Comanche Stabilator Horn Cracking Investigation

Final Analysis Report

International Comanche Society

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Hans Neubert, Airworthiness Committee Co-Chairman

DERT-605393-NM

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Problem Statement

ICS Members Denny Haskins/Eric Paul report horn cracks found in 3 PA24 singles of 6 inspected – Comanche Flyer March 2007

ICS Member Hans Neubert initiates fleetwide survey of member inspection findings via 2 websites and Comanche Flyer magazine

ICS Hq/Dave Fitzgerald initiates 3rd party survey using FAA registered owner database

Response to date are 800+ surveys submitted worldwide, 18 cracked horns found from estimated airworthy fleet of 4000+ aircraft (all models)

FAA performs metallurgical investigation at NIAR, stress corrosion cracking determined as primary cause (ref. NIAR Memorandum dated 31 Aug 2009)

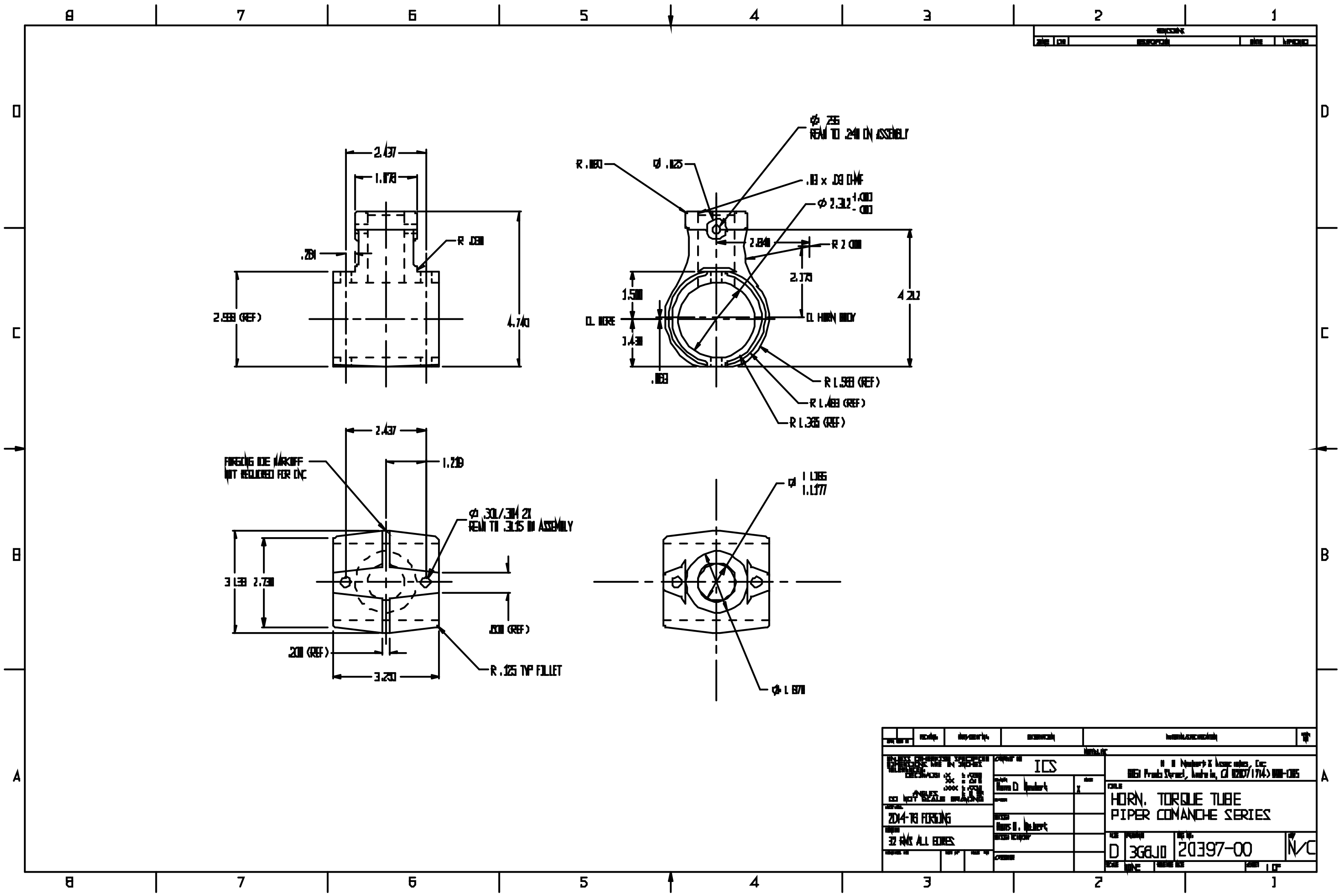
Analytical study initiated to determine stress state in horns and evaluate results to metallurgical SCC cracking threshold

Analytical Approach Used

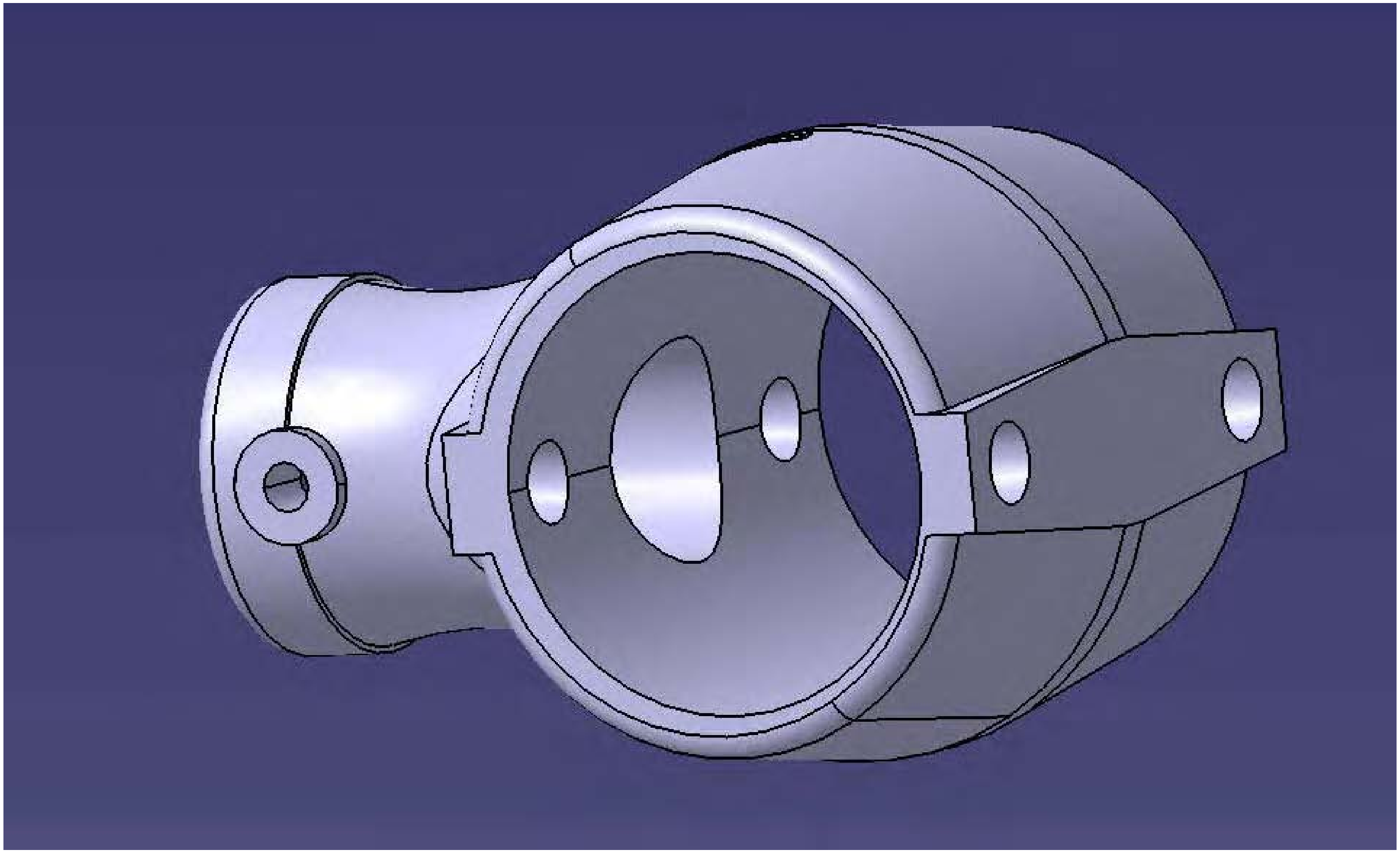
- Reverse engineer existing forged 2014-T6 horn and create dimensioned drawing
- Develop 3D model of horn from drawing and create 3D CAD Iges model
- Create Finite Element Model of complete Stabilator Torque Tube Assembly
- Incorporate FAA developed applied load conditions and combinations
- Run FEA model and capture all stress and displacement results
- Summarize all results within this report

Typical Cracked Horn

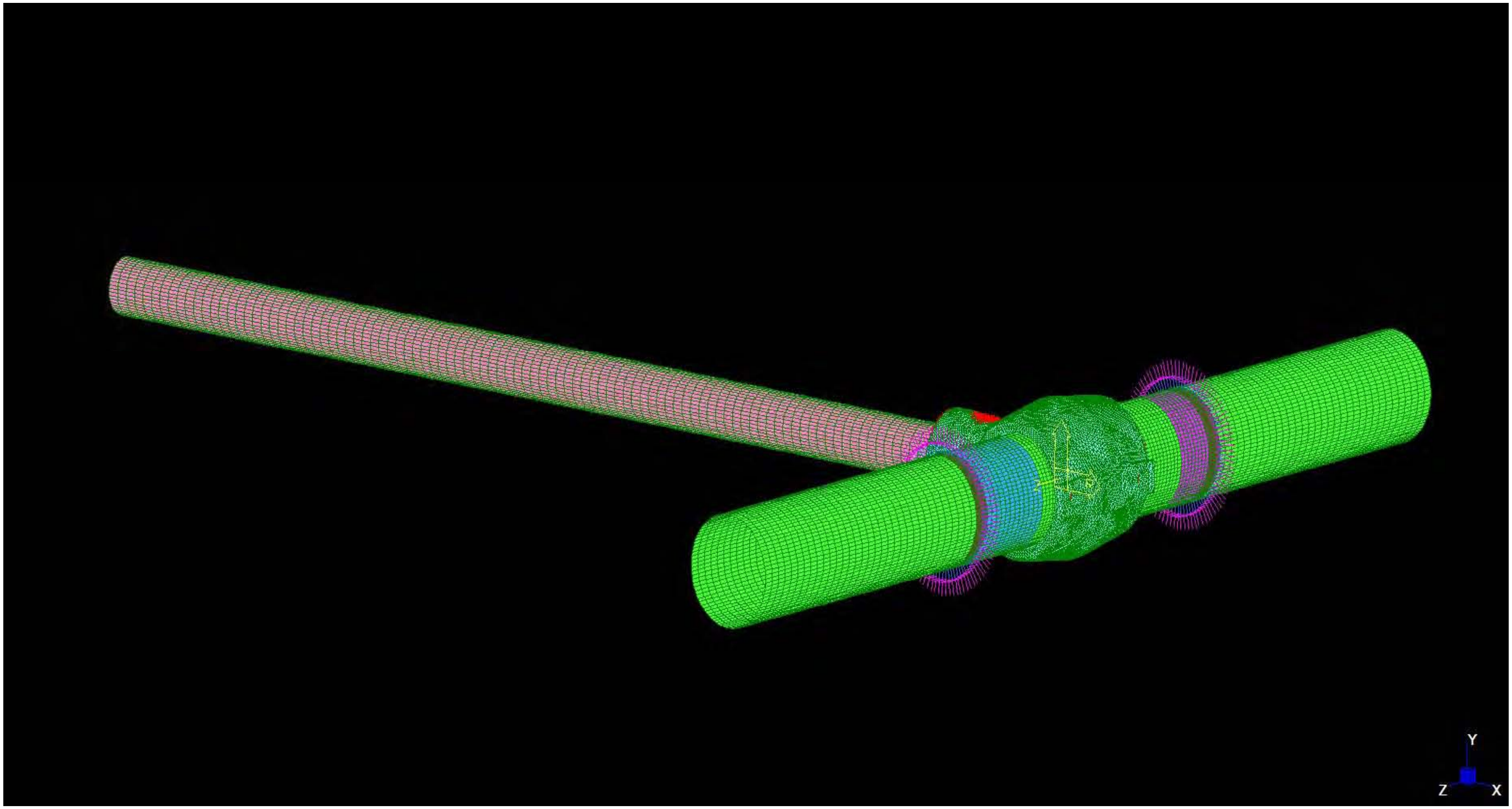
Reverse Engineered Horn Drawing



3D CAD Iges Model



FEA Model of Horn Created from Iges Model



FEA Model Development

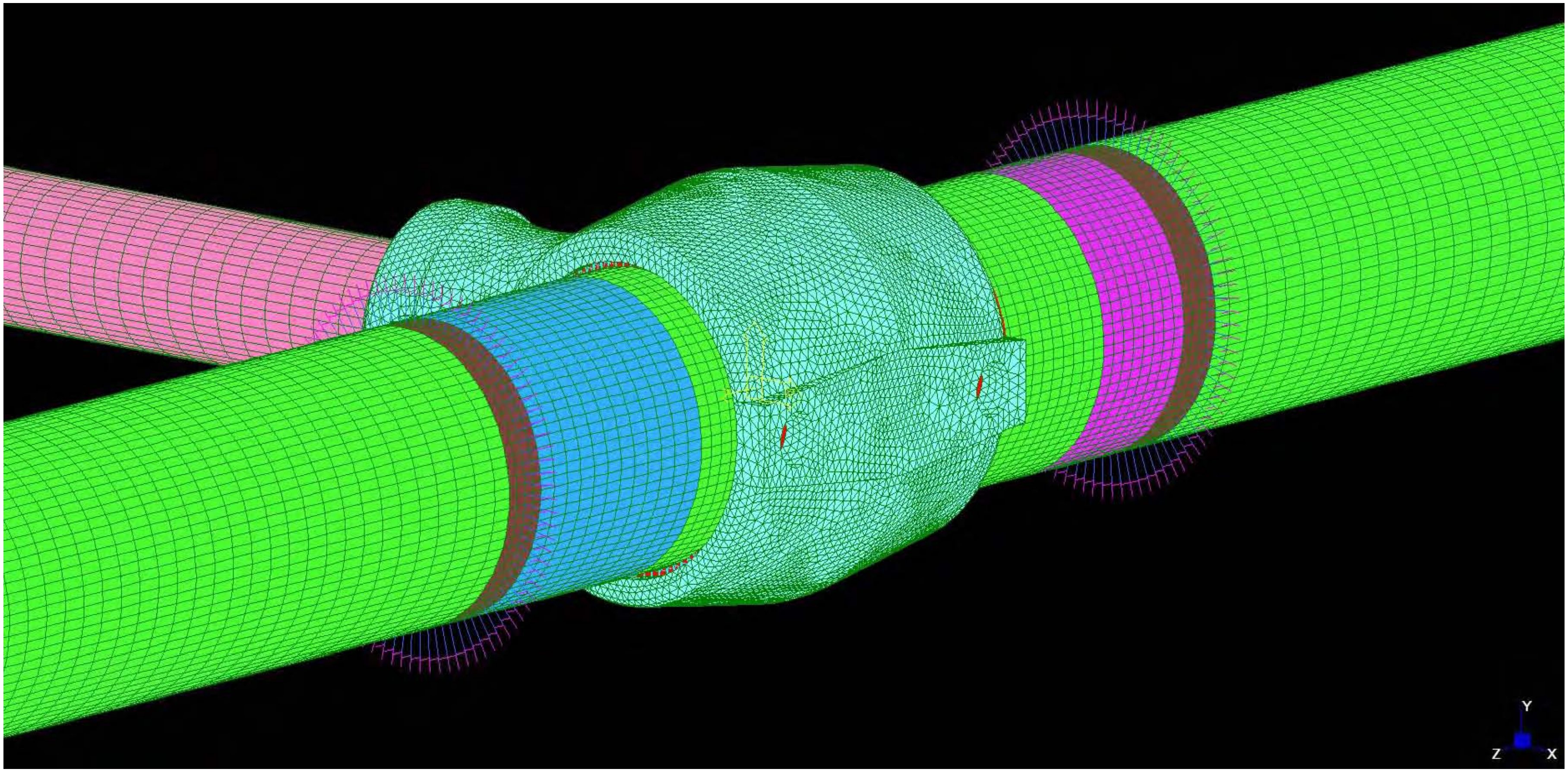
- Strand7 FEA Software
  - 65 York St., Sydney NSW 2000 Australia
- Model Development
  - Horn body as solid tetrahedral elements
  - Horn skin (.0005") as membrane elements*
  - Torque tube and attachments as shell elements**
  - Counterbalance arm as shell elements
  - Interference condition as equivalent pressure
  - Bolt preloads as equivalent force (distributed)

* Surface skin required since stress integration points on solid elements are interior to element surface

** Attachments to torque tube modeled with full combined thickness and plate offsets for correct EI

Close-Up View of Horn

(Torque Tube joined to Horn with rigid links)



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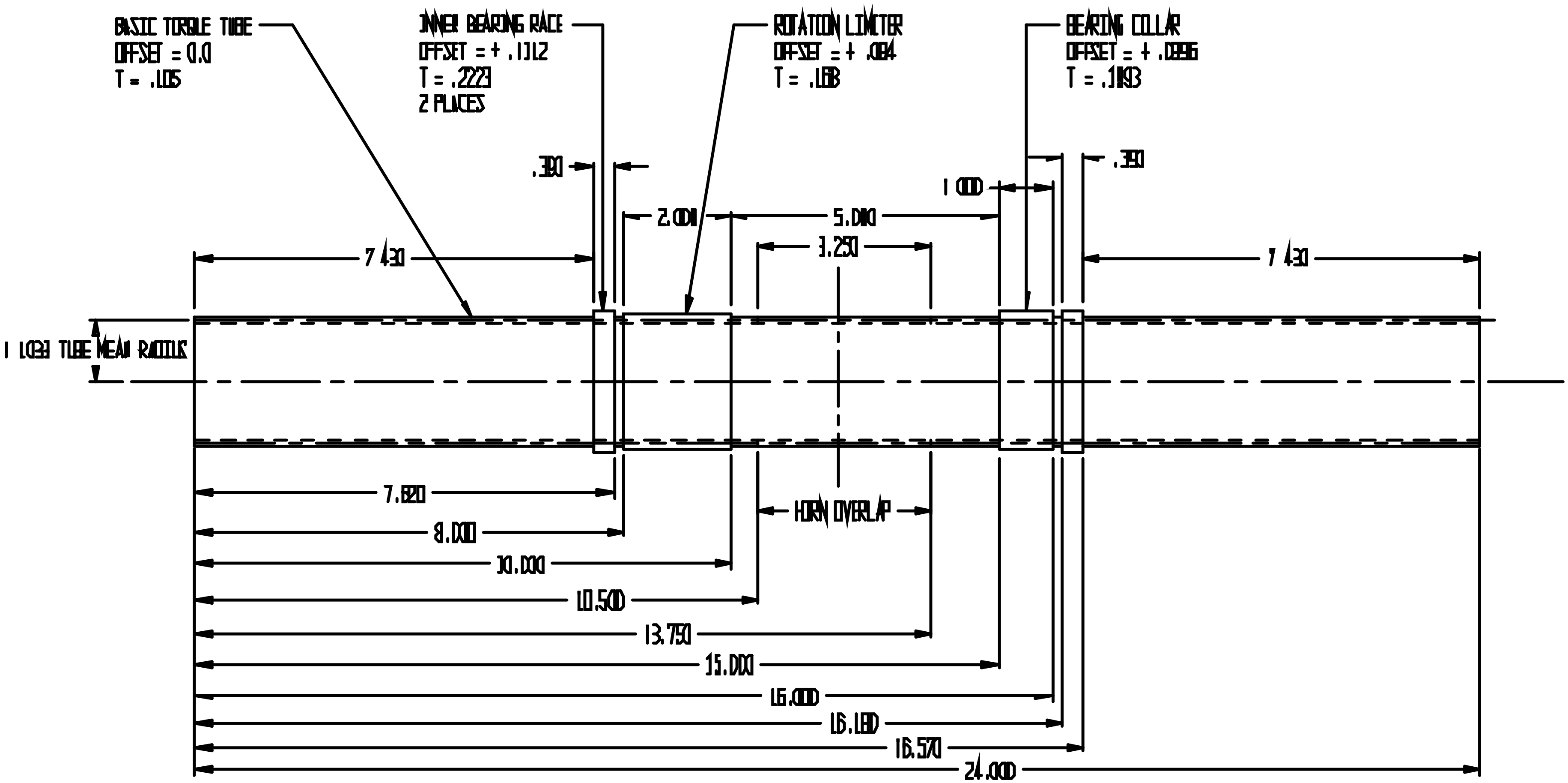
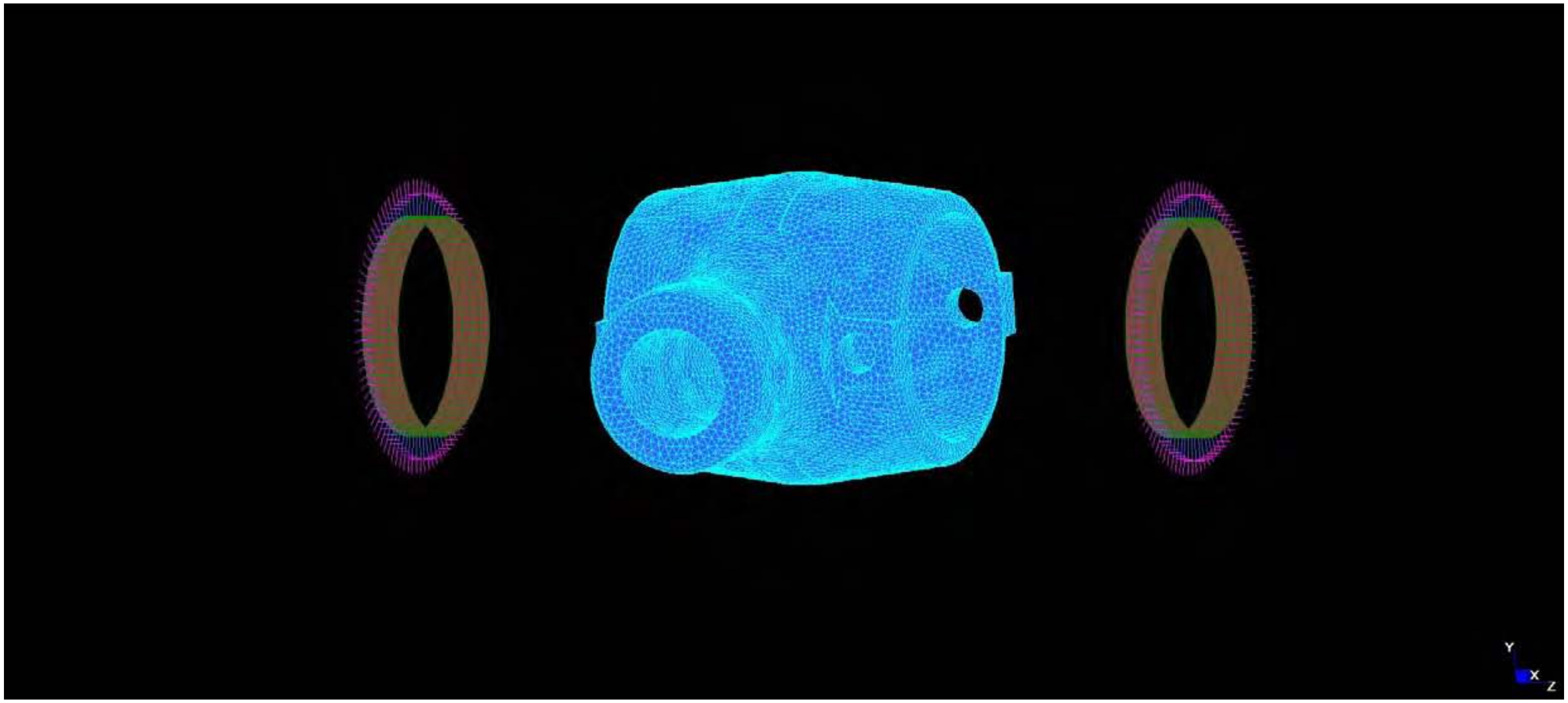
Torque Tube Attachments and Details



Boundary Conditions



Bearing race and torque tube as one element. Beam elements representing ball bearings. End of beams constrained in R & Z of the horn cylindrical coordinate system. Bearing is free to rotate in Theta. Global Y constraint at the end of the Counterbalance tube, representing the control cables.

Critical Dimensions

- Torque Tube
  - 2.3115 +.0003/-.0002 after plating per AMS 2400-3
  - (data from Simone Fevola, Piper's DER, 1-31-2005, reading from the screen of the tube drawing).
- Horn P/N 20397-00
  - a. Counterbalance Tube Bore

    1.1177 to 1.1185 (was 1.1182 to 1.1190) Change A dated 1-4-1957

    (Counterbalance bore data from Dallas Wehner, Piper Cust. Svc)
  - b. Torque Tube Bore

    2.312 +.001/-.0001

    (Torque Tube bore from Piper Drawing 20397)
- Counterbalance Arm Tube Outside Diameter
  - a. P/N 20398-00 (used on 24-1 to 24-102) and 20398-02 (used on 24-103 & Up), All Singles except 400

    1.1185 to 1.1187
  - b. P/N 22880-00, Used on Twins and 400

    1.1187 to 1.1202

    (Counterbalance tube data from Dallas Wehner, Piper Cust. Svc)
- Horn Material

    2014-T6 Aluminum Die Forging per AMS 4133, AMS-A-22771, and AMS-QQ-A-367

Load Conditions

- Four load conditions
  - Interference fit between horn and counterbalance tube – variable depending on tolerance
  - Horn attachment bolts – variable depending on torque
  - Rotation Limiter bolts – fixed at 60 in-lb torque
  - Counterbalance Arm bolt – fixed at 60 in-lb torque
- Interference Fit limits (diametric)
  - Singles: Max: .0010 Min: .0000
  - Twins/400: Max: .0025 Min: .0002

Load Cases Requested

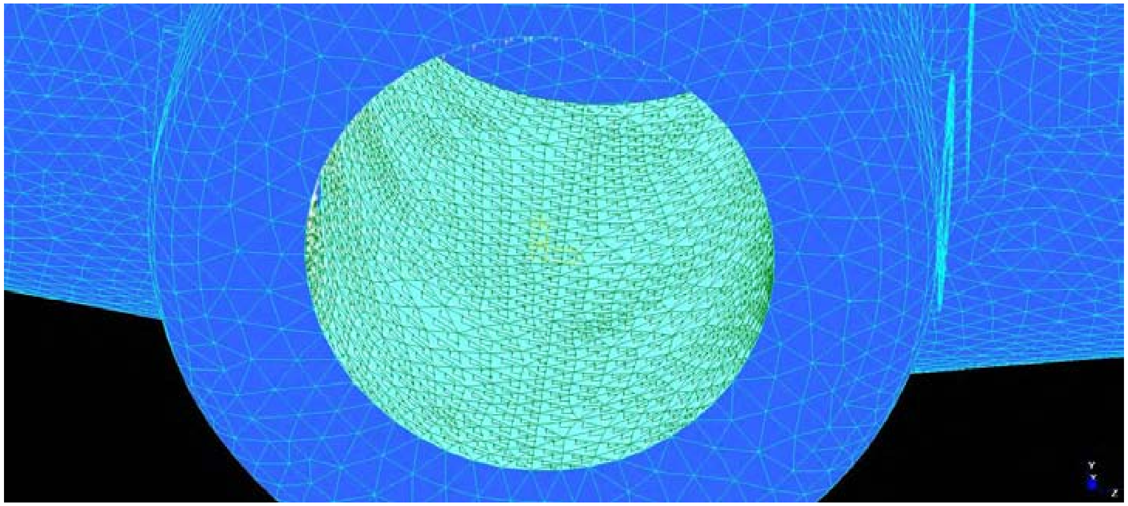
		Parameters							
	Name	counterbalance arm interference fit (A)		torque values - original installation (B)		torque values - new (C)		torque tube wall thickness (D)	
	Source	*drawing tolerances*		*current MM range*		*SB 1194 kit range*		*drawing low tolerance*	
Test Case	Description / Value	Low	High	Low	High	Low	High	Thin	Thick
Ab	counterbalance arm interference only - best	x							
Aw	counterbalance arm interference only - worst		x						
Bb	torque values - original only - best			x					
Bw	torque values - original only - worst				x				
Cb	torque values - new only - best					x			
Cw	torque values - new only - worst						x		
Db	torque tube wall thickness only - thin							x	
Dw	torque tube wall thickness only - thick								x
ABDb	combined counterbalance arm + original torque value + thin wall tube - best	x		x				x	
ABD1w	combined counterbalance arm + original torque value + thin wall tube - worst		x		x			x	
ABD2w	combined counterbalance arm + original torque value + thick wall tube - worst		x		x				x
ACD1w	combined counterbalance arm + SB kit torque value + thin wall tube - worst		x				x	x	
ACD2w	combined counterbalance arm + SB kit torque value + thick wall tube - worst		x				x		x

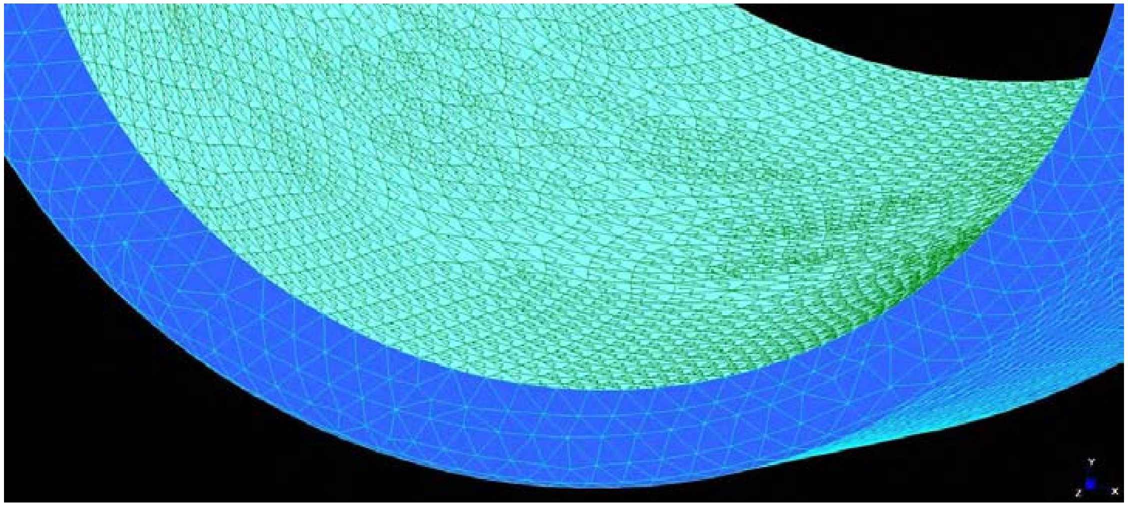
Note: For the combined cases, use simple additive superposition if the modeling shows that to be the pattern.

Load Condition Values

TORQUE TUBE HORN ANALYSIS PARAMETERS AND VALUES								
	COUNTERBALANCE ARM		ORIGINAL HORN		NEW HORN		TORQUE TUBE WALL	
TEST CASE	Diametral Interference	Equivalent Pressure	Torque	Bolt Preload	Torque	Bolt Preload	Singles	Twins/400
Ab	**0**	**0**	-----	-----	-----	-----	-----	-----
Aw	**0.001**	**2729**	-----	-----	-----	-----	-----	-----
Bb			**70**	**1124**	-----	-----	-----	-----
Bw			**140**	**2247**	-----	-----	-----	-----
Cb					**75**	**1204**	-----	-----
Cw					**95**	**1525**	-----	-----
Db							**0.105**	-----
Dw								**0.156**
ABDb	**0**	**0**	**70**	**1124**			**0.105**	
ABD1w	**0.001**	**2729**	**140**	**2247**			**0.105**	
ABD2w	**0.001**	**2729**	**140**	**2247**				**0.156**
ACD1w	**0.001**	**2729**			**95**	**1525**	**0.105**	
ACD2w	**0.001**	**2729**			**95**	**1525**		**0.156**
Twins/400	**0.0025**	**7255**	**140**	**2247**		**1525**		**0.156**
Notes:								
Tube ID	0.75							
Hub ID	1.1181							
Hub OD	1.8780							

Alignment of Bore Surfaces – Local x lengthwise





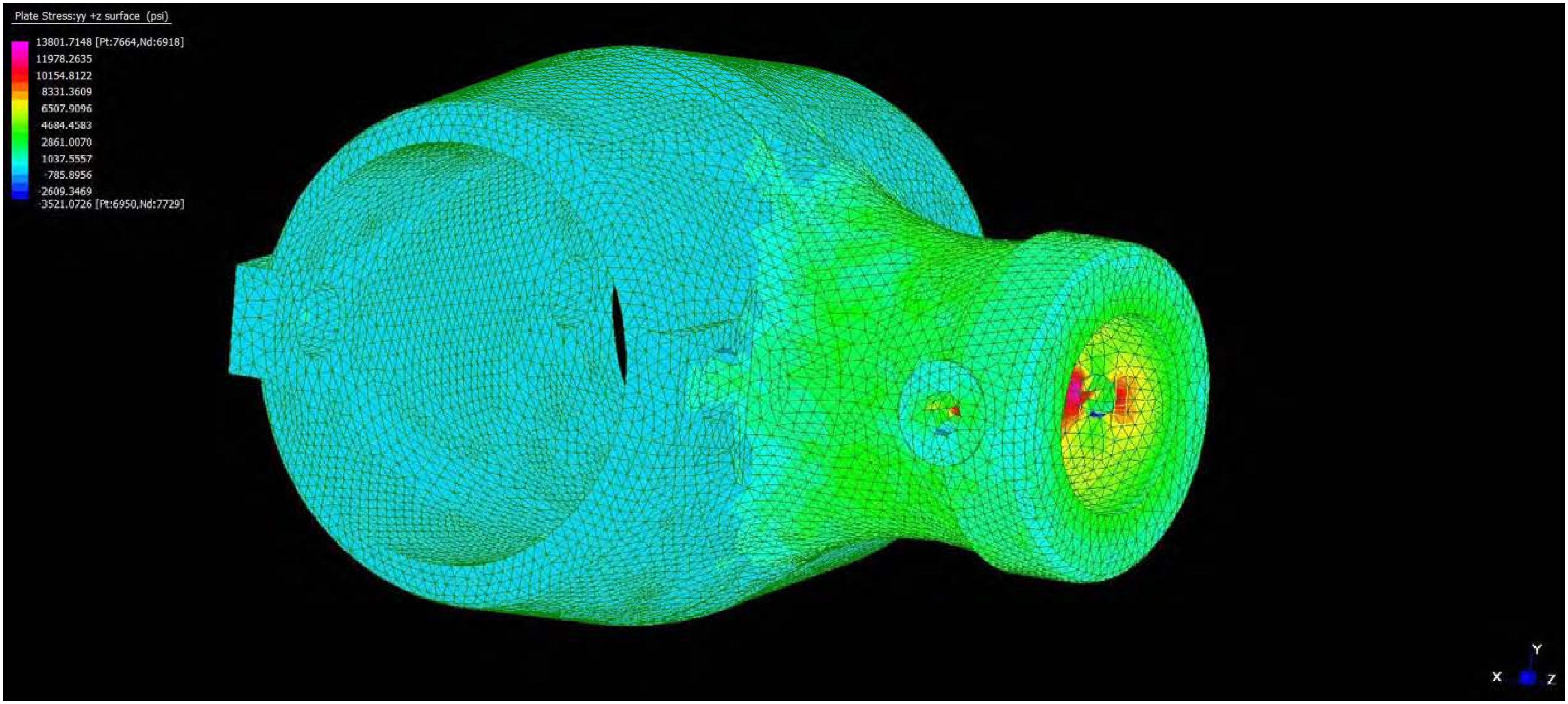
Final FEA Model

- 49015 Nodes, 180 Beams, 46452 Plates, 129,212 Bricks
- Solution time ~ 20 minutes
- Primary interest is horn skin stresses – other elements hidden
- Known cracks develop due to element local yy stress
- Contour plots show overall stress state
- Stress state at key locations from element results

- Results for Singles (except 400) shown next

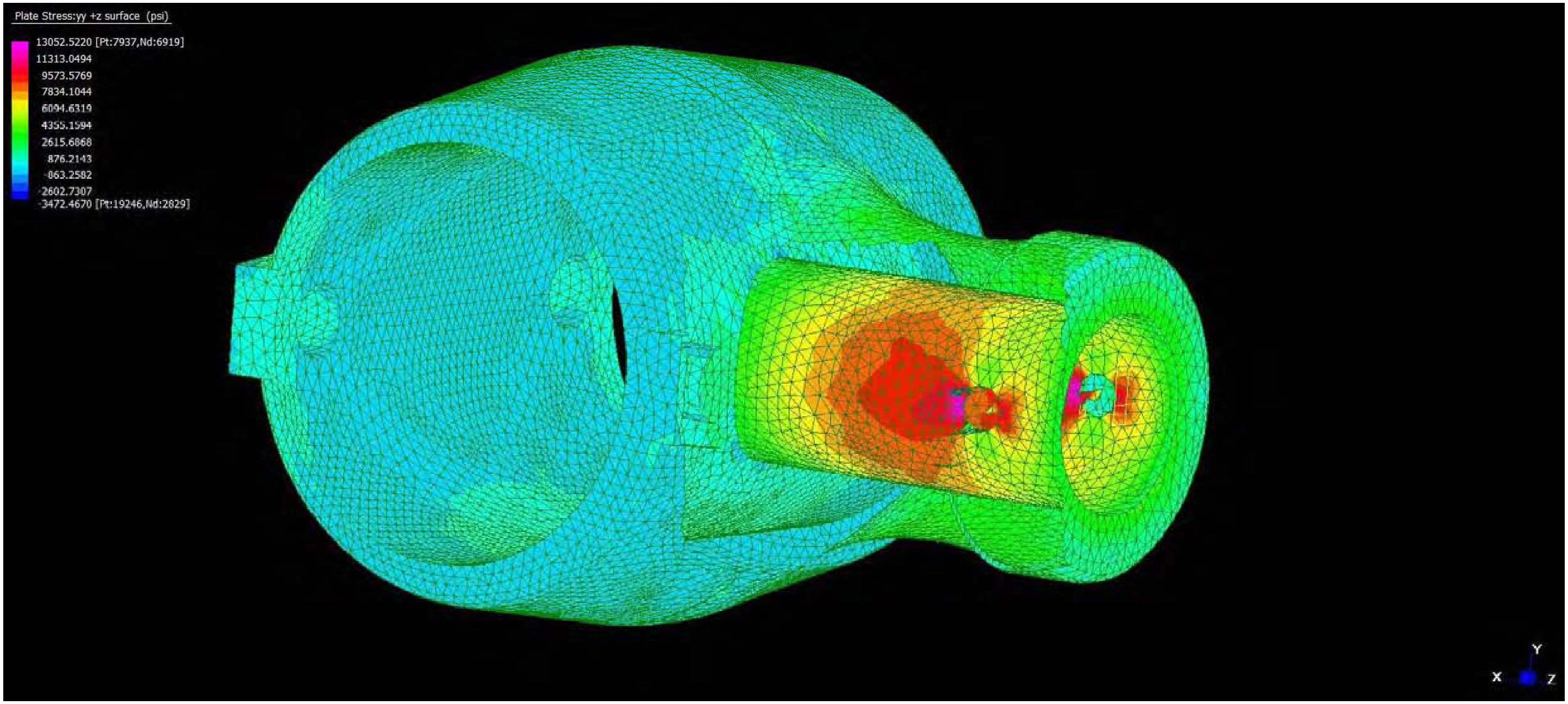
Condition Aw

(Interference Fit Only)



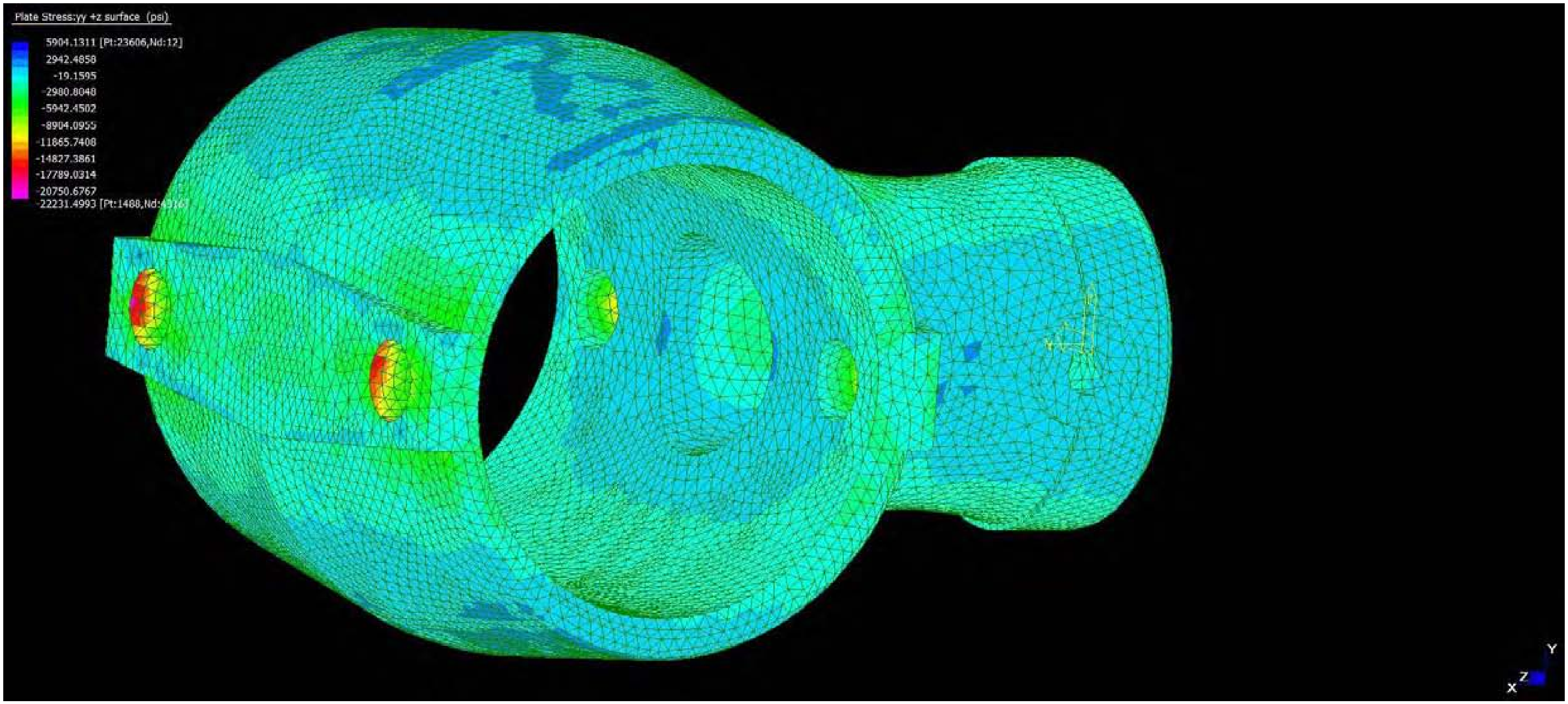
Condition Aw

(Selected Elements Hidden for Inside View)



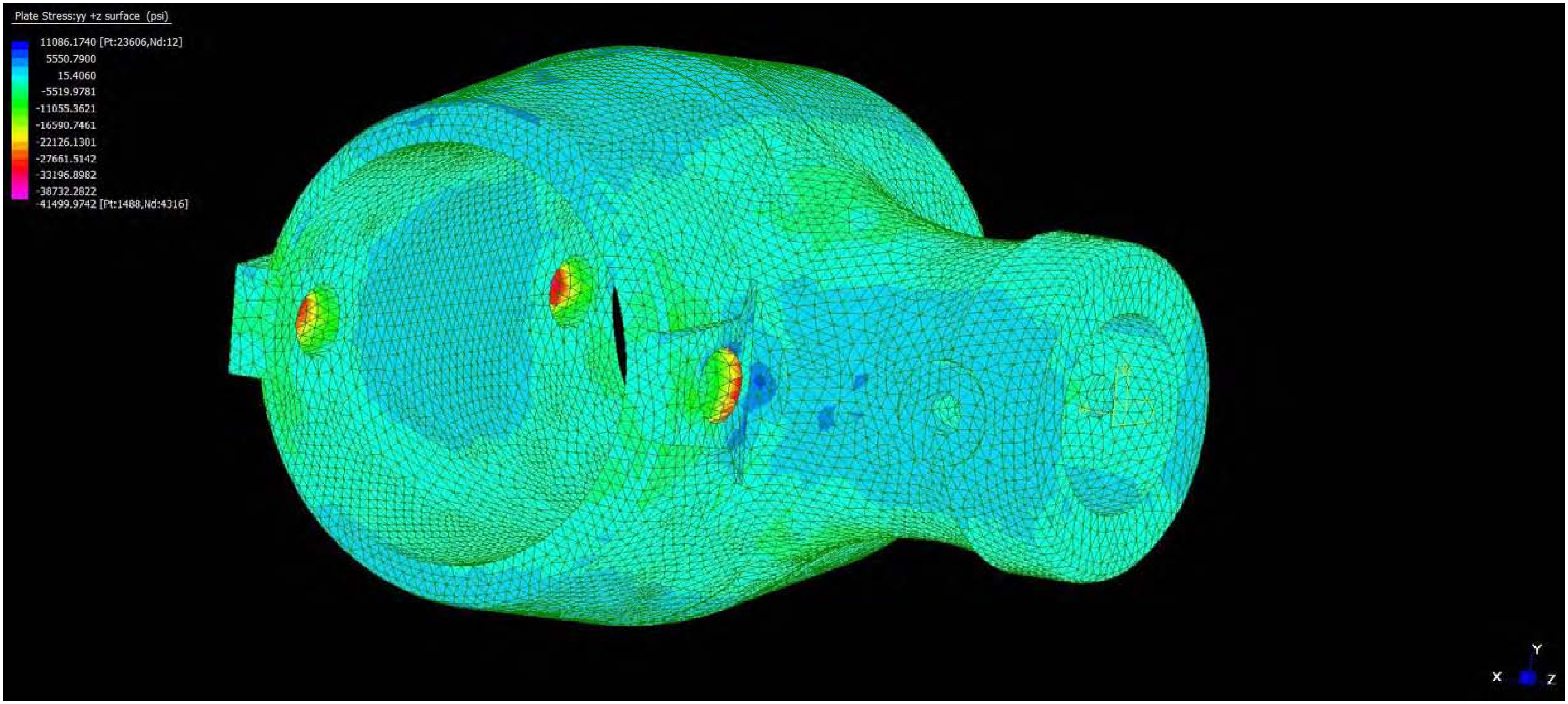
Condition Bb

(Bolt Load on Horn – Low Torque)



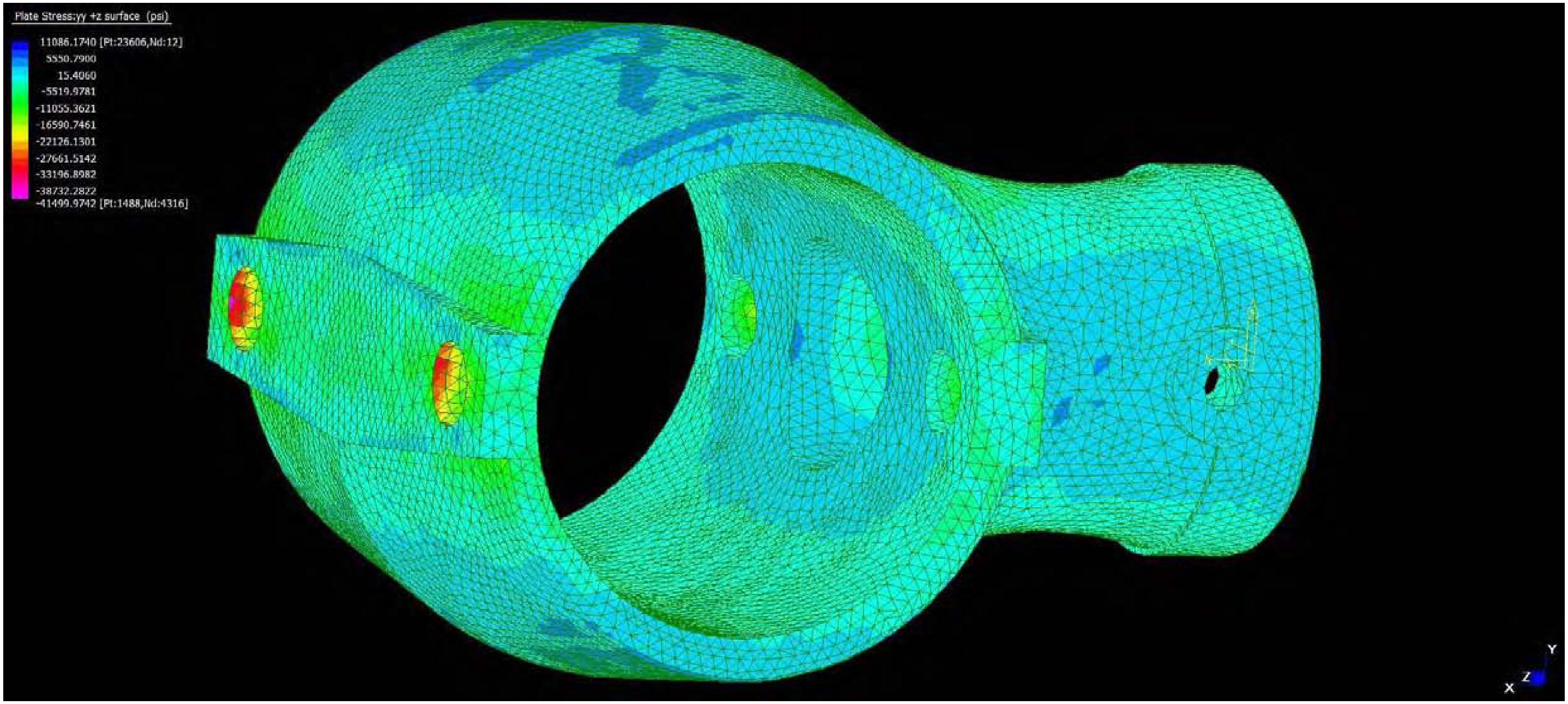
Condition Bw

(Bolt Load on Horn – High Torque)



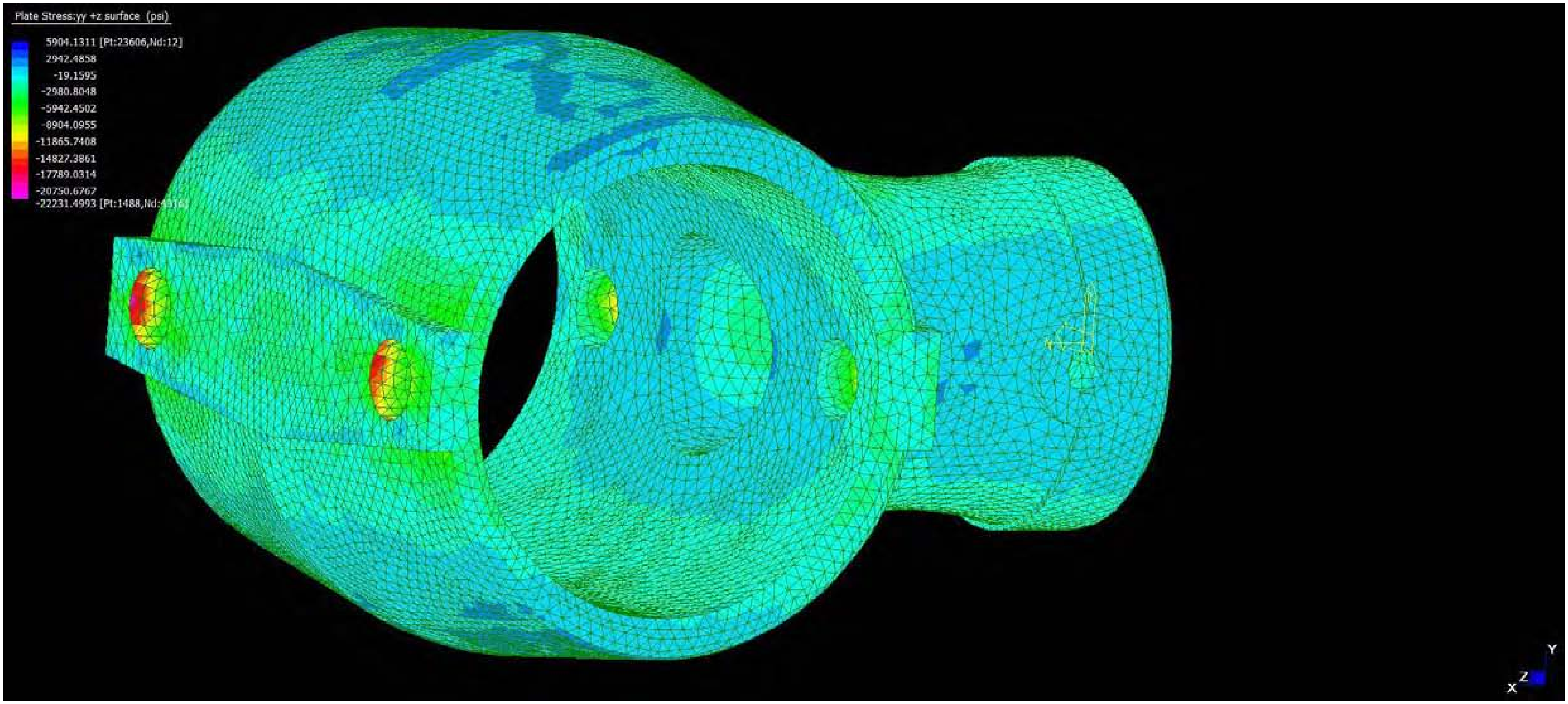
Condition Bw

(Bolt Load on Horn – High Torque)



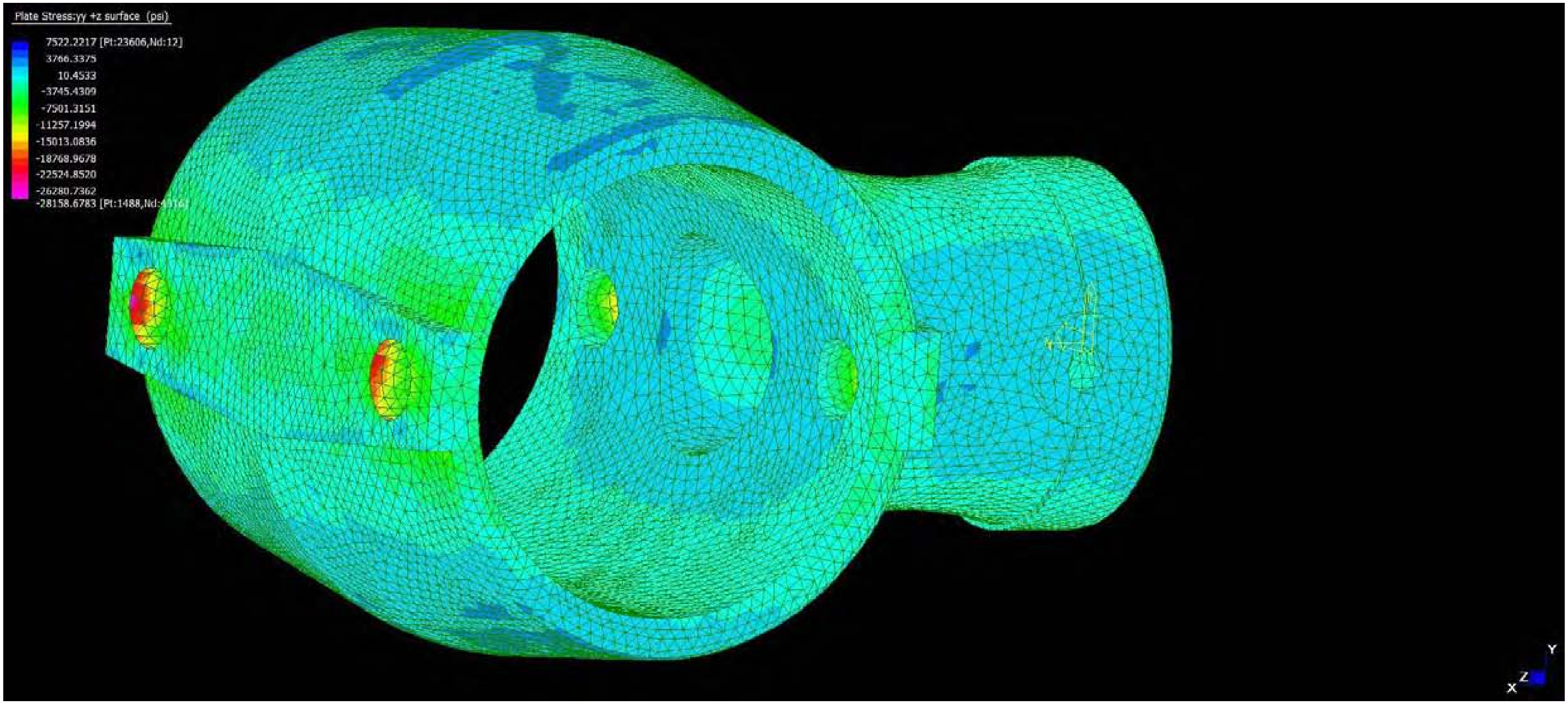
Condition Cb

(Bolt Load on Horn – New Horn – Low Torque)



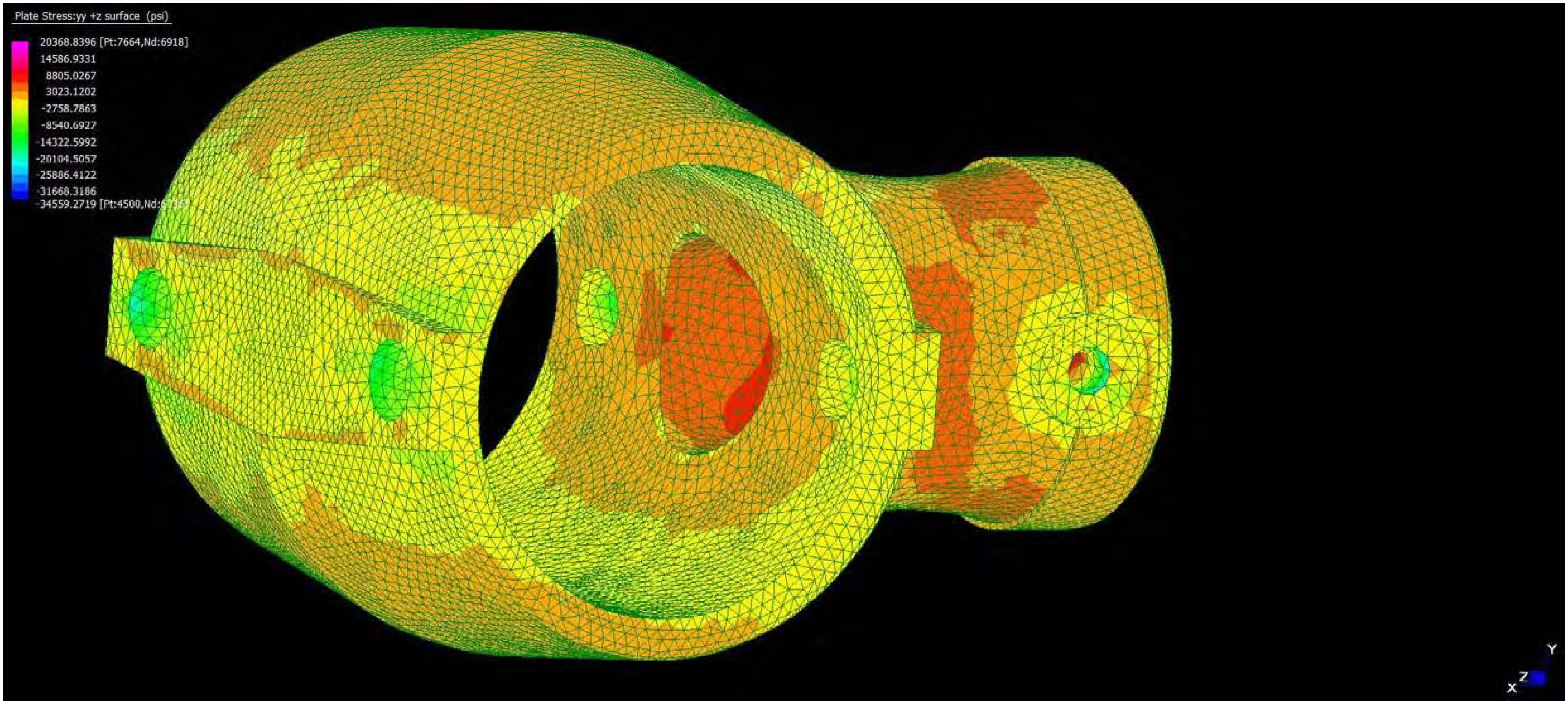
Condition Cw

(Bolt Load on Horn – New Horn – High Torque



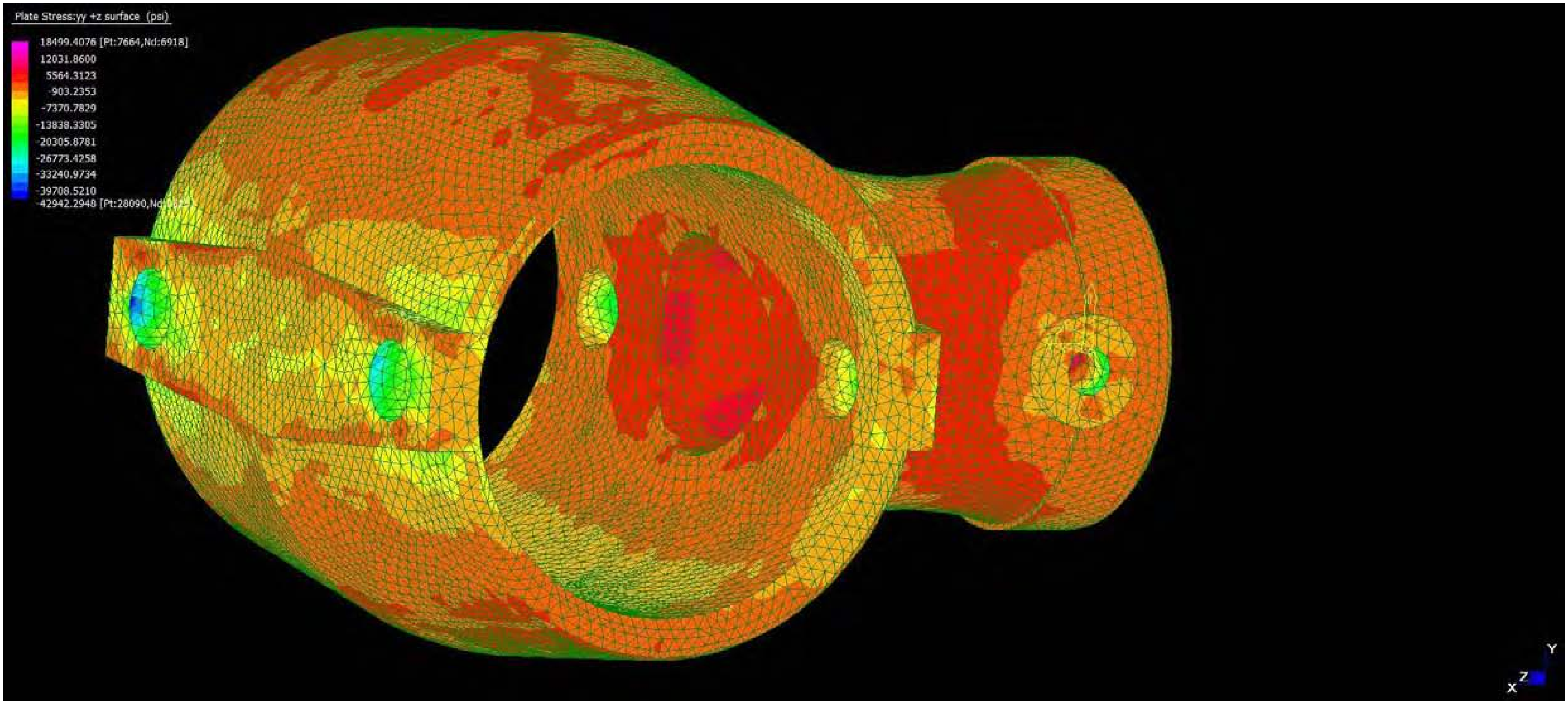
Condition ABDb

(Combined Case – Interference Fit – Low Torque)



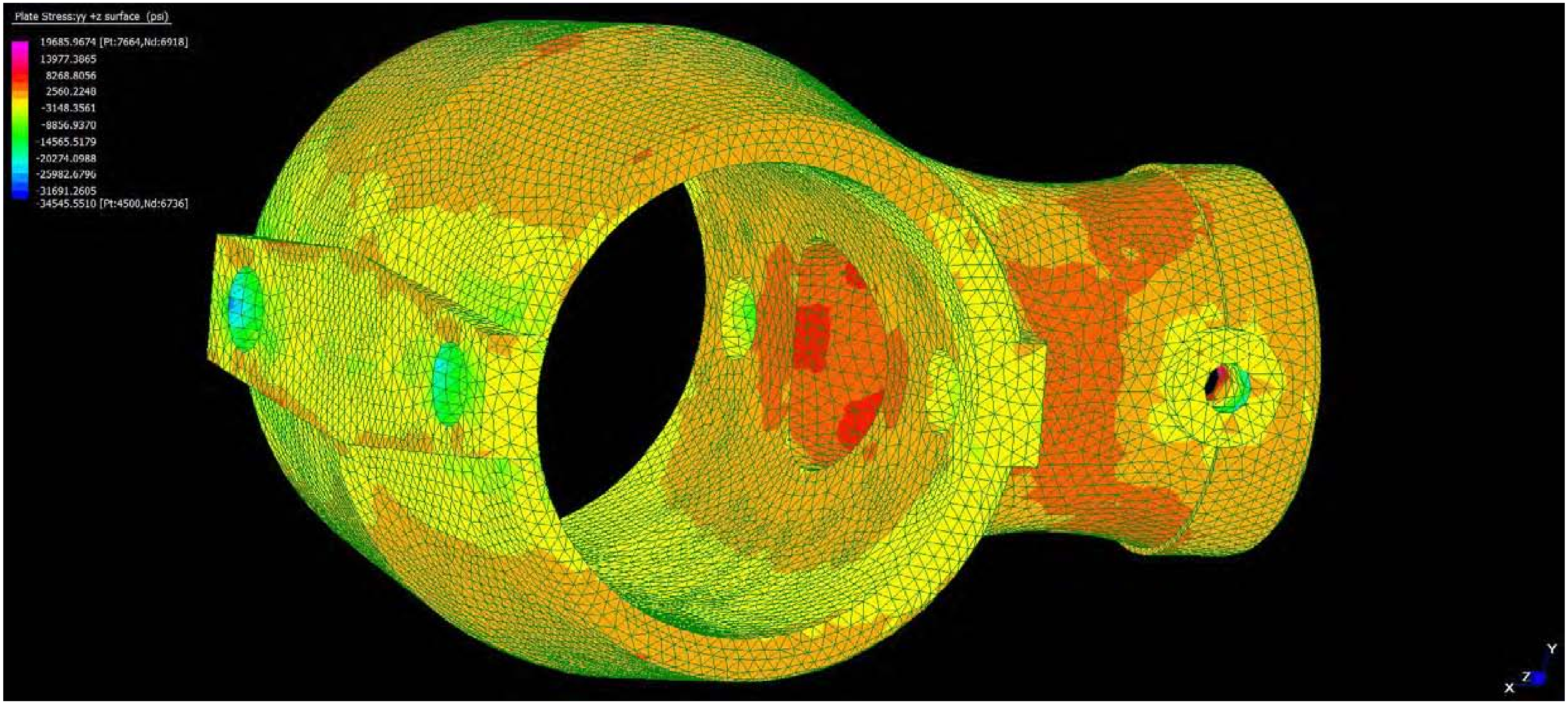
Condition ABD1w

(Combined Case – Interference Fit – High Torque)



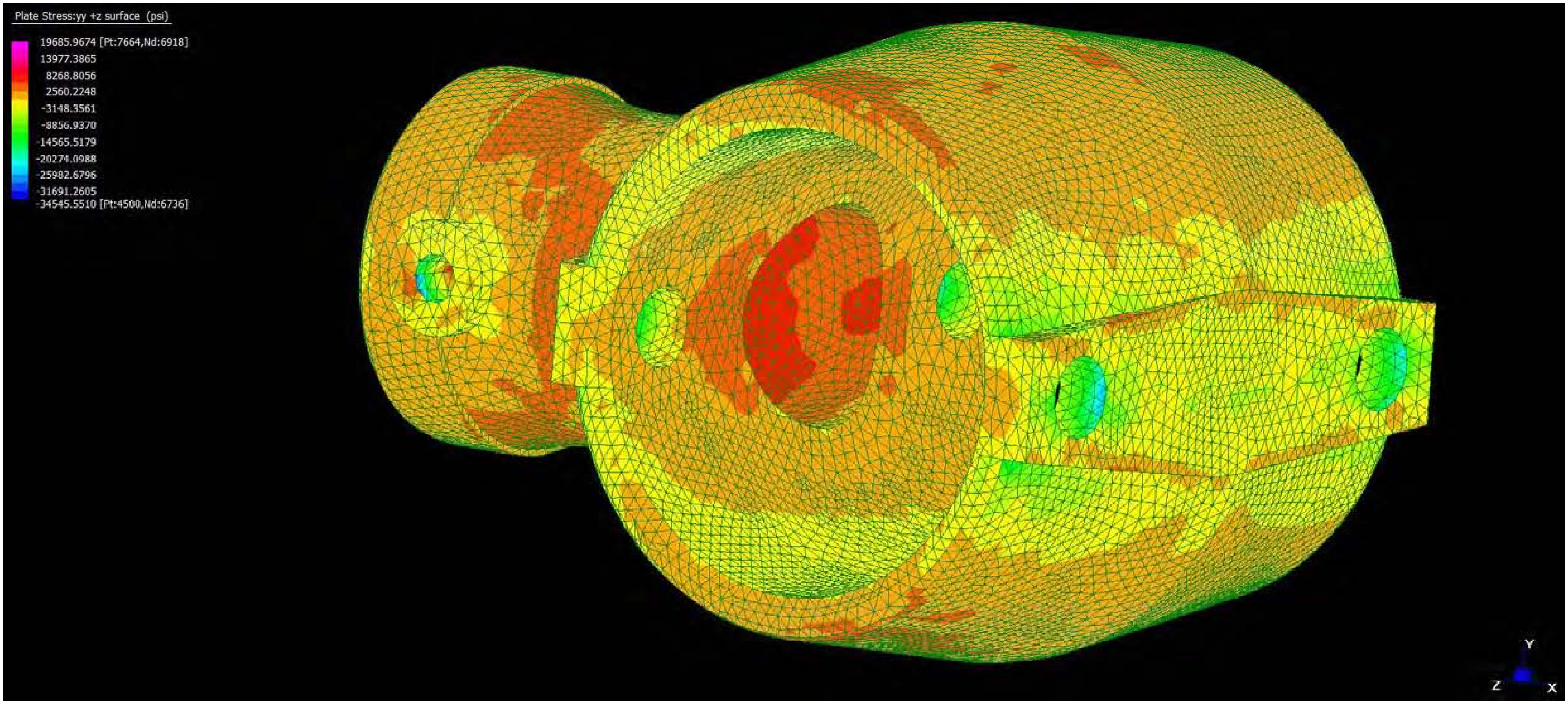
Condition ACD1w

(Combined Case – New Horn – High Torque)



Condition ACD1w

(Combined Case – New Horn – High Torque)

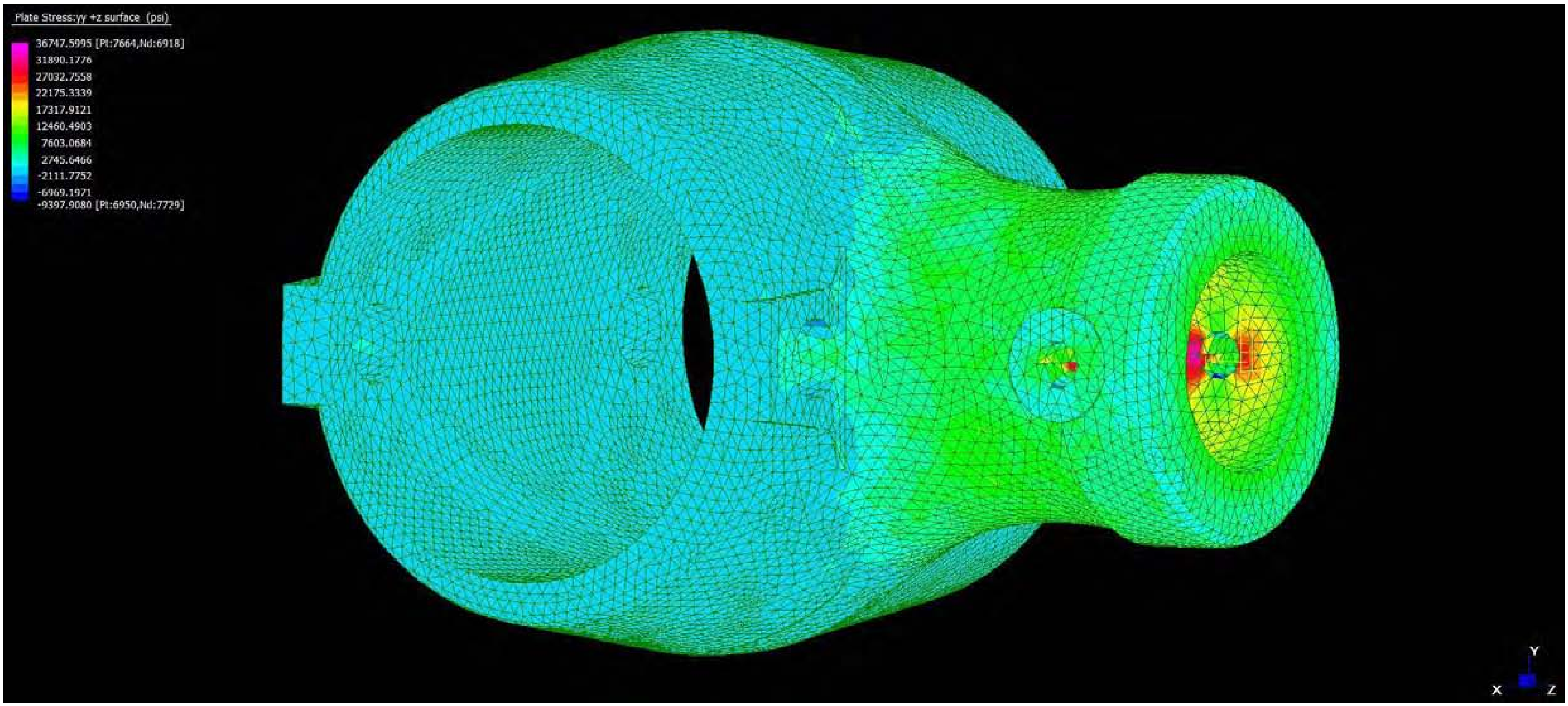


Final FEA Model – Twins/400

- FEA Model same as used for Singles, Except:
  - Interference Fit pressure increased to 7255 psi
  - Torque tube wall thickness increased to .161 inches
  - Torque tube mean radius reduced to 1.0753 inches
- Results for Twins/400 shown next

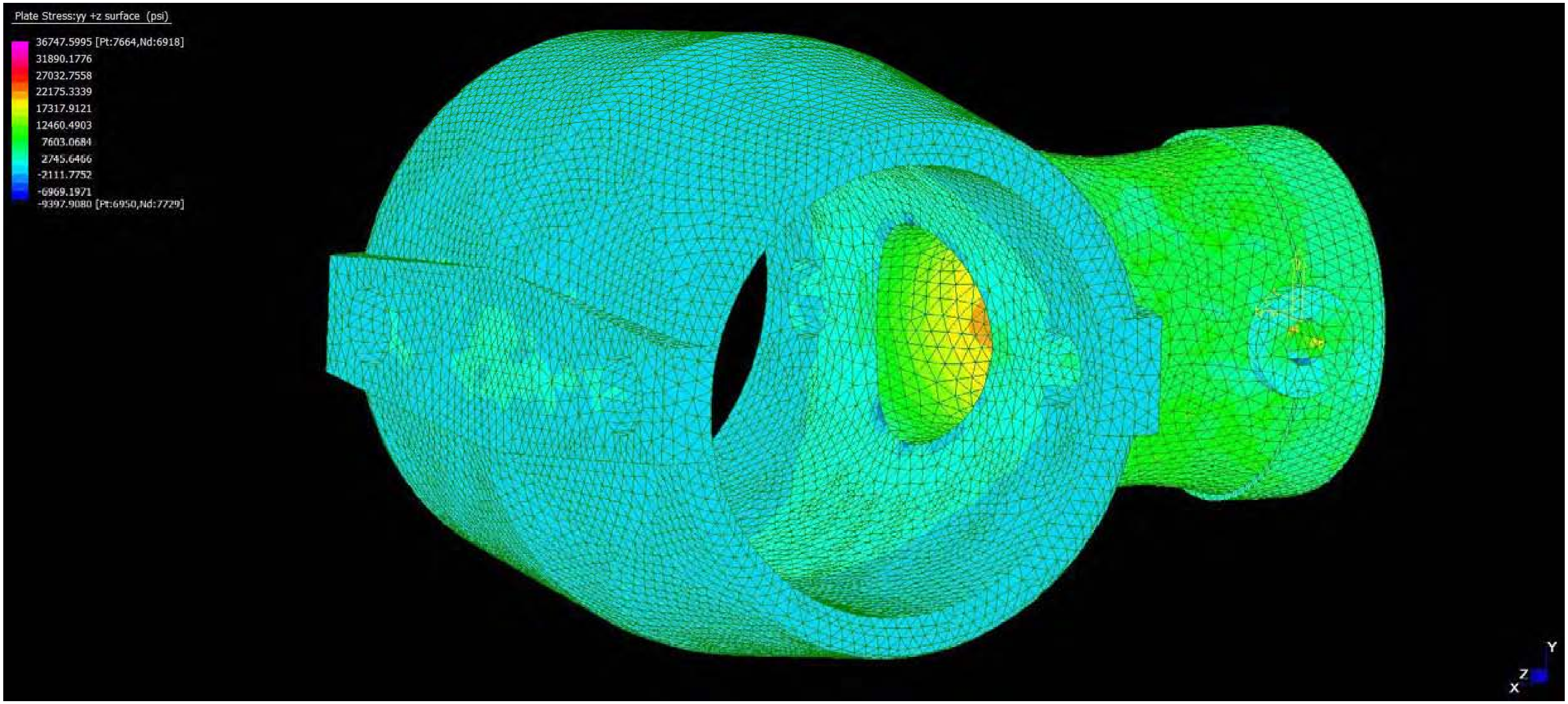
Condition Aw

(Interference Fit Only)



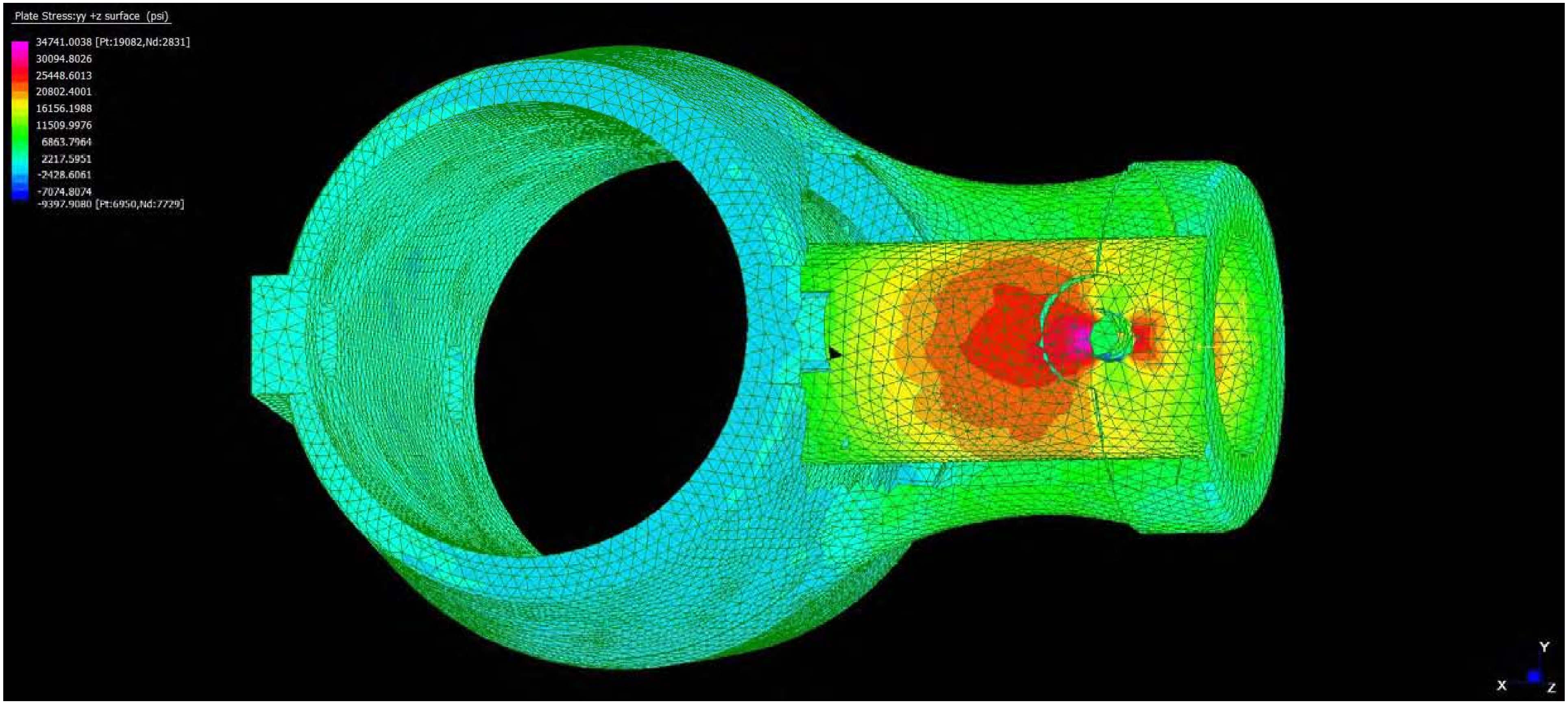
Condition Aw

(Interference Fit Only)



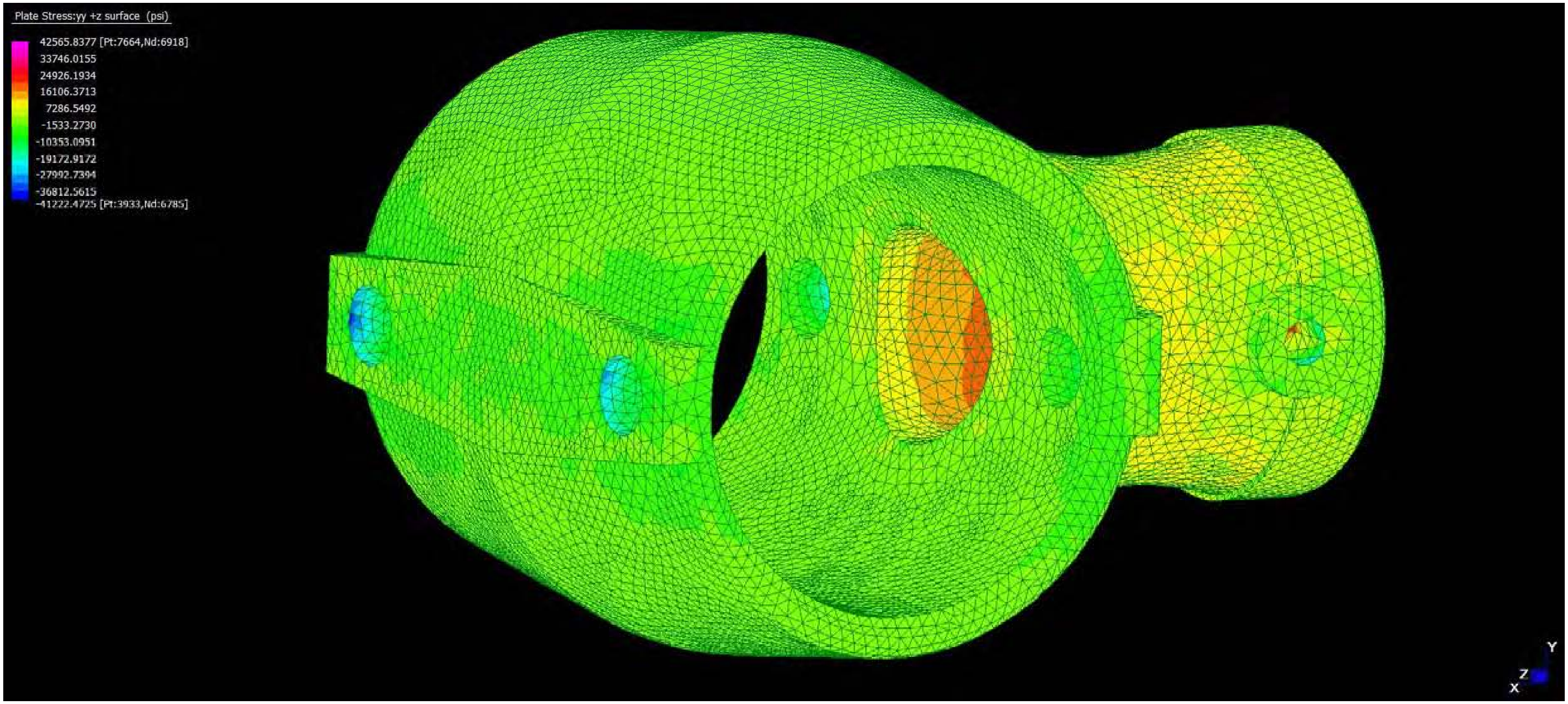
Condition Aw

(Interference Fit Only Cutaway)



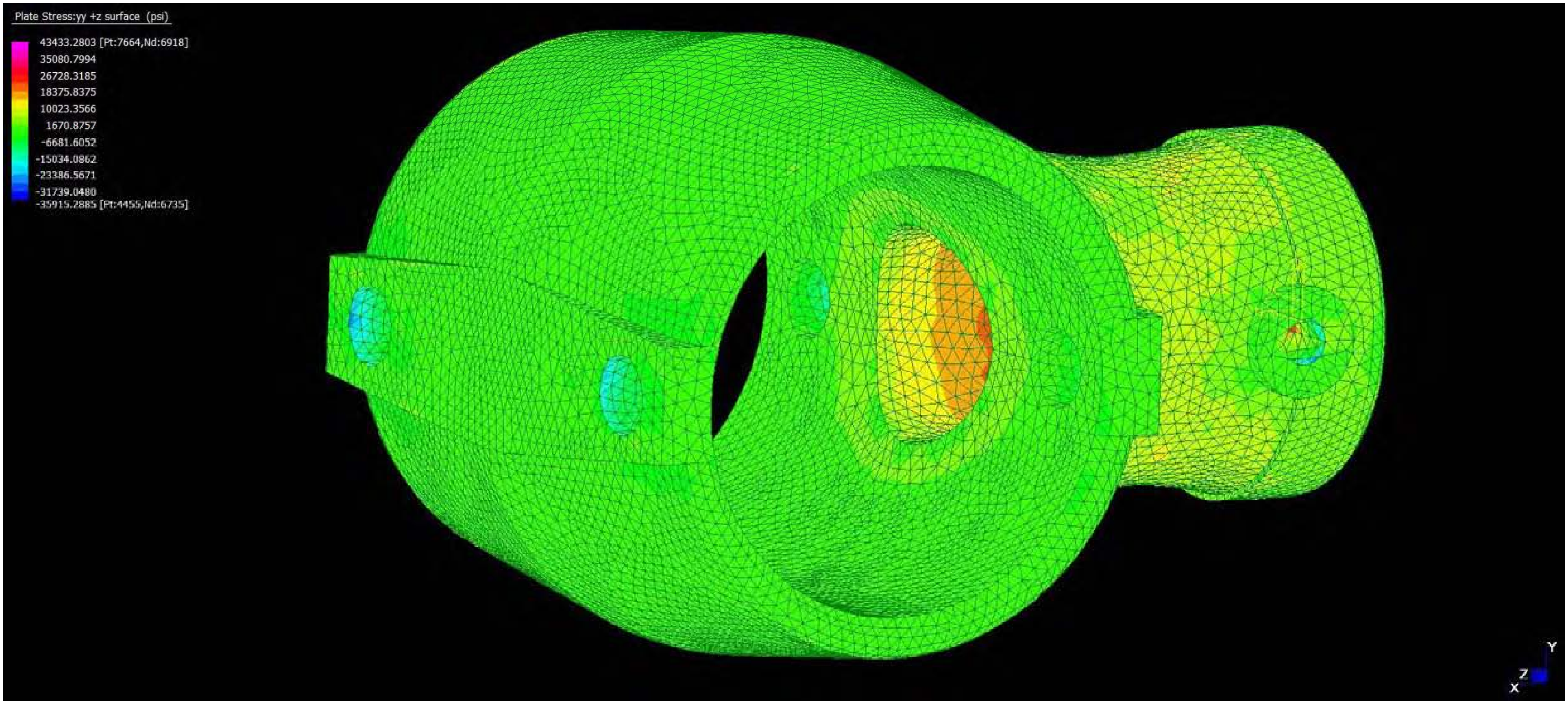
Condition ABD2w

(Interference Fit – High Bolt Torque – Thick Tube)



Condition ACD2w

(Interference Fit – New Horn Bolt Torque – Thick Tube)



Summary of Stress Results

Stress Resultants - Singles				
	Contour Plot Max/Min yy Stress		Max Stress at Crack Initiation Site	
Condition	Maximum	Minimum	Horn LHS	Horn RHS
Aw	13801	-3521		
Bb	5511	-20749	2054	1821
Bw	11086	-41500	4157	3650
Cb	5904	-22231	2201	1951
Cw	7522	-28158	2820	2476
ABDb	20369	-34559	6390	4962
ABD1w	18499	-42942	8493	4377
ACD1w	19685	-34546	7156	6862
Stress Resultants - Twins/400				
	Contour Plot Max/Min yy Stress		Max Stress at Crack Initiation Site	
Condition	Maximum	Minimum	Horn LHS	Horn RHS
Aw	36748	-9398		
ABD2w	52566	-41222	10448	7367
ACD2w	43433	-35915	9106	7039

Summary of Displacement Results

Diametral Displacements - Singles			
	Change in Diameter		
Condition	**Left Hand Side**	**Right Hand Side**	
ABDb	**0.0040**	**0.0020**	
ABD1w	**0.0065**	**0.0041**	
Diametral Displacements -Twins/400			
	Change in Diameter		
Condition	**Left Hand Side**	**Right Hand Side**	
ABD2w	**0.0040**	**0.0025**	
ACD2w	**0.0030**	**0.0016**	

Stress Corrosion Cracking Stress Data

TABLE 7.1.1.1

MEAN PLANE STRAIN FRACTURE TOUGHNESS DATA OF ALUMINUM ALLOY 2014 AT ROOM TEMPERATURE

CONDITION/HT	MEAN KIC ± STANDARD (KSI SQRT(IN)) DEVIATION	(NUMBER OF SPECIMENS)	
		PLATE	
CONDITION/HT	L-T	T-L	S-L
T651	23.3 ± 1.0 (10)	21.4 ± 1.2 (19)	17.8 ± 0.1 (2)
		FORGING	
CONDITION/HT	L-T	T-L	S-L
T6	27.9 ± 0.8 (2)	17.4 ± 1.7 (4)	16.9 ± 1.9 (5)
T611	-----	-----	17.8 ± 0.6 (2)
T652	28.8 ± 3.6 (12)	21.9 ± 3.2 (13)	18.1 ± 1.4 (3)
		FORGED BAR	
CONDITION/HT	L-T	T-L	S-L
T6	-----	16.7 ± 0.6 (2)	-----

Data Provided by Marv Nuss, FAA, KC Directorate

Summary

- Finite Element Model accurately depicts real structure
- If SCC stress threshold is 16 ksi, then all cases evaluated show local yy stress to be less that critical value
- If bolt threads and nut are lubricated, bolt preload can double at the same torque setting – Possible explanation
- Cause of horn cracking uncertain, at this time