

2007 USAF Aircraft Structural Integrity Program Conference

C-130 Center Wing Rainbow Fitting, Spare Redesign

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Big Picture

- **Service History, 7075-T6 extrusion**
- **MSD Risk Analysis of the Wing Joint Fitting**
- **Two Phase Redesign / Test Program for**
Increased Service Life
- **Implementation**



Overview / Slides

- **Contract Team**
- **Orientation on the A/C**
- **Program Overview / Dates**
- **Context, Past ASIPs**
 - *MSD & MED*
 - *Risk Assessment*
 - *USAF IRT*
 - *Service Bulletins*
- **Choices**
- **Applicability of Redesign**
- **Redesign Goals**
- **Approach**
- **Material Choice**
- **Modeling**
- **DADTA Methods**
- **DADTA Locations**
- **Model Progression**
- **Redesign Configuration**
- **Redesign Service Life**
- **Redesign Goals Achieved**
- **Future Plans**
- **Conclusions / Lessons Learned**



Contract Team

- **Government Task Leader = Peter Christiansen, ASIP Mgr**
- **USAF Program Manager = John Sykes, 1LT**
- **Alternate GTL = Hollie Sipe**
- **Mercer Engineering Research Center (MERC) Team =
Mary Schleider, Gerry Ringe, et al.**
- **LM Aero Team**



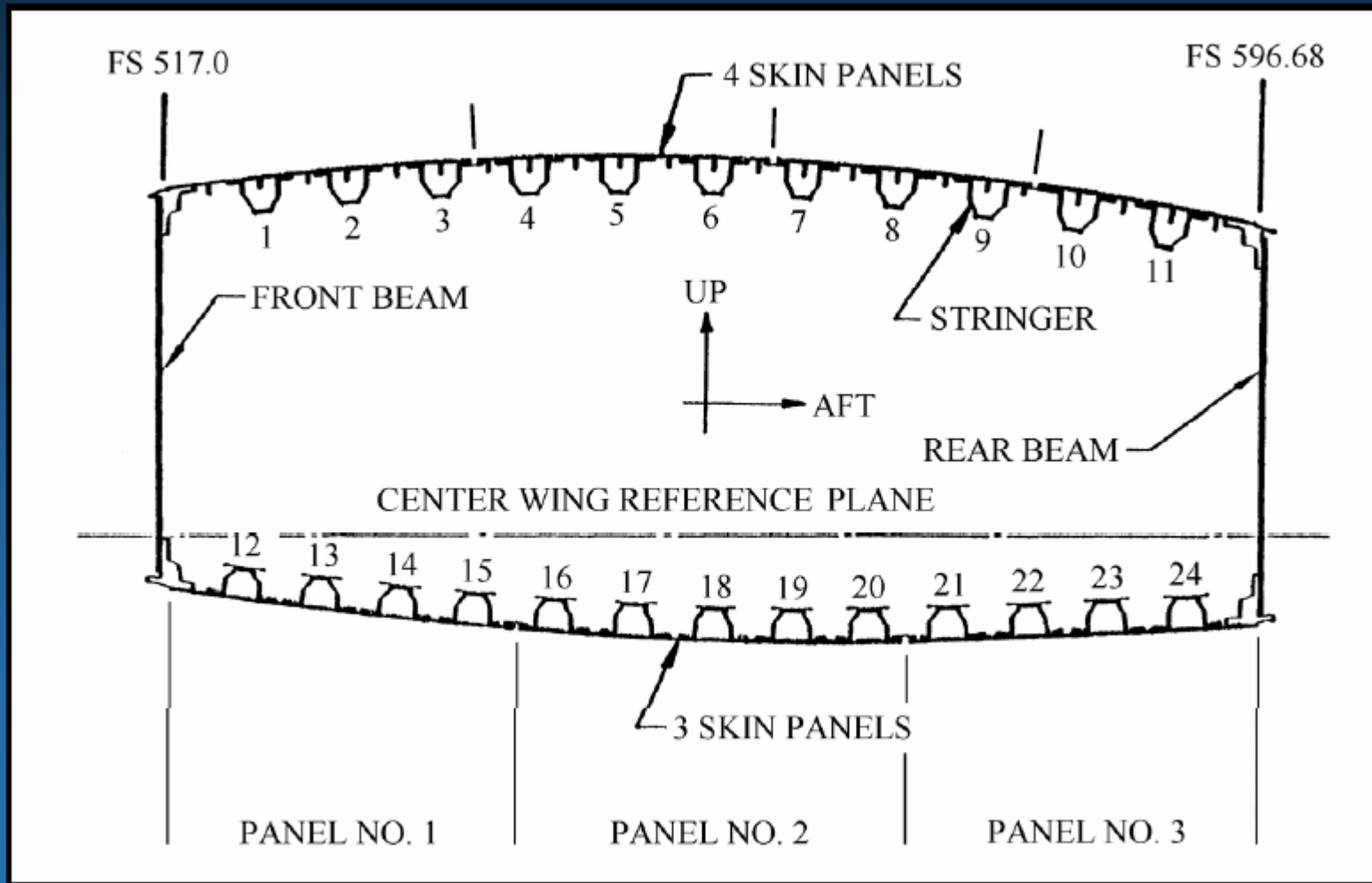
Orientation on the Aircraft

C-130 Center Wing Box

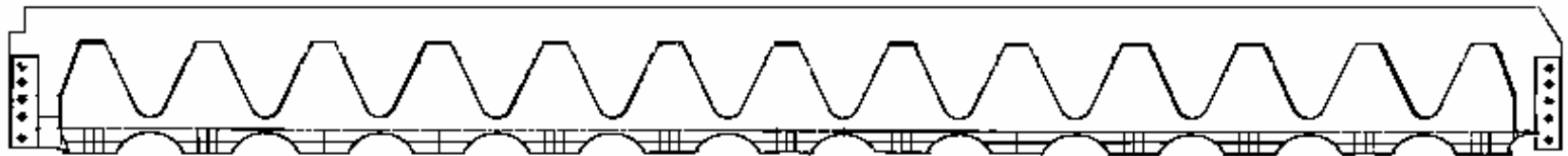


Orientation on the Aircraft

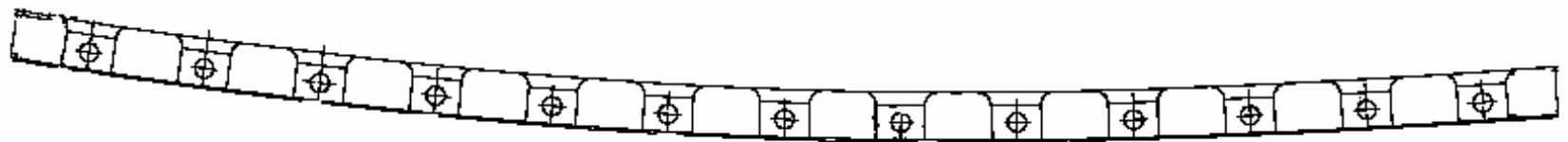
Center Wing Box, Section View



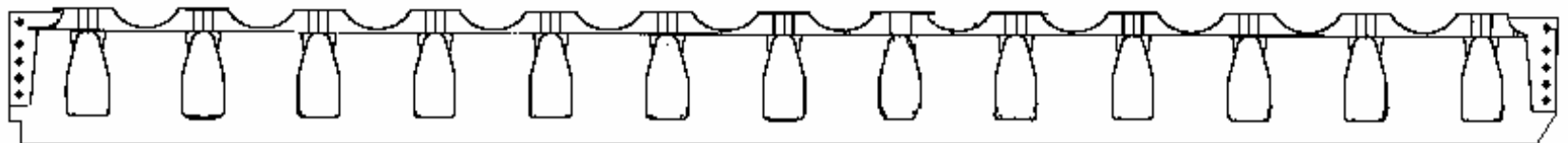
Orientation on the Aircraft



Looking Down



Looking Inboard



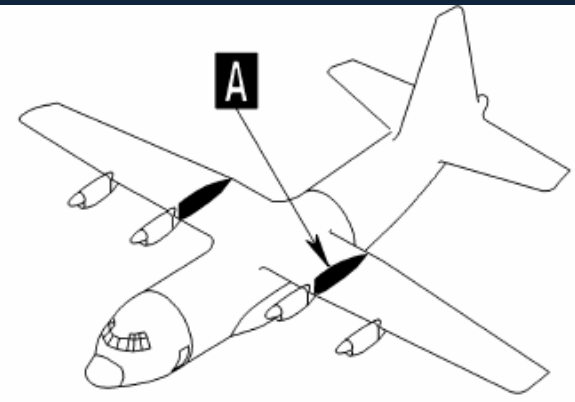
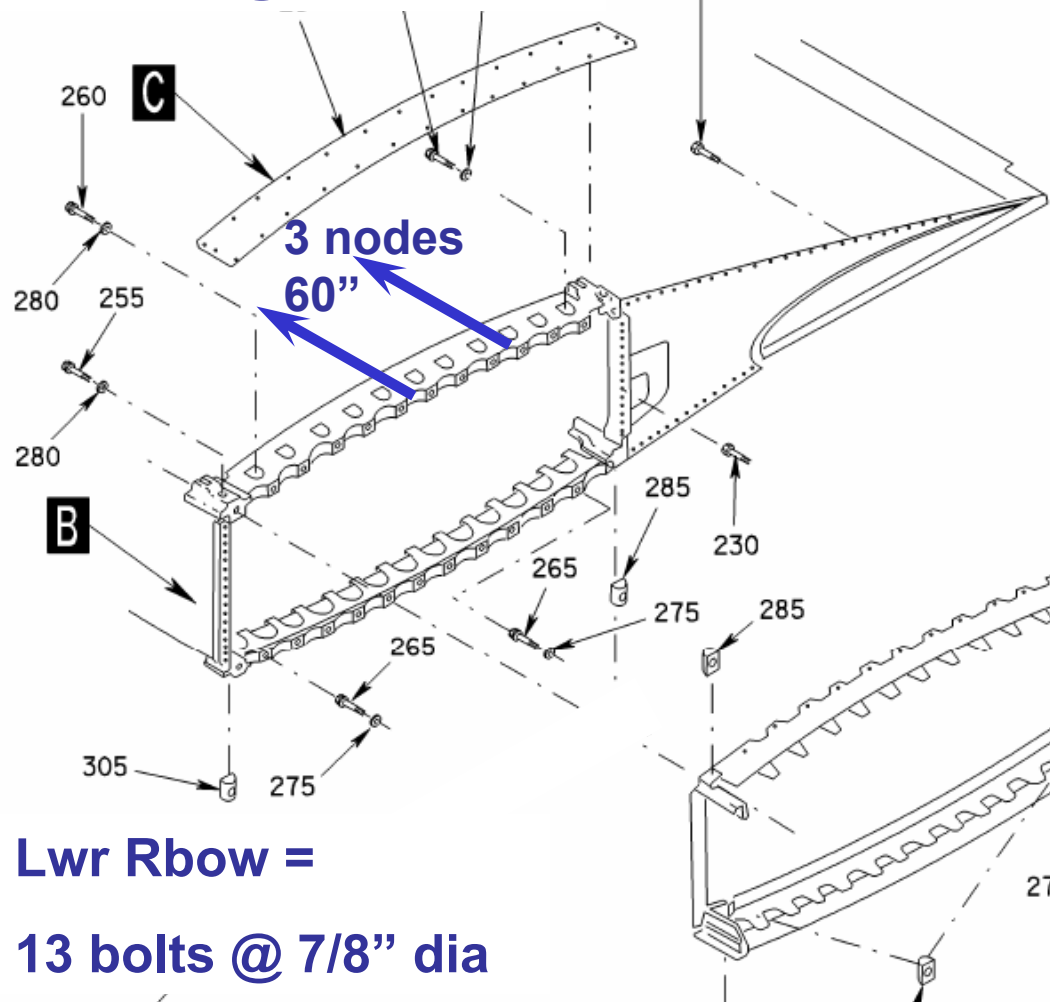
Looking Up



Orientation on the Aircraft

Upr Rbow =

11 bolts @ 3/4" dia



1968

Lwr Rbow =

13 bolts @ 7/8" dia

Program Overview / Dates



Phase 1 = 12 months, Sept 2006 to Sept 2007

- **Redesign the Center Wing Upper and Lower Rainbow Fittings for longer service life (LM Aero)**
- **Write a Test Plan (MERC)**

Phase 2 = 24 months, Sept 2007 to Sept 2009

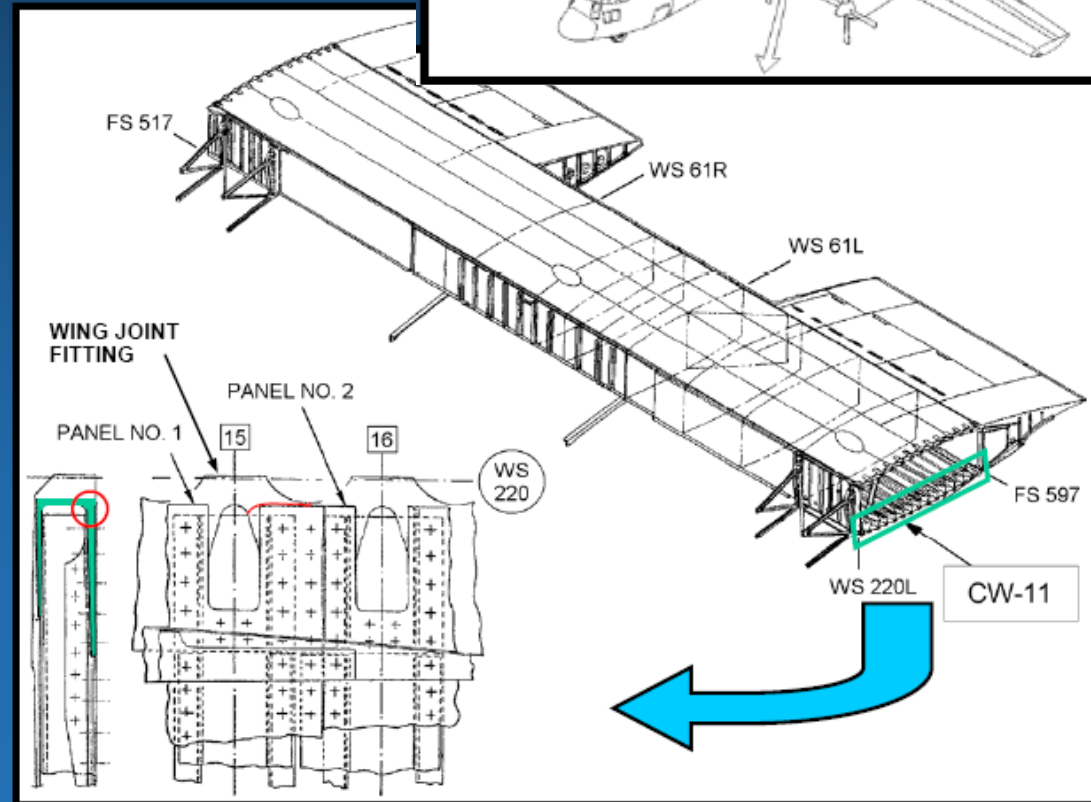
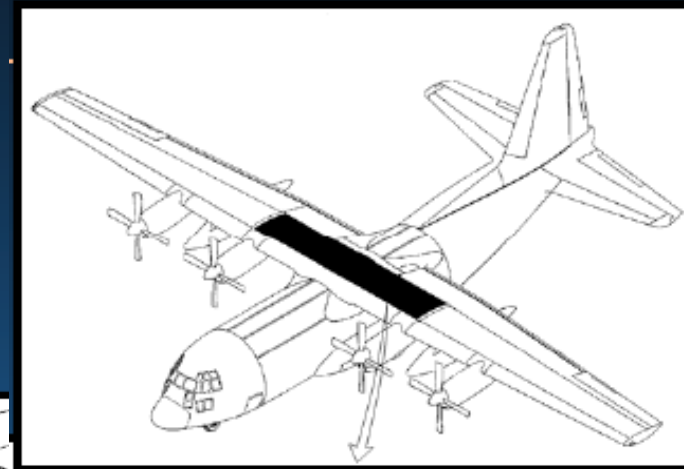
- **Coupon Tests on 7249 (AFRL)**
- **Build 3-node test articles and TKI articles (LM Aero)**
- **Fatigue and Static Test (MERC)**
- **Follow-On Analysis (LM Aero)**
- **Trial Kit Installation (MERC)**

Context, Past ASIP Presentations



2006 Presented on Risk Assessment Methodology for Wing Joint Ftg

- Prone to MSD Cracking
- Short “critical” crack length (0.07 in.)
- 35 A/C documented with in-service MSD/MED cracking:
 - Multiple Node Cracks (adjacent/non-adjacent)
 - Adjacent Panel Cracks
- Three adjacent Node cracks reduce strength to below Design Limit

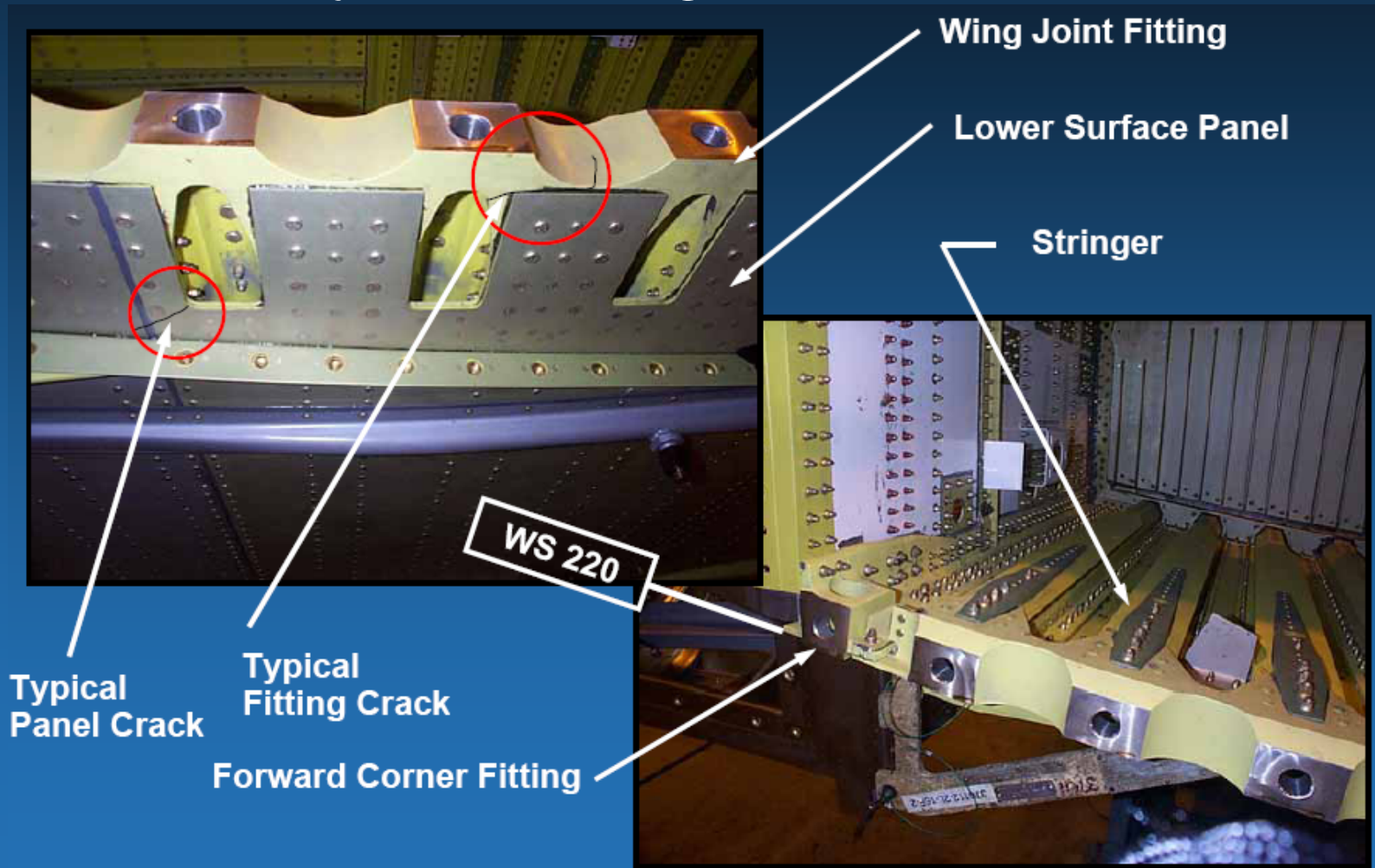




Context, Past ASIP Presentations

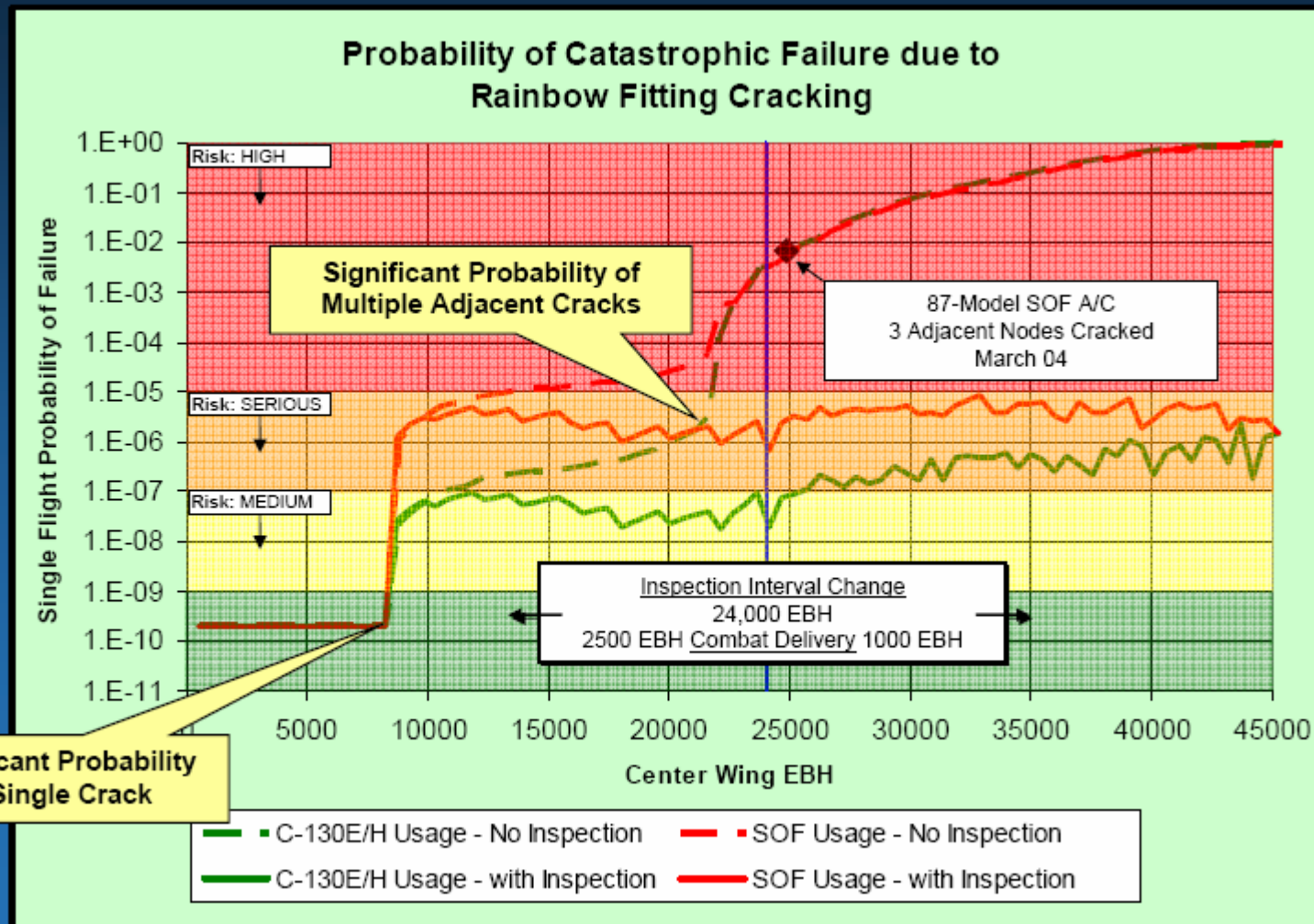
2006

– MSD Risk Analysis of the Wing Joint



Context, Past ASIP Presentations

2006



Context, Past ASIP Presentations



- **USAF IRT Assessment:**

“Rainbow Fitting Biggest Threat to Early Onset of Widespread Fatigue Damage”

- **Service Bulletin 82-771, Rev 2:**

“Wings – Center Wing Upper and Lower Rainbow Fitting Inspection for Cracks and Replacement”

Military:

- Initial = 10,000 EBH
- Recurring = 2,500 EBH (less than 25,000 EBH)
- Recurring = 1,000 EBH (more than 25,000 EBH)
- Replacement recommended at 25,000 EBH

- **USAF TCTOs**



Choices

- **Inspect frequently** > **Undesirable**
- **Retire** > **Unacceptable**
- **Replace** > **With What?**

– *Current Design*

- Frequent inspections and/or fitting replacements keep aircraft grounded for extended periods of time
- First inspection interval at 8,500 EBH (USAF)
- Frequency of recurring inspection
- Replacement recommended at 25,000 EBH = approximately half of center wing service life

Redesign CW rainbow fittings for extended SL

Applicability of Redesign



- **The new spare will replace C-130E/H/J :**
 - **Lower Fitting 398827-3/-4**
 - **Upper Fitting 398335-3/-4, -1/-2 (slotted)**

- **The new spare is NOT appropriate for SOF/ESL CW's**
 - **By design, SOF/ESL fittings occupy more space**



Redesign Goals

- **Redesign with no changes/impact to outer rainbows**
- **Design for retrofit, C-130E thru C-130J**
- **Design service life of 38,000 EBH or greater**
- **Using a Damage Tolerance approach:
Initial inspection interval \geq 20,000 EBH
Recurring inspection interval \geq 5,000 EBH**
- **No negative impacts to inspection intervals for center wing panels and stringers**



Redesign Goals

- **Minimum mods to existing structure and none to wing joint bolt cutouts in the skin panel and stringer legs**
- **Use updated materials and finish for improved fatigue and corrosion resistance**
- **Sleeves, Bushings, ForceMate**
- **Redesign stringer splice angles**
- **No change to bolts, i.e. grip or type**



Approach

- **Design Concept**
- **CATIA Model**
- **FE Model**
- **Durability and Damage Tolerance Analysis**
- **Static Analysis**
- **Evaluate Results to Program Goals and Customer Guidance**



Material Choice

- **Currently 7075-T6511 Extrusion**
- **Considered for Redesign**
 - **7249-T76511**
 - **7136-T76511**
 - **7055-T76511**
 - **Ti 6-4 MA**
 - **PH 13-8**
 - **Carbon Epoxy**
- **Matrix of Properties, Issues, Concerns, Risks**



Material Choice

**7136 info
submitted
for MMPDS**

Mechanical Property			7249-T76511 to 1.499"	7055-T76511 0.5" - 3.0"	7136-T76511 0.25" - 3.0"	7075-T6511 0.5" - 0.749"
			B-basis	B-basis	B-basis	B-basis
Tension	F _{tu}	L	86	94	93	85
		LT	83	87	93	81
		L-45	—	—	—	—
	F _{ty}	L	79	90	89	76
		LT	76	84	89	71
		L-45	—	—	—	—
	%e	L	7	10	7	7
E	L	10.4 x 10 ⁶	10.4 x 10 ⁶	10.4 x 10 ⁶	10.4 x 10 ⁶	
Compression	F _{cy}	L	82	92	91	76
		LT	83	91	91	77
	E _c	L	10.5 x 10 ⁶	10.8 x 10 ⁶	10.6 x 10 ⁶	10.7 x 10 ⁶

Alloy	SCC Threshold per ASTM G47 (ksi)	Exfoliation Rating per ASTM G34
Orientation	ST	ST
7075-T6511	5	ED
7249-T76511	25	EB
7055-T76511	66 (LT)	EB
7136-T76511	25	EB

Alloy	Fracture Toughness ksi (in) ^{1/2} Minimum	
	LT	TL
7075-T6511	26	19
7249-T76511	31	23
7055-T76511	27	23
7136-T76511	26	20

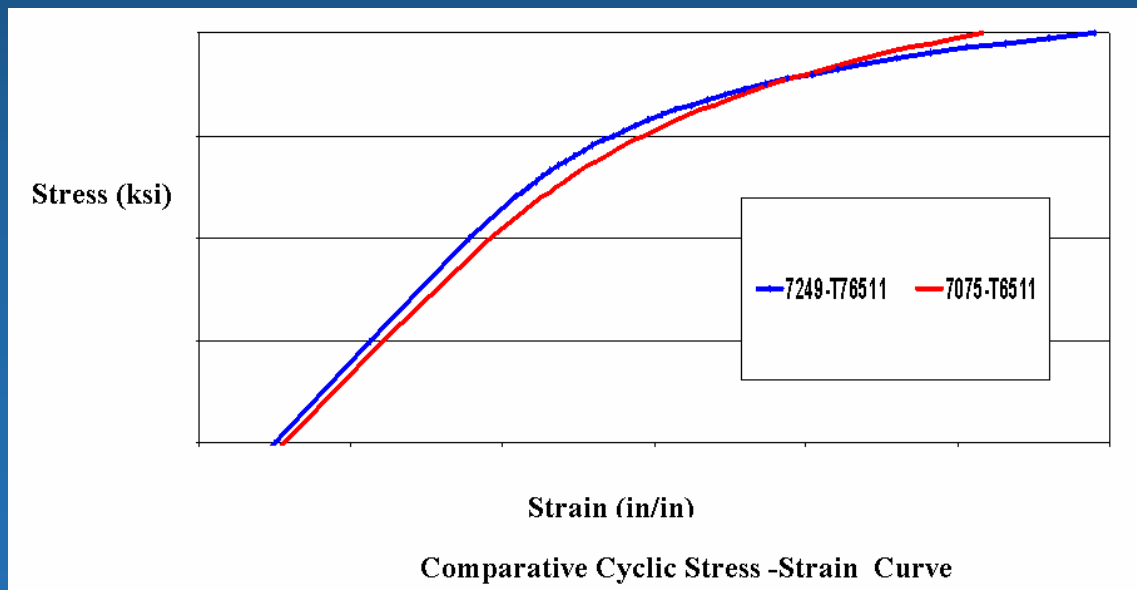
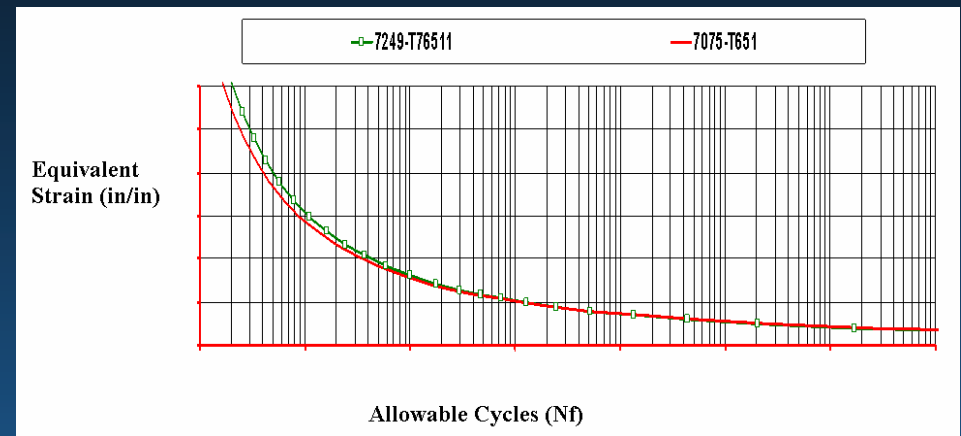
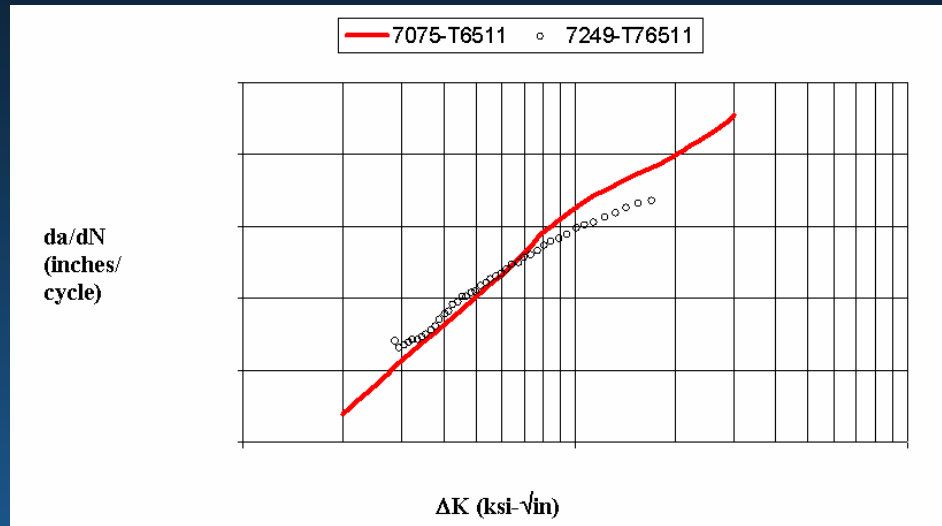


Material Choice

- **Replace with 7249-T76511**
 - ***Static Strength***
 - ***Corrosion / SCC***
 - ***Durability Data***
 - ***Application***
 - ***Availability of Existing Data, P-3 Wing Program***
 - ***Perform Specific Testing for Rainbow Application***



Material Choice





Modeling

- **Airframe Level**
- **Single Node Highly Detailed**
- **Preload**
- **Contact Forces**
- **Baseline FEMs**
- **Iterations**



DADTA Methods

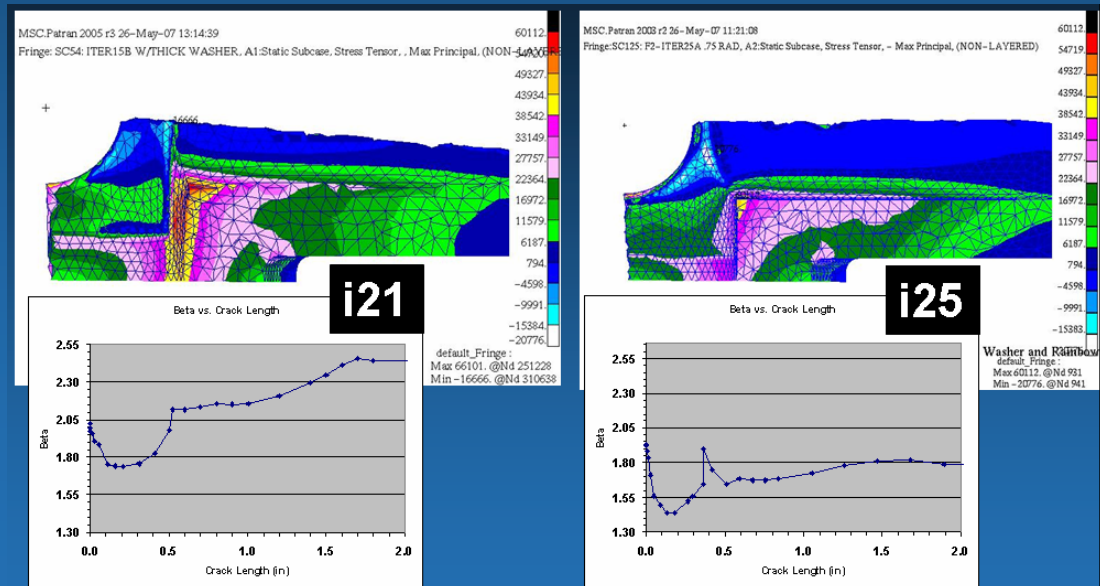
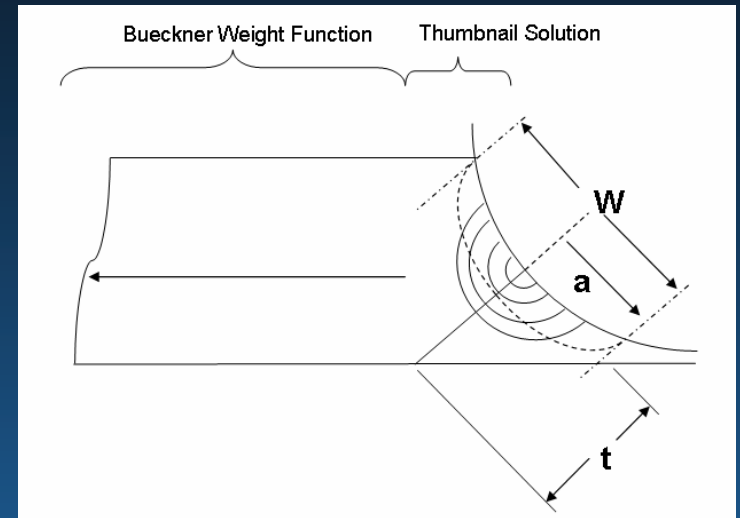
- **Distribution of stress normal to the projected critical plane along a series of paths (shown as tubes)**





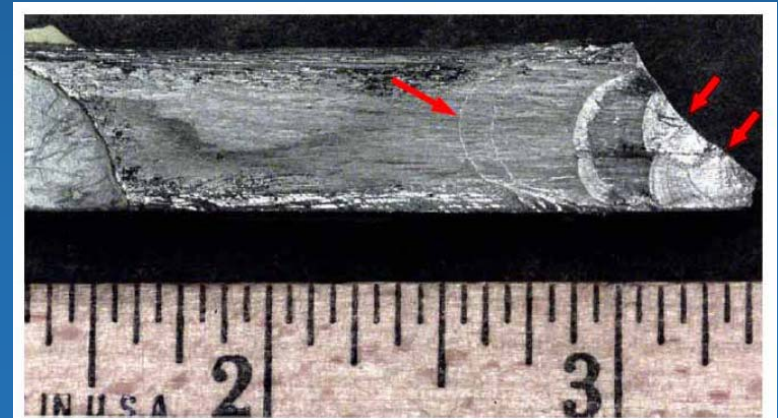
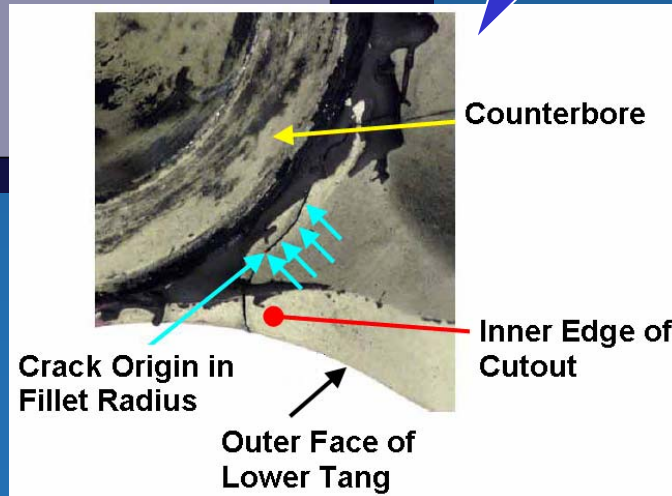
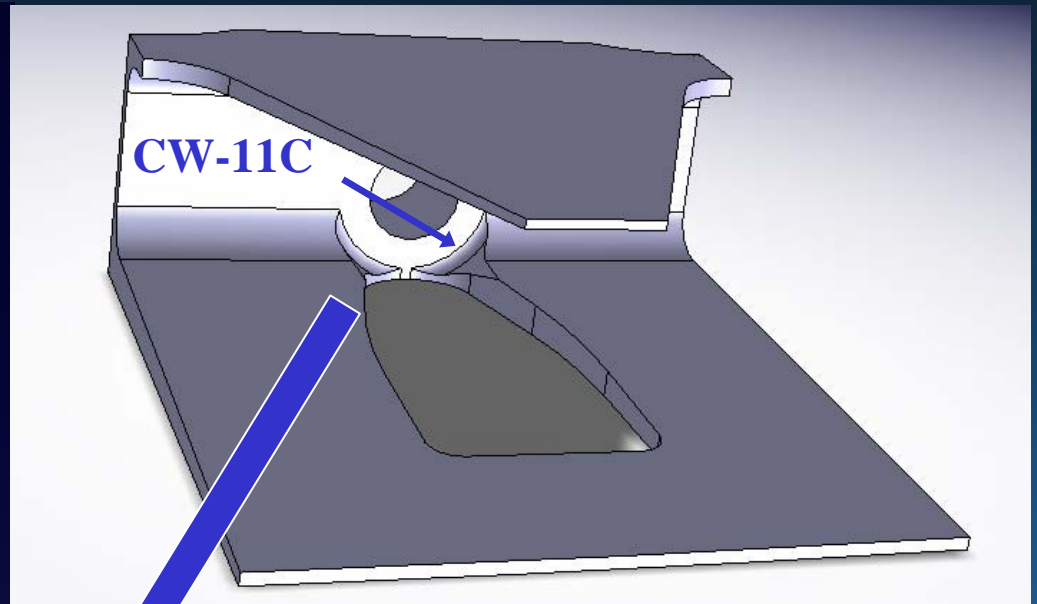
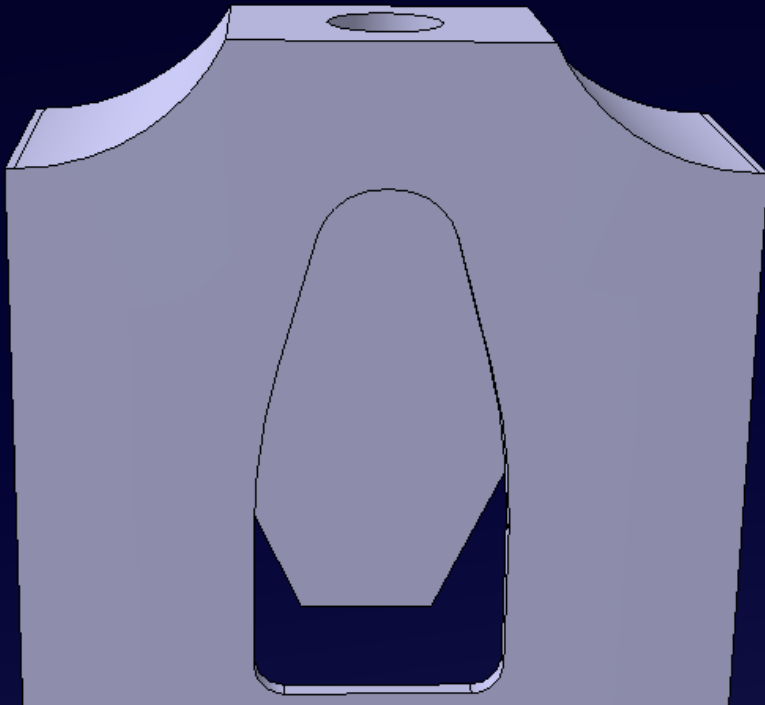
DADTA Methods

- Stress Intensity Factor using variable aspect ratio ellipses via Newman and Raju Thumbnail Flaw solution matched to stress distribution
- Weight function + Flange Bending + Internal Load Redistribution after transition to through-the-thickness
- Longer cracks solutions using stress distributions from global airframe level FEM
- JSSG2006 initial flaw criteria for Durability and for Damage Tolerance



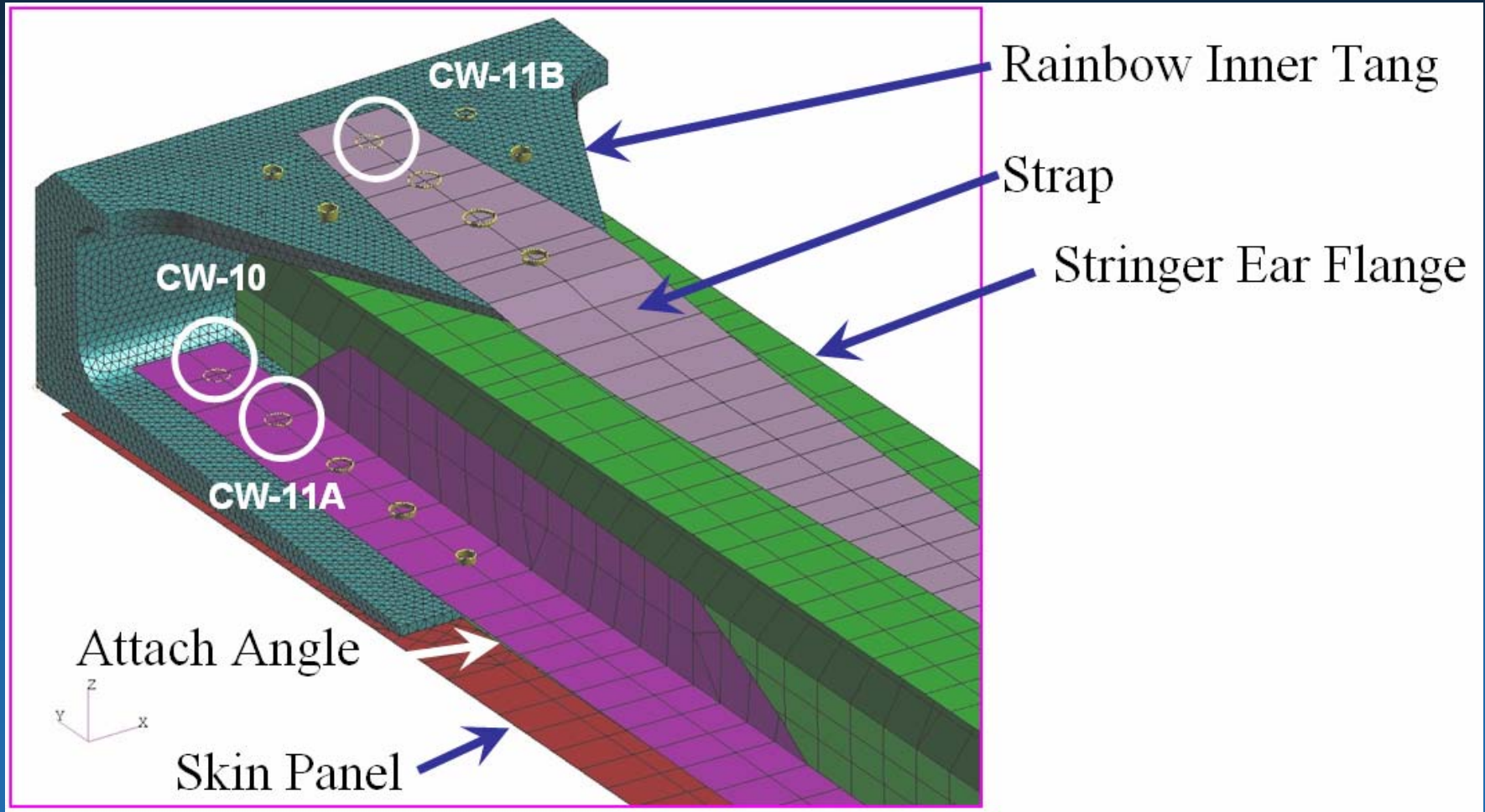


DADTA Locations



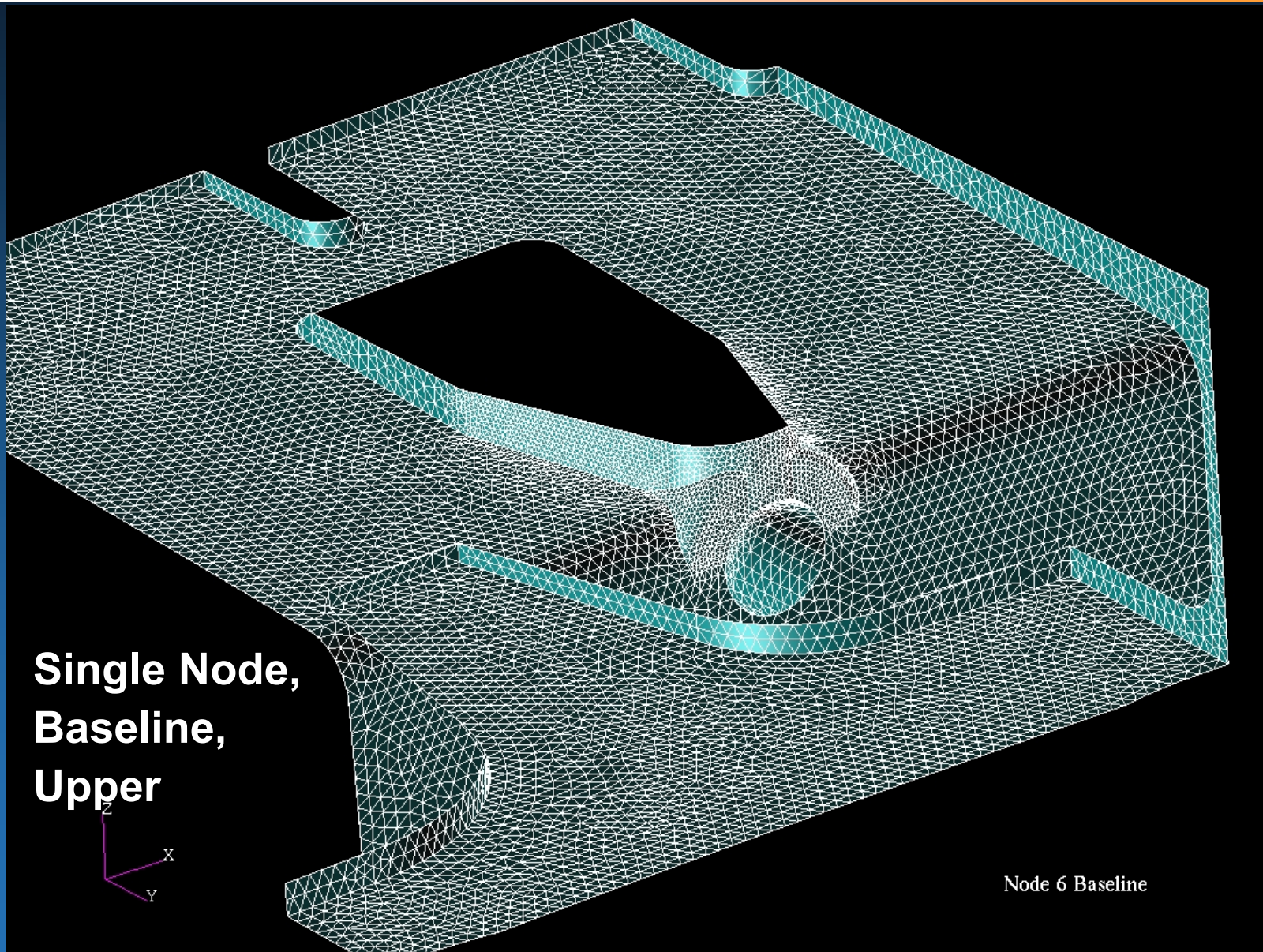


DADTA Locations

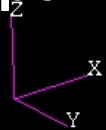




Model Progression



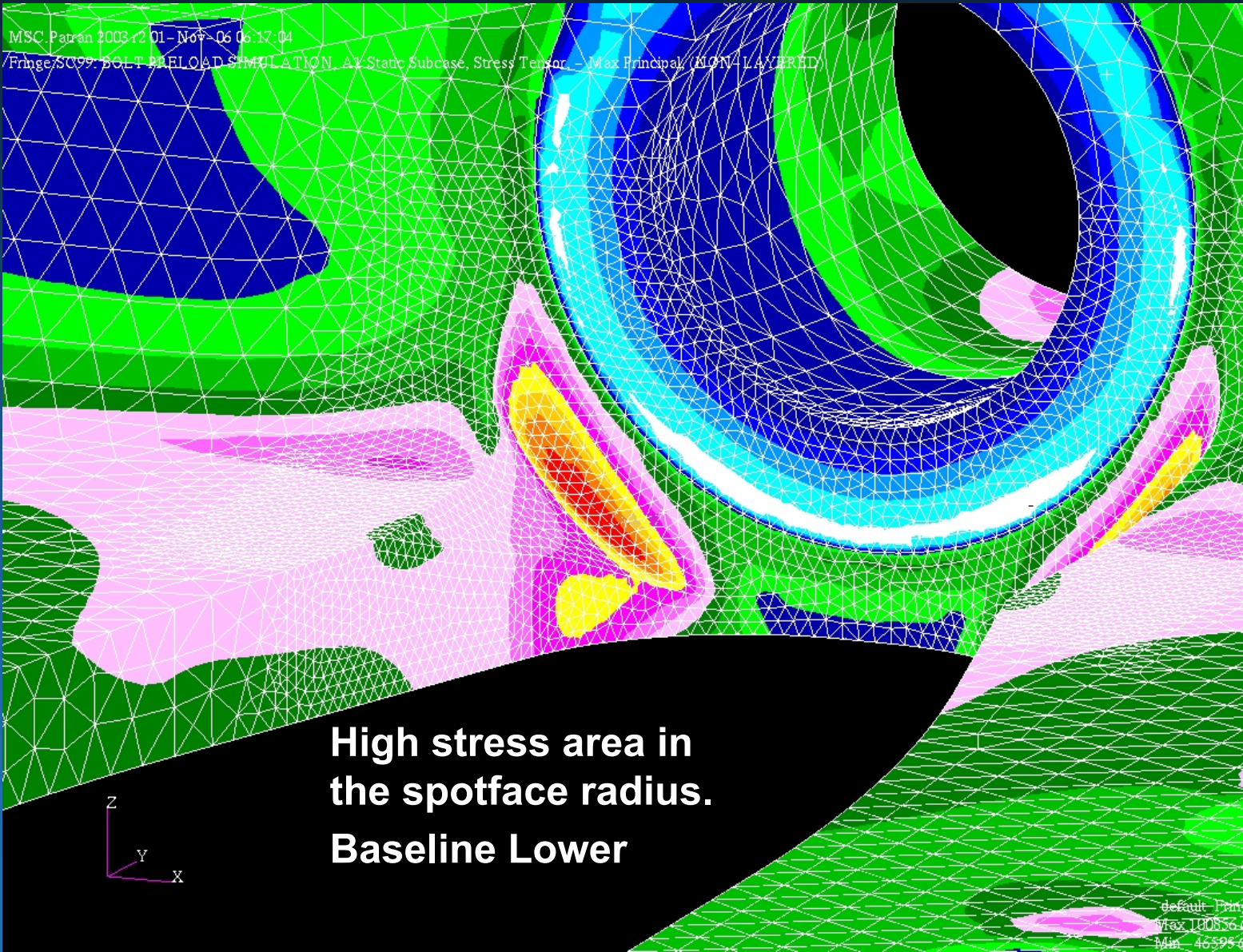
**Single Node,
Baseline,
Upper**



Node 6 Baseline



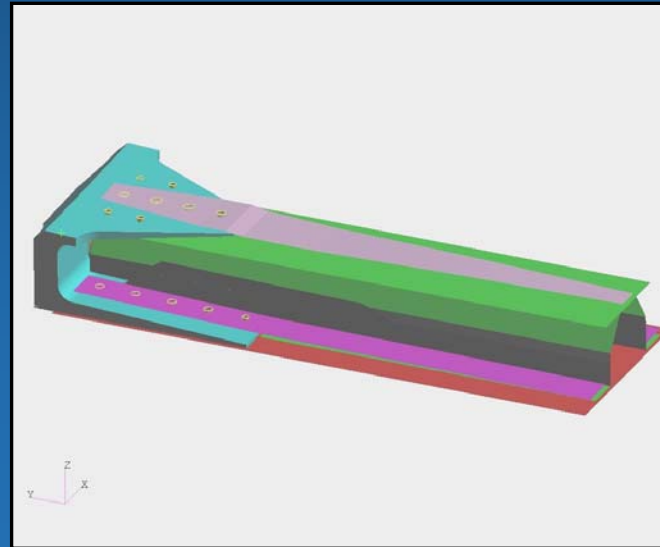
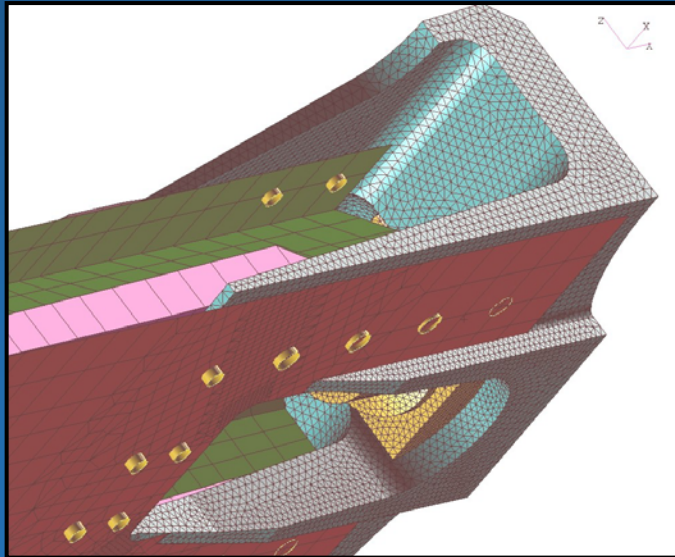
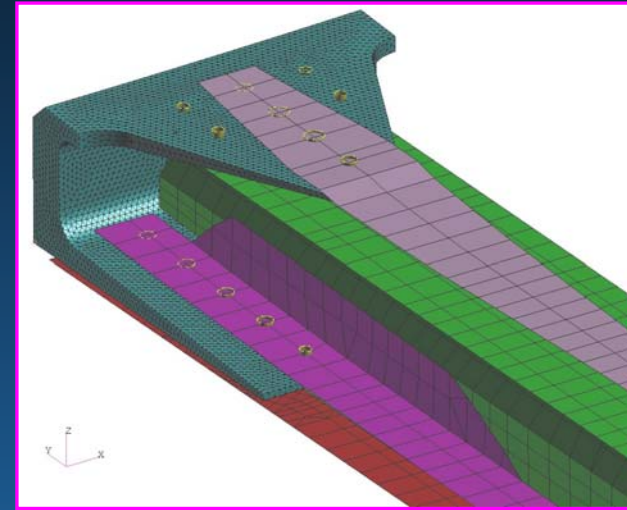
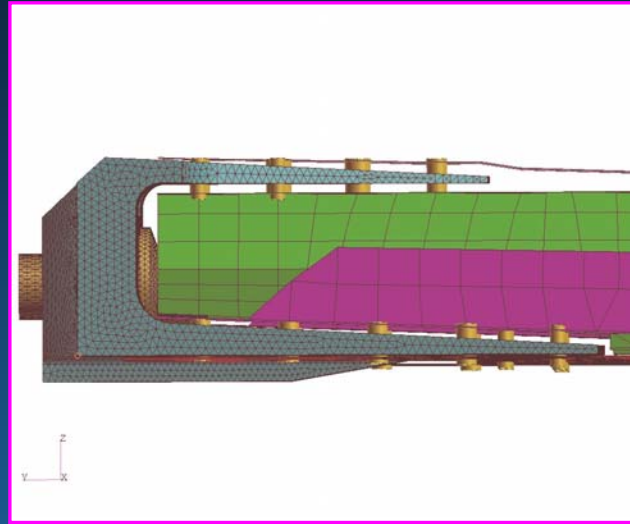
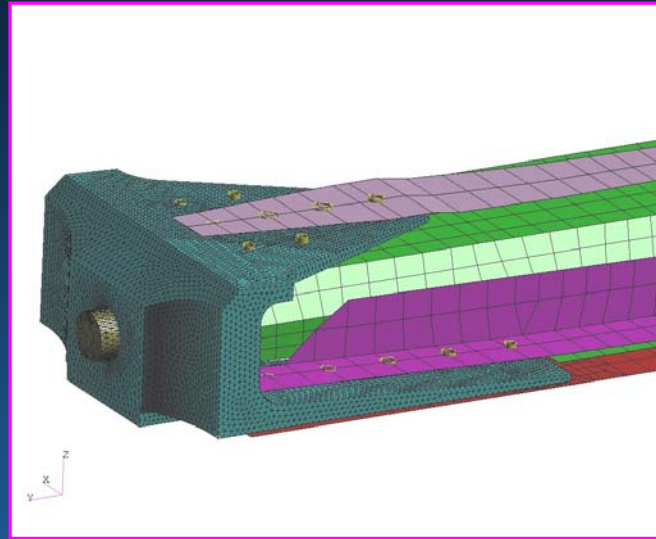
Model Progression



**High stress area in
the spotface radius.
Baseline Lower**



Model Progression



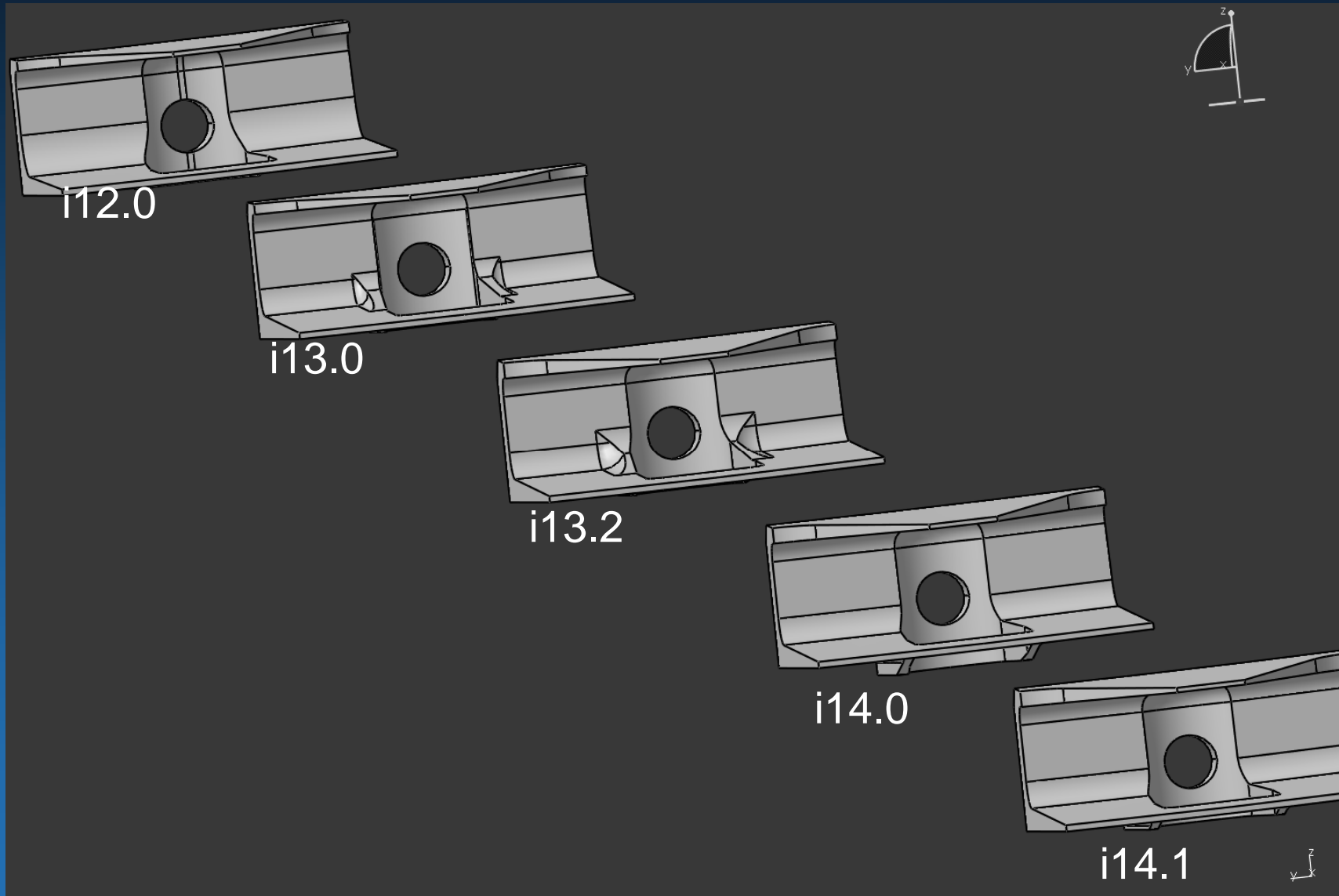


Model Progression



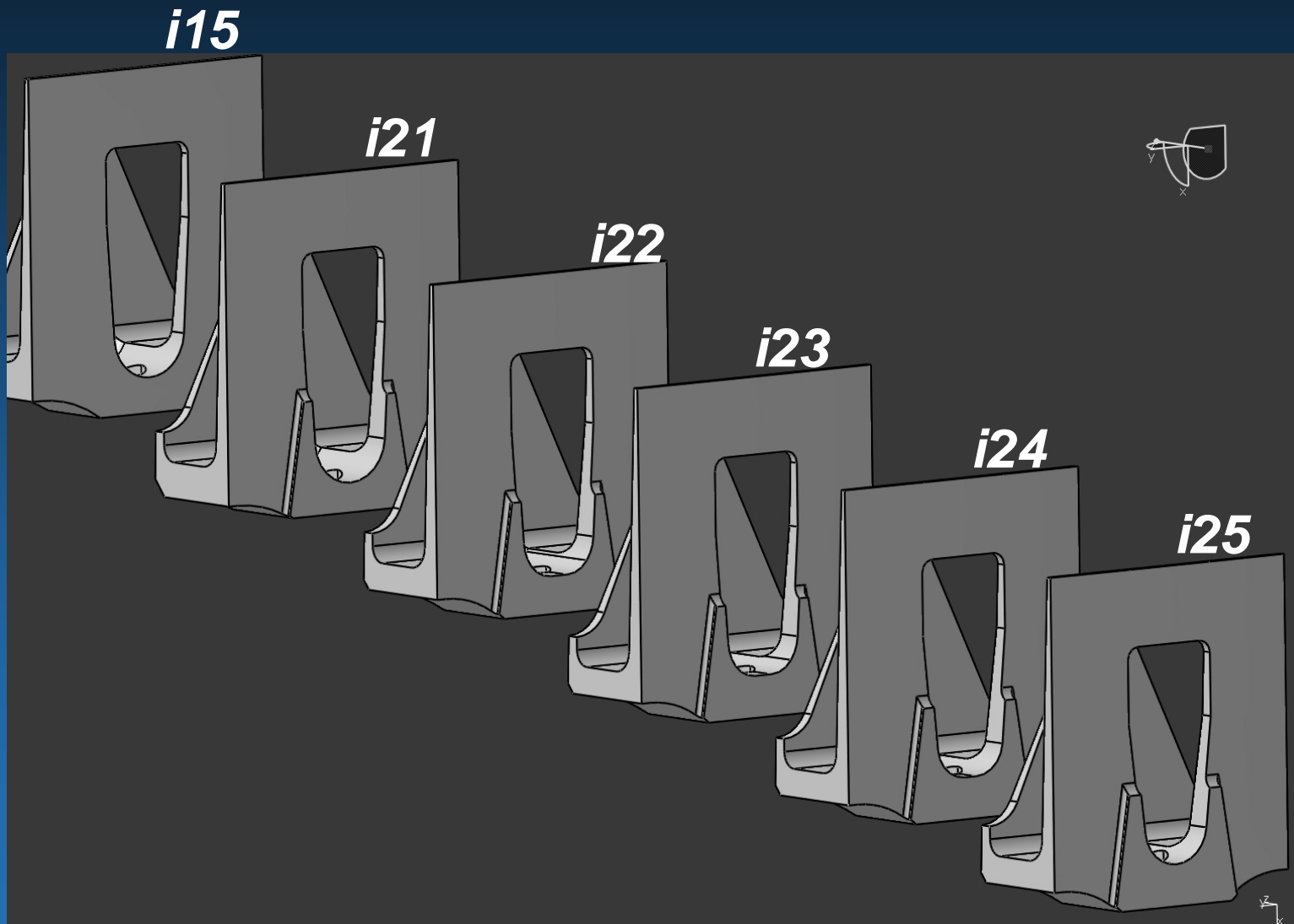


Model Progression



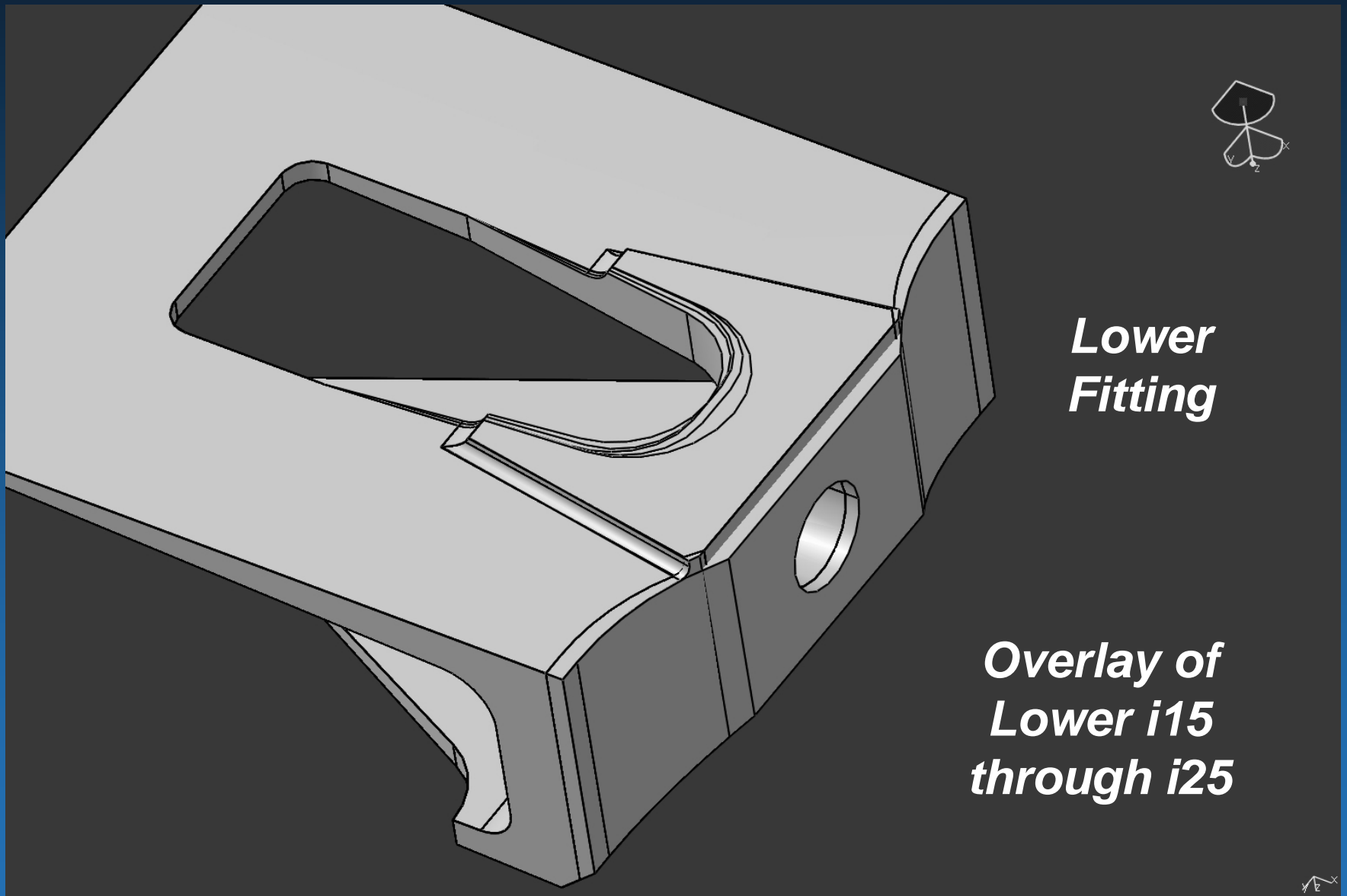


Model Progression





Model Progression

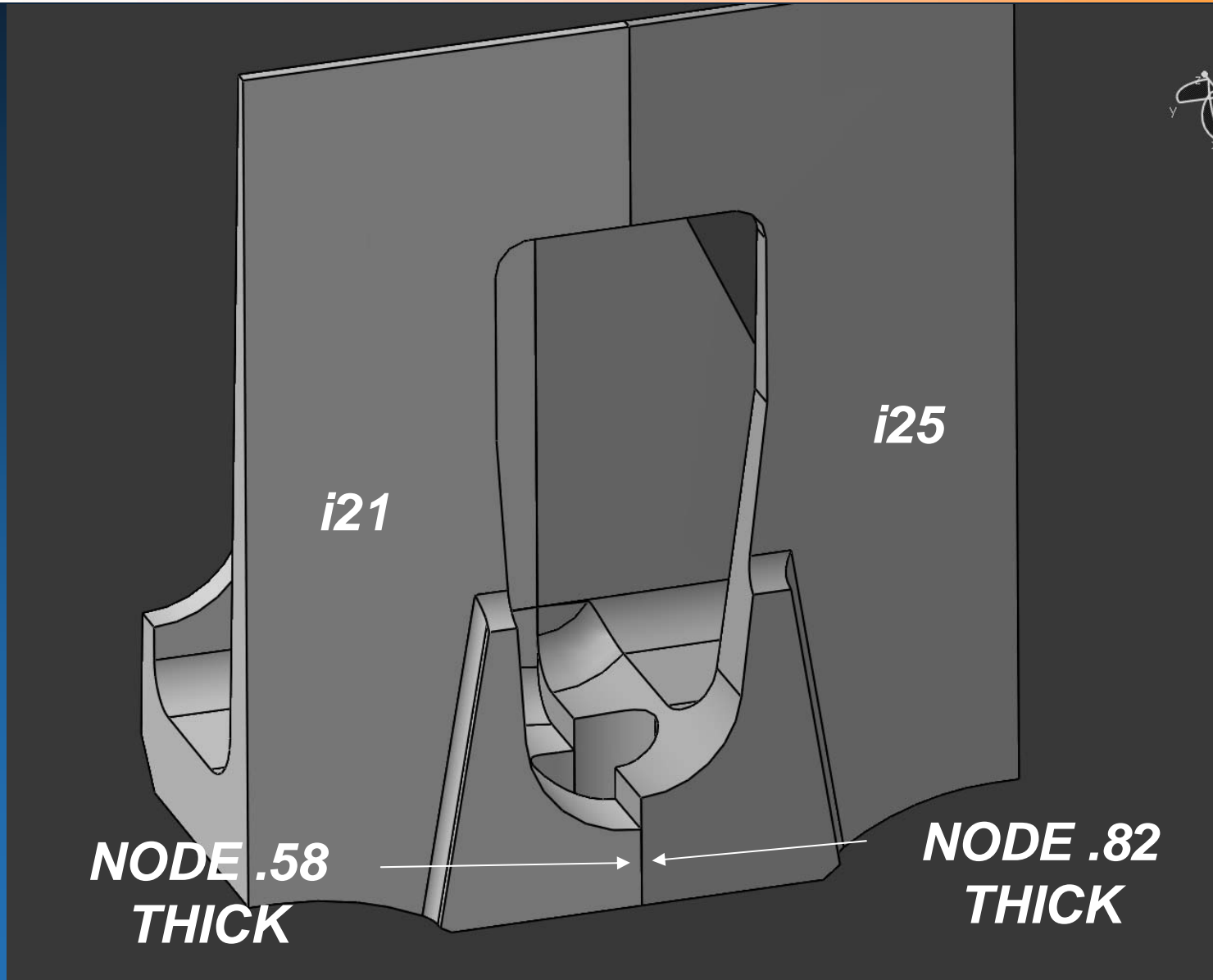


Lower Fitting

Overlay of Lower i15 through i25

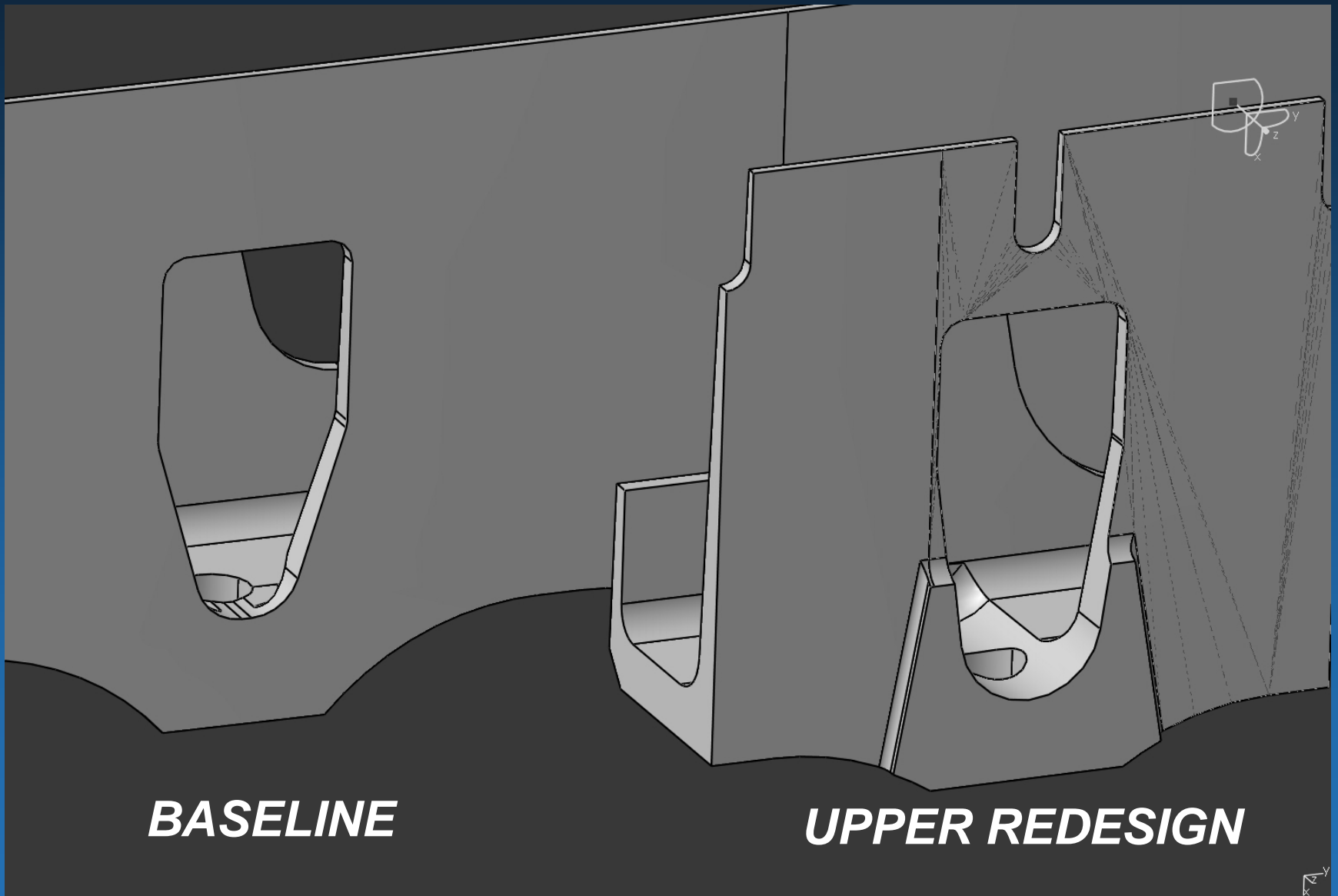


Model Progression





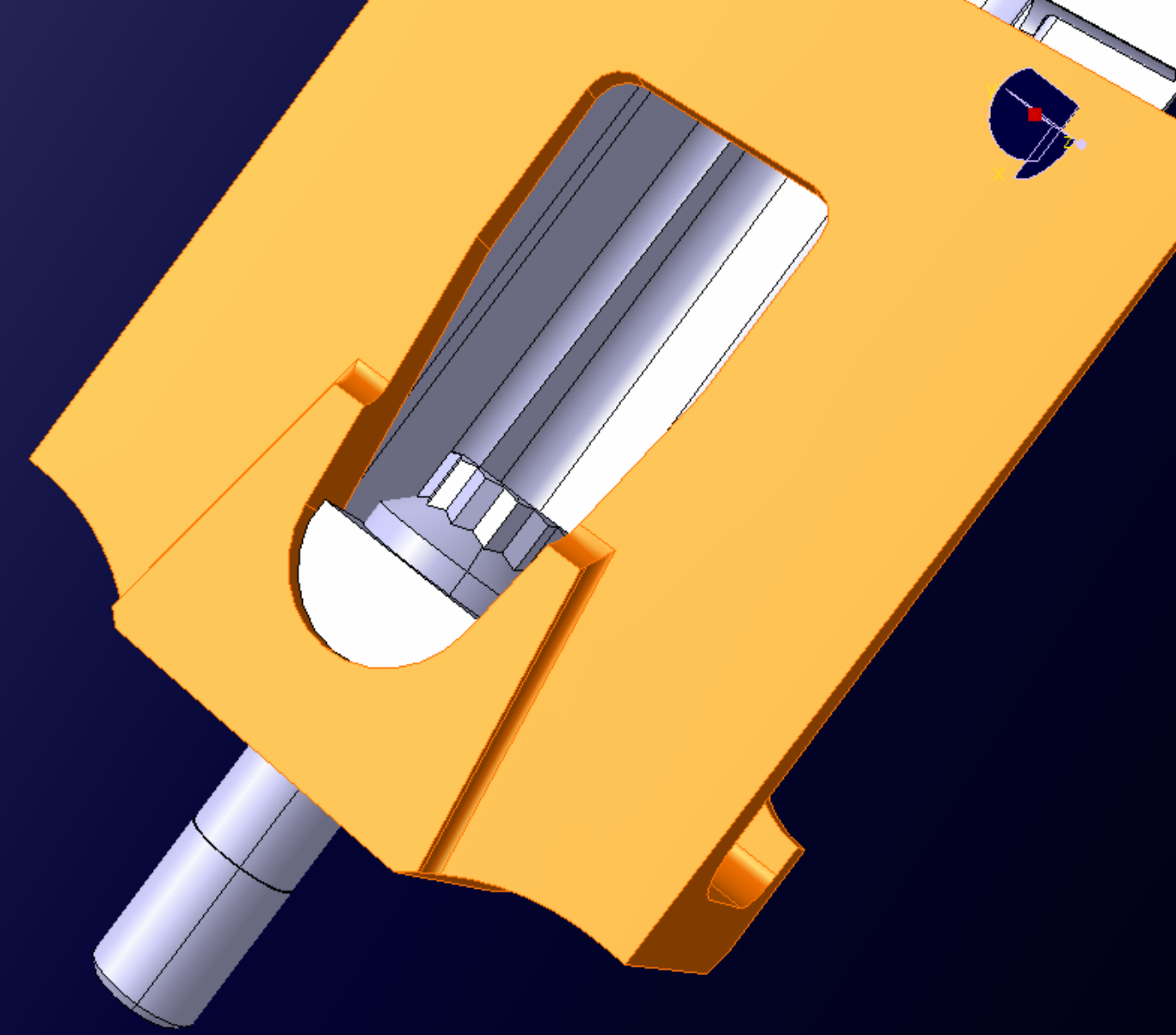
Model Progression



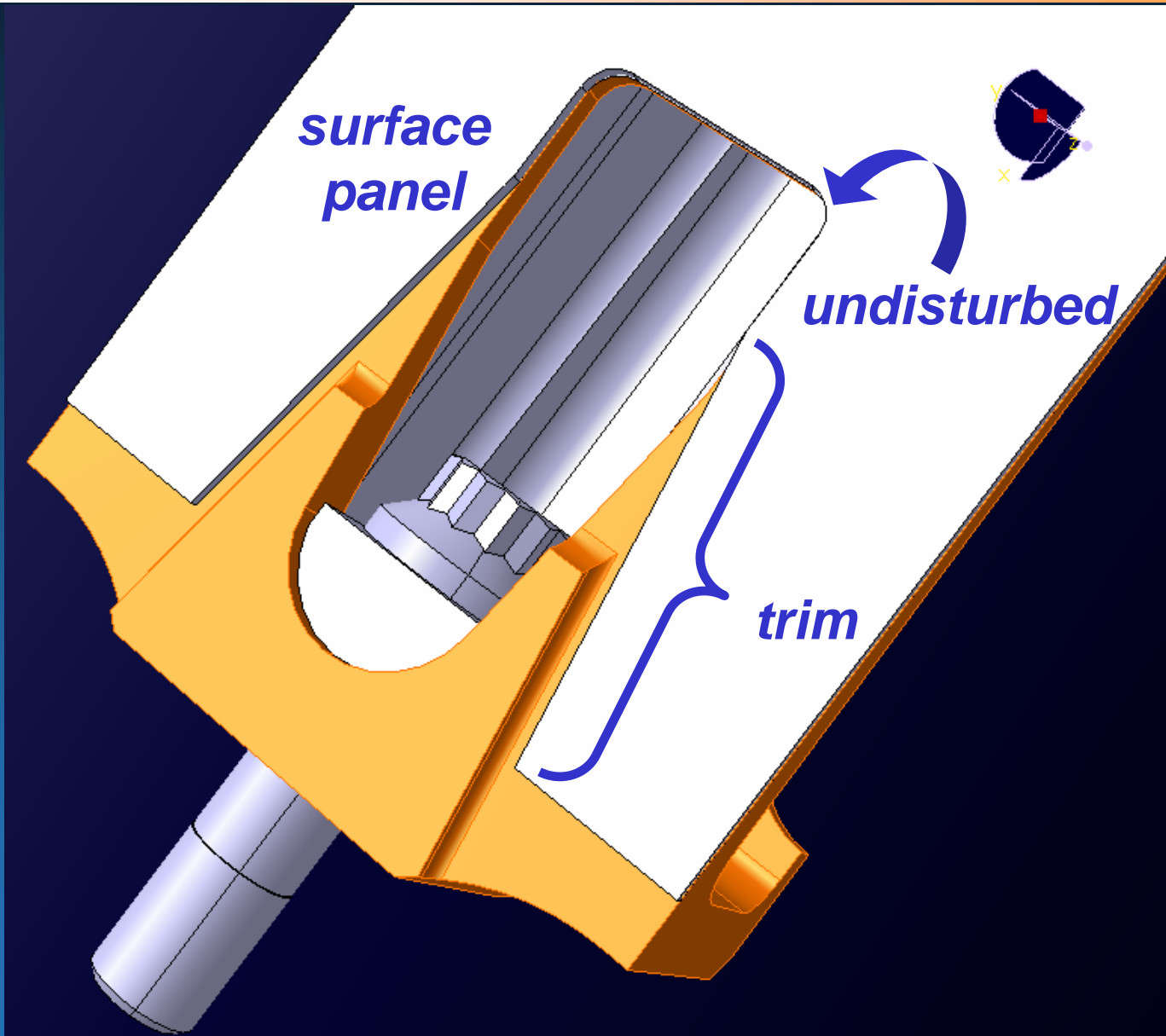
BASELINE

UPPER REDESIGN

Redesign Configuration



Redesign Configuration



Redesign Configuration

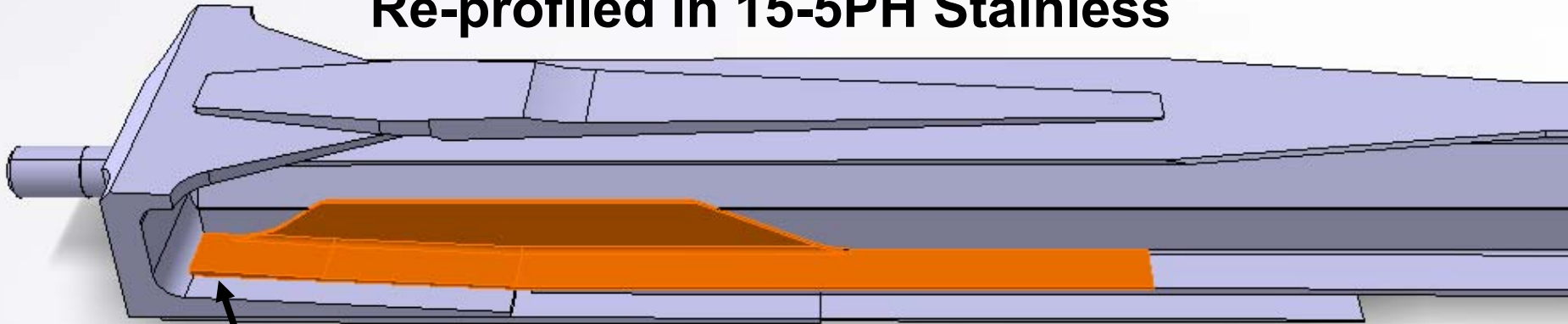


- **Redesign for Barrel Washer**
- **Longer Bolts**
- **Local Integral Pad (0.150”) to External Tang**
- **7249-T76511 with New Extrusion Profile**
- **Straight-Shank Fasteners in Coldworked Holes**
- **Bushings in Bolt Holes**
- **Profile and Material of Lwr Attach Angles (15-5PH SS bar.....was 7075-T73 forging)**

Redesign Configuration



**Attach Angle, Stringer Sidewall to Rainbow
Re-profiled in 15-5PH Stainless**

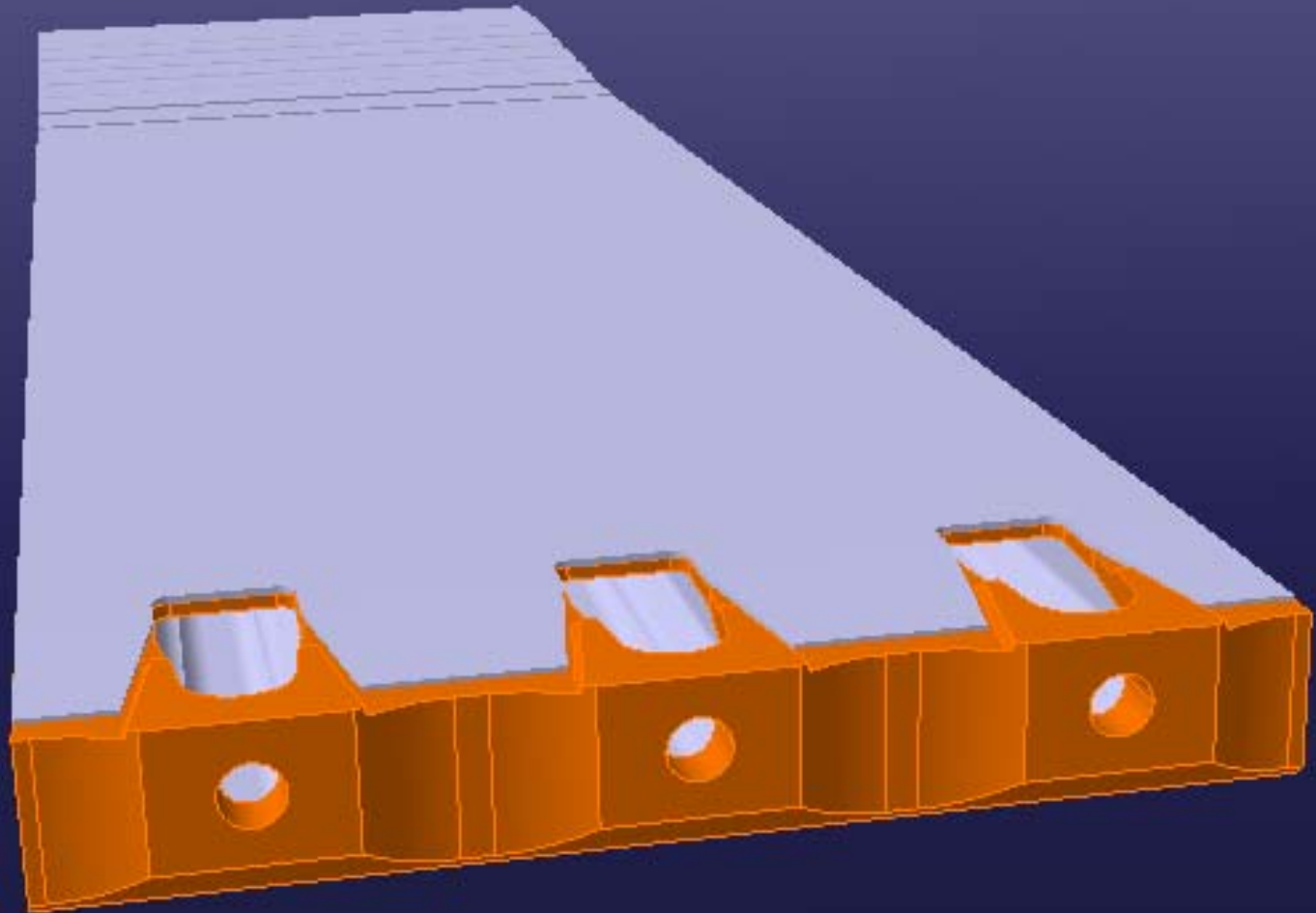


Reverse Taper

- 0.08" to approx $\frac{1}{4}$ "
- 0.11" to 0.07"

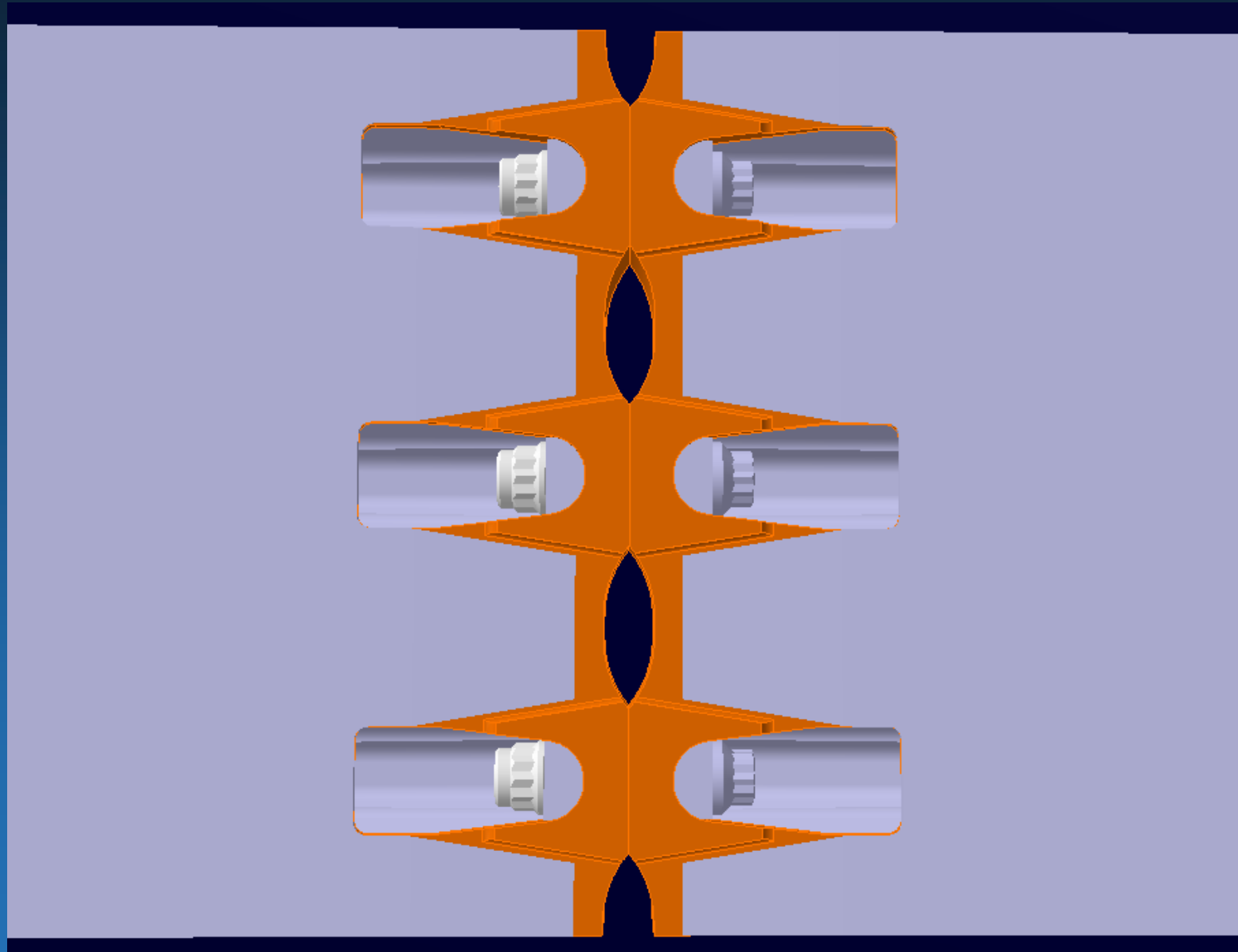


Redesign Test Configuration

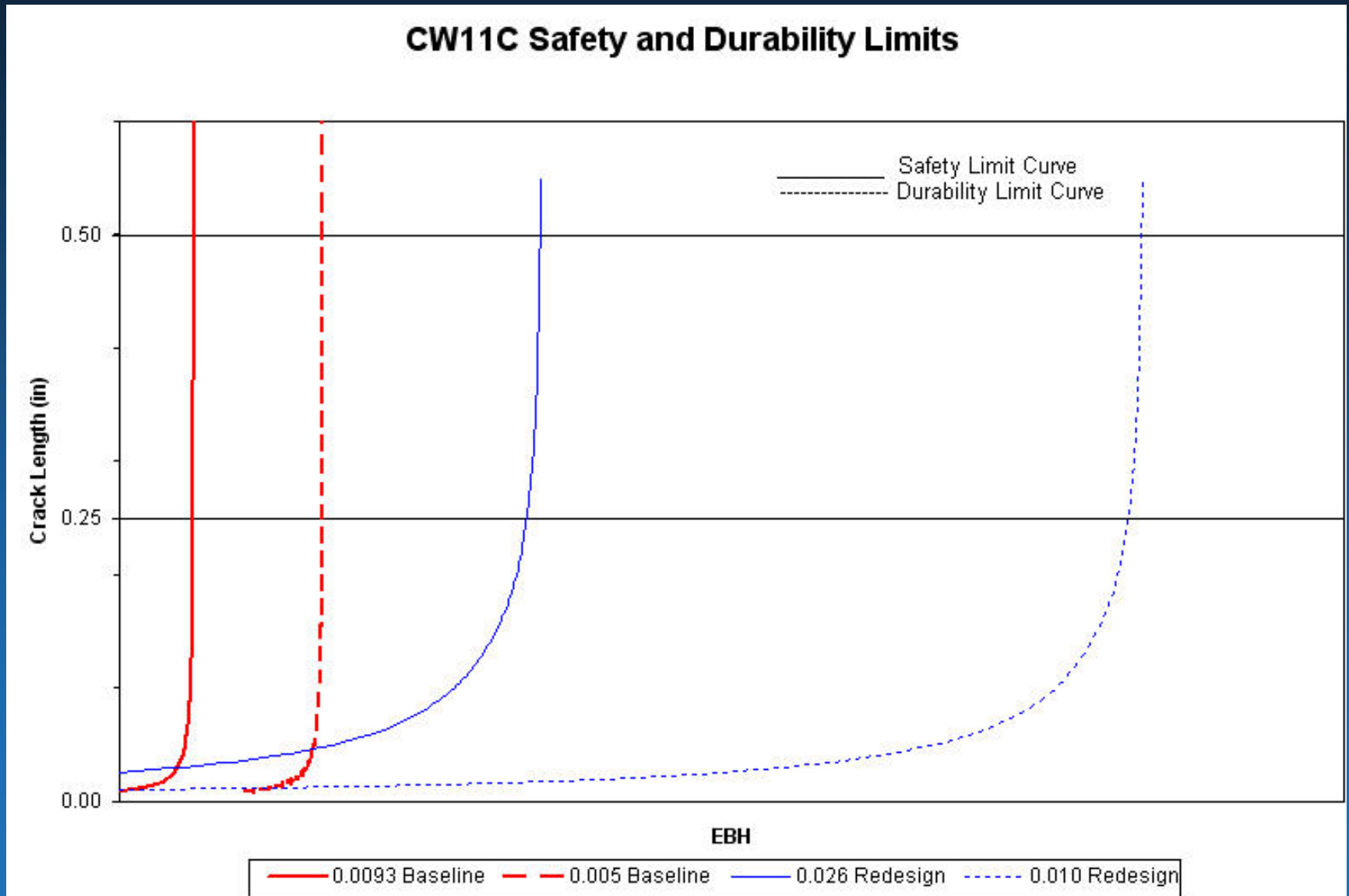




Redesign Test Configuration



Redesign Service Life



Redesign Goals Achieved



- All design goals were met with exception that:
 - *the redesign requires a trim to wing panel cutouts*
 - *the redesign requires a change in bolt length*
- All DADTA locations meet the 38,000 EBH goal using a scatter factor of 2, as required by JSSG.
- With the exception of CW-11A, all meet the SL requirement using a scatter factor of 4 (LM Aero self-imposed stretch goal)



Redesign Goals Achieved (cont'd)

- **Using a damage tolerance approach, the redesigned fittings have initial inspection intervals that greatly exceed the goal of 20,000 EBH or greater.**

- **By analysis, the initial inspection occurs beyond the goal for service life (38,000 EBH). As a result, the intent of another program goal is satisfied, i.e. “.....recurring inspection interval consistent with a damage tolerance approach of 5,000 EBH or greater”.**



Future Plans

- **Completion of an upper surface model**
- **Further analysis of upper rainbow fitting**
- **7249 coupon material testing**
- **ForceMate Analysis**
- **Fabricate and Assemble Test Articles**
- **Static and Fatigue Tests of 3-node articles**
- **Update of Analysis**
- **TKI**
- **Implementation**

Conclusions / Lessons Learned



- **Not Solved Simply by Barrel Washer Configuration**
- **External Pad**
- **Small Design Differences Can Have a Significant Impact on Service Life (1968 design and redesign)**
- **Analysis Indicates Significantly Longer Service Life (approximately five-fold improvement at CW-11C)**

C-130 Center Wing Rainbow Fitting, Spare Redesign



Questions