Damage Tolerance Analysis of Space Shuttle External Tank Lug Fillet Welds Using NASGRO

Abstract

The damage tolerance of the External Tank (ET) lug welds were reassessed because of an increase in the loads due to the removal of the protuberance air load (PAL) ramp. The analysis methods included detailed finite element analysis (FEA) of the ET welded lugs and FEA of the lug weld test configuration. The FEA results were used as input to the crack growth analysis code NASGRO to calculate the mission life capability of the ET lug welds and to predict the number of cycles to failure in the lug weld testing. The presentation presents the method of transferring the FEM results to the NASGRO model and gives correlations between FEM and NASGRO stress intensity calculations.

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NASGRO Consortium Meeting
06/14/06

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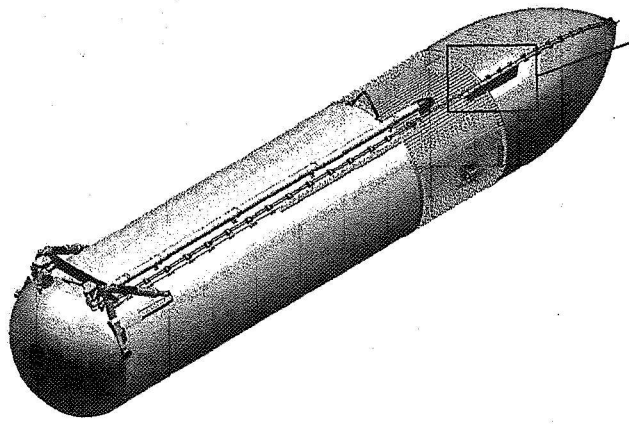
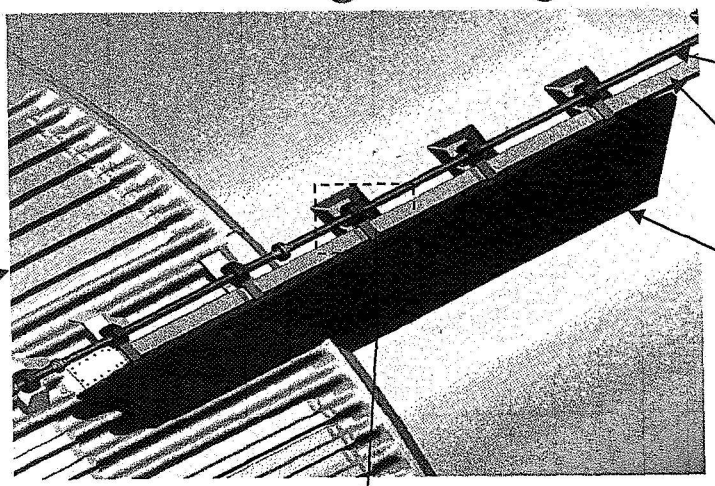
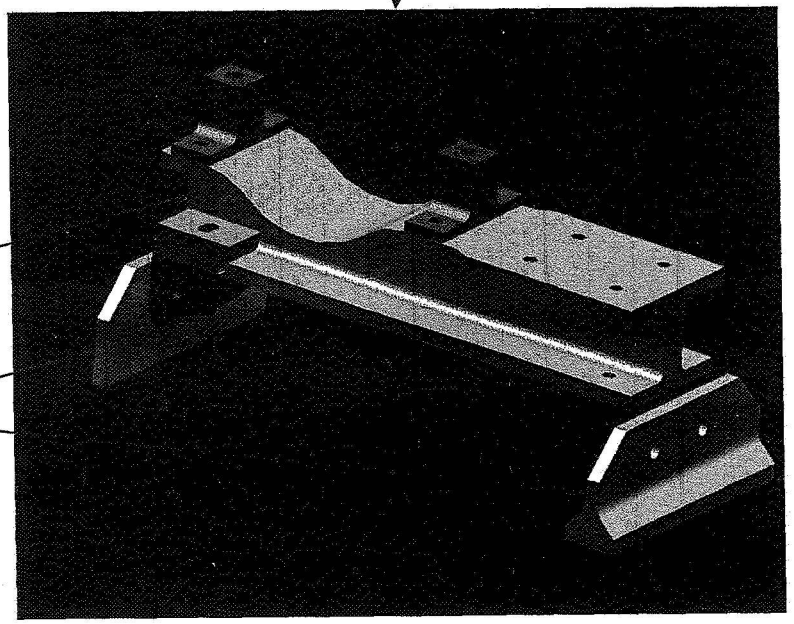
Damage Tolerance Assessment Branch – EM20

External Tank Welded Lug Configuration

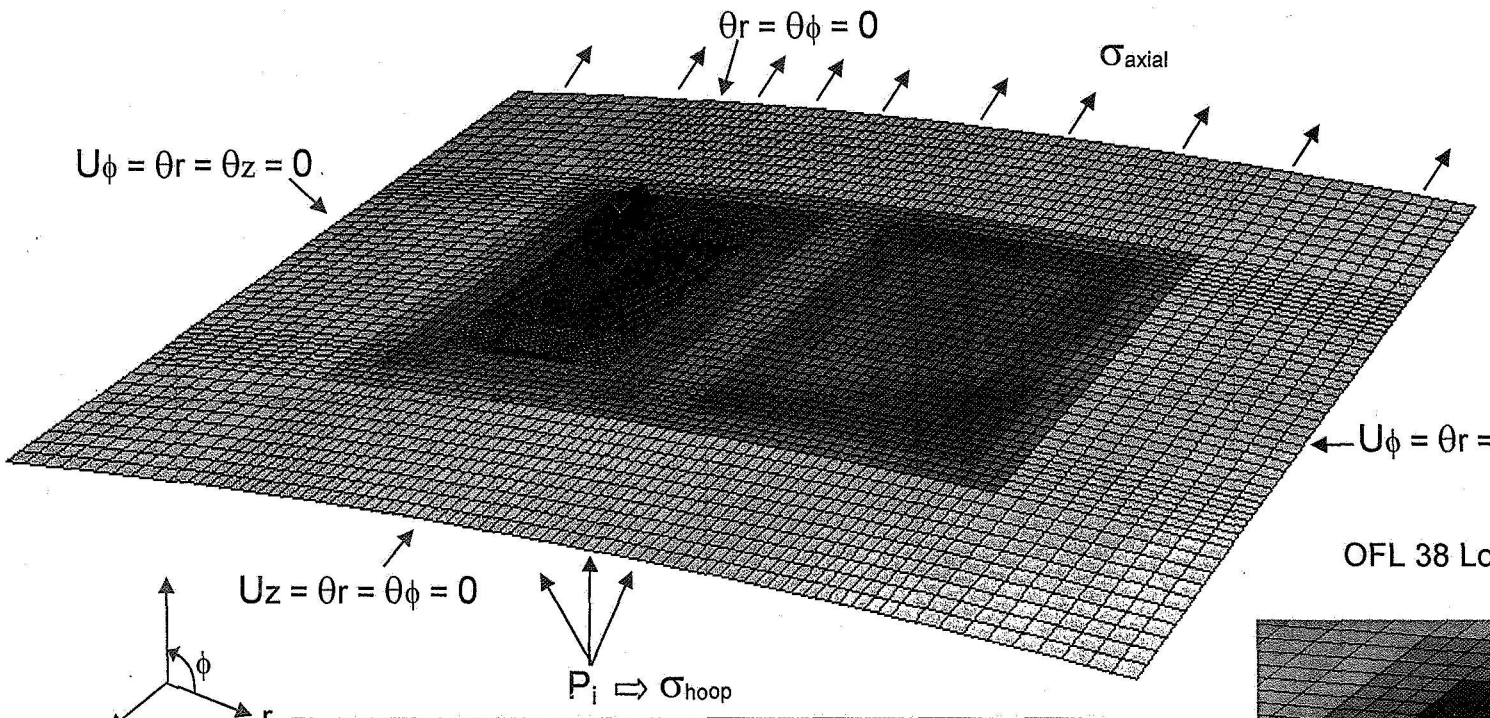
Issue: Reassessment of Lug Weld Damage Tolerance Due to PAL Ramp Removal



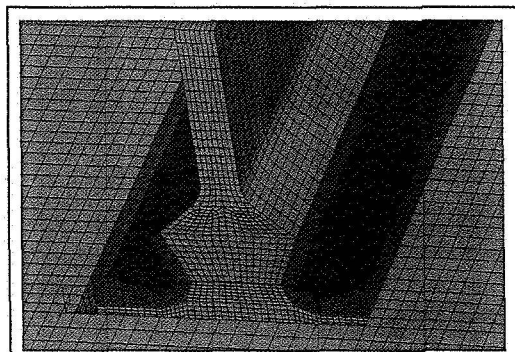




External Tank Configuration FEM Details Conditions

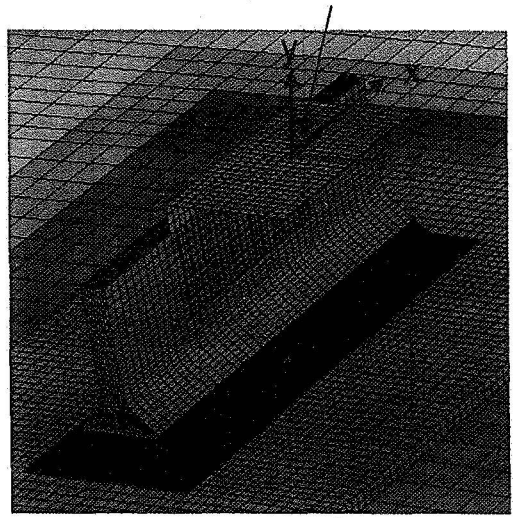


- Analysis code - ABAQUS
- Approx. representation of barrel section of LO_2 tank
- 8 node brick elements for lug and underlying pad
- 4 node shell elements for remainder of membrane

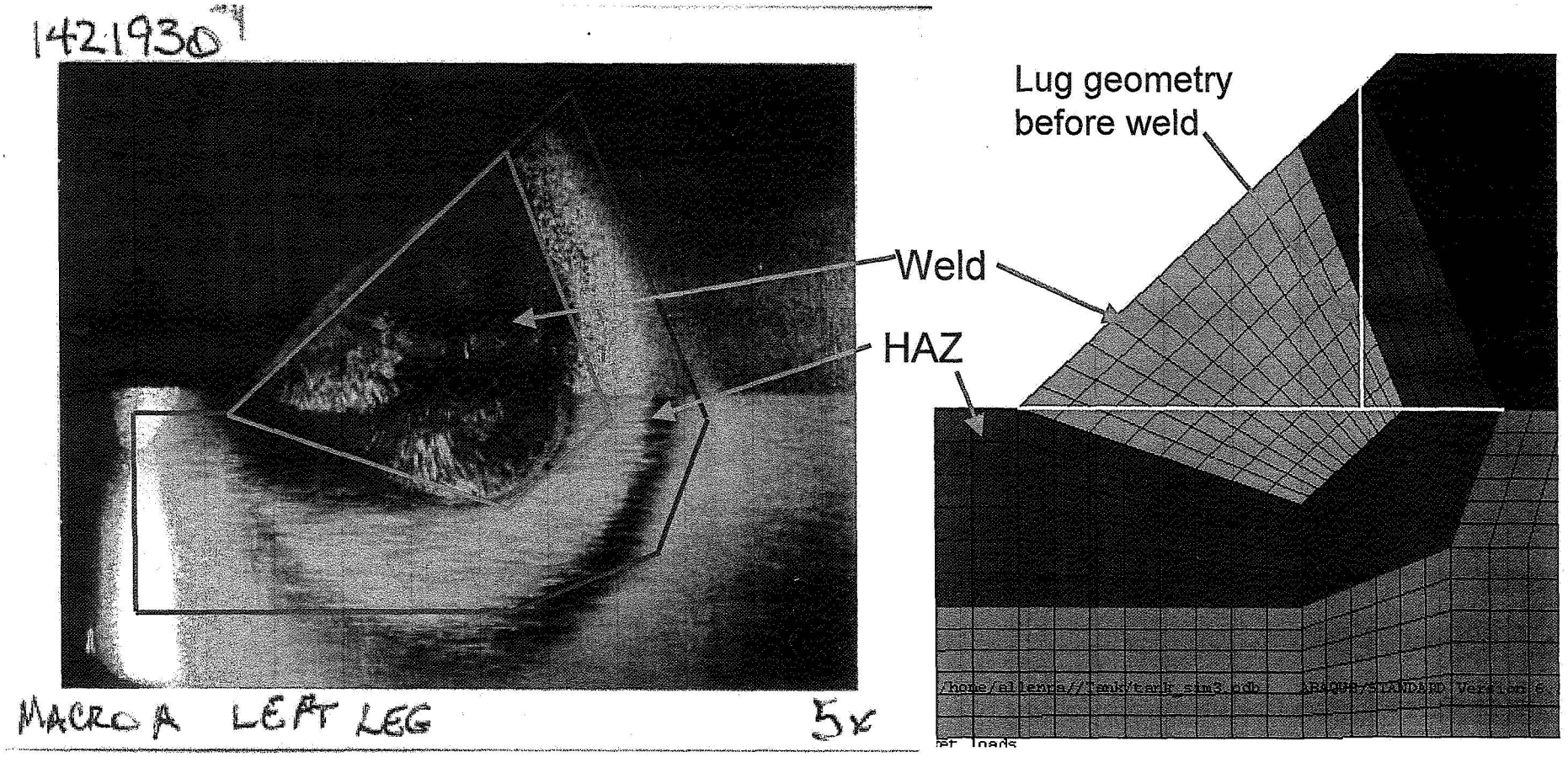


Section with end-pass weld elements removed to show weld mesh detail

OFL 38 Loads applied to bracket



3-Pass Weld Mesh Geometry Approximation

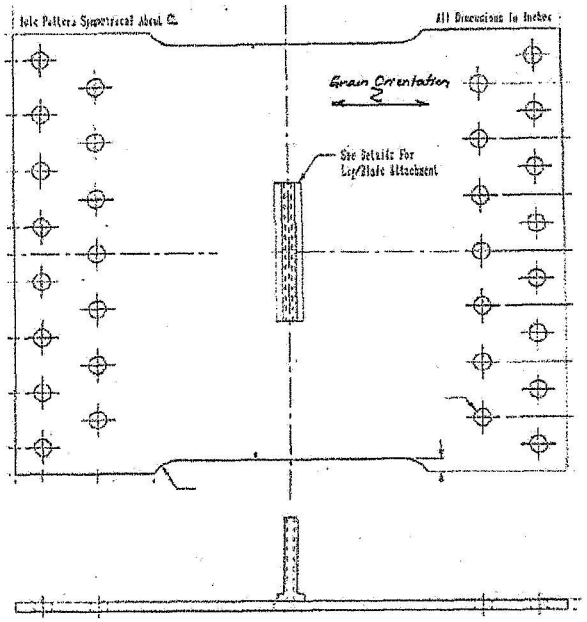


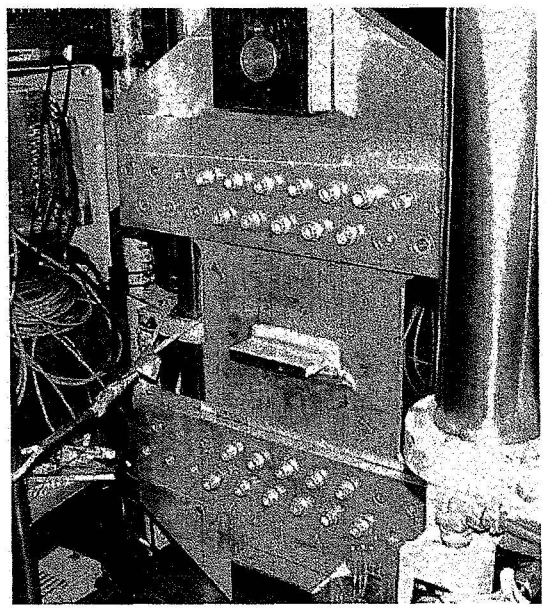
Weld macro courtesy of Michelle Worden, Lockheed-Martin MAF

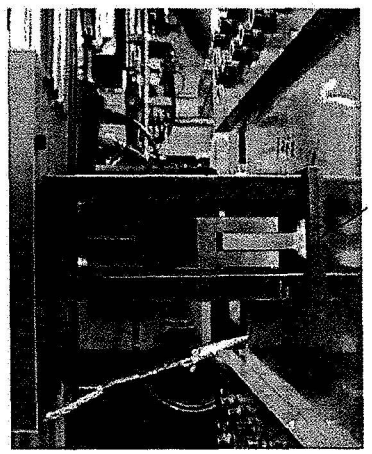
Lug Weld Test Configuration

- Welded lug bi-directional test set-up

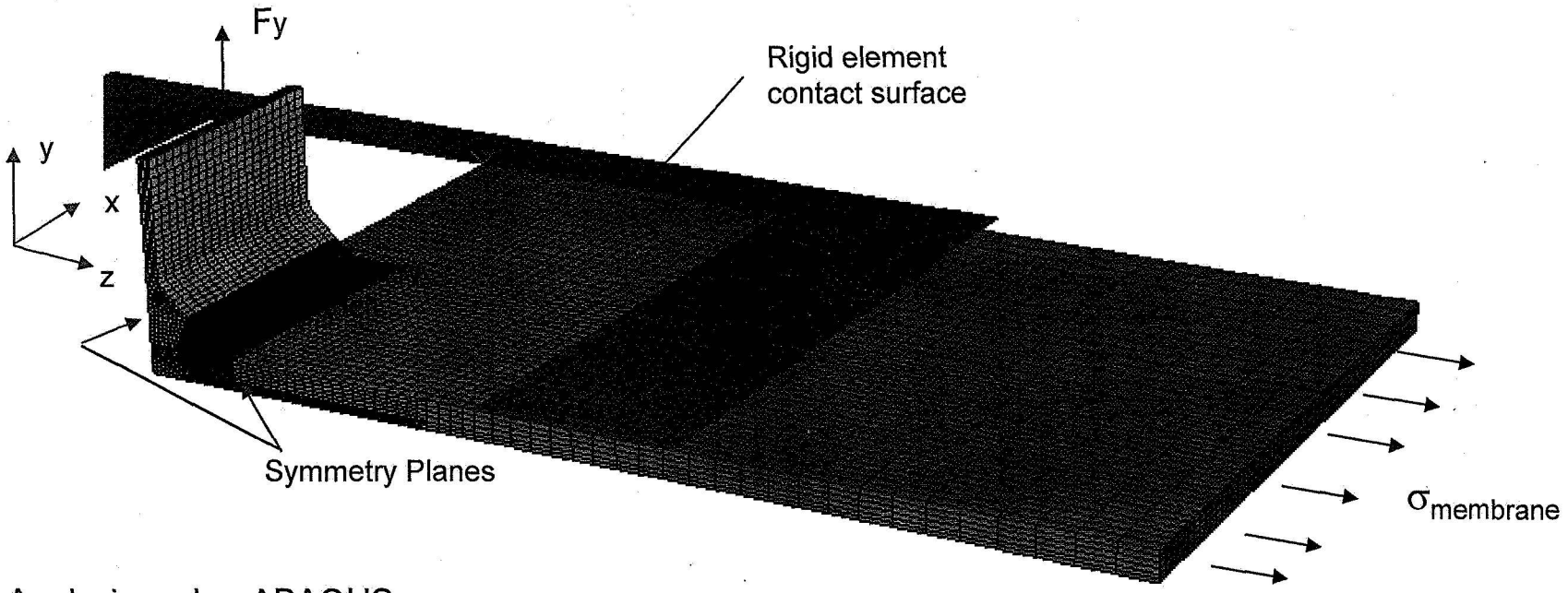
Test Configuration







Lug Weld Test Specimen FEM



- Analysis code - ABAQUS
- One-quarter symmetry FEM
- 8 node brick elements
- 4 node rigid shell elements for reaction plate contact surface

Task: Calculate Safe Life For LO_2 Tank Fillet Welds

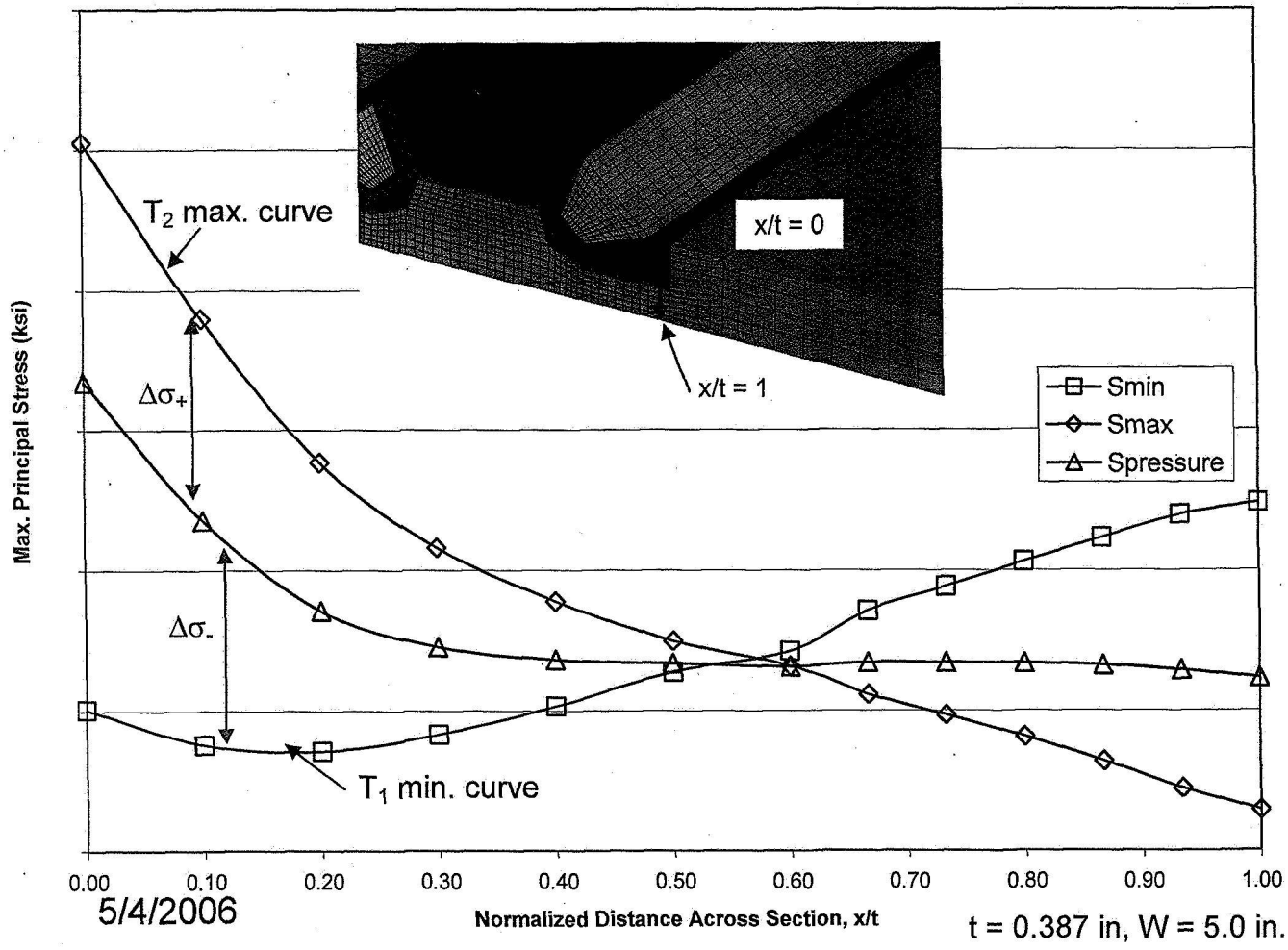
- Get stress distribution across plate at toe of weld from FEM for pressure only load and pressure plus cyclic lug loads at time t_1 and t_2.
- Apply nonlinear stress distributions to NASGRO SC02 module.
- Scale cyclic loads and # of cycles based on standard 300 Hz 45 second mission spectrum
- Assume MSFC-1249 penetrant NDE starting crack size, 2c = 0.150 in. , a = 0.075 in. (a/c=1)
- Calculate # of missions until leak or final fracture

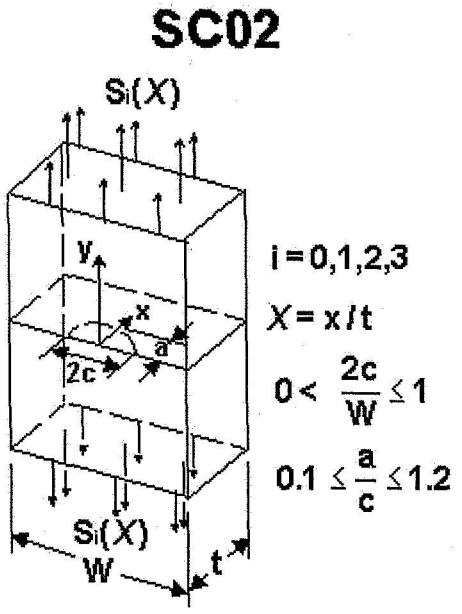
Results Summary

Material	$2C_{initial}$ (in.)	$a_{initial}$ (in.)	Missions to Failure	$2C_{final}$ (in.)	a_{final} (in.)
2219-T87 GTAW 201-300 F	0.150	0.075	5	1.01	0.239
2219-T87 GTAW Room Temp	0.150	0.075	8	1.07	0.223
2219-T87 GTAW, -320 F	0.150	0.075	23	1.89	0.286

Analysis Details

- Get stress distribution across plate at toe of weld from FEM for pressure only load and pressure plus cyclic lug loads at time T_1 and T_2.

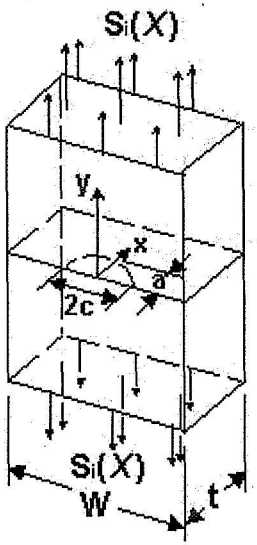




Analysis Details

Apply nonlinear stress distributions to NASGRO SC02 module.

SC02



i = 0,1,2,3

X = x / t

$0 < \frac{2c}{W} \leq 1$

$0.1 \leq \frac{a}{c} \leq 1.2$

- Let $S_0 = \Delta S_{min}$, $S_1 = \Delta S_{max}$, and $S_2 = S_{press}$
- Load Factor only applies to cyclic stress
- Then:

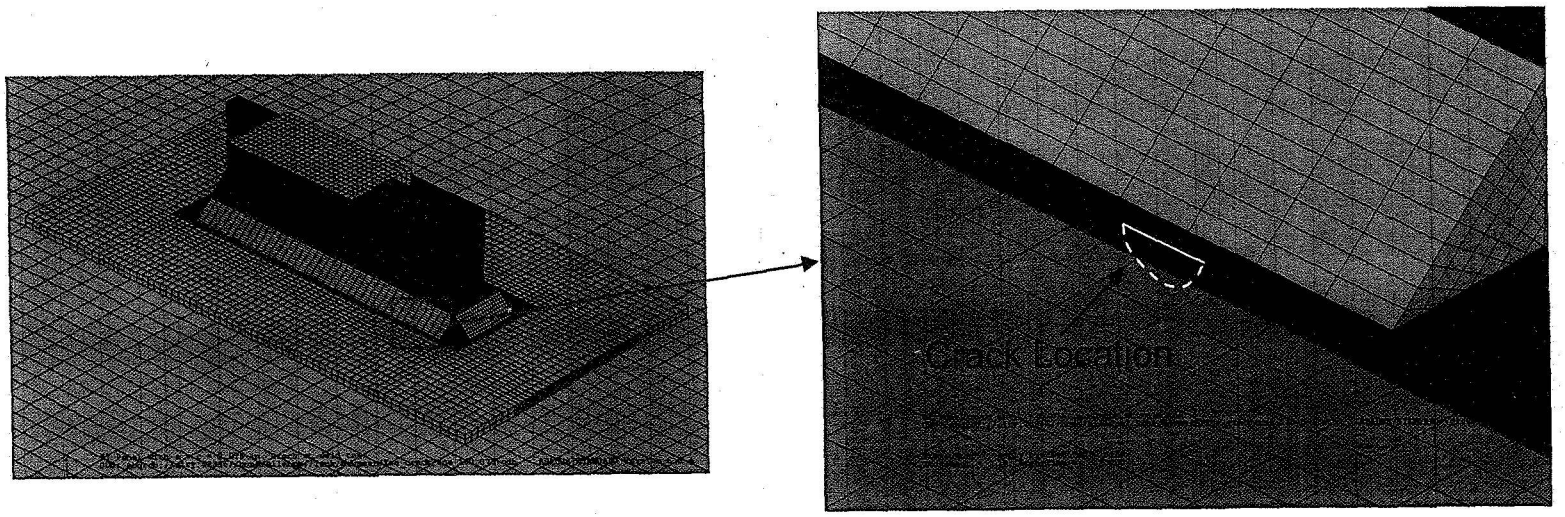
$$\sigma_{t1} = \left[LF_0^{T1} * S_0\right] + \left[LF_1^{T1} * S_1\right] + \left[LF_2^{T1} * S_2\right]$$

$$\sigma_{t2} = \left[LF_0^{T2} * S_0\right] + \left[LF_1^{T2} * S_1\right] + \left[LF_2^{T2} * S_2\right]$$

		Load Facctors, LF					
Step	Cycles	LF_0 @ T_1	LF_0 @ T_2	LF_1 @ T_1	LF_1 @ T_2	LF_2 @ T_1	LF_2 @ T_2
1	158	0.021	0.0	0.0	0.021	1.0	1.0
2	1207	0.084	0.0	0.0	0.084	1.0	1.0
3			0.0	0.0		1.0	1.0
4			0.0	0.0		1.0	1.0
5			0.0	0.0		1.0	1.0
6			0.0	0.0		1.0	1.0
7			0.0	0.0		1.0	1.0
8			0.0	0.0		1.0	1.0
9			0.0	0.0		1.0	1.0
10			0.0	0.0		1.0	1.0
11			0.0	0.0		1.0	1.0
12	318	0.917	0.0	0.0	0.917	1.0	1.0
13	171	1.000	0.0	0.0	1.000	1.0	1.0

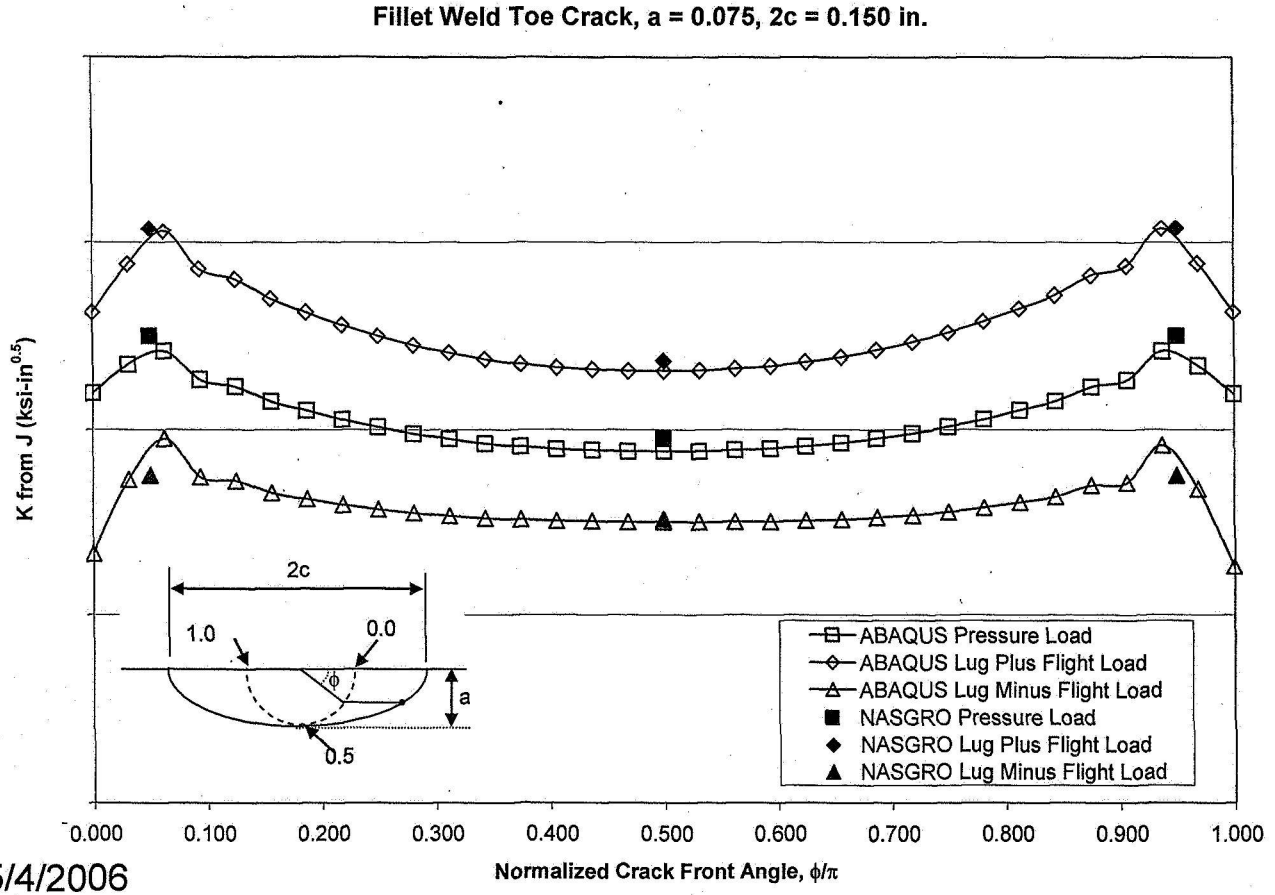
ET Panel FEM with NDE Size Elliptical Surface Crack

- Put a = c = 0.075 in. elliptical surface crack in highest stress location in HAZ at weld toe in ABAQUS FEM of ET barrel section panel.
- Get J and K_I from FEM for pressure only load and pressure plus cyclic lug loads at time T_1 and T_2.
- Compare with NASGRO SC02 predictions for K_I using nonlinear stress distributions on chart 8 for NASGRO inputs.



ET Configuration FEM and NASGRO K_I Comparisons

- NASGRO calculates discrete values of K_I, $K_I(a)$ and $K_I(c)$.
- ABAQUS calculates J for each node set around the crack front. – Convert J to K_I using equation below.
- Good correlation between NASGRO and FEM predictions

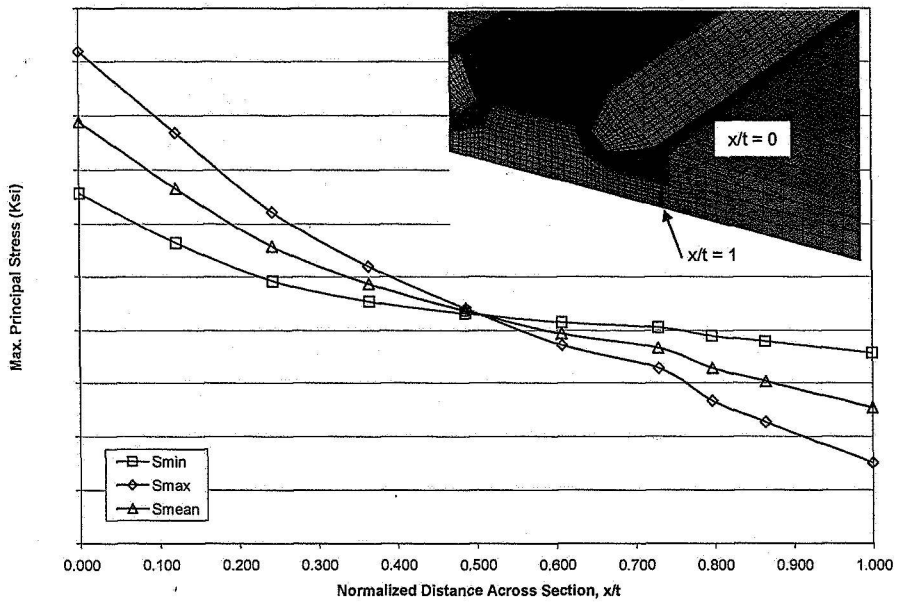


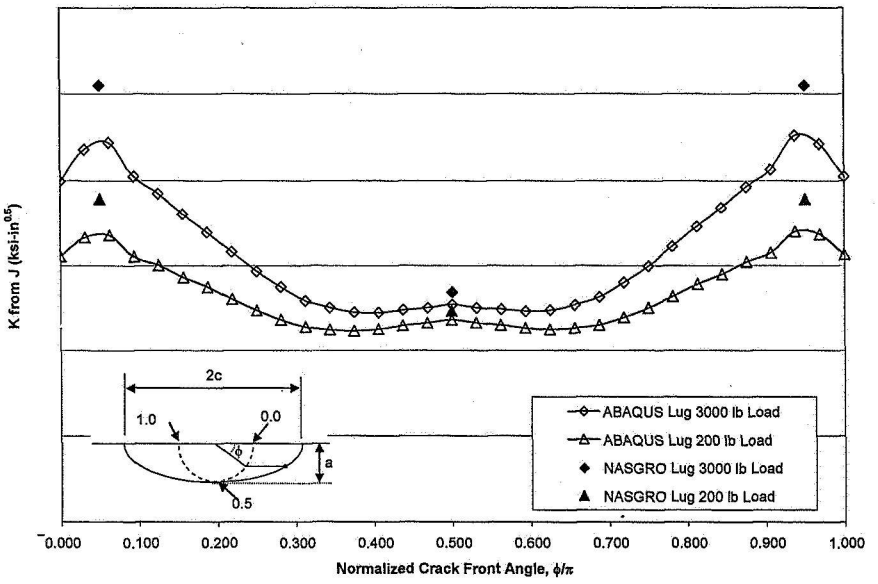
$$J = J_{total} = J_{el} + J_{pl}$$

$$K_J = \sqrt{\frac{JE}{(1-\nu^2)}}$$

Lug Test FEM and NASGRO K_I Comparisons

- NASGRO SIF predictions are conservative for K(c) and essentially match the FEM results for K(a)





Results Summary

Material	Stress Distribution Orientation	$2C_{initial}$ (in.)	$a_{initial}$ (in.)	Missions to Failure	$2C_{final}$ (in.)	a_{final} (in.)
2219-T87 GTAW Room Temp	Normal	0.40	0.20	6	1.25	0.21
2219-T87 GTAW Room Temp	Normal	0.50	0.25	1	0.84	0.25