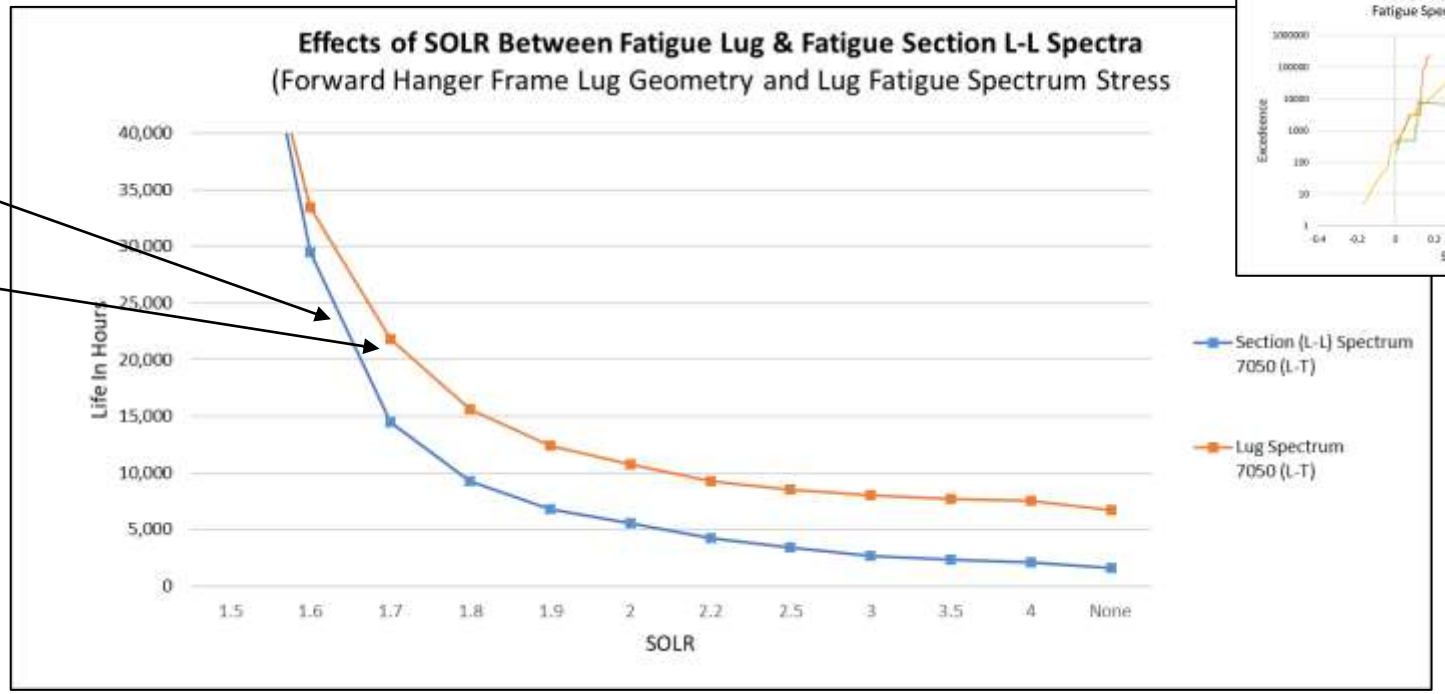
Both Analyses used:
1) Fwd Hanger Frame Lug Geometry
2) Fwd Hanger Frame Lug Stress (Fatigue)
3) 7050-T7451 (L-T) Material
4) Only the spectrum varied.

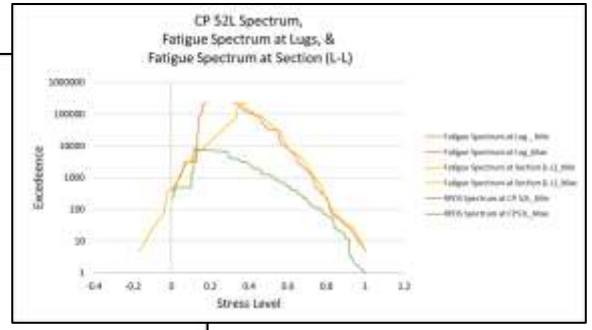
INFO:

Tension Stress Level (Fatigue Spectrum) – Lug = 21.01 ksi, Section L-L= 25.55 ksi

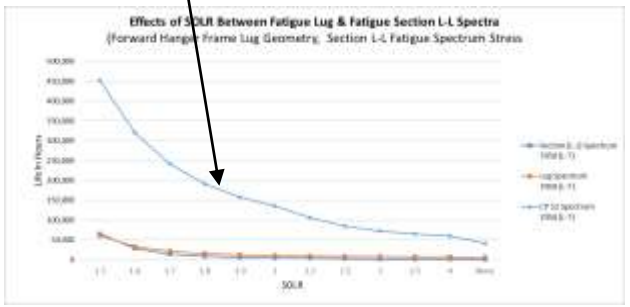
Thickness – Lug Area = 0.78 inches, Section L-L = 0.325 inches







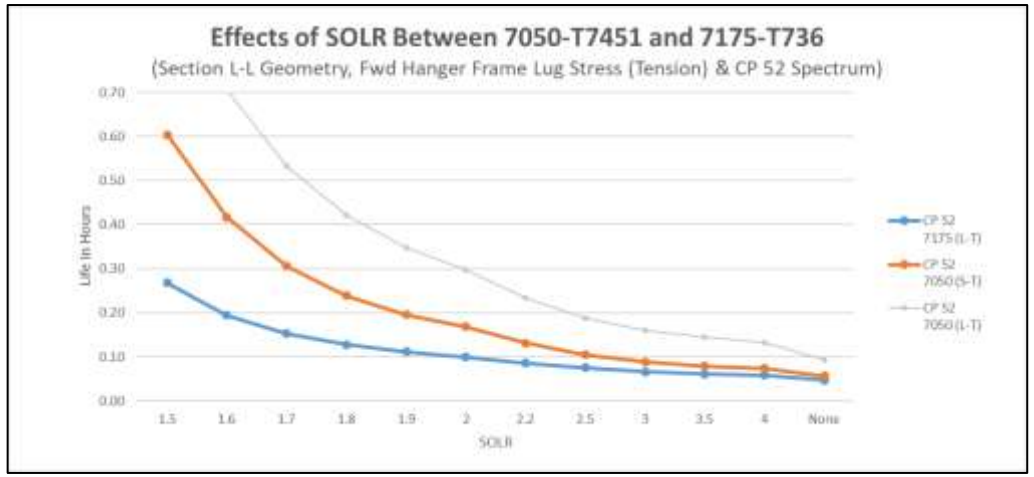
CP 52 Spectrum



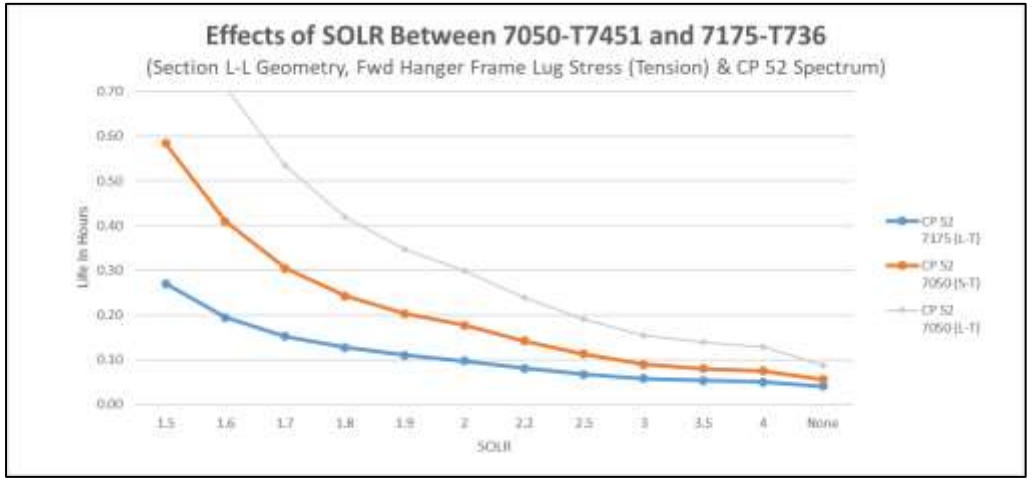
What we Learn from this comparison?
1) Exceedance Curve Shape is similar between Section L-L and the Lugs. Therefore, can compare severity
2) Section L-L Spectrum is more severe then the Lug Spectrum
3) Section L-L Stress level is higher then the Lug Stress level
4) It is likely that the SOLR for Section L-L will be lower then for the Lug.

DTA Analysis for Section L-L

Study was performed to see how the shape of the curves change with increased stress (life normalized).

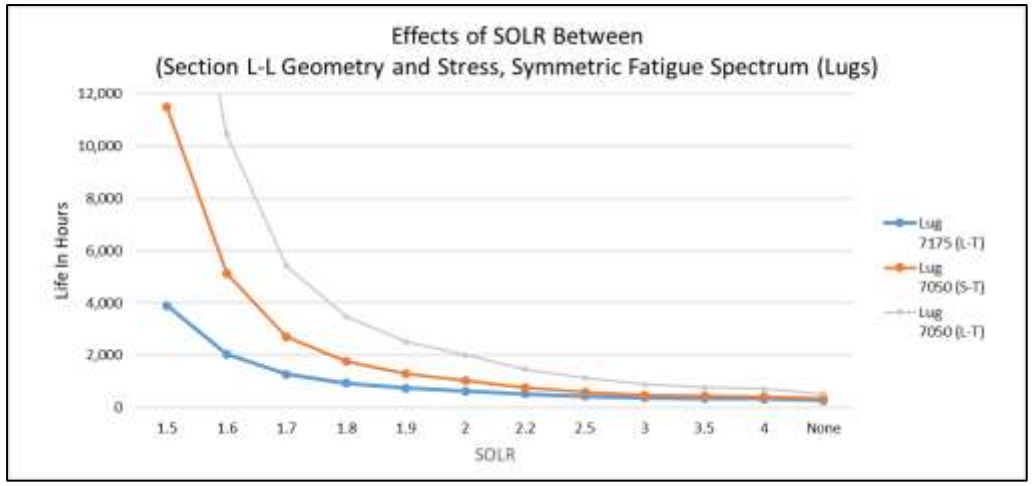


Increased Stress from 19.23 ksi to 25.55 ksi

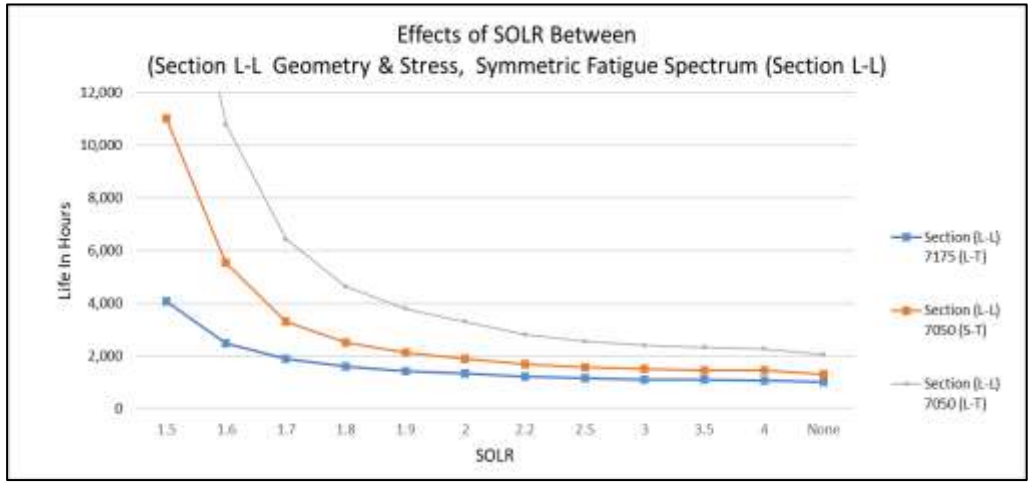


Change was insignificant in the shape.

Study was performed to see how the shape of the curves change between Lug and Section L-L spectra.



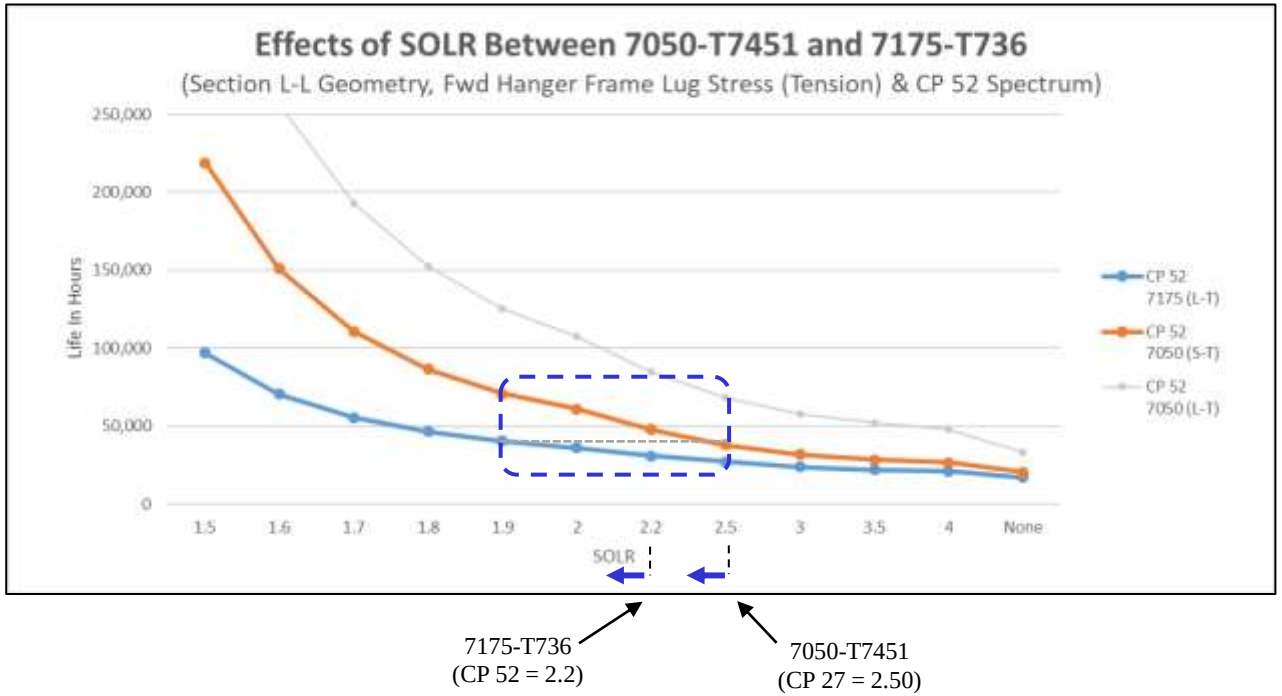
Lug Spectrum to Section L-L Spectrum.



Curves are further apart with the Section L-L spectrum

DTA Analysis for Section L-L

Fatigue Spectrum is significantly more severe then RPDS. This suggests that the retardation associated with the spectrum will also be lower then for RPDS.



The analyses used:

1) Section L-L Geometry
2) Fwd Hanger Frame Lug Stress (RPDS)
   a. Bearing Stress converted to Tension (19.23 ksi)
3) CP 52 Spectrum
4) Only the material varied.

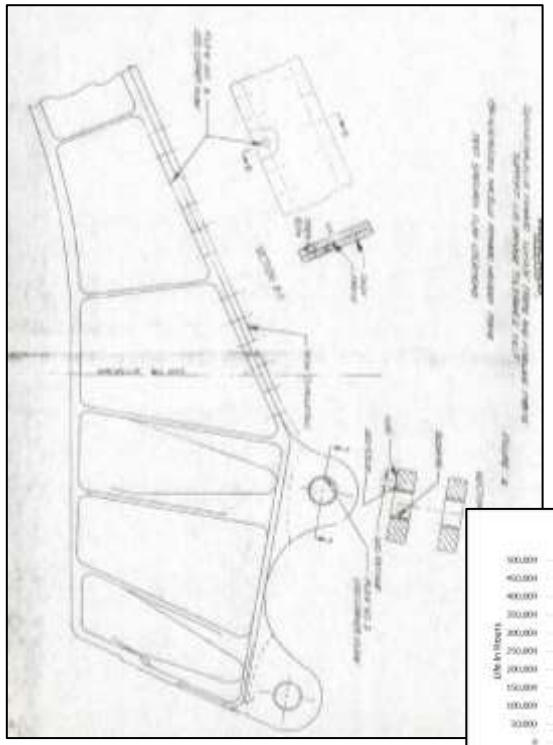
Notes:

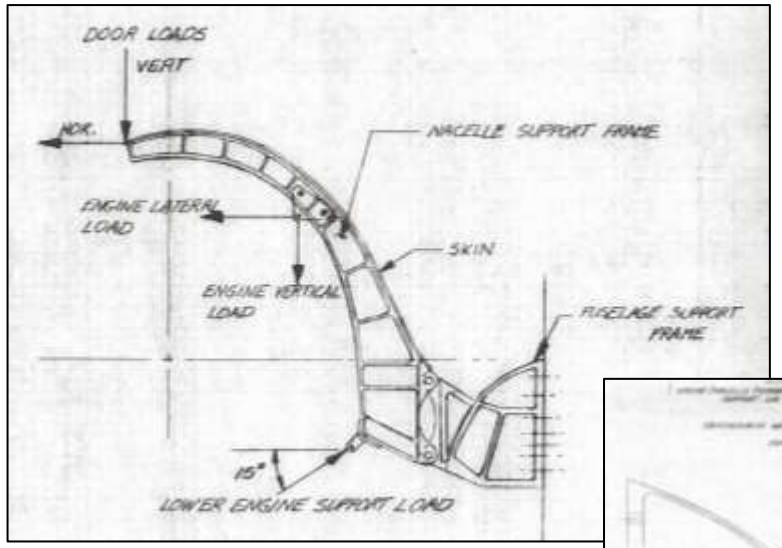
1) The Section L-L spectrum is more severe, but the resulting life vs SOLR plots show that the difference in life between the two is not significant.
2) The Section L-L stress is higher, but the resulting life vs SOLR plots show that the difference is insignificant.
3) In both cases, the high stress and more severe spectrum create for a larger difference between 7050-T7451 (S-T) and 7175-T736 (L-T)
4) The lower the SOLR the less change in SOLR is required to create for a larger difference in life.
5) The plot is based on a difference between L-T and S-T. However, the actual difference is between T-L and L-S.
6) Between all these points, the difference in life will actually be larger then what is shown here.

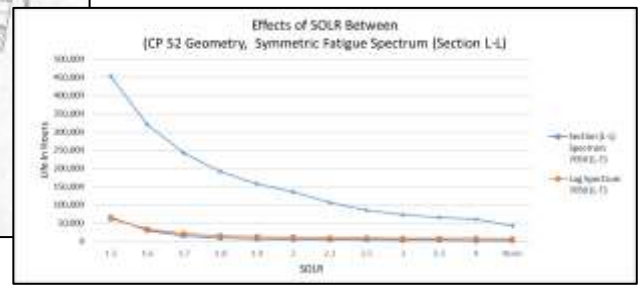
Additional Justification – DTA Test

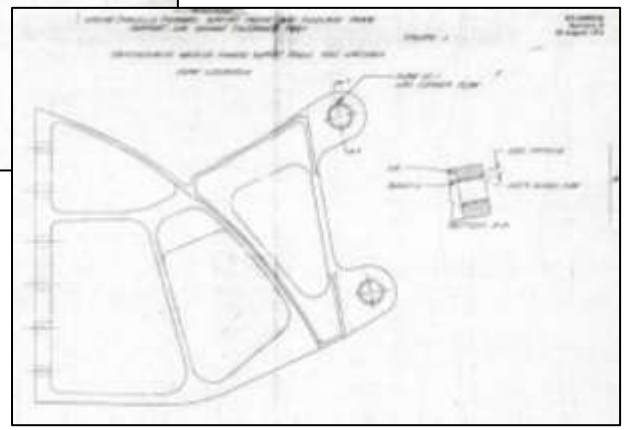
Original Damage Tolerance Test (Fwd Hanger Frame)

The pre-flawed forward hanger frame (7175-T736) was spectrum tested to one lifetime of design aircraft loads and then subsequently tested to limit design load to demonstrate adequate residual strength. The spectrum test was then continued for one additional lifetime. (6000 Hr Composite Fatigue Spectrum was used, which is more severe then current RPDS spectrum)









Low Risk For Fatigue Cracking.

Fleet History (Upper Lug):
1000 inspections recorded and only 2 to 3 crack indications found noted

Results: The pre-induced flaws **did not experience any growth** during 2 lifetimes of testing plus the residual strength test (limit load).

Summary

- Static Analysis
  - 7075-T7451 plate can be used to replace 7175-T736 forge by increasing the flange and/or web thicknesses in various locations, achieving a Margin of Safety greater than or equal to zero (MS $\geq$ 0).

- D&DT
  - A review of material properties and spectrum shows, analytically, that the 7050 is similar to or better than 7175 for the hanger frame spectrum and stress levels that are critical for fatigue damage.

- Testing
  - Original Hanger Frame Damage Tolerance (DT) test showed no growth associated with the 6,000 hour spectrum in the pre-cracked notches in 7175-T736 (T74) material. Low Risk to Fatigue
  - WS 110 Splice Fitting Test showed that for the spectrum and configuration tested, 7050 resulted in more life than 7175.

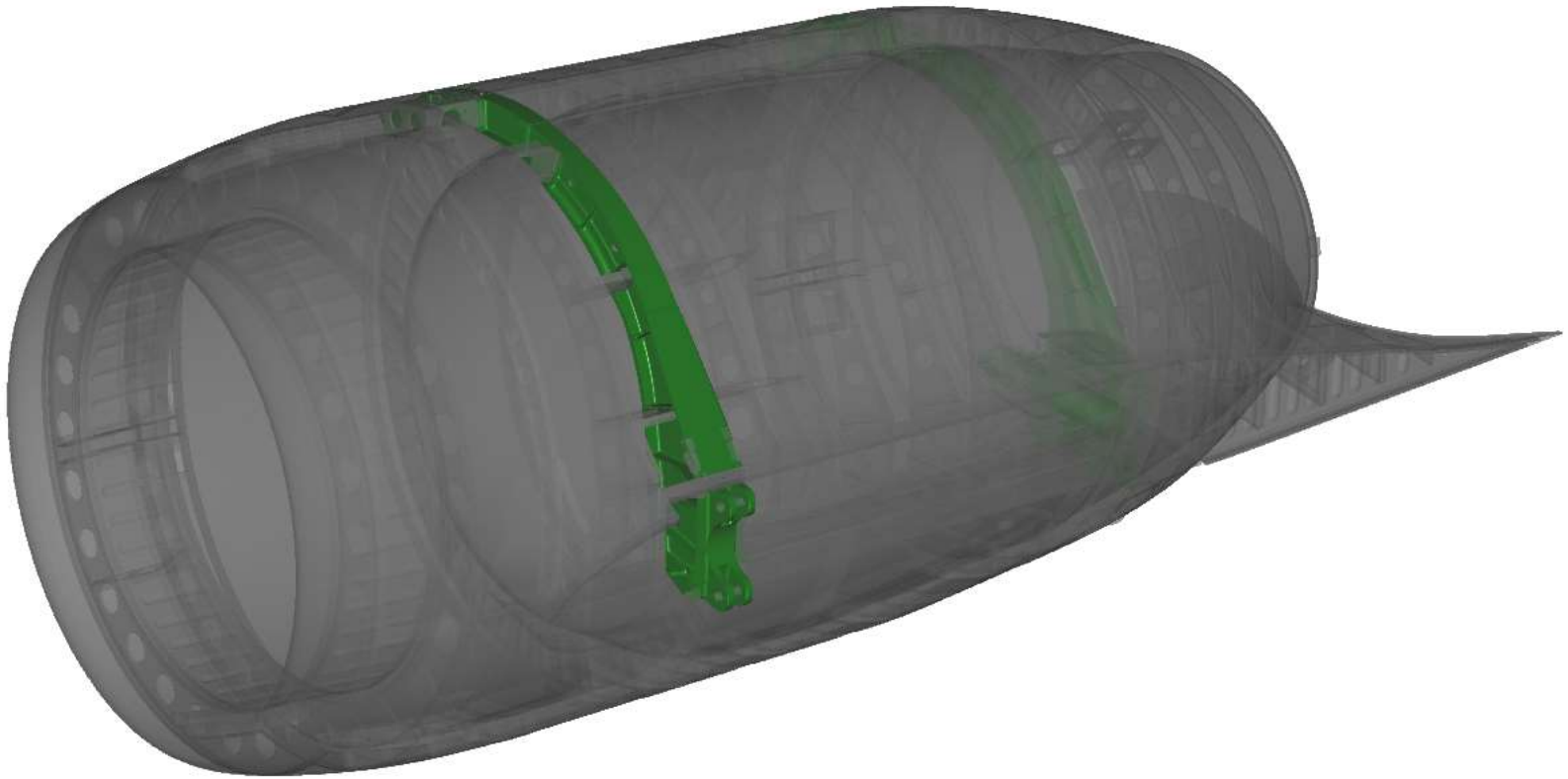
Recommendations

- Because Section L-L spectrum and stress level are more severe then the hanger frame lug, analysis for the remaining hanger frame lug cannot be based on the lug. Therefore, a spectrum, stress level, and SOLR will need to be developed for the hanger frame Section L-L.

- Spectrum testing for Section L-L and the upper lug to determine an SOLR value for 7050-T7451 at that location should be done also.

– Based on the fact that no growth occurred in the original Hanger Frame DT test, because WS 110 splice fitting showed 7050 to have more life than 7175, and because, analytically, the 7050 is shown to be similar to or better than 7175 for the hanger frame spectrum and stress levels, **it is recommended that no additionally damage tolerance component testing is necessary for the 7050-T7451 hanger frame.**

Questions



Appendix

Material Property Comparison – From Specs

Table 2A - Minimum tensile properties, inch/pound units

Nominal Thickness At Time of Heat Treatment Inches			Tensile Strength ksi	Yield Strength at 0.2% Offset ksi	Elongation in 2 Inches or 4D %
Up	to 3.000,	incl	76.0	66.0	7
Over 3.000	to 4.000,	incl	73.0	63.0	7
Over 4.000	to 5.000,	incl	70.0	61.0	7
Over 5.000	to 6.000,	incl	68.0	58.0	7

7175-T736
AMS 4149

7050-T7451
AMS 4050

Table 2A - Minimum tensile properties, inch/pound units

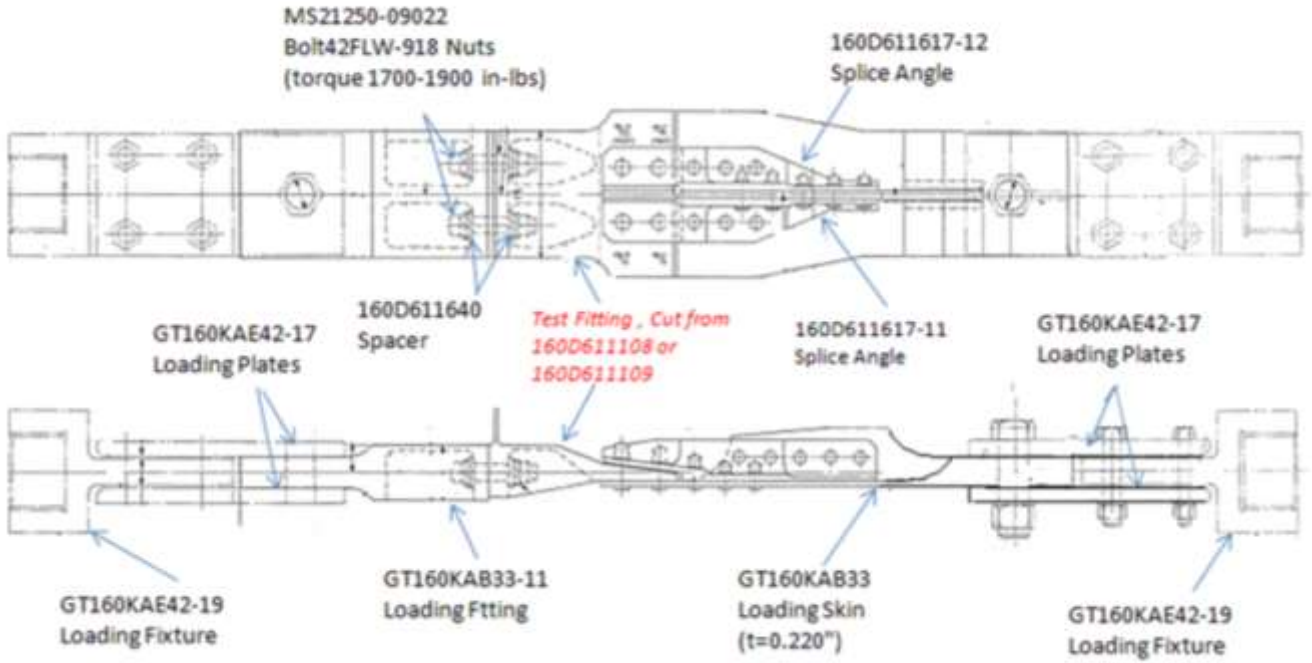
Nominal Thickness Inches	Specimen Orientation	Tensile Strength ksi	Yield Strength at 0.2% Offset ksi	Elongation in 2 Inches or 4D %
0.250 to 2.000, incl	Longitudinal	74.0	64.0	10
	Long Trans.	74.0	64.0	9
Over 2.000 to 3.000, incl	Longitudinal	73.0	63.0	9
	Long Trans.	73.0	63.0	8
	Short Trans.	68.0	59.0	3
Over 3.000 to 4.000, incl	Longitudinal	72.0	62.0	9
	Long Trans.	72.0	62.0	6
	Short Trans.	68.0	58.0	3
Over 4.000 to 5.000, incl	Longitudinal	71.0	61.0	9
	Long Trans.	71.0	61.0	5
	Short Trans.	67.0	57.0	3
Over 5.000 to 6.000, incl	Longitudinal	70.0	60.0	8
	Long Trans.	70.0	60.0	4
	Short Trans.	67.0	57.0	3
Over 6.000 to 7.000, incl	Longitudinal	69.0	59.0	7
	Long Trans.	69.0	59.0	4
	Short Trans.	66.0	56.0	3
Over 7.000 to 8.000, incl	Longitudinal	68.0	58.0	6
	Long Trans.	68.0	58.0	4
	Short Trans.	65.0	55.0	3

7175-T736 will have different material properties based on associated thickness in the forging. 7050-T7451 will only have one.

Justification for Change – DTA Test

WS 110 Splice Fitting Component Test

The purpose of original test was to demonstrate that the damage tolerance capability of the redesigned splice fitting (7050-T7451 aluminum alloy machining) is the same or better than the original production design (7175-T736 forging).



Severity of WS 110 usage spectrum is similar to Hanger Frame Upper Lug

Results: The average fatigue life of specimens made of 7050 was 27,570 EFH vs. 22,400 EFH for the 7175 specimens, which equates to approximately 23% higher for the 7050 specimens.