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LISTA DELLE PAGINE VALIDE / *LIST OF VALID PAGES*

PAGINA *PAGE*	EDIZIONE *ISSUE*	PAGINA *PAGE*	EDIZIONE *ISSUE*	PAGINA *PAGE*	EDIZIONE *ISSUE*	PAGINA *PAGE*	EDIZIONE *ISSUE*	PAGINA *PAGE*	EDIZIONE *ISSUE*
1 - 114	1								

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TABLE OF CONTENT

LIST OF TABLES 7
LIST OF FIGURES 7
LIST OF ACRONYMS 10

1. INTRODUCTION 11

1.1 SCOPE OF THE DOCUMENT 11

2. RELEVANT DOCUMENTS 12

2.1 APPLICABLE DOCUMENTS 12
2.2 REFERENCE DOCUMENTS 12

3. LTOF POSITION 13

4. VERIFIED ITEMS OF LTOF 14

5. L-TOF MODEL DESCRIPTION 16

5.1 USED SOFTWARE 16
5.2 MODEL UNITS 16
5.3 MODEL COORDINATE SYSTEM 17
5.4 MODEL MATERIALS 19
5.4.1 AL 7075 T7351 19
5.4.2 AL 2024 T81 20
5.4.3 CFRP 21
5.4.4 PLEXIGLAS 22
5.4.5 AEROWEB 5052 ALUMINIUM ALLOY – 1.8-3/4-25 22
5.4.6 AEROWEB 5052 ALUMINIUM ALLOY – 4.5-1/8-10 23
5.4.7 MAKROLON 23
5.4.8 DUMMY STEEL FOR BOLTED CONNECTIONS 24
5.5 FE MODEL DESCRIPTION 24
5.5.1 MAIN STRUCTURE 25
5.5.1.1 BEAM A 25
5.5.1.2 BEAM B 26
5.5.1.3 CORNER BEAM 26
5.5.1.4 USS UPPER BRACKET LOWER TOF 27
5.5.1.5 USS BRACKET LOWER TOF 27
5.5.1.6 INTERNAL BRACKETS 28
5.5.1.7 RODS 28
5.5.2 AEROGEL 29
5.5.3 HONEYCOMB CORE 30
5.5.4 HONEYCOMB SKINS 30
5.5.5 SENSOR BOXES 31
5.5.6 SENSOR BOX BRACKETS 32
5.5.7 PMTS AND PMT SUPPORTS 33
5.5.8 SCINTILLATORS 34
5.5.9 SCINTILLATORS SUPPORTS 35
5.6 MODEL BOUNDARY CONDITIONS 36
5.7 MODEL MASS BUDGET 37
5.8 MODEL CHECK 38
5.8.1 MODEL SIZE AND GEOMETRY 38
5.8.2 FREE-FREE AND HARDMOUNTED MODES 39
5.8.3 1 G CHECK 40
5.8.4 STRAIN ENERGY CHECK 41

6. DIMENSIONING LOADS 42

7. DIMENSIONING RULES 44

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7.1 SAFETY FACTORS 44
7.2 TEMPERATURE DERATING FACTOR 44
7.3 MARGINS OF SAFETY FOR STRUCTURE 44
7.3.1 TSAI HILL VERIFICATION 45
7.3.2 SANDWICH VERIFICATION 45

8. DYNAMIC ANALYSIS 46

8.1 EIGENFREQUENCIES AND MODE SHAPES 46
8.2 EFFECTIVE MASS 49

9. STATIC ANALYSIS 50

9.1 DISPLACEMENT ANALYSIS 50
9.2 STRESS ANALYSIS 51
9.2.1 BEAM A 52
9.2.2 BEAM B 53
9.2.3 CORNER BEAM 54
9.2.4 UPPER BRACKET 54
9.2.5 LOWER BRACKET 55
9.2.6 RING BRACKET 55
9.2.7 RODS 56
9.2.8 HONEYCOMB SKINS 57
9.2.9 INTERNAL HONEYCOMB SKINS 58
9.2.9.1 X y xy STRESS COMPONENT for intracell buckling verification 58
9.2.9.2 X y xy STRESS COMPONENT for wrinkling verification 59
9.2.10 EXTERNAL HONEYCOMB SKINS 60
9.2.10.1 X y xy STRESS COMPONENT for intracell buckling verification 60
9.2.10.2 X y xy STRESS COMPONENT for wrinkling verification 61
9.2.11 SENSOR BOXES BRACKETS PLATE 62
9.2.12 SENSOR BOXES BRACKETS BAR 62
9.2.13 PMT HORIZONTAL SUPPORT 63
9.2.14 SENSOR BOXES 64
9.2.14.1 X STRESS COMPONENT 64
9.2.14.2 Y STRESS COMPONENT 64
9.2.14.3 XY STRESS COMPONENT 65
9.2.15 SCINTILLATOR COVERS 66
9.2.15.1 X STRESS COMPONENT 66
9.2.15.2 Y STRESS COMPONENT 66
9.2.15.3 XY STRESS COMPONENT 67
9.2.16 BOXES/PMT SUPPORT 68
9.2.16.1 X STRESS COMPONENT 68
9.2.16.2 Y STRESS COMPONENT 68
9.2.16.3 XY STRESS COMPONENT 69
9.2.17 SCINTILLATORS SUPPORTS 70
9.2.18 HONEYCOMB CORE INTERNAL 73
9.2.18.1 Z COMPONENT 73
9.2.18.2 XZ COMPONENT 73
9.2.18.3 ZY COMPONENT 74
9.2.19 HONEYCOMB CORE EXTERNAL 75
9.2.19.1 Z COMPONENT 75
9.2.19.2 XZ COMPONENT 75
9.2.19.3 ZY COMPONENT 76
9.2.20 MARGINS OF SAFETY 77
9.3 JOINT ANALYSIS 80
9.3.1 JOINT 1: BRACKET-RING 81
9.3.2 JOINT 2: USS/U-BKT 84
9.3.3 JOINT 3: USS/L-BKT 87
9.3.4 JOINT 4: RING-HCOMB 90
9.3.4.1 BOLT ANALYSIS 92

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9.3.4.2 INSERTS VERIFICATION 93
9.3.5 JOINT 5: SCINTILLATOR SUPPORTS VERIFICATION 94
9.3.5.1 BOLT VERIFICATION 96
9.3.5.2 INSERTS VERIFICATION 97
9.3.6 JOINT 6: ROD END 98
9.3.6.1 LUG VERIFICATION 98
9.3.6.2 ROD-END VERIFICATION 99
9.3.6.3 BOLT VERIFICATION 99
9.3.7 MOS SUMMARY FOR JOINT ANALYSIS 100
9.3.8 FAIL SAFE JOINT ANALYSIS 100
9.4 BUCKLING ANALYSIS 101
9.4.1 BUCKLING ANALYSIS FOR THE RODS 102
9.4.2 BUCKLING ANALYSIS FOR THE MAIN STRUCTURE 103

10. CONCLUSIONS AND COMMENTS 105

ANNEX 1. BOLTS VERIFICATION EXAMPLE 106

ANNEX 2. HONEYCOMB VERIFICATION EXAMPLE 109

ANNEX 3. TABLE FOR SAFETY REVIEW FOR MAIN STRUCTURE 114

Questo documento contiene informazioni di proprietà di CARLO GAVAZZI SPACE SpA. Tutti i diritti sono riservati.
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LIST OF TABLES

Table 5-1 AL 7075 T7351 properties 19
Table 5-2 AL 7075 T7351 in FE model 19
Table 5-3 AL 2024 T81 properties 20
Table 5-4 AL 2024 T81 in FE model 20
Table 5-5: CFRP in FE model 21
Table 5-6: CFRP in FE model 21
Table 5-7: Plexiglas in FE model 22
Table 5-8: AeroWeb 5052 aluminum alloy – 1.8-3/4-25 22
Table 5-9: AeroWeb 5052 aluminum alloy – 1.8-3/4-25 in FE model 22
Table 5-10: AeroWeb 5052 aluminum alloy – 4.5-1/8-10 23
Table 5-11: AeroWeb 5052 aluminum alloy – 1.8-3/4-25 in FE model 23
Table 5-12: MAKROLON 23
Table 5-13: Model summary 24
Table 5-14: Model mass budget 37
Table 5-15: FEM Geometry Check 38
Table 5-16: FEM mass properties, free-free modes, hardmounted modes 39
Table 5-17: FEM 1g check 40
Table 5-18: FEM Strain Energy check 41
Table 6-1: Applied set of load cases 42
Table 6-2: Load case 4016 displacements 43
Table 7-1: Safety Factors for structure 44
Table 8-1: L-TOF SYSTEM natural frequencies 46
Table 9-1: MOS STRENGTH 77
Table 9-2: MOS CFRP 78
Table 9-3: SANDWICH VERIFICATION 79
Table 9-4: MoS definition for bolt analysis 80
Table 9-5: JOINT 1 83
Table 9-6: JOINT 2 86
Table 9-7: JOINT 3 89
Table 9-8: JOINT 4 92
Table 9-9: Ring/honeycomb inserts verification 93
Table 9-10: JOINT 5 96
Table 9-11: Scintillator/honeycomb inserts verification 97
Table 9-12: LUG verification 98
Table 9-13: Rod End verification 99
Table 9-14: Rod End Bolt verification 99
Table 9-15: Joint analysis MoS summary 100
Table 9-16: Joint Fail Safe analysis MoS summary 100
Table 9-17: Buckling calculation for the rod (Static Analysis) 102
Table 9-18: buckling calculation for the rod (Static Analysis) 102
Table 9-19: Buckling verification, main structure 103
Table 9-20: Buckling verification MoS summary 104

LIST OF FIGURES

Figure 3-1: Exploded view of AMS-02 subcomponents 13
Figure 5-1: General view of L-TOF 16
Figure 5-2: AMS-02 coordinate system 17
Figure 5-3: AMS-02 coordinate system 18
Figure 5-4: Main structure 25
Figure 5-5: Beam A 25
Figure 5-6: Beam B 26
Figure 5-7: Corner beam 26

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Figure 5-8: USS upper bracket lower tof 27
Figure 5-9: USS bracket lower tof 27
Figure 5-10: Internal brackets 28
Figure 5-11: Rods 28
Figure 5-12: Aerogel 29
Figure 5-13: Honeycomb core 30
Figure 5-14: Honeycomb skins 30
Figure 5-15: Sensor boxes 31
Figure 5-16: brackets that fix Sensor boxes to the structure 32
Figure 5-17: PMTs and PMT supports 33
Figure 5-18: Plexiglas and carbon fiber 34
Figure 5-19: Scintillators 34
Figure 5-20: Scintillators supports 35
Figure 5-21: Model boundary conditions 36
Figure 8-1: Mode 12 at 46.6 Hz 46
Figure 8-2: Mode 24 at 54.1 Hz 47
Figure 8-3: Mode 25 at 54.8 Hz 47
Figure 8-4: Mode 34 at 59.1 Hz 47
Figure 8-5: Mode 72 at 74.8 Hz 48
Figure 8-6: Mode 80 at 79.3 Hz 48
Figure 8-7: Mode 81 at 80.5 Hz 48
Figure 8-8: Effective masses for all axes 49
Figure 8-9: Cumulative effective masses for all axes 49
Figure 9-1: Maximum displacement – Load case 4016 50
Figure 9-2: Relative displacement – Load case 4016 51
Figure 9-3: Beam A, Load Case 4061, Layer Z2 52
Figure 9-4: Beam A, Load Case 4061, Layer Z1 52
Figure 9-5: Beam B, Load Case 4062, Layer Z2 53
Figure 9-6: Beam B, Load Case 1056, Layer Z2 53
Figure 9-7: Corner beam, Load Case 4015, Layer Z1 54
Figure 9-8: Upper bracket, Load Case 4031, Layer Z1 54
Figure 9-9: Lower bracket, Load Case 4045, Layer Z1 55
Figure 9-10: Ring bracket, Load Case 4028, Layer Z2 55
Figure 9-11: Rods, Load Case 4031 56
Figure 9-12: Honeycomb skins, Load Case 1017, Layer Z2 57
Figure 9-13: Honeycomb skins, Load Case 1027 58
Figure 9-14: Honeycomb skins, Load Case 4027 59
Figure 9-15: Honeycomb skins, Load Case 4046 60
Figure 9-16: Honeycomb skins, Load Case 4046 61
Figure 9-17: Sensor boxes brackets plate, Load Case 4058, Layer Z2 62
Figure 9-18: Sensor boxes brackets bar, Load Case 1028, ... 62
Figure 9-19: PMT horizontal support, Load Case 4054 63
Figure 9-20: Sensor boxes X component, Load Case 4045, Layer 3 64
Figure 9-21: Sensor boxes Y component, Load Case 4032, Layer 1 64
Figure 9-22: PMT horizontal support core, Load Case 1015, Layer 3 65
Figure 9-23: Scintillator covers X component, Load Case 4045, Layer 1 66
Figure 9-24: Scintillator covers Y component, Load Case 4032, Layer 2 66
Figure 9-25: Scintillator covers XY component, Load Case 4028, Layer 5 67
Figure 9-26: Boxes/PMT support X component, Load Case 4058 Layer1 68
Figure 9-27: Boxes/PMT support Y component, Load Case 4045 Layer3 68
Figure 9-28: Boxes/PMT support XY component, Load Case 1024 Layer1 69
Figure 9-29: Scintillator supports CAD Model 70
Figure 9-30: Scintillator supports FE Model 70
Figure 9-31: Scintillator Supports Constrains And Applied Forces 71
Figure 9-32: Scintillators support X component, element 1413 71
Figure 9-33: Scintillators support Y component, element 1027 72
Figure 9-34: Scintillators support X component, element 361 72
Figure 9-35: Honeycomb core internal Z component, Load Case 4041 73

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Figure 9-36: Honeycomb core internal XZ component, Load Case 1020 73
Figure 9-37: Honeycomb core internal ZY component, Load Case 4042 74
Figure 9-38: Honeycomb core external Z component, Load Case 4045 75
Figure 9-39: Honeycomb core external XZ component, Load Case 1032 75
Figure 9-40: Honeycomb core external ZY component, Load Case 4058 76
Figure 9-41: JOINT1: Bracket-ring bolts 81
Figure 9-42: JOINT 1: Maximum axial force, element 11807, load case 4031 82
Figure 9-43: JOINT 1: Maximum resultant force, element 1785, load case 4015 82
Figure 9-44: JOINT 2: USS/U-BKT bolts 84
Figure 9-45: JOINT 2: Maximum axial force, node 10788 , load case 4031 85
Figure 9-46: JOINT 2: Maximum shear force, node 10788, load case 4031 85
Figure 9-47: JOINT 3: USS/L-BKT bolts 87
Figure 9-48: JOINT 3: Maximum axial force, node 19925, load case 4028 88
Figure 9-49: JOINT 3: Maximum resultant force, node 19921, load case 4045 88
Figure 9-50: JOINT 4: RING-HCOMB 90
Figure 9-51: JOINT 4: Maximum axial force, element 826, load case 4045 91
Figure 9-52: JOINT 4: Maximum resultant force, element 825, load case 4031 91
Figure 9-53: Insert Dimensions 93
Figure 9-54: JOINT 5: Honeycomb 94
Figure 9-55: JOINT 5: Maximum axial force, element 7080, load case 1033 95
Figure 9-56: JOINT 5: Maximum resultant force, element 28256, load case 4062 95
Figure 9-57: Lugs 98
Figure 9-58: Rod-End 99
Figure 9-59: Main structure analyzed for buckling 101
Figure 9-60: Axial force on the rod 102

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LIST OF ACRONYMS

AD	APPLICABLE DOCUMENT
AMS	ALPHA MAGNETIC SPECTROMETER
CLA	COUPLED LOAD ANALYSIS
CFRP	CARBON FIBER-REINFORCED PLASTICS
DoF	DEGREE of FREEDOM
FEM	FINITE ELEMENT MODEL
LC	LOAD CASE
LMSO	LOCKHEED MARTIN SPACE OPERATION
LTOF	LOWER TOF
MC	MAXIMUM COMBINED
MoS	MARGINS of SAFETY
NA	NOT AVAILABLE
NSM	NON STRUCTURAL MASS
RD	REFERENCE DOCUMENT
SF	SAFETY FACTOR
SPC	SINGLE POINT CONSTRAIN
TOF	TIME OF FLIGHT
USS	UNIQUE SUPPORT STRUCTURE
VM	VON MISES

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1. INTRODUCTION

1.1 SCOPE OF THE DOCUMENT

This document describes the models and methodologies utilized to verify by analysis the structural requirements of the L-TOF assembly.

The result of these analyses will demonstrate that L-TOF assembly is compliant with all structural requirements:

- The first natural frequency greater than 50Hz (AD 1) (see Chapter 7.3.1).

- All the MoS of the structure positive, under applicable design loads (see Chapters 9.2.20 ,9.3.7 and 9.3.8)

In the ANNEX 3 **Fracture Classification table for AMS-02 L-TOF** is presented

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2. RELEVANT DOCUMENTS

2.1 APPLICABLE DOCUMENTS

AD # (ID)	Doc Number	Issue	Date	Rev	Title
AD 1	JSC-28792		August, 2003	C	AMS-02 STRUCTURAL VERIFICATION PLAN
AD 2			March 2, 2004		MEMORANDUM: LTOF Strut Loads from the AMS-02 DCLA Cycle 1

2.2 REFERENCE DOCUMENTS

RD # (ID)	Doc Number	Issue	Date	Rev	Title
RD. 1	MIL-HDBK-5	H	Dec, 1998		Metallic Materials and Elements for Aerospace Vehicle Structures
RD. 2					LMSO bolt verification guidelines
RD. 3	NSTS 1700.7B		13/01/89		Safety policy and requirements for payloads using the space transportation system
RD. 4	NSTS 1700.7B ISS ADD		Dec, 1995		Safety Policy and Requirements
RD. 5	NTS08307		July 6, 1998	A	Criteria for preloaded bolt
RD. 6			June, 1973		E. F. BRUHN – Analysis Design of Flight Vehicle Structures
RD. 7	ESA PSS-03-1202	1	March 1987		Insert Design Handbook

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3. LTOF POSITION

In the following figure the position of the Lower TOF in the AMS-02 Exploded view is presented.

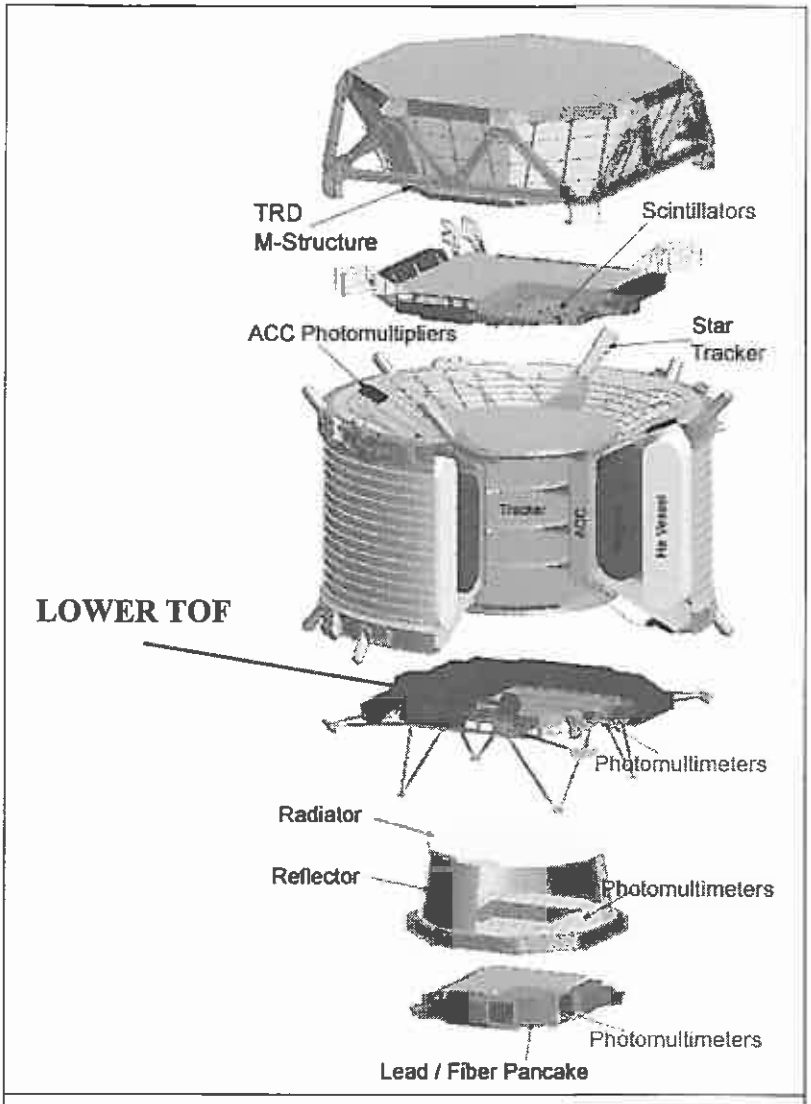

Figure 3-1: Exploded view of AMS-02 subcomponents

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4. VERIFIED ITEMS OF LTOF

In the following tables the verified items are showed:

L-TOF VERIFIED ITEMS LIST				
ITEM	PART NUMBER	MATERIAL	FAILURE MODE	REFERENCE PAGE
BEAM A	ams TOF 04-01-001 LT	Al 7075 T7351	Strength (part + lugs)	52
			Buckling	101
BEAM B	ams TOF 04-01-002 LT	Al 7075 T7351	Strength (part + lugs)	53
			Buckling	9.4 101
CORNER BEAM	ams TOF 04-01-003 LT	Al 7075 T7351	Strength (part + lugs)	54
			Buckling	101
UPPER BRACKET	ams TOF 04-01-021 LT	Al 7075 T7351	Strength (part + lugs)	54
			Buckling	101
LOWER BRACKET	ams TOF 04-01-020 LT	Al 7075 T7351	Strength (part + lugs)	55
			Buckling	101
INTERNAL BRACKET	ams TOF 04-01-018 LT ams TOF 04-01-019 LT	Al 7075 T7351	Strength (part + lugs)	55
			Buckling	101
RODS	ams TOF 04-01-01-001 LT ams TOF 04-01-02-001 LT	Al 7075 T7351	Strength (part + lugs)	56
			Buckling	101
HONEYCOMB SKINS	ams TOF 04-02-001 LT ams TOF 04-02-002 LT	Al 2024 T81	Strength (part + lugs)	57
			Buckling	101
SENSOR BOXES BRACKETS PLATE	ams TOF 04-01-011 LT ams TOF 04-01-010 LT ams TOF 04-01-009 LT ams TOF 04-01-008 LT ams TOF 04-01-007 LT ams TOF 04-01-006 LT ams TOF 04-01-005 LT ams TOF 04-01-004 LT	Al 7075 T7351	Strength	62
			Buckling	101
SENSOR BOXES BRACKETS BAR			Maximum Combined	62
PMT HORIZ SUPPORT	ams TOF 05-01 UT ams TOF 05-02 UT	MAKROLON	Strength	63
			Buckling	101
SENSOR BOXES	ams TOF 02-001 LT ams TOF 02-002 LT ams TOF 01-001 LT ams TOF 01-01-001 LT	CFRP	Strength	64
SCINTILLATORS COVERS	TBD	CFRP	Strength	66
BOXES/PMT SUPPORT	ams TOF 05-05-001 UT ams TOF 05-05-002 UT ams TOF 05-05-003 UT ams TOF 05-05-004 UT ams TOF 05-05-005 UT ams TOF 05-05-006 UT	CFRP	Strength	68
SCINTILLATORS SUPPORTS	TBD	CFRP	Strength	70
HONEYCOMB CORE	ams TOF 04-02-003 LT	core-AL 5052	Sandwich Verification	73
ROD END	TBD	NA	Strength, Maximum Combined	99

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L-TOF VERIFIED ITEMS LIST				
ITEM	PART NUMBER	MATERIAL	FAILURE MODE	REFERENCE PAGE
JOINT 1	NAS 1351 - 5		Strength, bearing	81
JOINT 2	NAS 1351 – 6		Strength, bearing	84
JOINT 3	NAS 1351 – 4		Strength, bearing	87
JOINT 4	NAS 1351 – 4		Strength, bearing	90
JOINT 5	M3		Strength, bearing	94
JOINT 6	NAS 1351 – 6		Strength, bearing	99

FAILURE	VERIFICATION APPLIED
Strength	Von Mises on shell
	Maximum combined on bar
	Tsay Hill on composite
	Maximum combined and separation on bolt
Buckling	Local Buckling
Sandwich Verification	Combined Load Strength
	Intracell Buckling
	Wrinkling

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5. L-TOF MODEL DESCRIPTION

In the following image a view of the entire L-TOF FE model is presented.

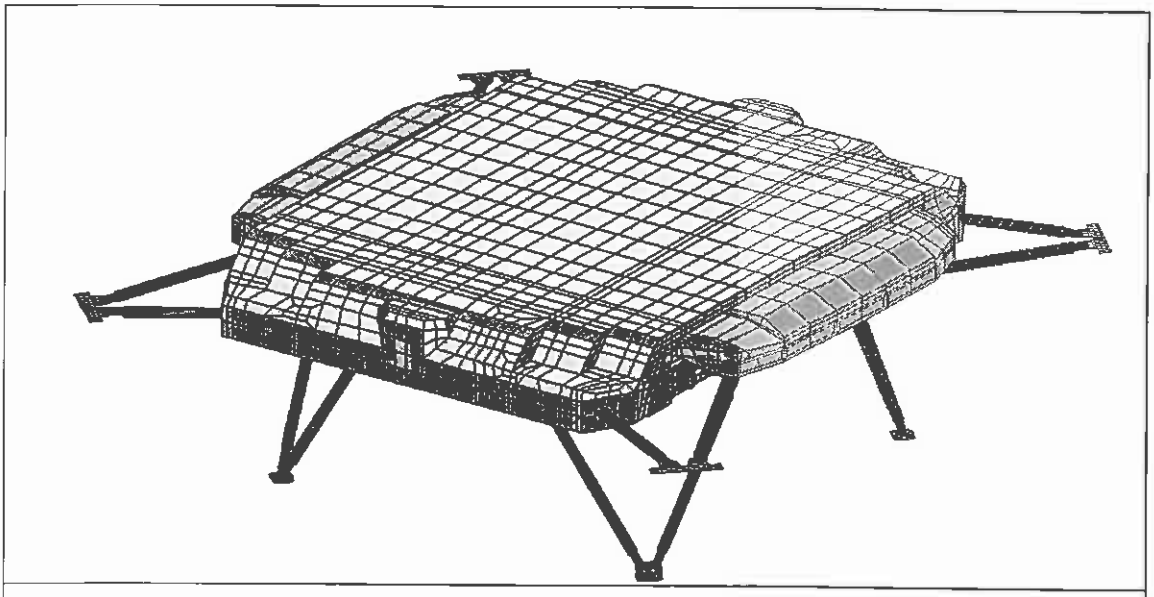

Figure 5-1: General view of L-TOF

In the following chapters the structural Finite Element Model is described (the model used is "LTOF_040518.bdf").

5.1 USED SOFTWARE

The software used for FEM pre and post processing is MSC/PATRAN 2003r2.
The software used for Finite Element analysis is MSC/NASTRAN V2001.

5.2 MODEL UNITS

Default FEM units (otherwise specified) are:

- Length [m]
- Masses [Kg]
- Forces [N]
- Moments [Nm]
- Material densities [Kg/m^3]
- Young's modules [N/m^2]
- Stresses [N/m^2]
- Displacements [m]

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5.3 MODEL COORDINATE SYSTEM

For the L-TOF model, the AMS-02 coordinate system (Coord 11 in Figure 5-2) is used:

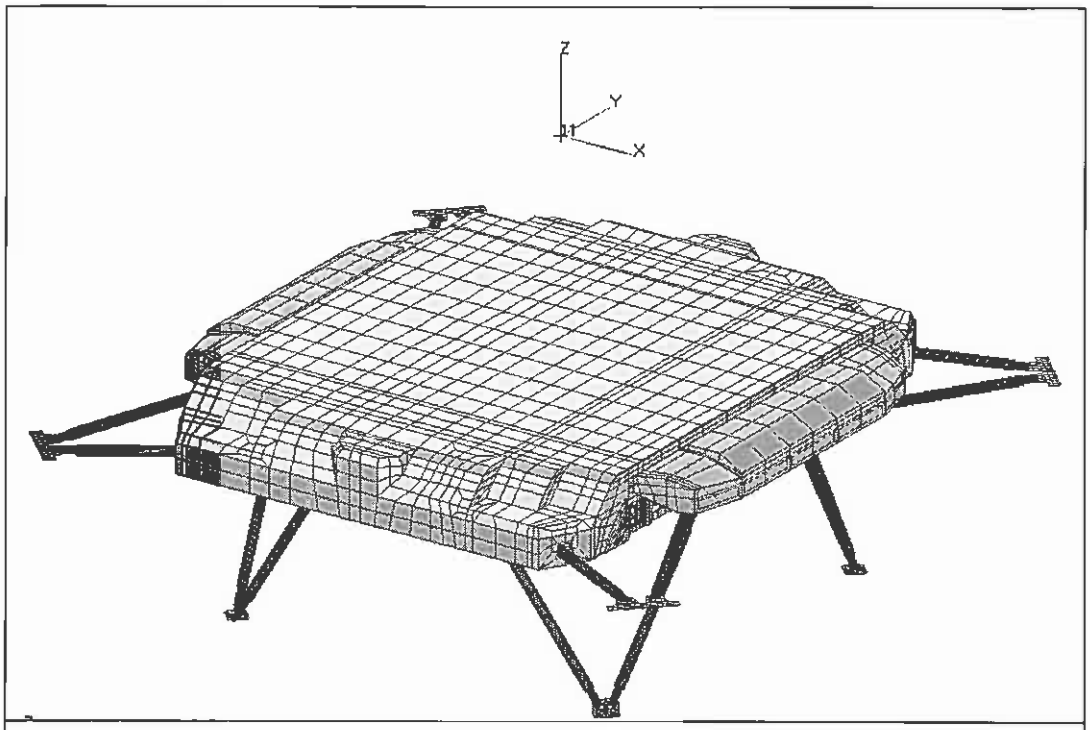
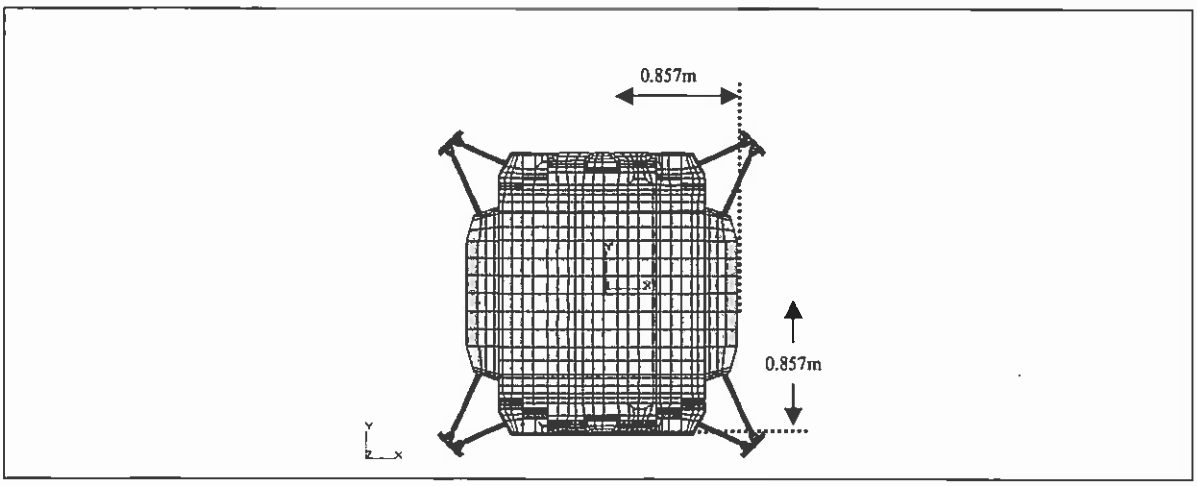


Figure 5-2: AMS-02 coordinate system

In the following figure two views of the position of the AMS-02 CoG are presented:



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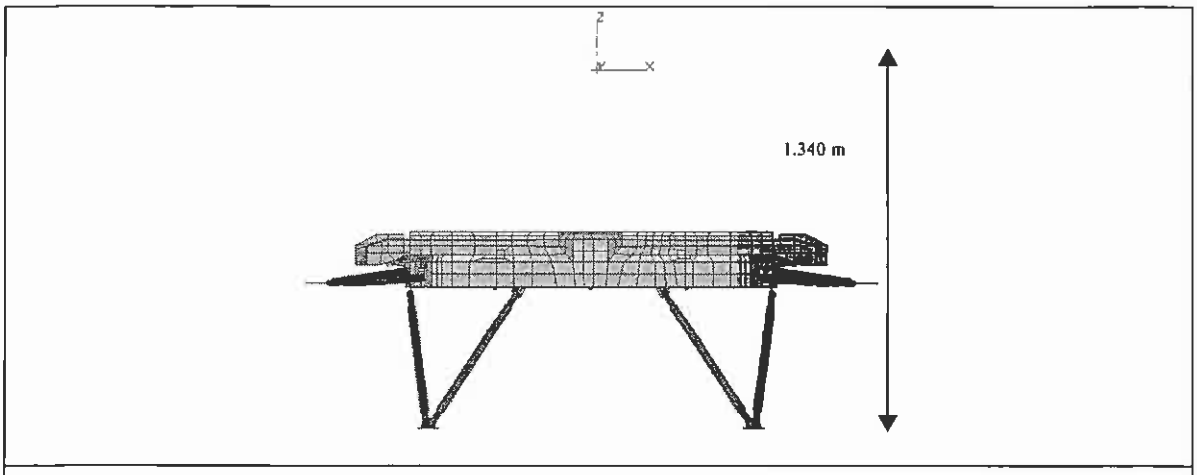

Figure 5-3: AMS-02 coordinate system

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5.4 MODEL MATERIALS

In the following tables

- the properties of each material
- the items made of each material
- the corresponding NASTRAN card

are shown.

5.4.1 AL 7075 T7351

7075 Aluminium Alloy		
Source	MIL-HDBK-5H	
Specification	AMS 4078 and AMS-QQ-A-250/12	
Form	Plate	
Temper	T7351	
Thickness [in]	0.250 - 0.499	
Mechanical Properties		
	[MPa]	**[ksi]**
Ftu	468.84	68
Fty	393.00	57
Fcy	386.11	56
Fsu	262.00	38
Fbru	703.27	102
Fbry	544.69	79
E	71016	10300
Physical Properties		
	[kg/m^3]	**[lb/in^3]**
ρ	2796	0.101
ν	0.33	

Table 5-1 AL 7075 T7351 properties

NASTRAN CARD::	`MAT1 3 7.1+10 2.67+10 .33 2796.`
ITEMS:	Brackets Extensions Box supports

Table 5-2 AL 7075 T7351 in FE model

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5.4.2 AL 2024 T81

2024 Aluminium Alloy		
Source	MIL-HDBK-5H	
Specification	AMS-QQ-A-250/4	
Form	Sheet	
Temper	T81	
Thickness [in]	0.010 - 0.249	
Mechanical Properties		
	[MPa]	**[ksi]**
Ftu	461.95	67
Fty	399.90	58
Fcy	399.90	58
Fsu	275.79	40
Fbru	689.48	100
Fbry	572.26	83
E	72395	10500
Physical Properties		
	[kg/m^3]	**[lb/in^3]**
ρ	2768	0.1
ν	0.33	

Table 5-3 AL 2024 T81 properties

NASTRAN CARD:	`MAT1 1 7.24+10 2.72+10 .33 2796.`
ITEMS:	Honeycomb skins

Table 5-4 AL 2024 T81 in FE model

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5.4.3 CFRP

CFRP		
Source	Vendor data Sheet	
Specification fiber	T 300	
Form	Plain Weave fabric	
Temper	-	
Thickness [in]	0.010 +/- 10%	
Mechanical Properties		
	[MPa]	**[ksi]**
Ftu	850	123
Fcu	700	102
Fsu	105	15
Et	75000	10878
Ec	70000	10153
Ebend	950	138
G	12000	9900
Physical Properties		
	[kg/m^3]	**[lb/in^3]**
ρ	1400	0.051
ν	0.28	

Table 5-5: CFRP in FE model

NASTRAN CARD:	MAT8 5 7.+10 7.+10 .28 1.2+10 1.2+10 1.2+10 1400. -2.-6 -2.-6 20.
ITEMS:	Sensor boxes Scintillators skins Box supports

Table 5-6: CFRP in FE model

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5.4.4 PLEXIGLAS

SOURCE	MATWEB
PROPERTIES:	E= 7.0E+9 Pa ν= 0.4 ρ= 1150 kg/m^3
ITEMS:	Scintillators core
NASTRAN CARD:	MAT1 7 7.+9 2.5+9 .4 1150.

Table 5-7: Plexiglas in FE model

5.4.5 AEROWEB 5052 ALUMINIUM ALLOY – 1.8-3/4-25

AEROWEB 5052 – 1.8-3/4-25		
Source	HEXCEL CATALOG	
Material	5052 Aluminium Alloy	
Form	Hexagonal cell Honeycomb	
Cell size [in]	3/4	
Nominal foil thickness [in]	2.50E-03	
Mechanical Properties		
	[MPa]	[ksi]
Fty (L direction)	0.74	0.11
Fty (W direction)	0.46	0.07
E11	0.2	0.03
E22	0.2	0.03
E33	215	31.18
G13	182	26.40
G23	96	13.92
G12	0.1	0.02
Physical Properties		
	[kg/m^3]	[lb/in^3]
ρ	28.83	0.001

Table 5-8: AeroWeb 5052 aluminum alloy – 1.8-3/4-25

NASTRAN CARD:	MAT9 6 200000. 200000. 2.15+8 1.82+8 9.6+7 100000. 35.3063
ITEMS:	Honeycomb core internal PMT supports core

Table 5-9: AeroWeb 5052 aluminum alloy – 1.8-3/4-25 in FE model

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5.4.6 AEROWEB 5052 ALUMINIUM ALLOY – 4.5-1/8-10

AEROWEB 5052 – 4.5-1/8-10		
Source	HEXCEL CATALOG	
Material	5052 Aluminium Alloy	
Form	Hexagonal cell Honeycomb	
Cell size [in]	1/8	
Nominal foil thickness [in]	1.00E-03	
Mechanical Properties		
	[MPa]	[ksi]
Fty (L direction)	2.3	0.33
Fty (W direction)	1.5	0.22
E11	0.2	0.03
E22	0.2	0.03
E33	1034	149.97
G13	483	70.05
G23	214	31.04
G12	0.1	0.01
Physical Properties		
	[kg/m^3]	[lb/in^3]
ρ	72	0.0026

Table 5-10: AeroWeb 5052 aluminum alloy – 4.5-1/8-10

NASTRAN CARD:	MAT9 9 400000. 400000. 1.03+9 4.8+8 2.14+8 200000. 35.3063
ITEMS:	Honeycomb coreexternal

Table 5-11: AeroWeb 5052 aluminum alloy – 1.8-3/4-25 in FE model

5.4.7 MAKROLON

MAKROLON		
Source	BAYER PLASTIC	
Specification	makrolon 1239	
Speciality grades	Blow molding	
Mechanical Properties		
	[MPa]	[ksi]
Flu	NA	NA
Fty	60	8.75
E	2350	340.8
Physical Properties		
	[kg/m^3]	[lb/in^3]
ρ	1200	0.043

Table 5-12: MAKROLON

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5.4.8 DUMMY STEEL FOR BOLTED CONNECTIONS

A dummy material with reference properties of steel is used for beam elements that represent bolted connections:

The corresponding NASTRAN BULK data card is:

```
MAT1     4        2.01+11 7.67+10 .31     7944.
```

5.5 FE MODEL DESCRIPTION

In this chapter the components of L-TOF Finite Element Model are presented:

GRID POINTS	28678
ELEMENTS	
CBAR	1342
CBUSH	12
CHEXA	4828
CONM2	76
CPENTA	12
CQUAD4	21725
CTRIA3	680
RBE2	665

Table 5-13: Model summary

L-TOF NASTRAN model subcomponents are presented in the following chapters:

- MAIN STRUCTURE
- BEAM A
- BEAM B
- CORNER BEAM
- USS UPPER BRACKET
- USS BRACKET
- INTERNAL BRACKETS
- RODS
- AEROGEL
- HONEYCOMB SKINS
- SENSOR BOXES
- SENSOR BOX BRACKETS
- PMTS AND PMT SUPPORTS
- SCINTILLATORS
- SCINTILLATORS SUPPORTS

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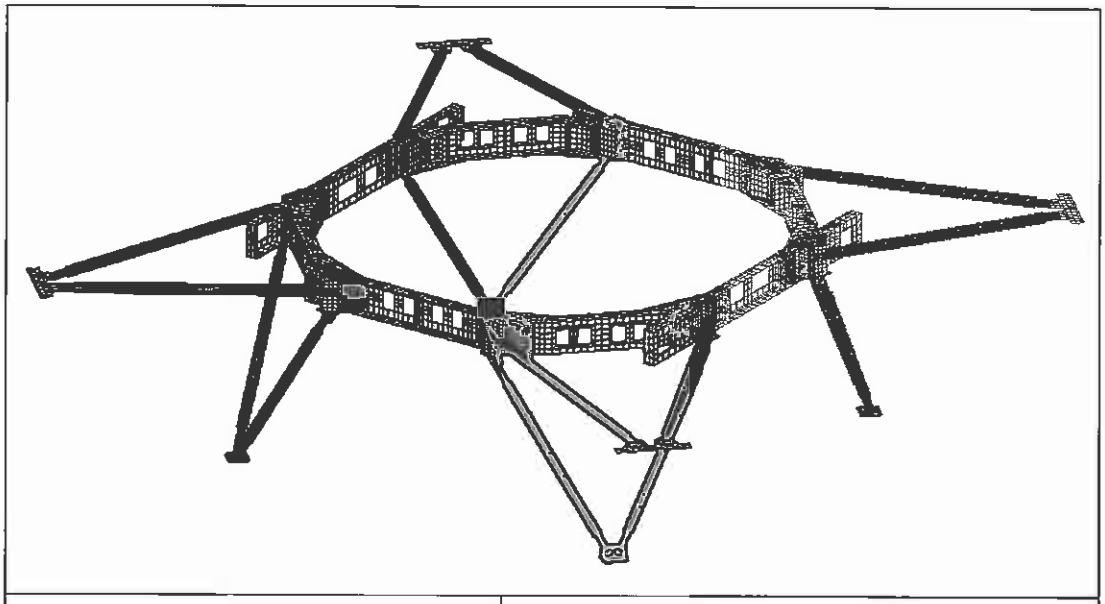
5.5.1 MAIN STRUCTURE

The main structure of the L-TOF is presented in the following figure:

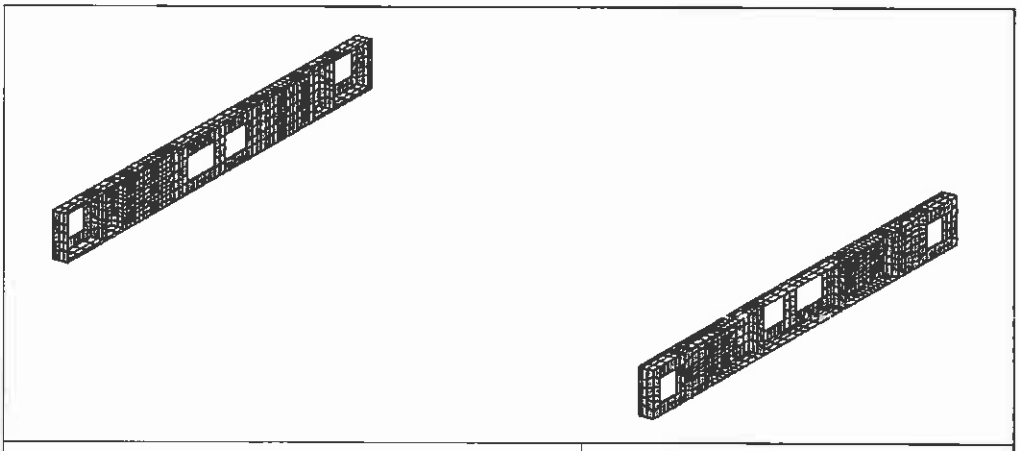


Material	AL 7075 T7351, dummy steel
Thickness range [m]	[0.002, 0.025]
FEM elements	Shell, bar, solid, RBE2

Figure 5-4: Main structure

In the following chapters the subcomponents are presented:

5.5.1.1 BEAM A



Material	AL 7075 T7351
Thickness range [m]	[0.002, 0.010]
FEM elements	Shell

Figure 5-5: Beam A

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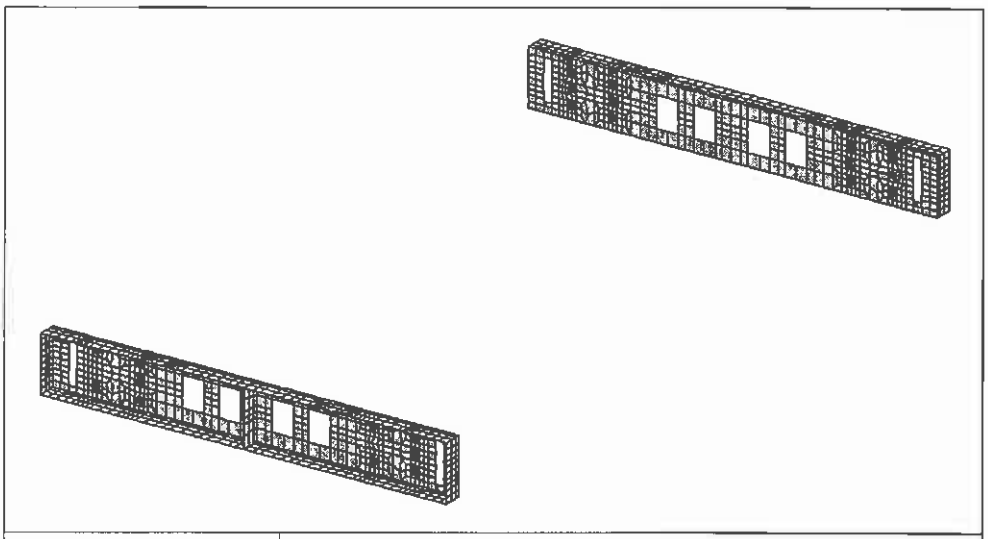
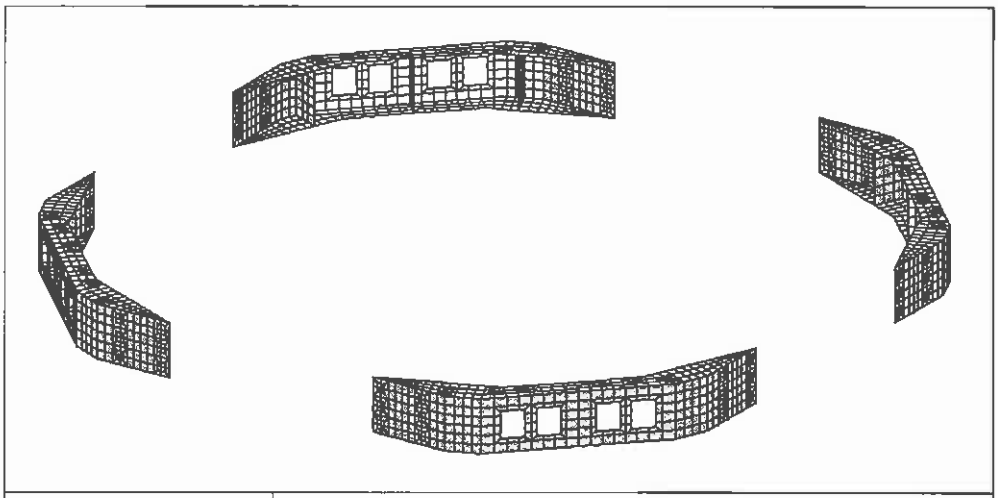
5.5.1.2 BEAM B



Material	AL 7075 T7351
Thickness range [m]	0.004
FEM elements	Shell

Figure 5-6: Beam B

5.5.1.3 CORNER BEAM



Material	AL 7075 T7351
Thickness range [m]	[0.004, 0.006]
FEM elements	Shell

Figure 5-7: Corner beam

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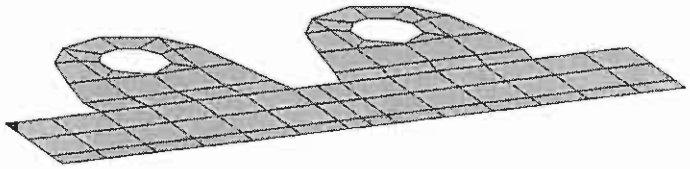
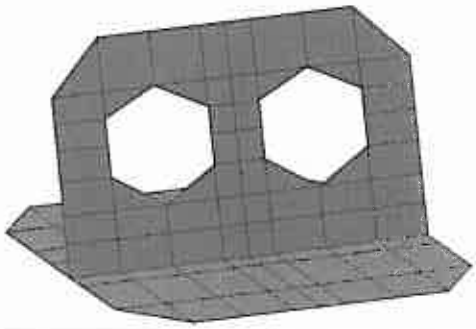
5.5.1.4 USS UPPER BRACKET LOWER TOF



Material	AL 7075 T7351
Thickness range [m]	[0.010, 0.025]
FEM elements	Shell

Figure 5-8: USS upper bracket lower tof

5.5.1.5 USS BRACKET LOWER TOF



Material	AL 7075 T7351
Thickness range [m]	[0.006, 0.010]
FEM elements	Shell

Figure 5-9: USS bracket lower tof

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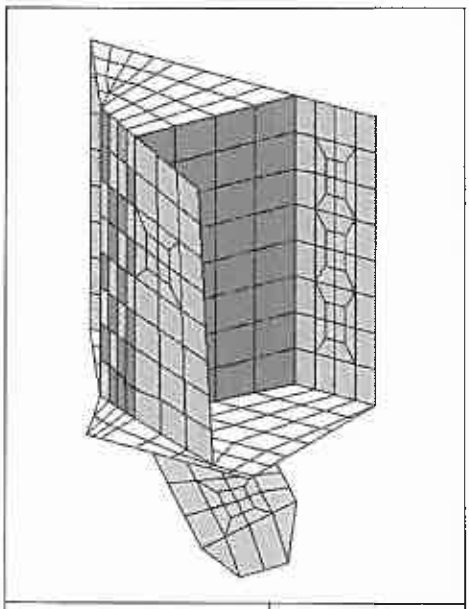
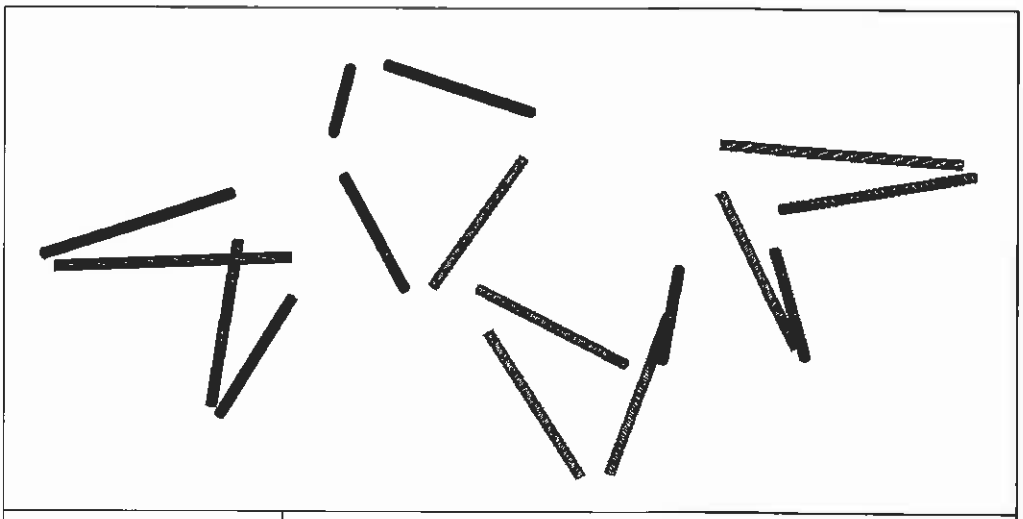
5.5.1.6 INTERNAL BRACKETS



Material	AL 7075 T7351
Thickness range [m]	[0.005, 0.010]
FEM elements	Shell, solid

Figure 5-10: Internal brackets

5.5.1.7 RODS



Material	AL 7075 T7351
Thickness range [m]	[Diameter 28.575mm, Thickness 1.25mm]
FEM elements	Bar

Figure 5-11: Rods

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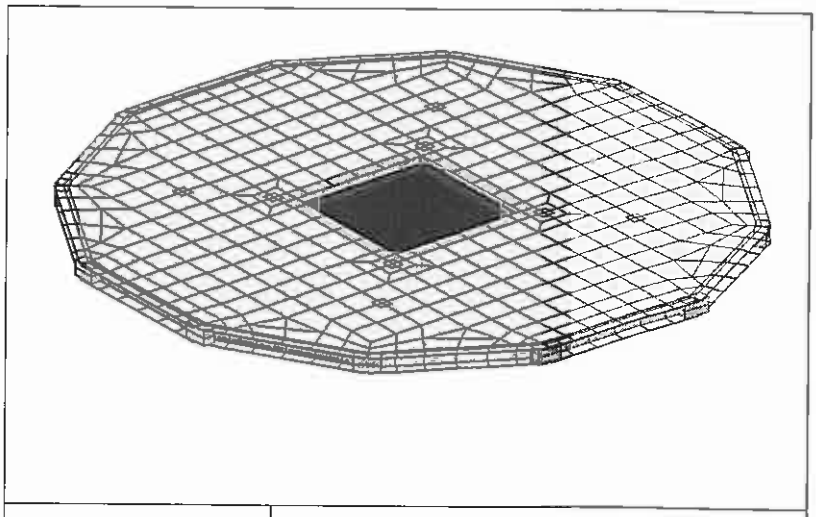
5.5.2 AEROGEL



Material	CFRP
Thickness range [m]	[0.0015, 0.0035]

Figure 5-12: Aerogel

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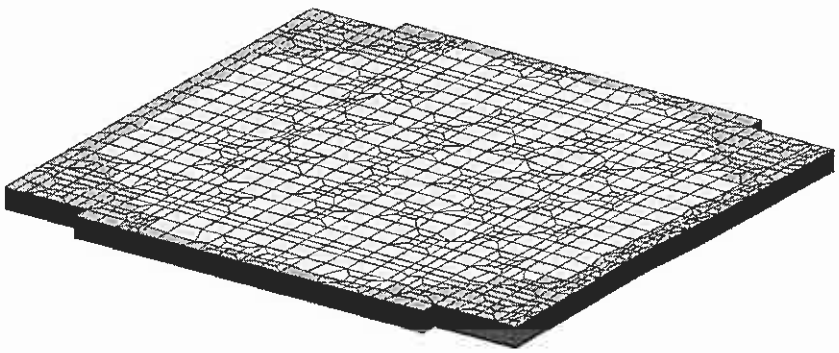
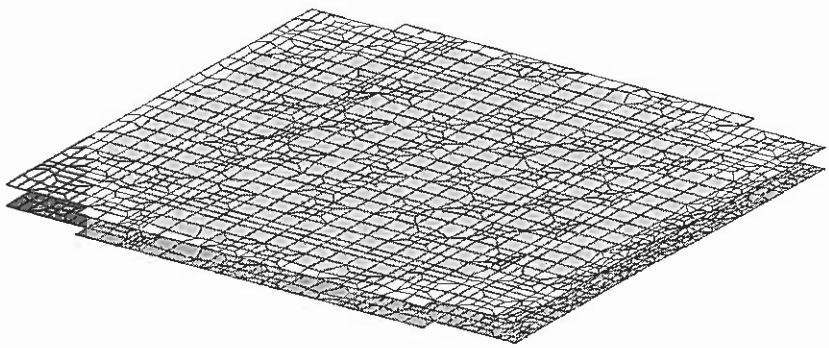
5.5.3 HONEYCOMB CORE



Material	Honeycomb HexWeb 5052
Thickness range [m]	0.05
FEM elements	solid

Figure 5-13: Honeycomb core

5.5.4 HONEYCOMB SKINS



Material	AL 2024 T81
Thickness range [m]	[0.0005, 0.00125]
FEM elements	Shell

Figure 5-14: Honeycomb skins

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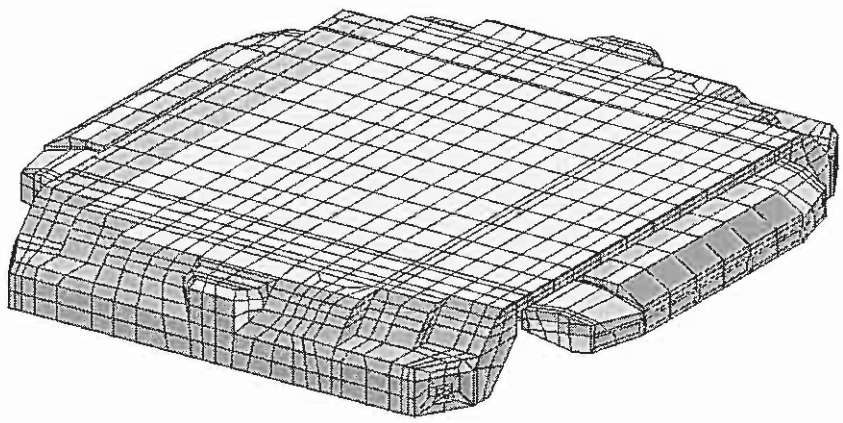
5.5.5 SENSOR BOXES



Material	CFRP
Thickness range [m]	Three 0.25 mm plies
FEM elements	Shell

Figure 5-15: Sensor boxes

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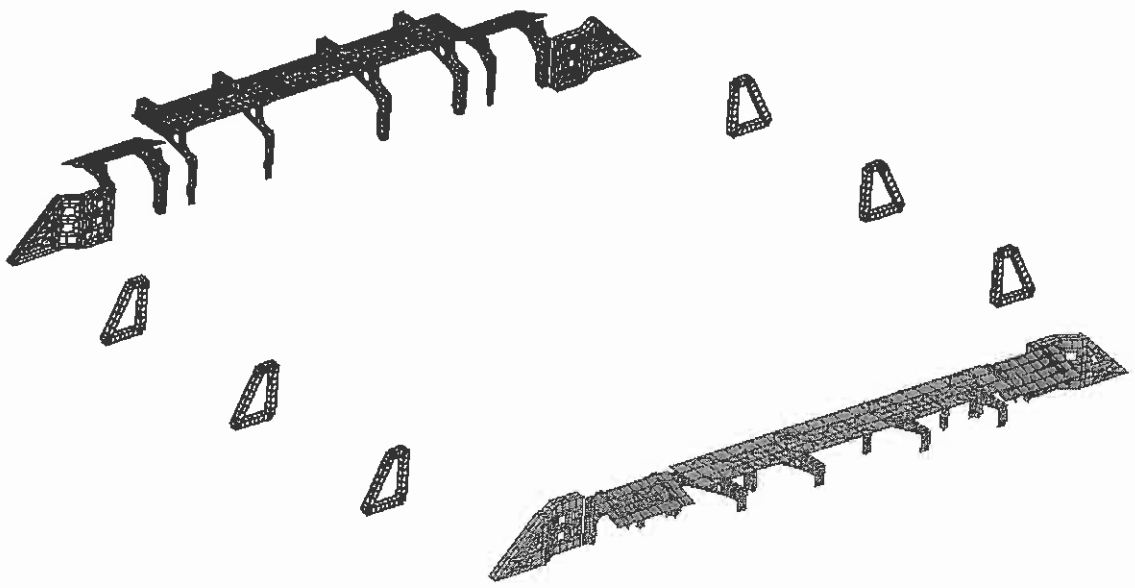
5.5.6 SENSOR BOX BRACKETS



Material	CFRP, AL 7075 T7351
Thickness range [m]	[0.0075, 0.010]
FEM elements	Shell, bar

Figure 5-16: brackets that fix Sensor boxes to the structure

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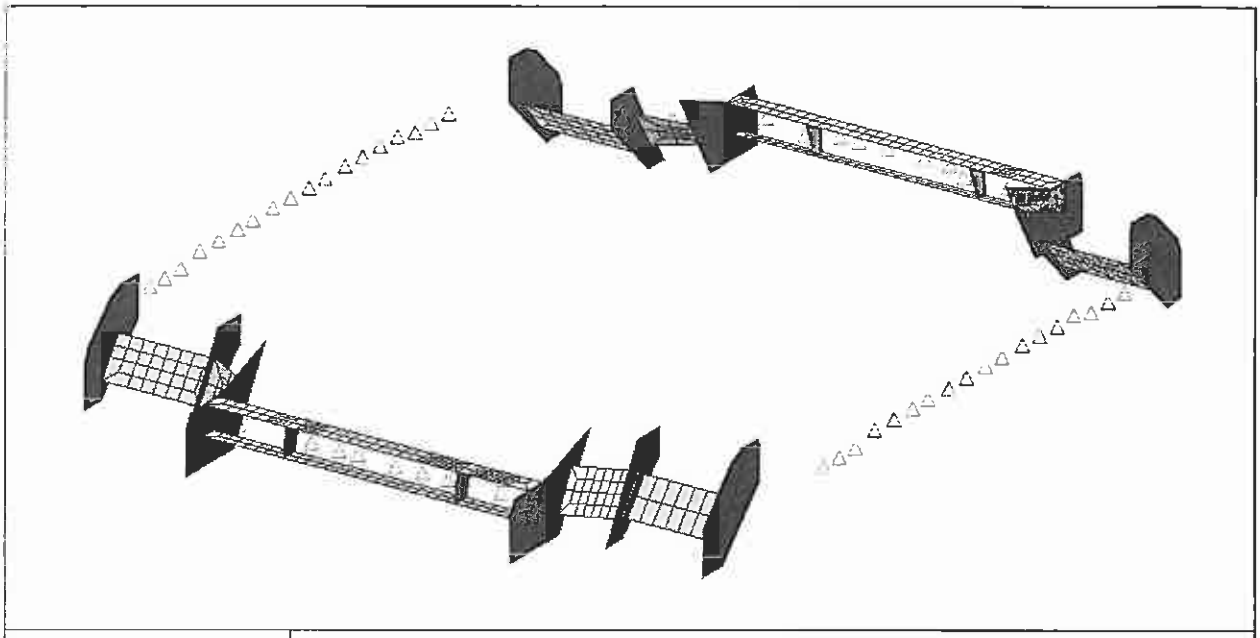
5.5.7 PMTS AND PMT SUPPORTS



Material	CFRP, honeycomb, NSM
Thickness range [m]	[0.003, 0.006]
FEM elements	Shell, CONM2

Figure 5-17: PMTs and PMT supports

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5.5.8 SCINTILLATORS

The scintillators are shown in the following figures:

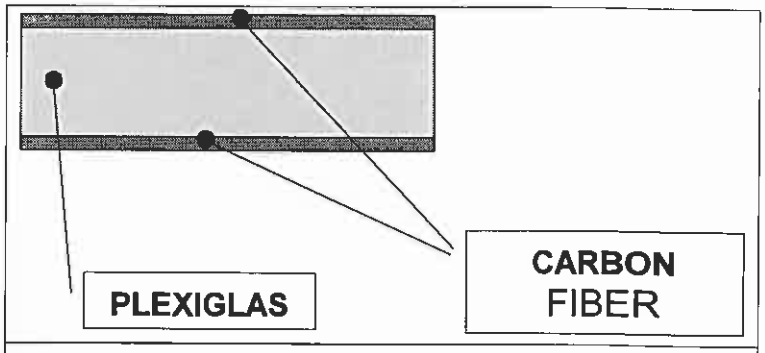
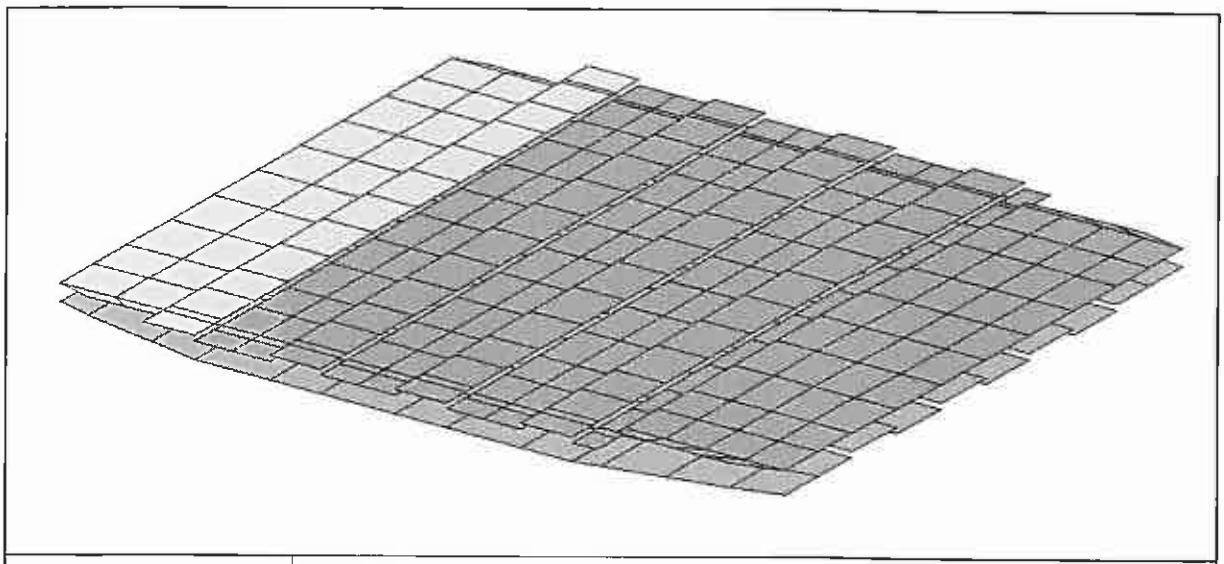


Figure 5-18: Plexiglas and carbon fiber



Material	CFRP, Plexiglas
Thickness range [m]	0.011
FEM elements	Shell

Figure 5-19: Scintillators

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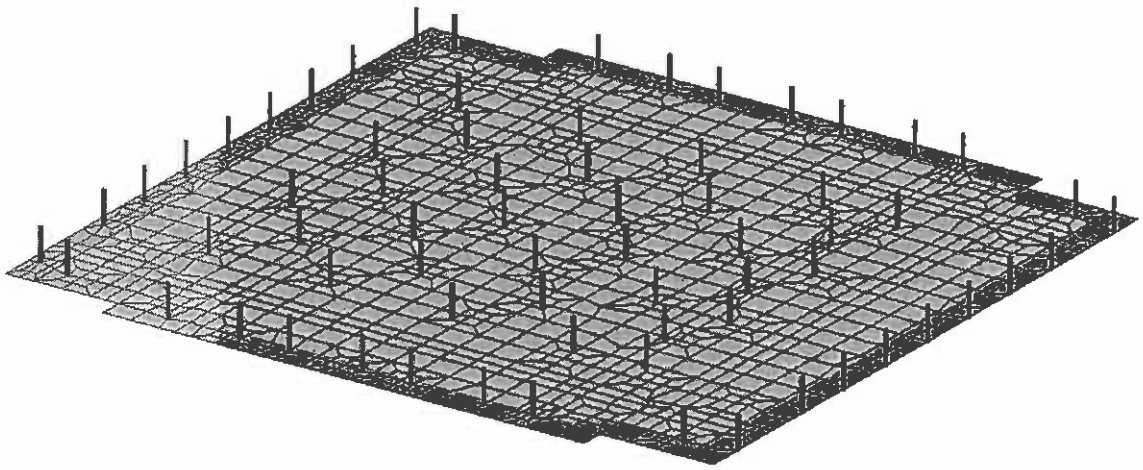
5.5.9 SCINTILLATORS SUPPORTS

The scintillators supports of L-TOF are shown in the following figure:
For detailed analysis of the components see 9.2.13



Material	Dummy Bar With Dummy Material
Diameter [m]	0.005
FEM elements	Bar

Figure 5-20: Scintillators supports

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5.6 MODEL BOUNDARY CONDITIONS

The L-TOF external structure is connected to the USS through 24 NAS 1351-4 bolts and 12 NAS 1351-6 bolts. In the Finite Element Model, the Single Point Constraint (SPC) bulk data card has been used at the end of the bolts, leaving unconstrained the rotational Degrees of Freedom (DoFs).

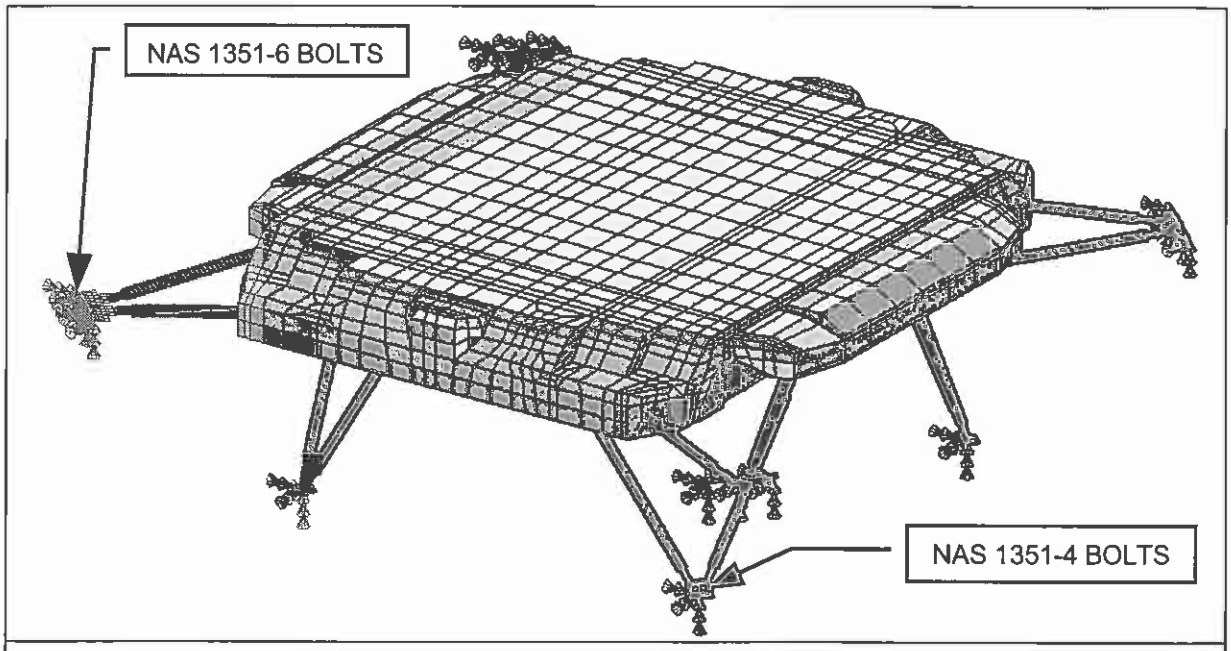

Figure 5-21: Model boundary conditions

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5.7 MODEL MASS BUDGET

The mass of the model is without any contingency.

LTOF MASS BUDGET	ITEM	CAD MASS [kg]	FEM MASS [kg]	REMARKS
MAIN STRUCTURE	RODS	18.45	18.45	
	RING	24.49	24.49	
	SUPPORT BOXES	2.88	2.88	
	PLATE HONEYCOMB	5.87	5.87	
	HONEYCOMB	3.26	3.26	
	INSERTS	2.92	2.92	
	PMT SUPPORTS	1.49	1.49	
		59.35	**59.35**	
ELECTRONICS	SCINTILLATORS	39.56	39.56	
	BOXES	13.31	13.31	
	PMT	22.11	22.11	
		74.97	**74.97**	
AEROGEL	AEROGEL	13.83	13.83	
		13.83	**13.83**	
	TOTAL MASS	**148.15**	**148.15**	

Table 5-14: Model mass budget

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5.8 MODEL CHECK

5.8.1 MODEL SIZE AND GEOMETRY

In the following tables the summary of the check runs that verify the mathematical correctness of the assembly model is shown:

MATHEMATICAL MODEL VERIFICATION RESULTS
GEOMETRY CHECK

MODEL FILE NAMES :
LTOF_040518.bdf

RUN FILE NAMES
LTOF_040518_constrain.dat, LTOF_param.blk

MODEL UNITS
Length=m, mass=Kg, density=Kg/m^3, Young mod.=N/m^2, Stress=N/m^2, Deformation=m, Strain En=N*m=Joule.

```
                    M O D E L   S U M M A R Y

                NUMBER OF GRID      POINTS    =    28676

                NUMBER OF CBAR      ELEMENTS =     1342
                NUMBER OF CBUSH     ELEMENTS =       12
                NUMBER OF CHEXA     ELEMENTS =     4828
                NUMBER OF CONM2     ELEMENTS =       76
                NUMBER OF CPENTA    ELEMENTS =       12
                NUMBER OF CQUAD4    ELEMENTS =    21725
                NUMBER OF CTRIA3    ELEMENTS =      680

                NUMBER OF RBE2      ELEMENTS =      665
```

E L E M E N T G E O M E T R Y T E S T R E S U L T S S U M M A R Y
TOTAL NUMBER OF TIMES TOLERANCES WERE EXCEEDED

ELEMENT TYPE	ASPECT/ SKEW ANGLE	MINIMUM TAPER RATIO	MAXIMUM INTER. ANGLE	SURFACE/FACE INTER. ANGLE	WARP FACTOR	EDGE POINT OFFSET RATIO	JACOBIAN LENGTH RATIO	DETERMINANT
BAR	N/A	N/A	N/A	N/A	N/A	0	N/A	N/A
HEXA	N/A	0	N/A	N/A	0	N/A	0	0
PENTA	N/A	0	N/A	N/A	0	N/A	0	0
QUAD4	94	435	577	611	0	N/A	N/A	N/A
TRIA3	10	N/A	N/A	0	N/A	N/A	N/A	N/A

N/A IN THE ABOVE TABLE INDICATES TESTS THAT ARE NOT APPLICABLE TO THE ELEMENT TYPE AND WERE NOT PERFORMED.
FOR ALL ELEMENTS WHERE GEOMETRY TEST RESULTS HAVE EXCEEDED TOLERANCES,

```
QUAD4    ELEMENT ID    10150 PRODUCED SMALLEST SKEW ANGLE       OF      12.40 (TOLERANCE =      30.00).
QUAD4    ELEMENT ID    28121 PRODUCED LARGEST  TAPER RATIO      OF       0.89 (TOLERANCE =       0.50).
QUAD4    ELEMENT ID    10150 PRODUCED SMALLEST INTERIOR ANGLE   OF       9.36 (TOLERANCE =      30.00).
QUAD4    ELEMENT ID    28141 PRODUCED LARGEST  INTERIOR ANGLE   OF     171.63 (TOLERANCE =     150.00).
TRIA3    ELEMENT ID    22941 PRODUCED SMALLEST SKEW ANGLE       OF       5.10 (TOLERANCE =      10.00).
```

Table 5-15: FEM Geometry Check

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5.8.2 FREE-FREE AND HARDMOUNTED MODES

MATHEMATICAL MODEL VERIFICATION RESULTS
MASS PROPERTIES, FREE-FREE MODES, HARDMOUNTED MODES

MODEL FILE NAMES
LTOF_040518.bdf

RUN FILE NAMES
LTOF_040518_modal_free.dat, LTOF_040518_constrain.dat, LTOF_param.blk

MODEL UNITS
Length=m, mass=Kg, density=Kg/m^3, Young mod.=N/m^2, Stress=N/m^2, Deformation=m, Strain En=N*m=Joule.

PARAMETERS:	
	PARAM,PRGPST,NO
	PARAM,COUPMASS,0
PARAM,POST,0	PARAM,GRDPNT,0
PARAM,PRTMAXIM,YES	PARAM,K6ROT,1.
PARAM,AUTOSPC,YES	PARAM,WTMASS,1.

MASS PROPERTIES

```
                    O U T P U T   F R O M   G R I D   P O I N T   W E I G H T   G E N E R A T O R
                                          REFERENCE POINT =        0
                                                   M O
*  1.481494E+02  0.000000E+00  0.000000E+00  0.000000E+00 -1.056284E+02  5.377691E+00 *
*  0.000000E+00  1.481494E+02  0.000000E+00  1.056284E+02  0.000000E+00 -2.898484E+00 *
*  0.000000E+00  0.000000E+00  1.481494E+02 -5.377691E+00  2.898484E+00  0.000000E+00 *
*  0.000000E+00  1.056284E+02 -5.377691E+00  1.115568E+02 -8.735792E-02 -2.109423E+00 *
* -1.056284E+02  0.000000E+00  2.898484E+00 -8.735792E-02  1.120731E+02 -3.849595E+00 *
*  5.377691E+00 -2.898484E+00  0.000000E+00 -2.109423E+00 -3.849595E+00  6.993908E+01 *
                                                   S
                                 *  1.000000E+00  0.000000E+00  0.000000E+00 *
                                 *  0.000000E+00  1.000000E+00  0.000000E+00 *
                                 *  0.000000E+00  0.000000E+00  1.000000E+00 *
                                                 DIRECTION
     MASS AXIS SYSTEM (S)     MASS              X-C.G.        Y-C.G.        Z-C.G.
        X                 1.481494E+02      0.000000E+00 -3.629910E-02 -7.129858E-01
        Y                 1.481494E+02     -1.956460E-02  0.000000E+00 -7.129858E-01
        Z                 1.481494E+02     -1.956460E-02 -3.629910E-02  0.000000E+00
                                                   I(S)
                                 *  3.604999E+01 -1.785443E-02  4.284468E-02 *
                                 * -1.785443E-02  3.670482E+01  1.537750E-02 *
                                 *  4.284468E-02  1.537750E-02  6.968716E+01 *
                                                   I(Q)
                                 *  3.670530E+01                             *
                                 *                3.604945E+01               *
                                 *                             6.968723E+01  *
                                                     Q
                                 * -2.720242E-02 -9.996291E-01  1.286424E-03 *
                                 * -9.996298E-01  2.720304E-02  4.665839E-04 *
                                 * -5.014055E-04 -1.273255E-03 -9.999990E-01 *
```

RIGID BODY NORMAL MODE CHECK

MODE	EXTRACTION	EIGENVALUE	RADIANS	CYCLES
1	1	-4.293683E-06	2.072120E-03	3.297882E-04
2	2	-1.856150E-06	1.362406E-03	2.168336E-04
3	3	-6.489167E-07	8.055537E-04	1.282078E-04
4	4	-5.891527E-07	7.675628E-04	1.221614E-04
5	5	-1.319769E-07	3.632863E-04	5.781880E-05
6	6	4.376617E-07	6.615600E-04	1.052905E-04
7	7	4.515175E-07	6.719505E-04	1.069442E-04
8	8	6.144526E-07	7.838702E-04	1.247568E-04
9	9	1.200959E-06	1.095883E-03	1.744151E-04
10	10	5.980666E+03	7.733476E+01	1.230821E+01

HARDMOUNTED NORMAL MODE CHECK

R E A L E I G E N V A L U E S

MODE	EXTRACTION	EIGENVALUE	RADIANS	CYCLES
1	1	5.543344E+03	7.445364E+01	1.184966E+01
2	2	6.783889E+03	8.236436E+01	1.310870E+01
3	3	5.324313E+04	2.307447E+02	3.672416E+01
4	4	5.532755E+04	2.352181E+02	3.743612E+01
5	5	5.593894E+04	2.365141E+02	3.764240E+01
6	6	5.768690E+04	2.401810E+02	3.822599E+01
7	7	6.040279E+04	2.457698E+02	3.911547E+01
8	8	6.246653E+04	2.499331E+02	3.977808E+01
9	9	7.823571E+04	2.797065E+02	4.451667E+01
10	10	8.133491E+04	2.851927E+02	4.538984E+01

Table 5-16: FEM mass properties, free-free modes, hardmounted modes

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5.8.3 1 G CHECK

MATHEMATICAL MODEL VERIFICATION RESULTS
1g CHECK

MODEL FILE NAMES :
LTOF_040518.bdf

RUN FILE NAMES
LTOF_subcases_1gchk.blk, LTOF_grav_1gchk.blk, LTOF_param.blk, LTOF_040518_1g.dat,

PARAMETERS:	
PARAM,POST,0	PARAM,PRGPST,NO
PARAM,PRTMAXIM,YES	PARAM,COUPMASS,0
PARAM,AUTOSPC,YES	PARAM,GRDPNT,0
	PARAM,K6ROT,1.
	PARAM,WTMASS,1.

UNITY GRAVITY LOADING CHECK(COORD 0)M= 148.15 Kgg=9.81Fxyz=1 453.35 N

OLOAD RESULTANT

	T1	T2	T3	R1	R2	R3
10001	1.453346E+03	0.000000E+00	0.000000E+00	0.000000E+00	-1.036215E+03	5.275515E+01
10002	0.000000E+00	1.453346E+03	0.000000E+00	1.036215E+03	0.000000E+00	-2.843413E+01
10003	0.000000E+00	0.000000E+00	1.453346E+03	-5.275515E+01	2.843413E+01	0.000000E+00

SPCFORCE RESULTANT

	T1	T2	T3	R1	R2	R3
10001	-1.453346E+03	-2.050626E-10	1.290754E-10	-1.164153E-07	1.036215E+03	-5.275515E+01
10002	-3.652385E-10	-1.453346E+03	-1.848237E-10	-1.036215E+03	5.308539E-08	2.843413E+01
10003	2.145648E-10	-1.058953E-10	-1.453346E+03	5.275515E+01	-2.843413E+01	-6.705523E-08

EPSILON

LOAD SEQ. NO.	EPSILON	EXTERNAL WORK
1	-2.3627894E-12	5.4185241E-02
2	-6.6241999E-13	3.1549722E-02
3	-1.5311575E-12	9.2123844E-02

Table 5-17: FEM 1g check

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5.8.4 STRAIN ENERGY CHECK

MATHEMATICAL MODEL VERIFICATION RESULTS
STRAIN ENERGY CHECK

MODEL FILE NAMES :
LTOF_040407.bdf

RUN FILE NAMES
LTOF_040518_strain_energy.dat, LTOF_param.blk

COMAND:
GROUNDCHECK(SET=ALL,THRESH=1.E-3)=YES

PARAMETERS:	
	PARAM,PRGPST,NO
	PARAM,COUPMASS,0
PARAM,POST,0	PARAM,GRDPNT,0
PARAM,PRTMAXIM,YES	PARAM,K6ROT,1.
PARAM,AUTOSPC,YES	PARAM,WTMASS,1.

STRAIN ENERGY CHECK [J]

```
   RESULTS OF RIGID BODY CHECKS OF MATRIX KGG      (G-SET)  FOLLOW:
PRINT RESULTS IN ALL SIX DIRECTIONS AGAINST THE LIMIT OF   1.000000E-03
            DIRECTION        STRAIN ENERGY        PASS/FAIL
            ---------        -------------        ---------
                1              2.485593E-05          PASS
                2              1.372502E-05          PASS
                3              5.223730E-05          PASS
                4              7.452529E-07          PASS
                5              1.606411E-05          PASS
                6              1.533024E-05          PASS

   RESULTS OF RIGID BODY CHECKS OF MATRIX KNN      (N-SET)  FOLLOW:
PRINT RESULTS IN ALL SIX DIRECTIONS AGAINST THE LIMIT OF   1.000000E-03
            DIRECTION        STRAIN ENERGY        PASS/FAIL
            ---------        -------------        ---------
                1              2.351149E-05          PASS
                2              8.571646E-06          PASS
                3              5.115501E-05          PASS
                4              2.696623E-06          PASS
                5              7.812814E-06          PASS
                6              1.490704E-05          PASS

RESULTS OF RIGID BODY CHECKS OF MATRIX KNN+AUTO (N+AUTOSPC-SET)  FOLLOW:
PRINT RESULTS IN ALL SIX DIRECTIONS AGAINST THE LIMIT OF   1.000000E-03
            DIRECTION        STRAIN ENERGY        PASS/FAIL
            ---------        -------------        ---------
                1              2.351149E-05          PASS
                2              8.571646E-06          PASS
                3              5.115501E-05          PASS
                4              2.696623E-06          PASS
                5              7.812814E-06          PASS
                6              1.490704E-05          PASS

   RESULTS OF RIGID BODY CHECKS OF MATRIX KFF      (F-SET)  FOLLOW:
PRINT RESULTS IN ALL SIX DIRECTIONS AGAINST THE LIMIT OF   1.000000E-03
            DIRECTION        STRAIN ENERGY        PASS/FAIL
            ---------        -------------        ---------
                1              2.351149E-05          PASS
                2              8.571646E-06          PASS
                3              5.115501E-05          PASS
                4              2.696623E-06          PASS
                5              7.812814E-06          PASS
                6              1.490704E-05          PASS
```

Table 5-18: FEM Strain Energy check

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6. DIMENSIONING LOADS

The dimensioning loads are based on the results of the CLA performed by LMSO (and provided by the mail "lotfinterface2-041.xls"), using the FEM Model of the entire AMS-02. The Dimensioning Loads used (series 1000, 2000 and 4000) are composed by both inertial loads and enforced displacement of the constraints. In the following table the set of the load cases used for the analysis is presented: in the first table the entire set is showed with the inertial loads applied; in the second table the enforced displacements of load case 4001 are presented.

Load Case	Nx (g)	Ny (g)	Nz (g)	Rx (rad/sec^2)	Ry (rad/sec^2)	Rz (rad/sec^2)
1001-1064	+3.7	+1.4	+1.4	+4.5	+8.4	+3.9
	-0.4	-1.6	-1.5	-4.1	-11.0	-4.1
2001-2064	+1.2	+0.7	+2.1	+5.2	+10.7	+6.0
	-1.3	-0.6	-5.6	-4.7	-13.9	-4.8
4001-4064	+1.7	+1.1	+2.7	+12.5	+14.7	+12.1
	-2.0	-1.1	-7.4	-11.1	-18.1	-10.0

Table 6-1: Applied set of load cases

Sets 1000 and 2000 are applied in AMS-02 center of gravity in launch configuration.
Set 4000 is applied in AMS-02 Center of gravity in landing configuration (with empty tank)

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LOAD CASE 4016 DISPLACEMENTS						
GRID	Tx [m]	Ty [m]	Tz [m]	Rx [rad]	Ry [rad]	Rz [rad]
160001	-0.00223	-0.00729	-0.00474	-	0.00224	-
160002	-0.00229	-0.00729	-0.00501	-	0.00361	-
160003	-0.00234	-0.0073	-0.00528	-	0.00536	-
160004	-0.00548	0.00322	-0.00354	-	0.00021	-
160005	-0.00559	0.00322	-0.00386	-	0.00096	-
160006	-0.0057	0.00323	-0.00419	-	0.00185	-
160007	0.00608	-0.00296	-0.0003	-	-0.00139	-
160008	0.00605	-0.00296	-0.00012	-	-0.00126	-
160009	0.00603	-0.00296	0.00006	-	-0.00111	-
160010	0.0036	0.00539	0.00177	-	-0.00445	-
160011	0.00362	0.00539	0.00186	-	-0.00451	-
160012	0.00364	0.00539	0.00194	-	-0.00457	-
160013	0.00838	0.00147	-0.00317	-0.00225	-0.00083	0.00005
160014	0.00919	0.00106	-0.00235	-0.00066	-0.00258	-0.00038
160015	0.00845	0.00115	-0.00114	-0.00075	-0.00395	0.00108
160016	0.00917	0.0012	-0.00019	-0.00095	-0.00418	-0.00067

Table 6-2: Load case 4016 displacements

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7. DIMENSIONING RULES

7.1 SAFETY FACTORS

The L-TOF system has to show positive MoS applying the following SF:

SAFETY FACTORS	Yield	Ultimate
Metallic structures	1.25	2.0
Non metallic structures	NA	2.0
Fasteners (Nominal)	1.25	2.0
Joint separation	1.2	NA
Joints fitting factor	1.15	1.15
Buckling	NA	2.0
Sandwich verification	NA	2.0
Fasteners (Fail Safe)	NA	1.0

Table 7-1: Safety Factors for structure

7.2 TEMPERATURE DERATING FACTOR

For all the material the temperature degradation factor is considered, as per RD 1 at 60°C (140°F) (landing temperature) the worst temperature degradation factor for the material is 6% with respect to the material nominal mechanical characteristics. This temperature degradation factor is applied to all the material.

7.3 MARGINS OF SAFETY FOR STRUCTURE

The MoS is defined as:

$$MoS_Y = \frac{\sigma_y}{SF_Y \cdot \sigma_{Load}} - 1.0$$ for the yield strength, and

$$MoS_U = \frac{\sigma_u}{SF_U \cdot \sigma_{Load}} - 1.0$$ for the ultimate strength, where:

- σ_Y the yield strength of the material,
- σ_U the ultimate strength of the material,
- SF_Y the safety factor for yield strength,
- SF_U the safety factor for ultimate strength,
- σ_{Load} the maximum Von Mises equivalent stress due to external loads.

The MoS for stresses indicates the amount by which the allowable stress, defined by the material characteristics, exceeds the actual stress due to the applied loads, taking into account the applicable SF, defined in Chapter 7.1 .

It is required that MoS are positive for all load cases, for all structural elements.
Additional MoS can be defined to evaluate margins for generic results.

$$MoS = \frac{A}{SF \cdot B} - 1.0$$

- A allowable
- B actual value
- SF applicable safety factor

It is required that Margins of Safety are positive for all load cases and operative conditions, for all elements.

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7.3.1 TSAI HILL VERIFICATION

For the CFRP plates, TSAI HILL verification for composite materials is used:

TSAI HILL VERIFICATION: $$\left(\frac{\sigma_x \cdot SF}{F_{tu}}\right)^2 - \frac{(\sigma_x \cdot SF)\cdot(\sigma_y \cdot SF)}{F_{tu}^2} + \left(\frac{\sigma_y \cdot SF}{F_{tu}}\right)^2 + \left(\frac{\tau_{xy} \cdot SF}{F_{su}}\right) < 1$$

7.3.2 SANDWICH VERIFICATION

According with chapter 12 of Bruhn (RD. 4), sandwich verification is performed (combined load strength, intracell buckling and wrinkling); in ANNEX 2 the example of the honeycomb verification is presented.

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8. DYNAMIC ANALYSIS

In this section, results in terms of frequencies, mode shapes and effective masses are included.

8.1 EIGENFREQUENCIES AND MODE SHAPES

In the following tables the modes with associated mass greater than 5% of the constrained L-TOF system are shown.

MODE	FREQ [Hz]	% EFF. MASS		
		X DIRECTION	Y DIRECTION	Z DIRECTION
12	46.6	6.3%	< 1%	< 1%
24	54.1	33.1%	< 1%	11.3%
25	54.8	9.8%	< 1%	21.5%
34	59.1	5.1%	< 1%	< 1%
72	74.9	< 1%	9.5%	< 1%
80	79.4	< 1%	8.5%	< 1%
81	80.5	< 1%	45.7%	< 1%

Table 8-1: L-TOF SYSTEM natural frequencies

In the following figures the shapes of the modes with effective mass greater than 5% are presented:

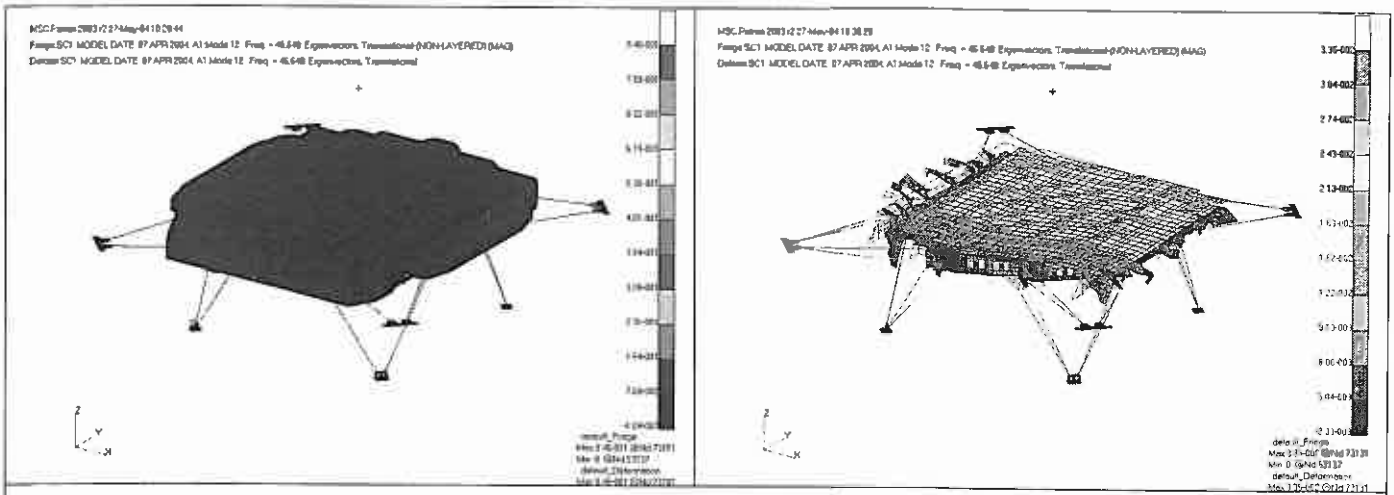

Figure 8-1: Mode 12 at 46.6 Hz

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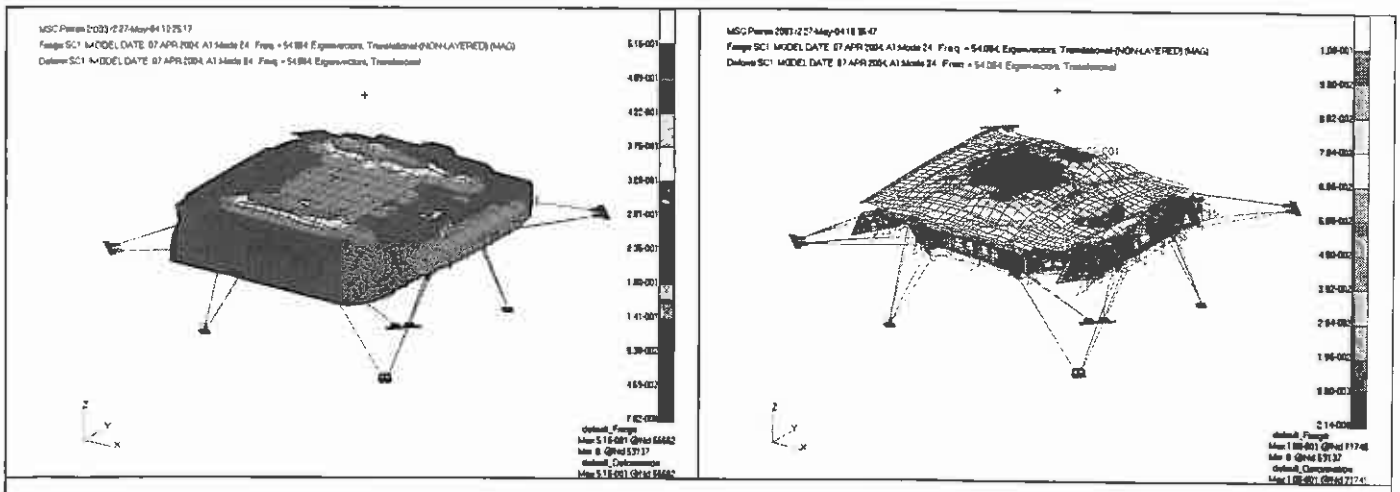

Figure 8-2: Mode 24 at 54.1 Hz

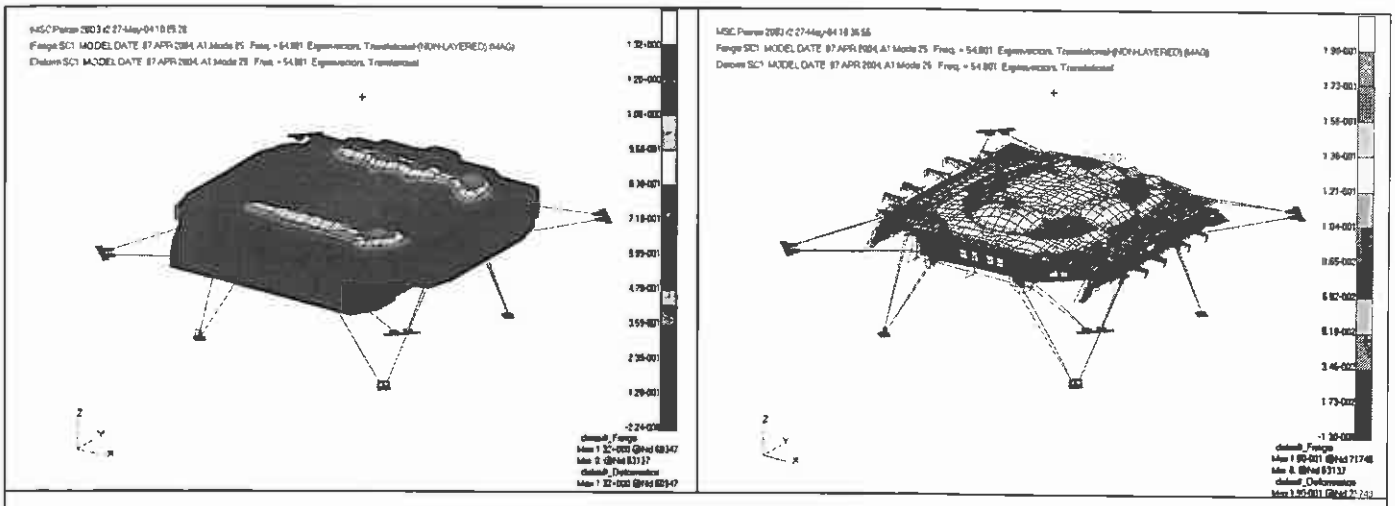

Figure 8-3: Mode 25 at 54.8 Hz

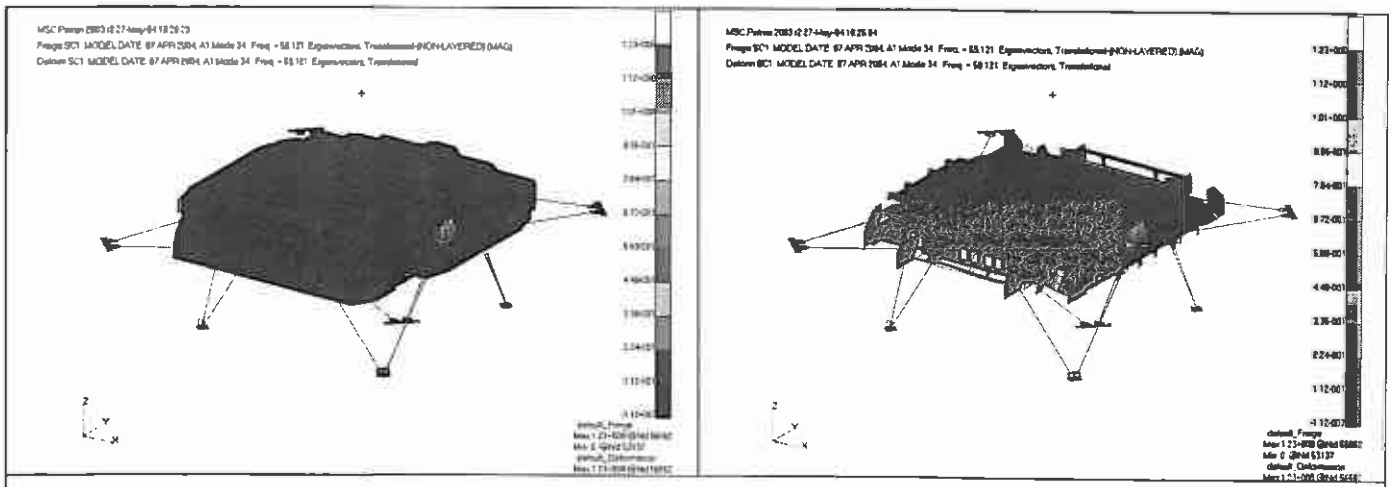

Figure 8-4: Mode 34 at 59.1 Hz

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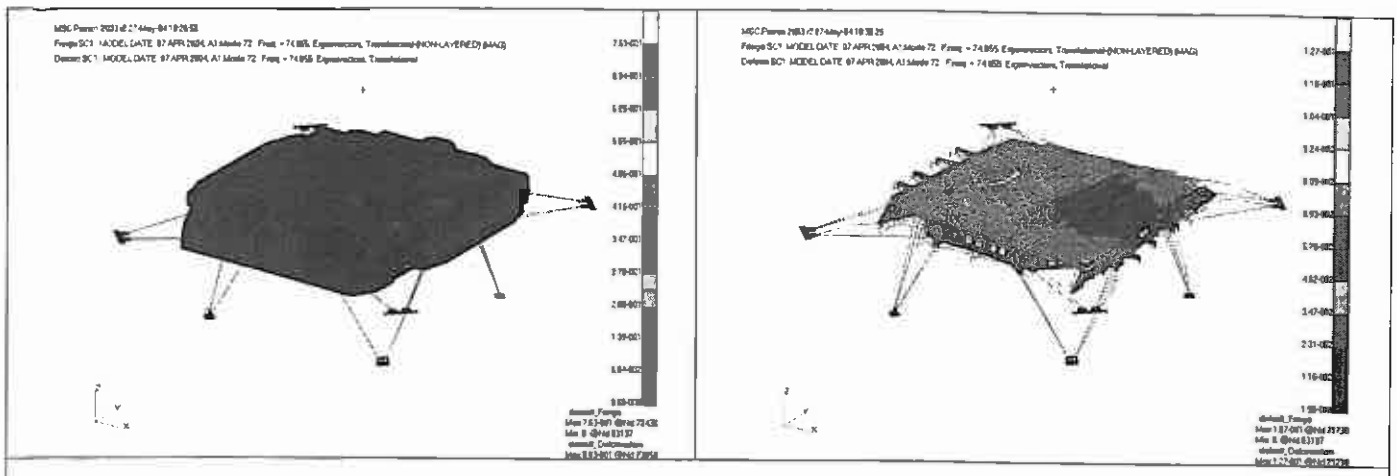

Figure 8-5: Mode 72 at 74.8 Hz

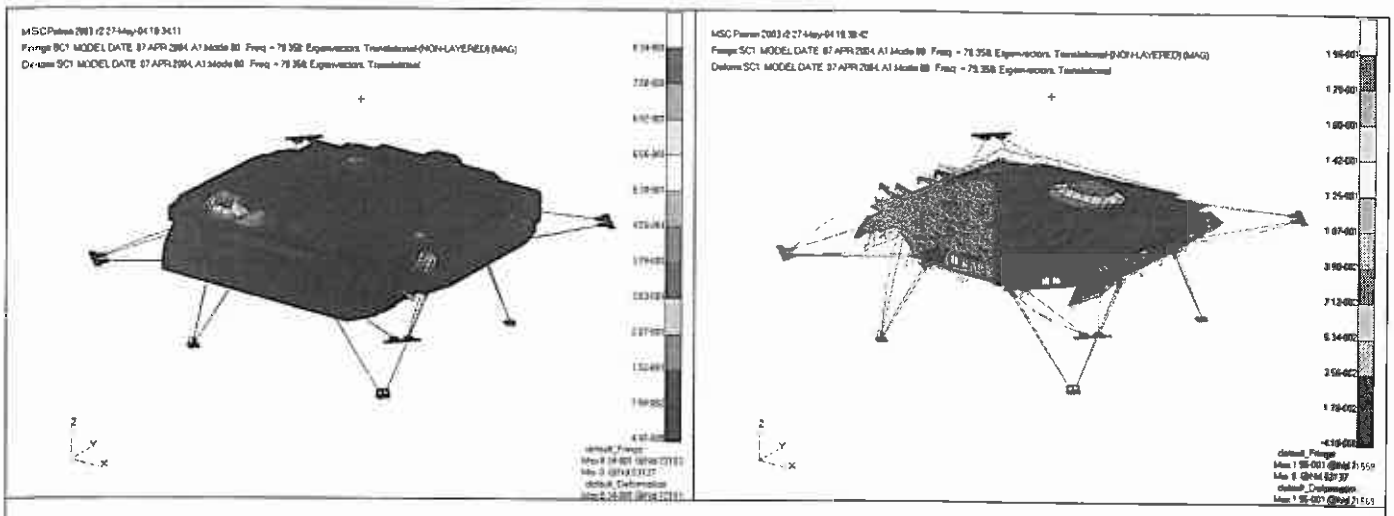

Figure 8-6: Mode 80 at 79.3 Hz

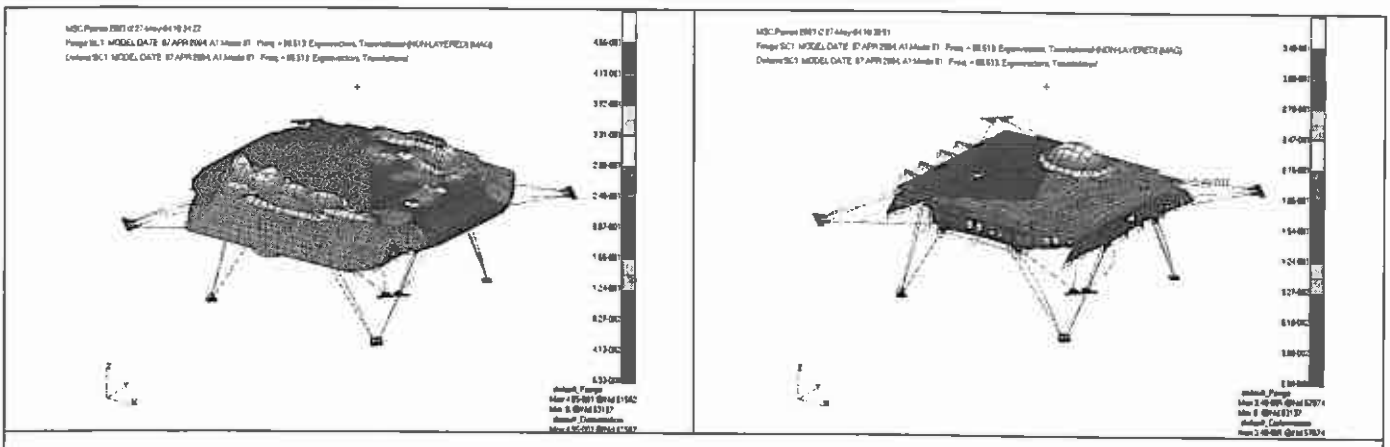

Figure 8-7: Mode 81 at 80.5 Hz

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8.2 EFFECTIVE MASS

Effective masses are reported in the following figures:

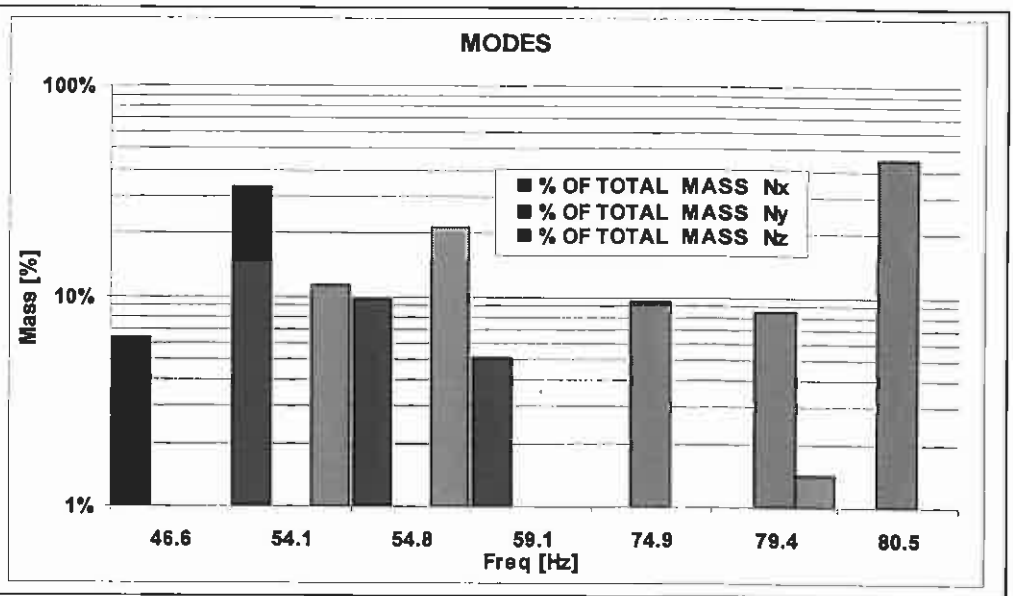

Figure 8-8: Effective masses for all axes

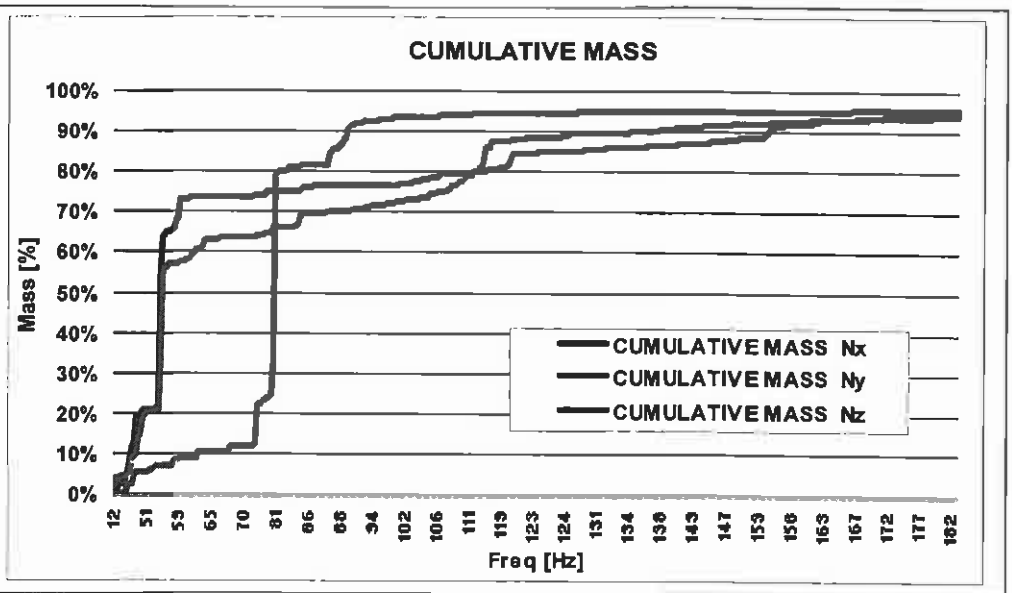

Figure 8-9: Cumulative effective masses for all axes

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9. STATIC ANALYSIS

In the following sections, static analysis results are described for nominal configuration.

Four different types of analyses are performed:

9.1 DISPLACEMENT ANALYSIS
9.2 STRESS ANALYSIS
9.3 JOINT ANALYSIS
9.4 BUCKLING ANALYSIS

9.1 DISPLACEMENT ANALYSIS

The worst condition is for **NODE 119348** for **Load Case 4016**.
The resulting displacement is **1.77E-2 m**.
Following figure shows displacements for this subcase.

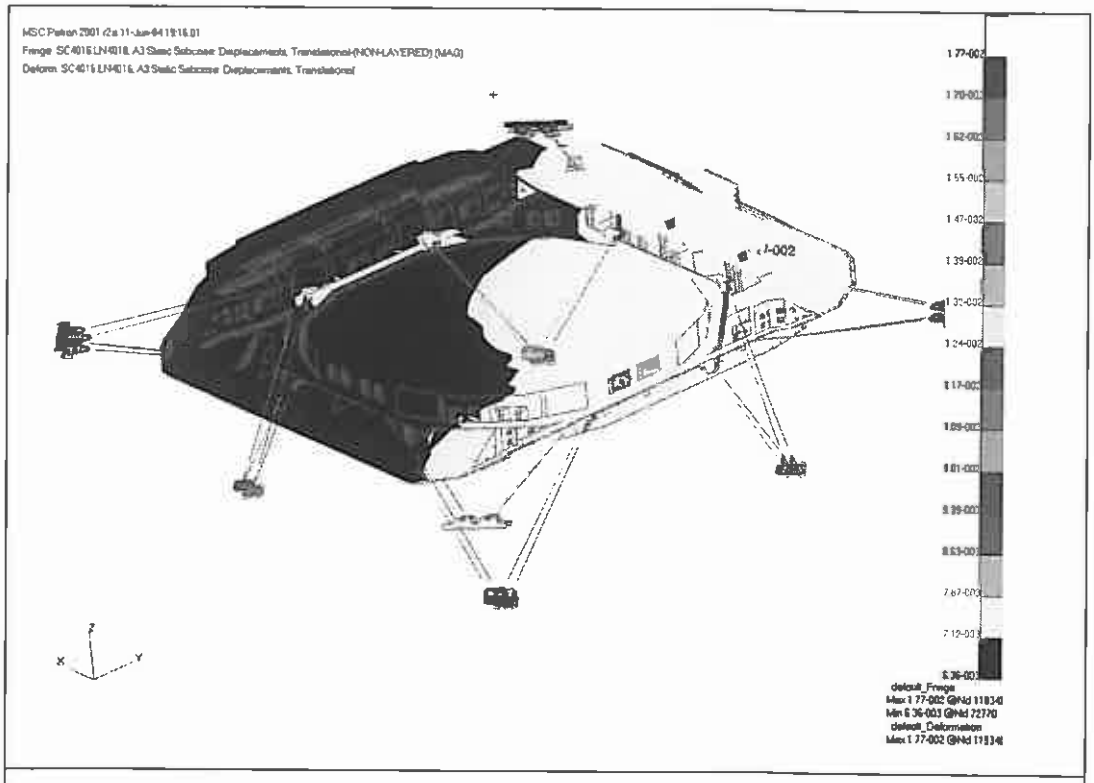

Figure 9-1: Maximum displacement – Load case 4016

It has to be noted that this value of displacement is due both to deformation and to enforced displacement (see table 6-2). In order to have a better understanding just of the deformation, a further plot is presented, where the enforced displacement at node 160001 is subtracted to the total displacement an any node. In such a case the node having the maximum displacement is **NODE 119348**. The resulting relative displacement is **1.75E-2 m**.

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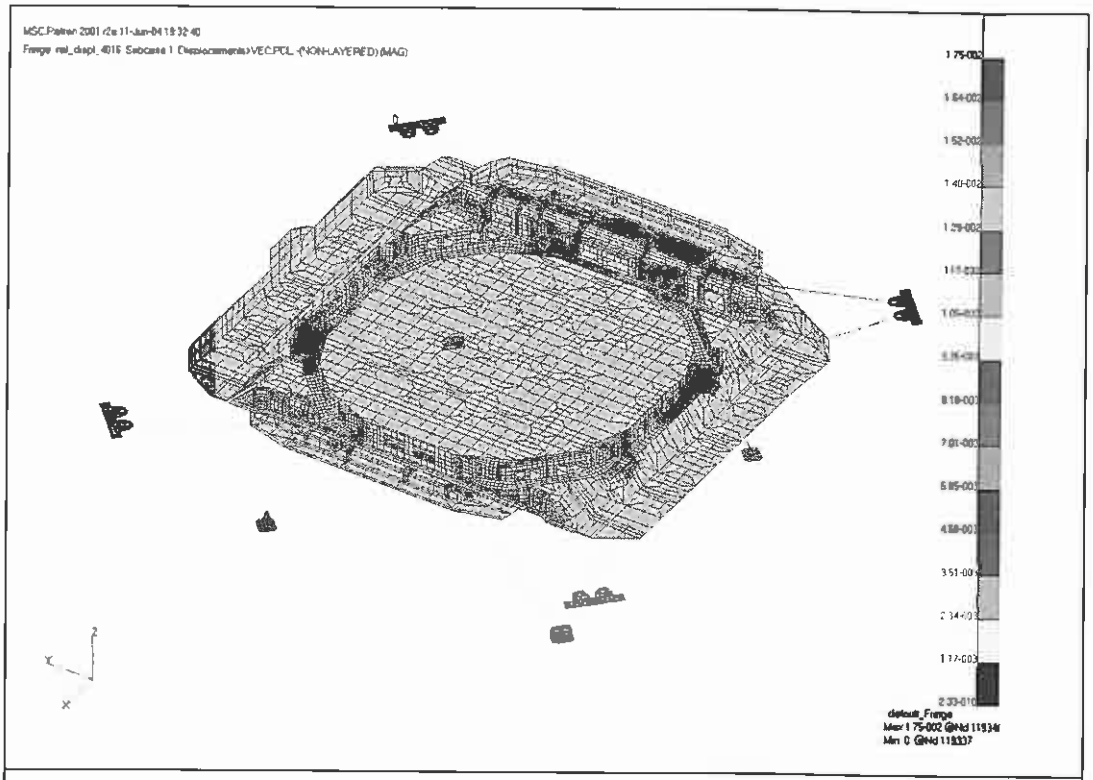

Figure 9-2: Relative displacement – Load case 4016

9.2 STRESS ANALYSIS

For each safety critical item the stress contour and MoS calculation is shown in the next pages.
The structure is divided in the following items:

9.2.1 BEAM A
9.2.2 BEAM B
9.2.3 CORNER BEAM
9.2.4 UPPER BRACKET
9.2.5 LOWER BRACKET
9.2.6 RING BRACKET
9.2.7 RODS
9.2.8 HONEYCOMB SKINS
9.2.9 INTERNAL HONEYCOMB SKINS
9.2.10 EXTERNAL HONEYCOMB SKINS
9.2.11 SENSOR BOXES BRACKETS PLATE
9.2.12 SENSOR BOXES BRACKETS BAR
9.2.13 PMT HORIZONTAL SUPPORT
9.2.14 SENSOR BOXES
9.2.15 SCINTILLATOR COVERS
9.2.16 BOXES/PMT SUPPORT
9.2.17 SCINTILLATORS SUPPORTS
9.2.18 HONEYCOMB CORE INTERNAL
9.2.19 HONEYCOMB CORE EXTERNAL

Summary of stress analysis results are shown in 9.2.20 (MARGINS OF SAFETY).

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9.2.1 BEAM A

The worst condition is for **ELEMENT 16297** for **Load Case 4061** at **Layer Z2**.
The resulting Von Mises stress is: **f_{VM} = 300 MPa**.
Following figure shows stress distribution for this subcase.

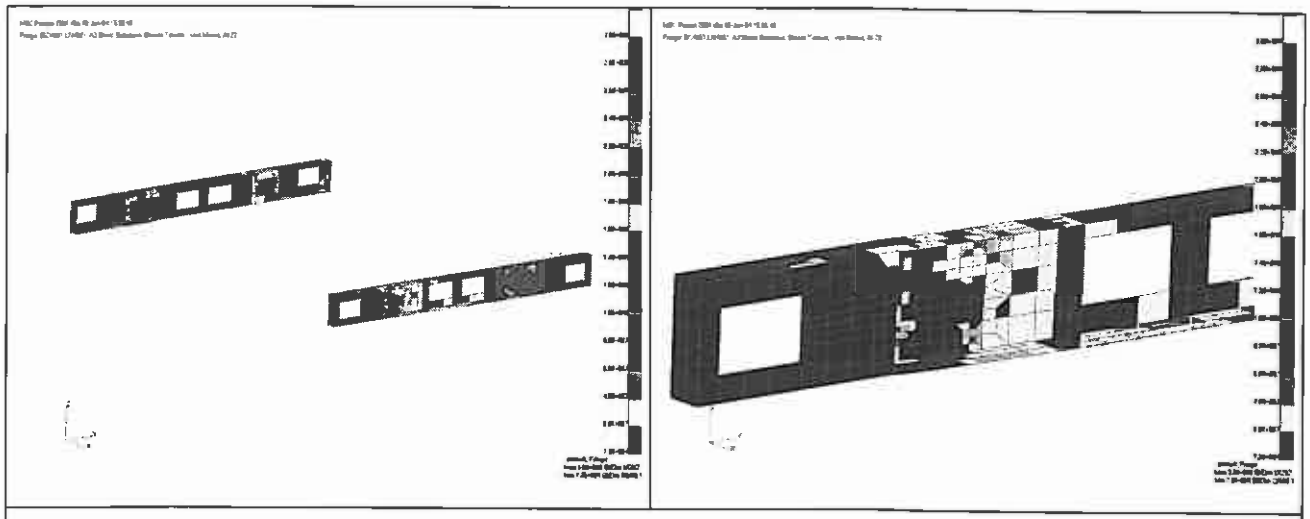

Figure 9-3: Beam A, Load Case 4061, Layer Z2

The high value of stress is due to the presence of the rigid connection elements. The VM verification is performed erasing the elements near the connection and additional Bearing verifications (see 9.3.1) is performed using connection bolt shear force.

The worst condition is for **ELEMENT 16293** for **Load Case 4061** at **Layer Z1**.
The resulting Von Mises stress is: **f_{VM} = 211 MPa**.
Following figure shows stress distribution for this subcase.

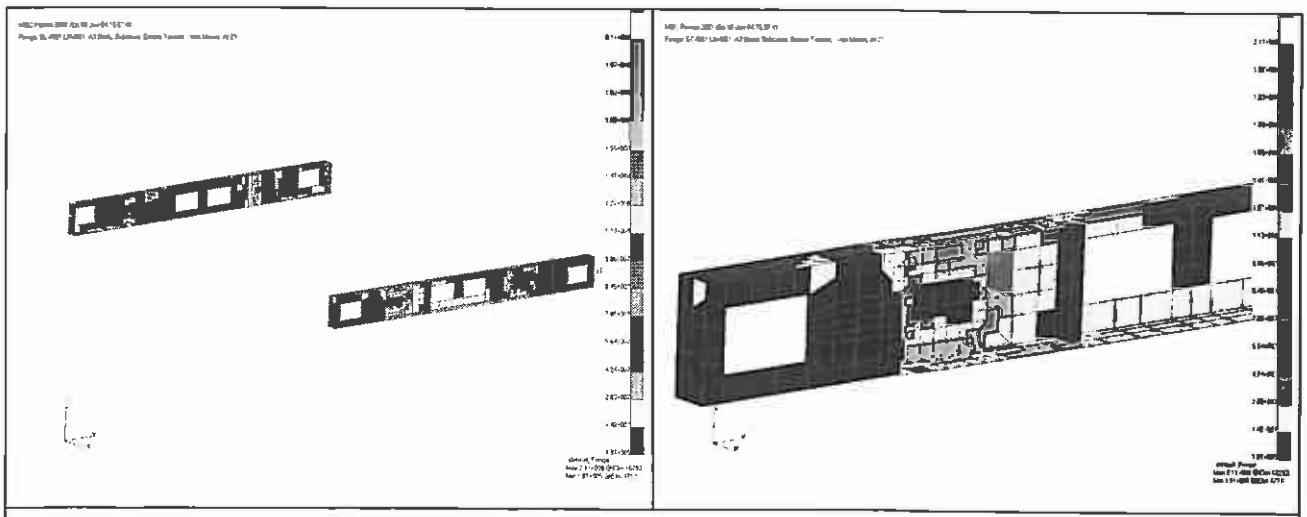

Figure 9-4: Beam A, Load Case 4061, Layer Z1

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9.2.2 BEAM B

The worst condition is for **ELEMENT 15035** for **Load Case 4062** at **Layer Z2**.
The resulting Von Mises stress is: **f_{VM} = 234 MPa**.
Following figure shows stress distribution for this subcase.

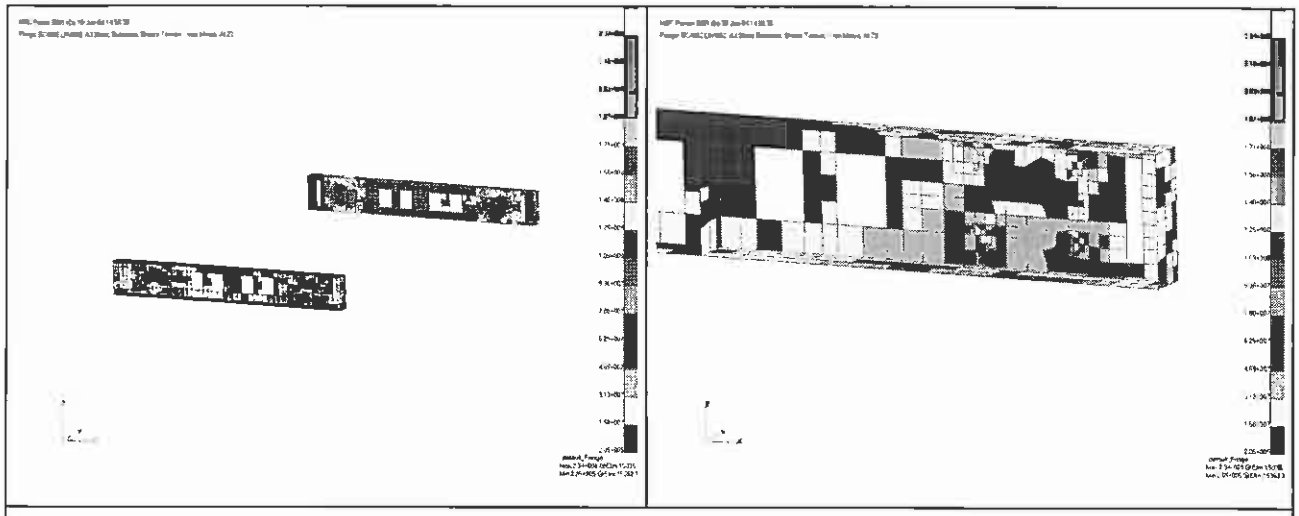

Figure 9-5: Beam B, Load Case 4062, Layer Z2

The high value of stress is due to the presence of the rigid connection elements. The VM verification is performed erasing the elements near the connection and additional Bearing verifications (see 9.3.1) is performed using connection bolt shear force.

The worst condition is for **ELEMENT 14903** for **Load Case 1056** at **Layer Z2**.
The resulting Von Mises stress is: **f_{VM} = 206 MPa**.
Following figure shows stress distribution for this subcase.

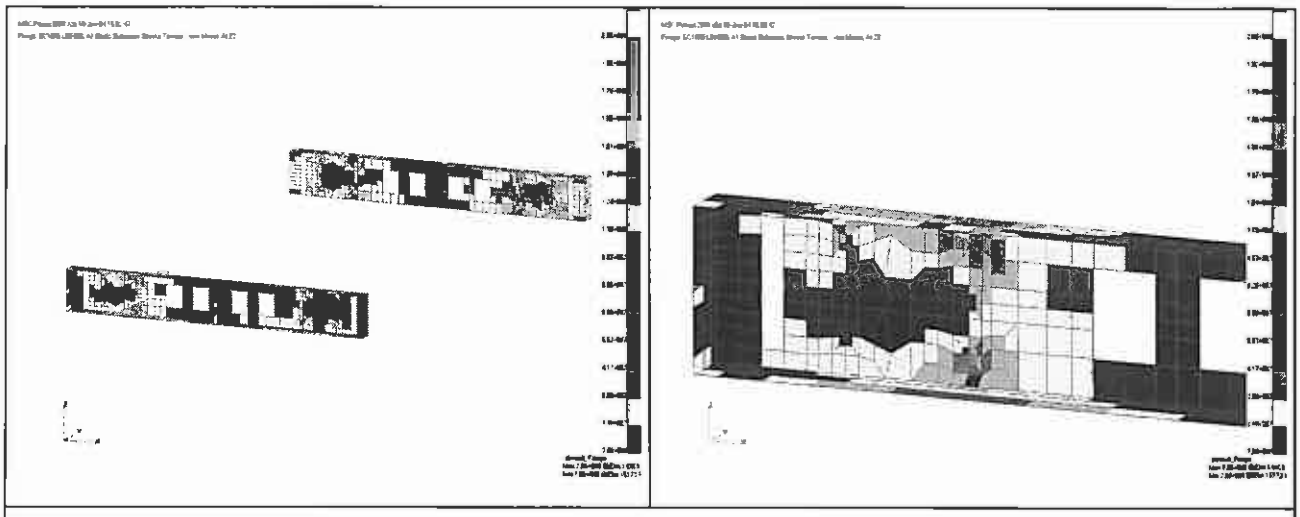

Figure 9-6: Beam B, Load Case 1056, Layer Z2

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9.2.3 CORNER BEAM

The worst condition is for **ELEMENT 17785** for **Load Case 4015** at **Layer Z1**.
The resulting Von Mises stress is: **f_{VM} = 76 MPa**.
Following figures show stress distribution for this subcase.

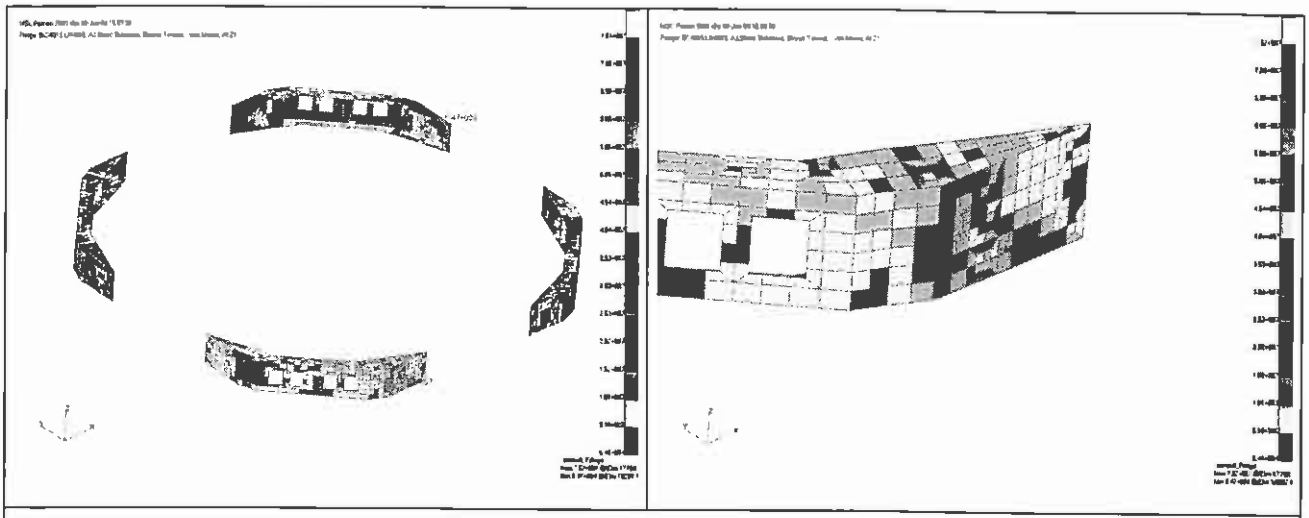

Figure 9-7: Corner beam, Load Case 4015, Layer Z1

9.2.4 UPPER BRACKET

The worst condition is for **ELEMENT 2446** for **Load Case 4031** at **Layer Z1**.
The resulting Von Mises stress is: **f_{VM} = 74 MPa**.
Following figure shows stress distribution for this subcase.

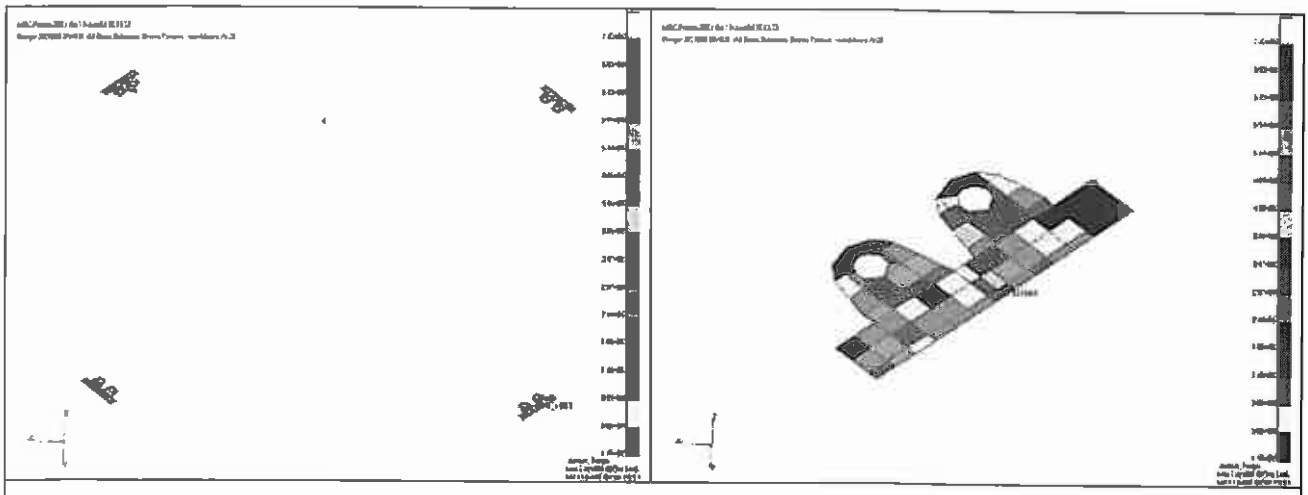

Figure 9-8: Upper bracket, Load Case 4031, Layer Z1

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9.2.5 LOWER BRACKET

The worst condition is for **ELEMENT 2111** for **Load Case 4045** at **Layer Z1.**
The resulting Von Mises stress is: **f_{VM} = 69 MPa**.
Following figure shows stress distribution for this subcase.

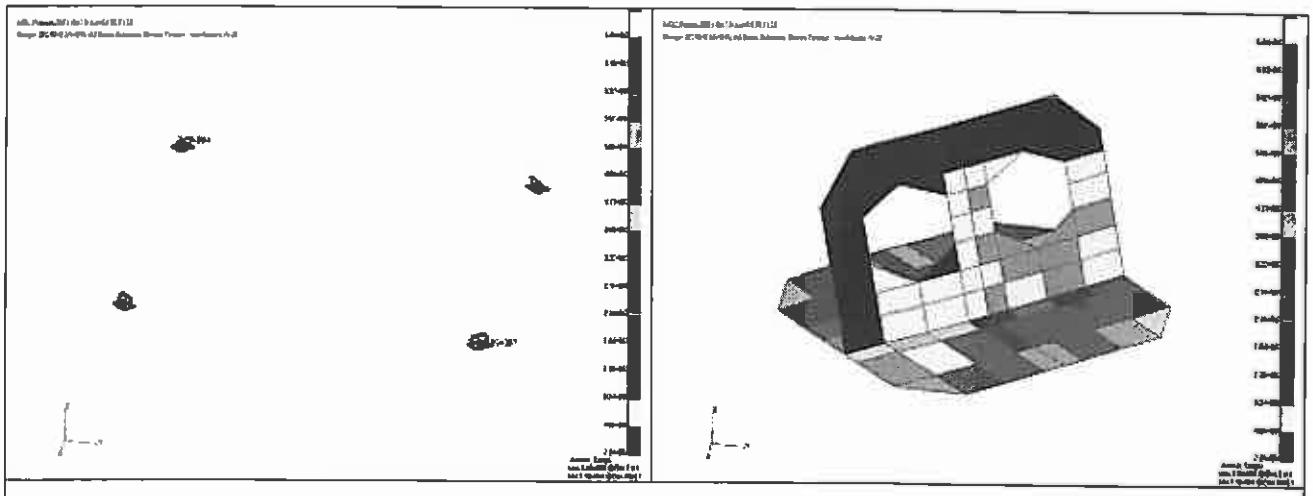

Figure 9-9: Lower bracket, Load Case 4045, Layer Z1

9.2.6 RING BRACKET

The worst condition is for **ELEMENT 14819** for **Load Case 4028** at **Layer Z2.**
The resulting Von Mises stress is: **f_{VM} = 92 MPa**.
Following figure shows stress distribution for this subcase.

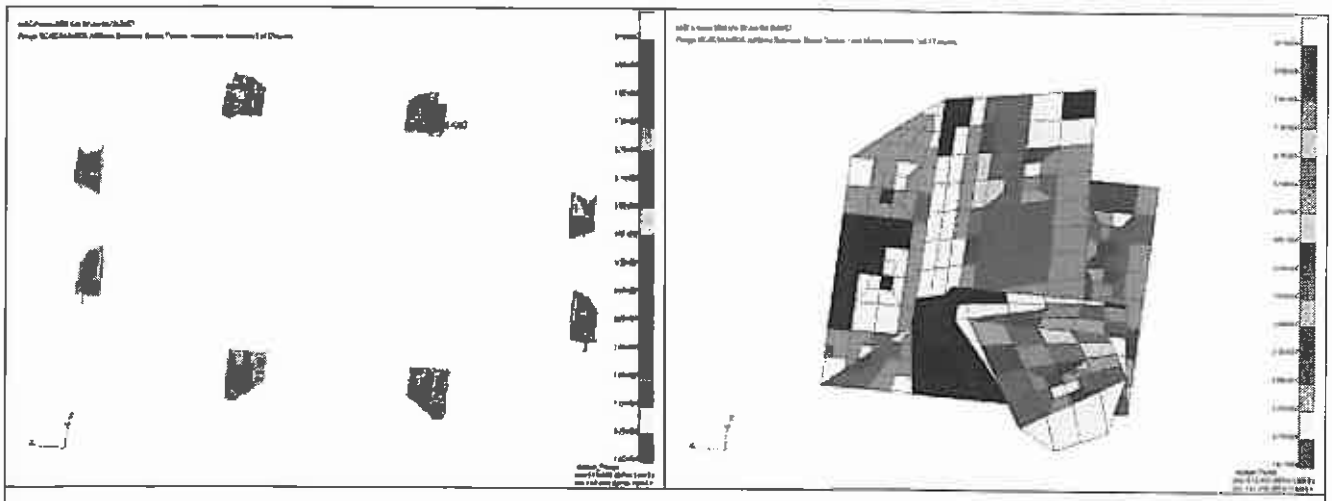

Figure 9-10: Ring bracket, Load Case 4028, Layer Z2

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9.2.7 RODS

The worst condition is for **ELEMENT 4798** for **Load Case 4031.**
The resulting stress is: **f = 101 MPa.**
Following figure shows stress distribution for this subcase.

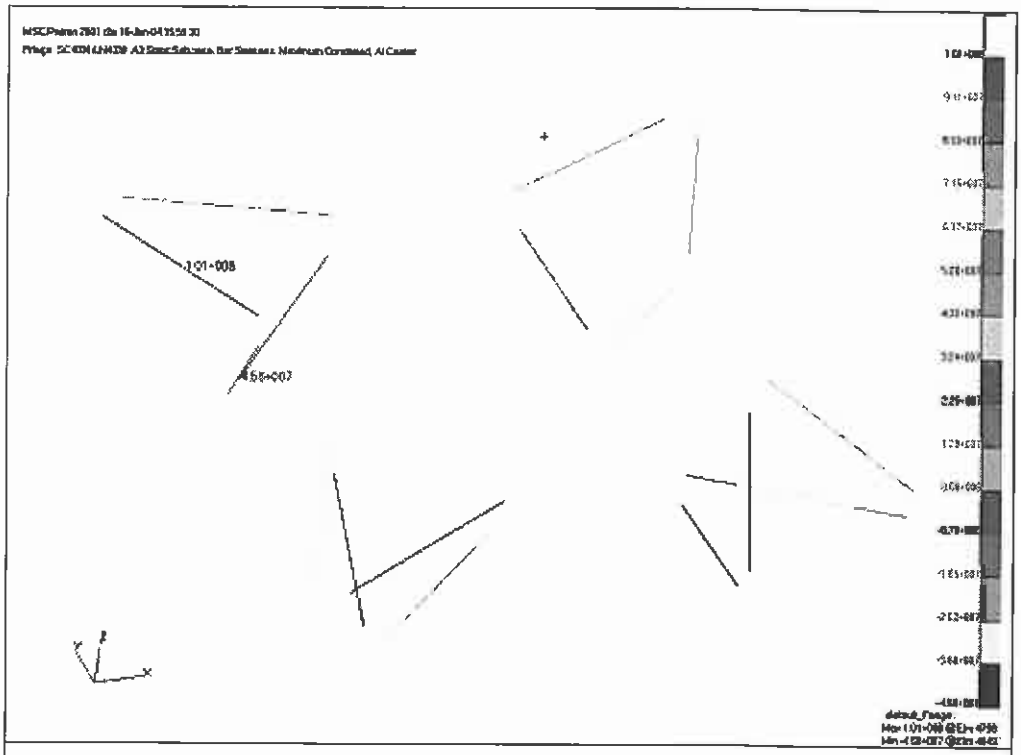

Figure 9-11: Rods, Load Case 4031

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9.2.8 HONEYCOMB SKINS

The worst condition is for **ELEMENT 4982** for **Load Case 1017** at **Layer Z2.**
The resulting Von Mises stress is: **f_{VM} = 44.8 MPa**.
Following figure shows stress distribution for this subcase.

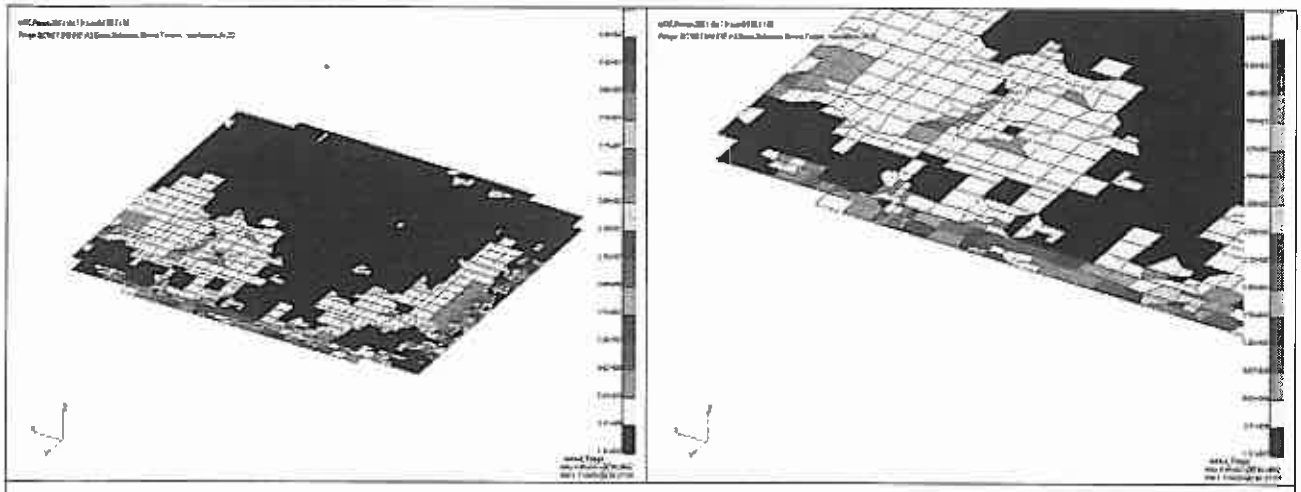

Figure 9-12: Honeycomb skins, Load Case 1017, Layer Z2

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9.2.9 INTERNAL HONEYCOMB SKINS

9.2.9.1 X Y XY STRESS COMPONENT FOR INTRACELL BUCKLING VERIFICATION

The worst combination of σ_X σ_Y τ_{XY} is for **ELEMENT 4952** for **Load Case 1027.**
The resulting of the components for this element are:
σ_X **= -3.4 MPa**.
σ_Y **= 26.8 MPa**
τ_{XY} **= -4.9 MPa**.
Following figure shows stress distribution for. σ_Y case. The max σ_Y value correspond to element 4952

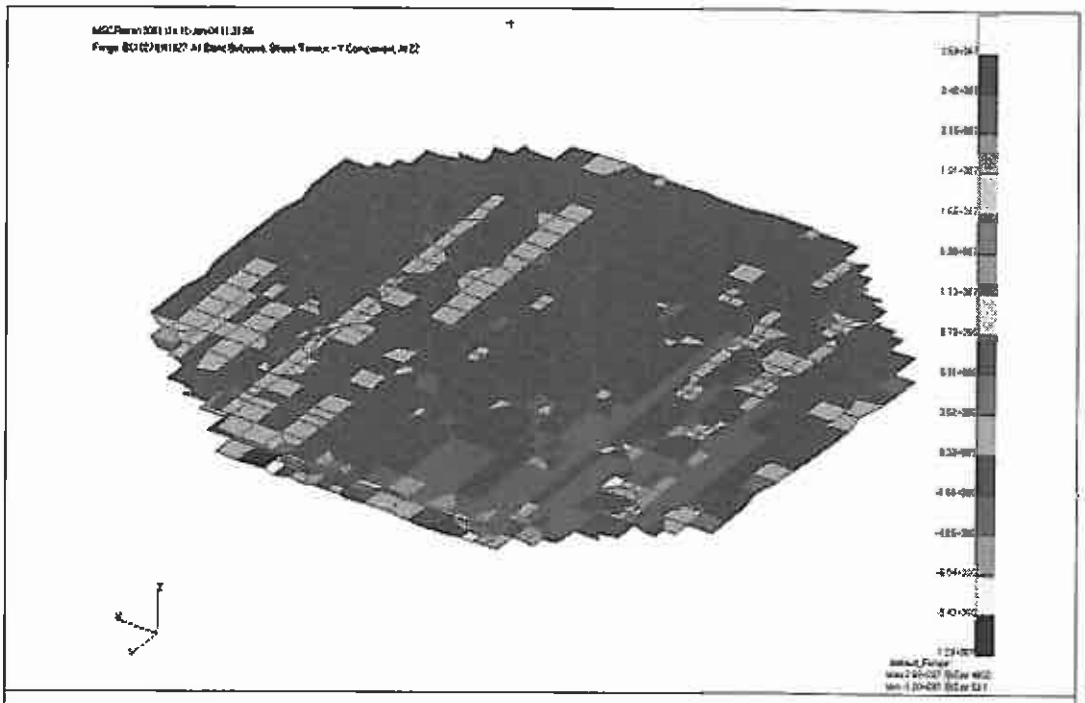

Figure 9-13: Honeycomb skins, Load Case 1027

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9.2.9.2 X Y XY STRESS COMPONENT FOR WRINKLING VERIFICATION

The worst combination of σ_X σ_Y τ_{XY} is for **ELEMENT 27498** for **Load Case 4027**
The resulting of the components for this element are:
σ_X **= -25 MPa.**
σ_Y **= -9.5 MPa**
τ_{XY} **= 6.9 MPa.**
Following figure shows stress distribution for. σ_X case. The min σ_X value correspond to element 27498

Figure 9-14: Honeycomb skins, Load Case 4027

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9.2.10 EXTERNAL HONEYCOMB SKINS

9.2.10.1 X Y XY STRESS COMPONENT FOR INTRACELL BUCKLING VERIFICATION

The worst combination of σ_X σ_Y τ_{XY} is for **ELEMENT 28156** for **Load Case 4046.**
The resulting of the components for this element are:
σ_X **= -31.7 MPa.**
σ_Y **= -10.2MPa**
τ_{XY} **= -7.8 MPa.**
Following figure shows stress distribution for. σ_x case. The min σ_x value correspond to element 28156

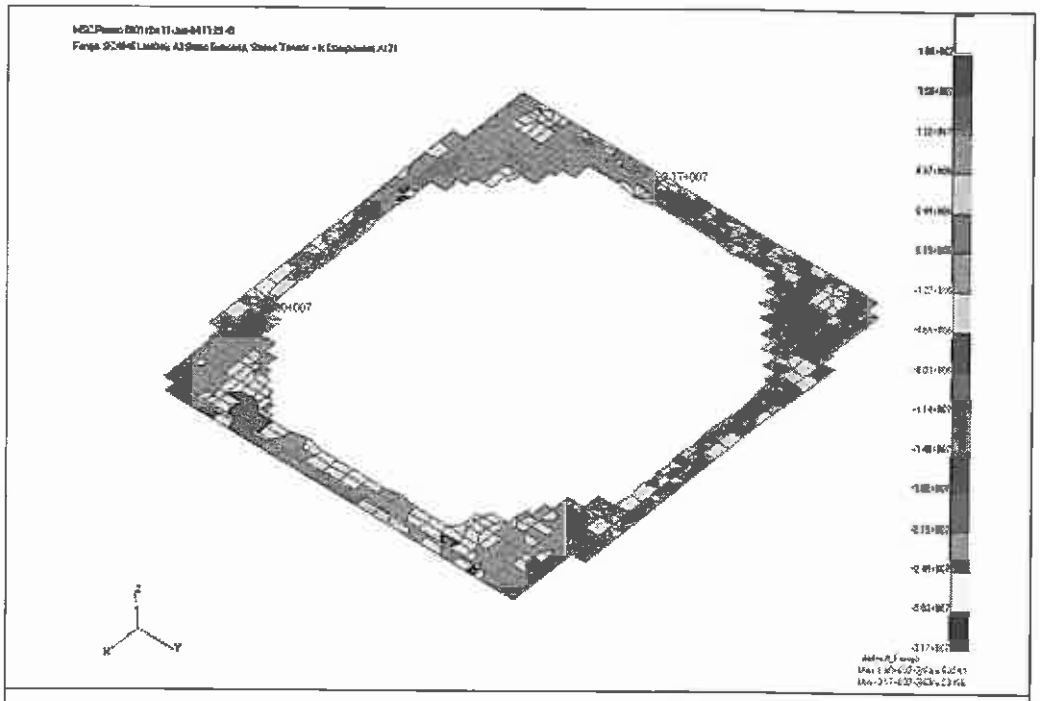

Figure 9-15: Honeycomb skins, Load Case 4046

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9.2.10.2 X Y XY STRESS COMPONENT FOR WRINKLING VERIFICATION

The worst combination of σ_X σ_Y τ_{XY} is for **ELEMENT 28156** for **Load Case 4046.**
The resulting of the components for this element are:
σ_X **= -31.7 MPa**.
σ_Y **= -10.2MPa**
τ_{XY} **= -7.8 MPa**.
Following figure shows stress distribution for. σ_x case. The min σ_x value correspond to element 28156

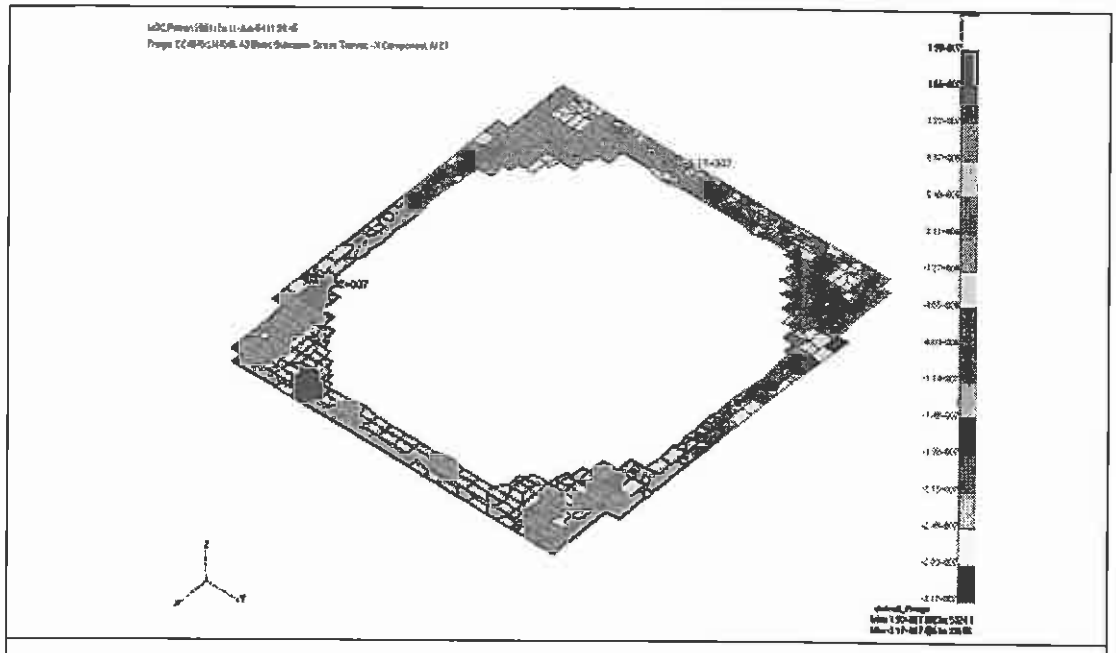

Figure 9-16: Honeycomb skins, Load Case 4046

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9.2.11 SENSOR BOXES BRACKETS PLATE

The worst condition is for **ELEMENT 21696** for **Load Case 4058** at **Layer Z2.**
The resulting Von Mises stress is: f_{VM} **= 54 MPa**.
Following figure shows stress distribution for this subcase.

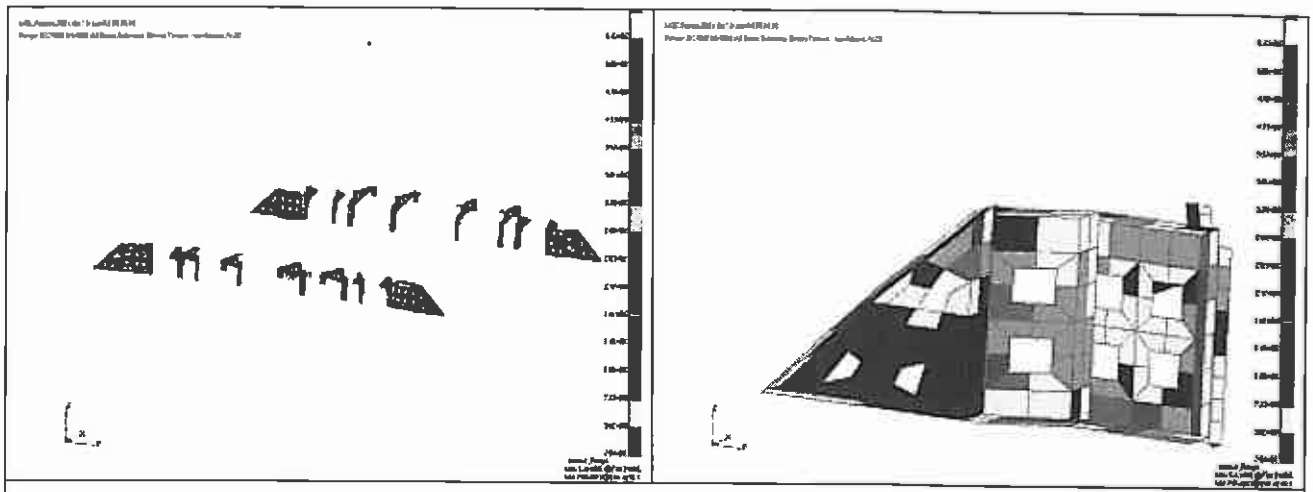

Figure 9-17: Sensor boxes brackets plate, Load Case 4058, Layer Z2

9.2.12 SENSOR BOXES BRACKETS BAR

The worst condition is for **ELEMENT 22632** for **Load Case 1028.**
The resulting stress is: f_{MC} **= 123 MPa**.
Following figure shows stress distribution for this subcase.

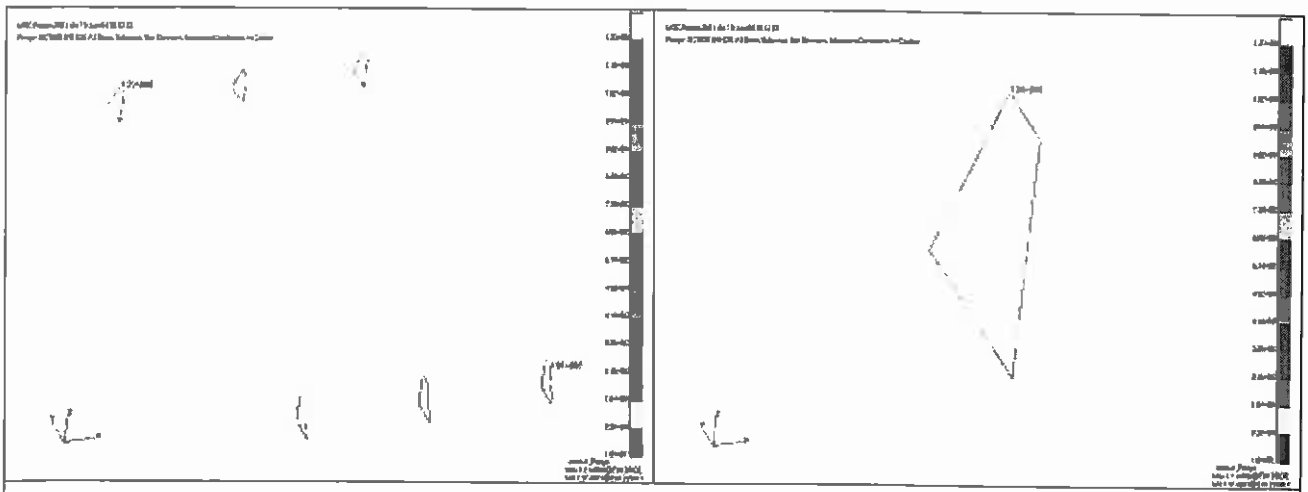

Figure 9-18: Sensor boxes brackets bar, Load Case 1028,

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9.2.13 PMT HORIZONTAL SUPPORT

The worst condition is for **ELEMENT 21271** for **Load Case 4054** at **Layer Z1**.
The resulting Maximum Combined stress is: **f_{VM} = 28 MPa.**
Following figure shows stress distribution for this subcase.

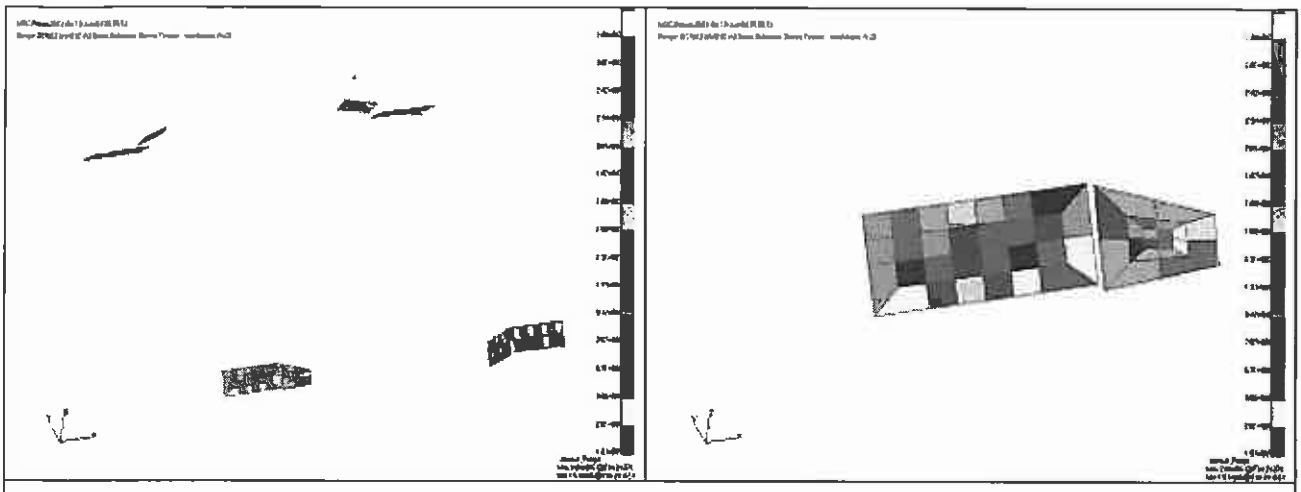

Figure 9-19: PMT horizontal support, Load Case 4054

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9.2.14 SENSOR BOXES

9.2.14.1 X STRESS COMPONENT

The min σ_x condition is for **ELEMENT 21043** for **Load Case 4045** at **Layer 3.**
The resulting stress is: σ_X **= -67 MPa**.
Following figure shows stress distribution for this subcase.

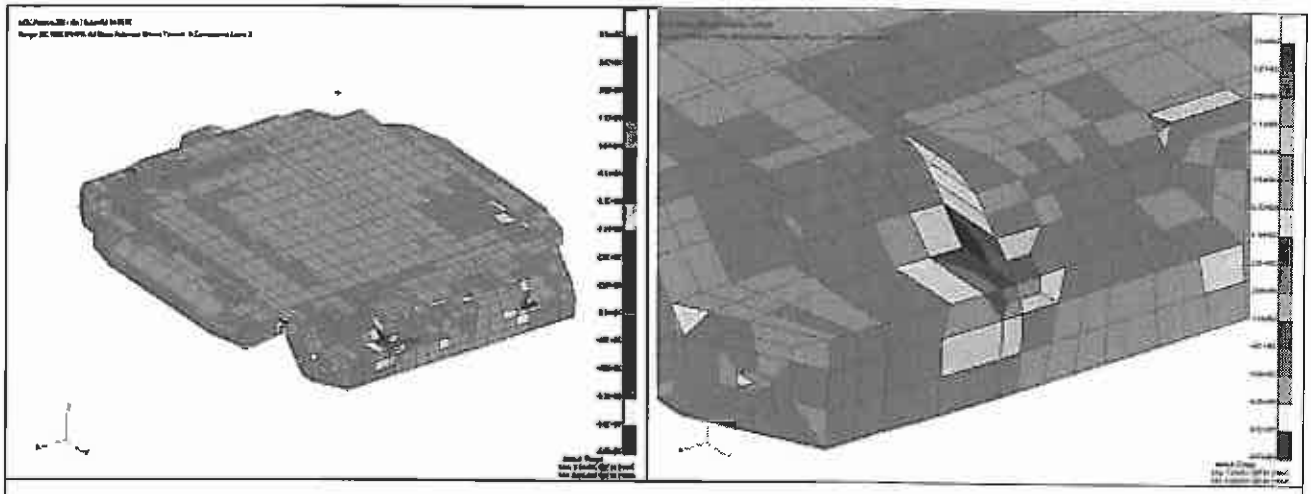

Figure 9-20: Sensor boxes X component, Load Case 4045, Layer 3

9.2.14.2 Y STRESS COMPONENT

The max σ_y condition is for **ELEMENT 21043** for **Load Case 4032** at **Layer 1.**
The resulting stress is: σ_Y **= 68 MPa**.
Following figure shows stress distribution for this subcase.

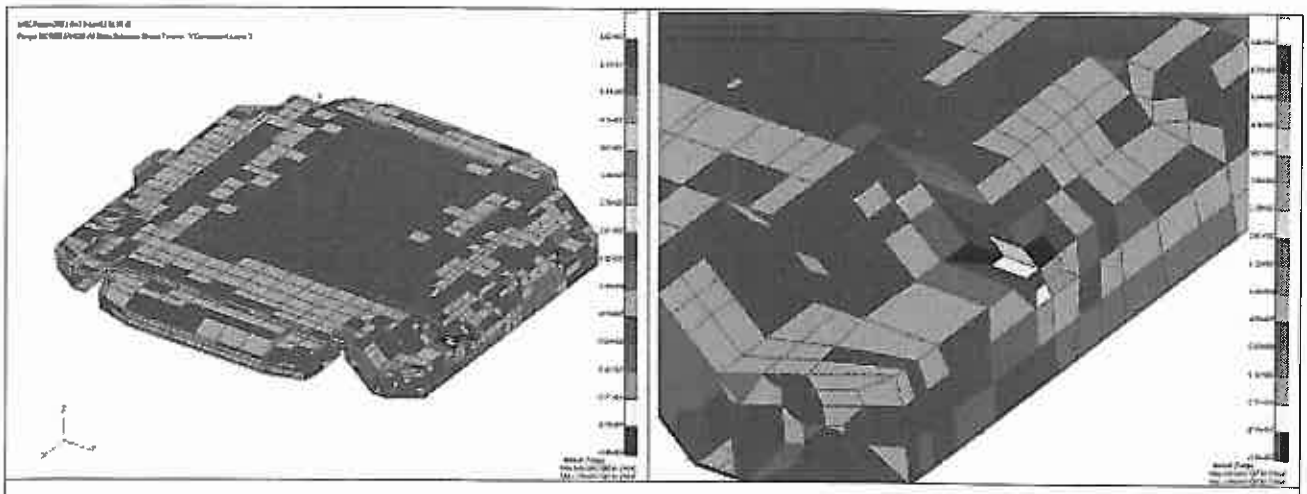

Figure 9-21: Sensor boxes Y component, Load Case 4032, Layer 1

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9.2.14.3 XY STRESS COMPONENT

The max τ_{xy} is for **ELEMENT 6935** for **Load Case 1015** at **Layer 3.**
The resulting stress is: τ_{XY} **= 27 MPa**.
Following figure shows stress distribution for this subcase.

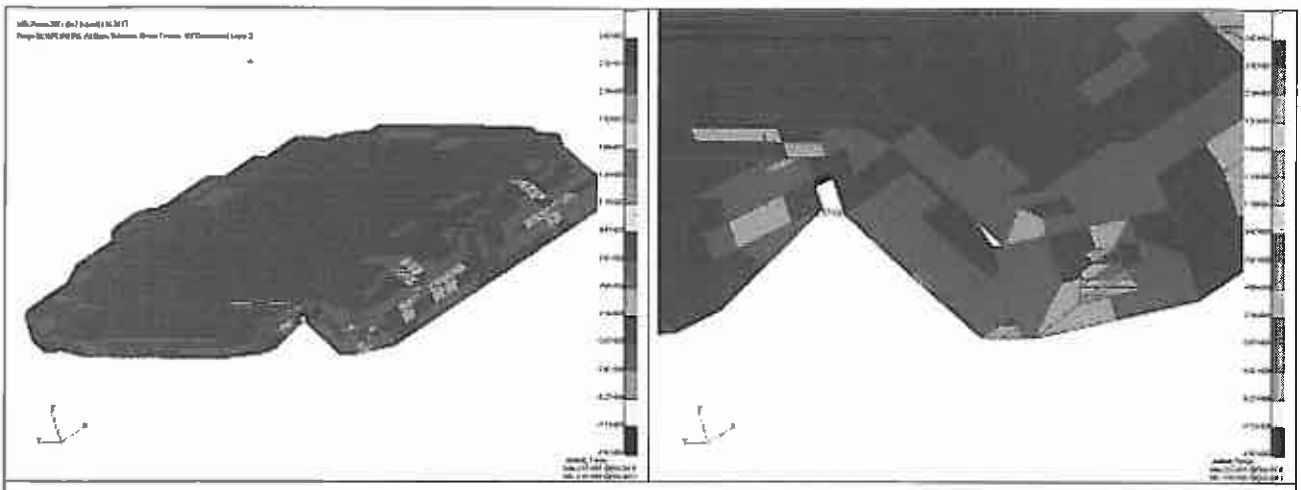

Figure 9-22: PMT horizontal support core, Load Case 1015, Layer 3

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9.2.15 SCINTILLATOR COVERS

9.2.15.1 X STRESS COMPONENT

The min σ_x condition is for **ELEMENT 10150** for **Load Case 4045** at **Layer 1.**
The resulting stress is: σ_X **= -8.4 MPa**.
Following figure shows stress distribution for this subcase.

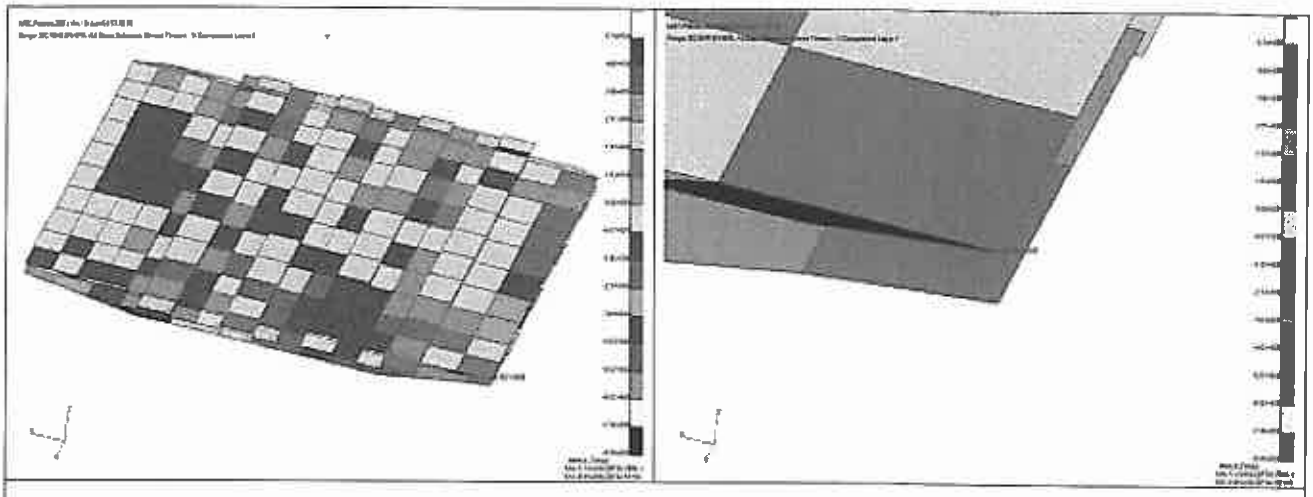

Figure 9-23: Scintillator covers X component, Load Case 4045, Layer 1

9.2.15.2 Y STRESS COMPONENT

The max σ_y condition is for **ELEMENT 10289** for **Load Case 4032** at **Layer 2.**
The resulting stress is: σ_Y **= 8.9 MPa**.
Following figure shows stress distribution for this subcase

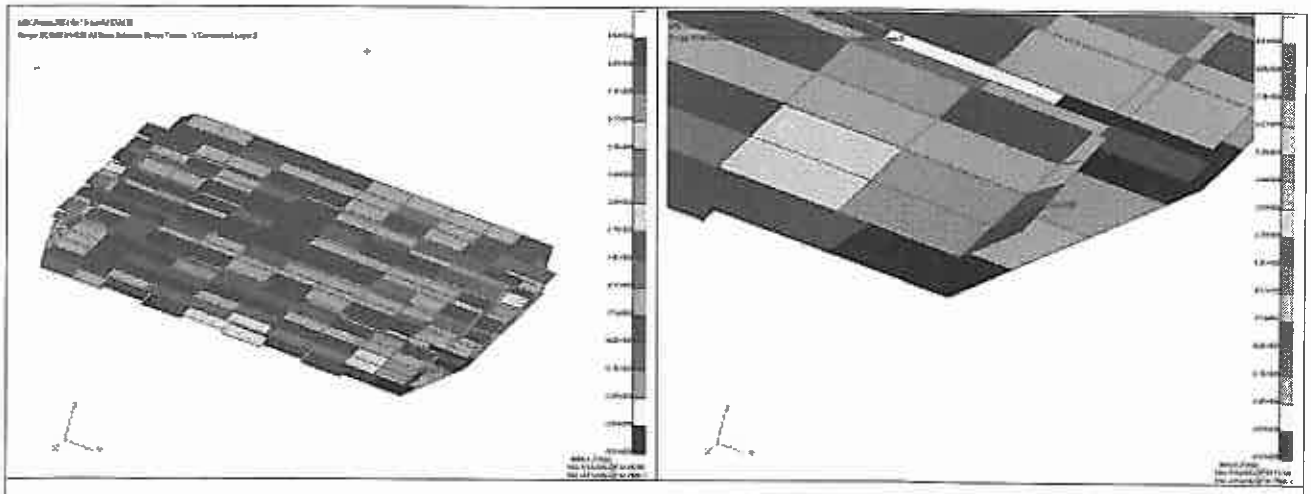

Figure 9-24: Scintillator covers Y component, Load Case 4032, Layer 2

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9.2.15.3 XY STRESS COMPONENT

The max τ_{xy} is for **ELEMENT 10096** for **Load Case 4028** at **Layer 5.**
The resulting stress is: σ_{XY} **= 2.3 MPa**.
Following figure shows stress distribution for this subcase.

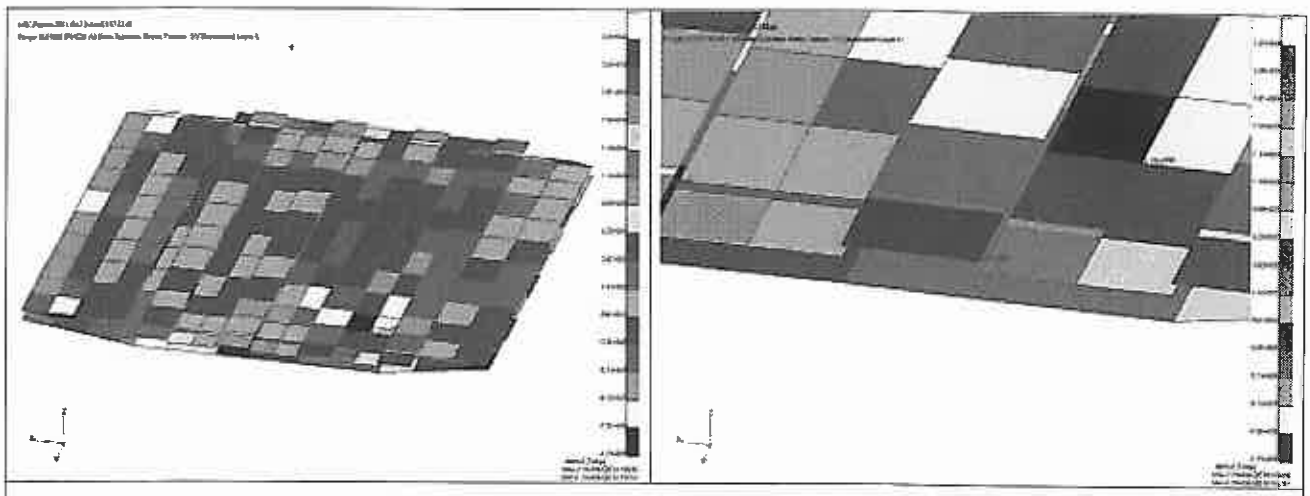

Figure 9-25: Scintillator covers XY component, Load Case 4028, Layer 5

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9.2.16 BOXES/PMT SUPPORT

9.2.16.1 X STRESS COMPONENT

The max σ_x condition is for **ELEMENT 20967** for **Load Case 4058** at **Layer1**
The resulting stress is: σ_X **= 96 MPa**.
Following figure shows stress distribution for this subcase.

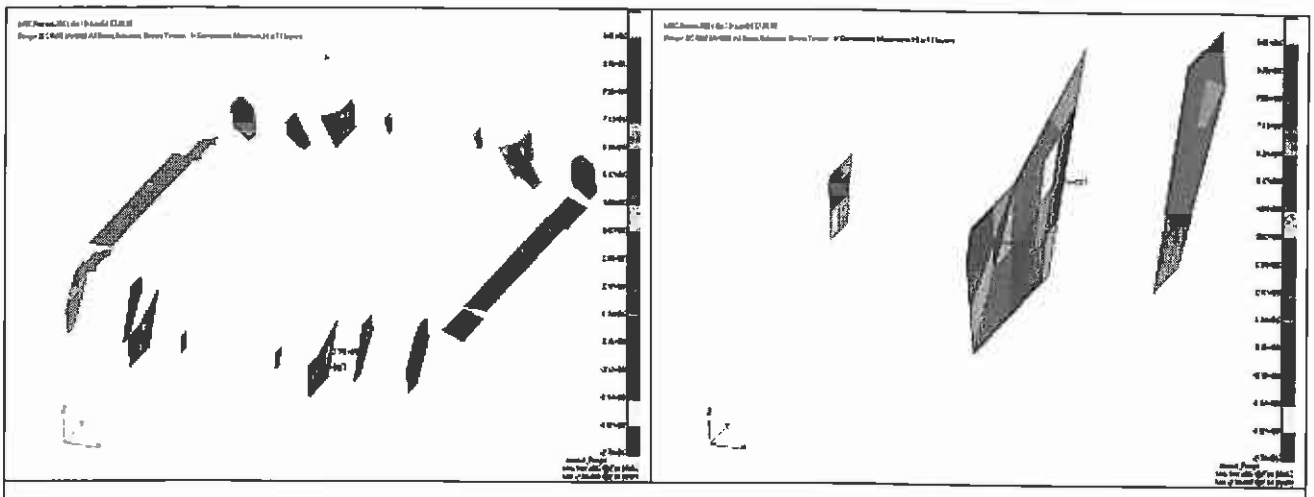

Figure 9-26: Boxes/PMT support X component, Load Case 4058 Layer1

9.2.16.2 Y STRESS COMPONENT

The min σ_y condition is for **ELEMENT 21069** for **Load Case 4045** at Layer3
The resulting stress is: σ_Y **= -120 MPa**.
Following figure shows stress distribution for this subcase

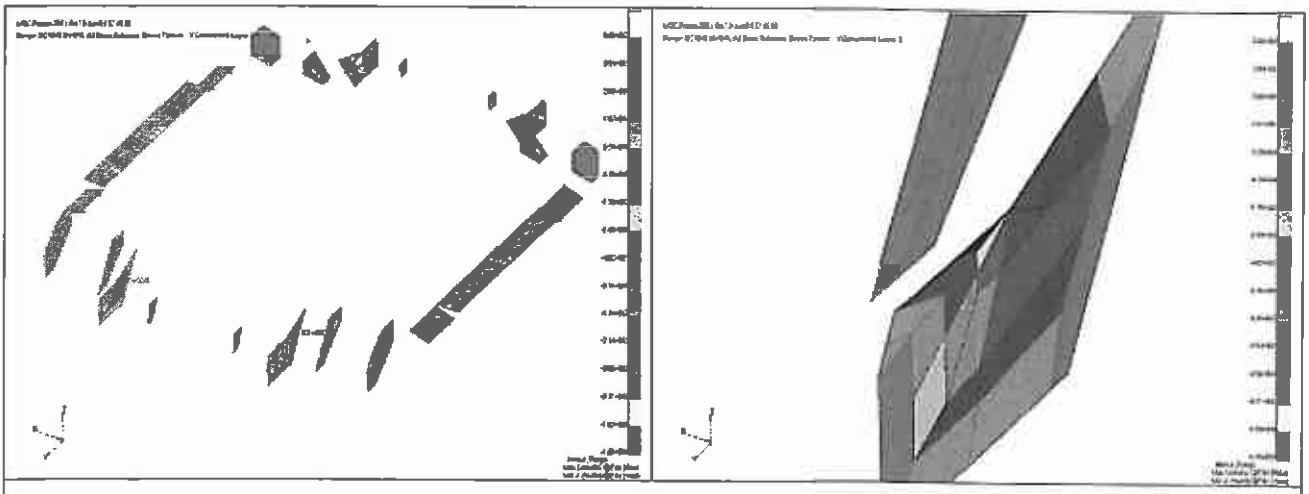

Figure 9-27: Boxes/PMT support Y component, Load Case 4045 Layer3

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9.2.16.3 XY STRESS COMPONENT

The min τ_{xy} is for **ELEMENT 20957** for **Load Case 1024** at **Layer1.**
The resulting stress is: σ_{XY} **= -24 MPa.**
Following figure shows stress distribution for this subcase.

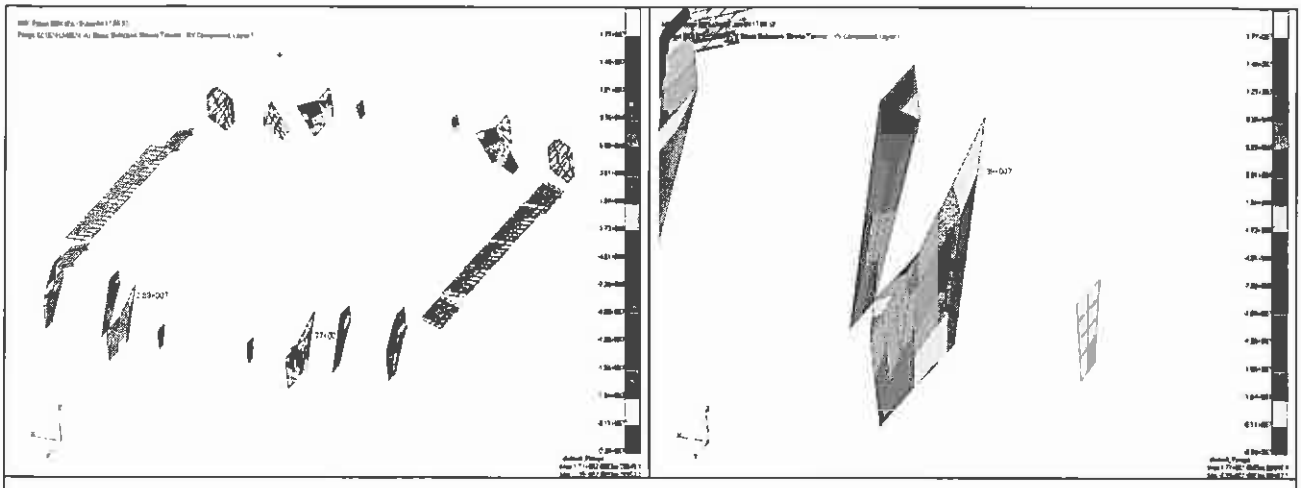

Figure 9-28: Boxes/PMT support XY component, Load Case 1024 Layer1

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9.2.17 SCINTILLATORS SUPPORTS

For the analysis of the scintillators supports the following method is used:

- Take the forces acting on the items that model the scintillators supports from the analysis of the entire FEM (see chapter 9.3.5).
- Create a FE Model of the scintillators supports.
- Apply the forces to the new scintillators supports model.
- Verify the stress of the scintillators supports.

From the FEM analysis the forces obtained are:

- 212 N in axial direction
- 742 N in transverse direction

in the following figure the entire set of scintillators supports is presented:

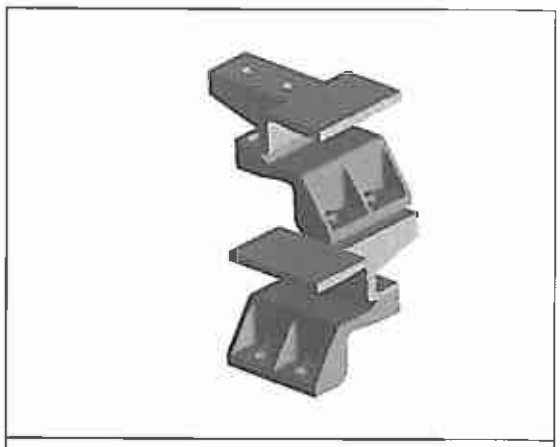

Figure 9-29: Scintillator supports CAD Model

Every couple of Support there is the Scintillator Covers (made in CFRP); only a couple of them is verified: in the following figure the FE Model of the couple scintillators supports is presented:

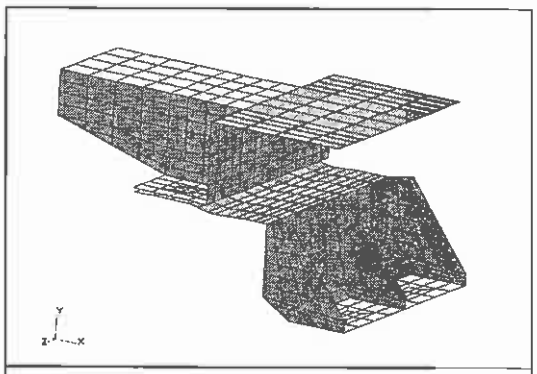

Figure 9-30: Scintillator supports FE Model

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The constrains model the connection between the two scintillator covers and the forces are applied uniformly on the parts of the structure in contact with the two scintillators (see following figure). The forces acting on every parts of the couple are: 212 axial and 742 transverse.

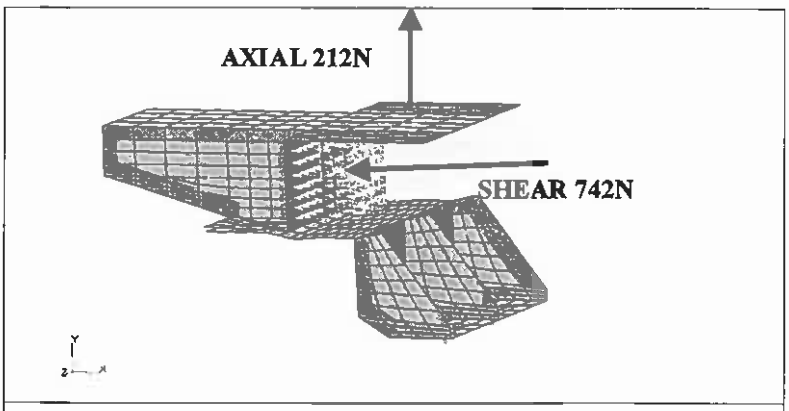

Figure 9-31: Scintillator Supports Constrains And Applied Forces

The resulting X component stress for the min σ_x condition is: σ_X **= 120 MPa**.
Following figure shows the deformation and the stress distribution.

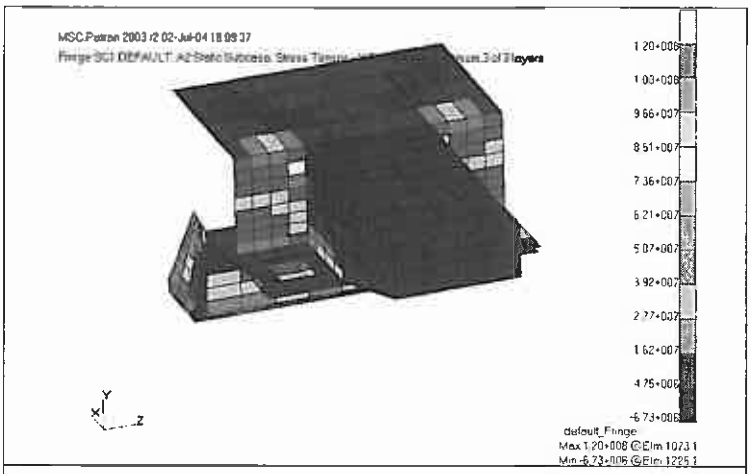

Figure 9-32: Scintillators support X component, element 1413

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The resulting Y component stress for the max σ_y condition is: σ_Y **= 210 MPa**.
Following figure shows the deformation and the stress distribution.

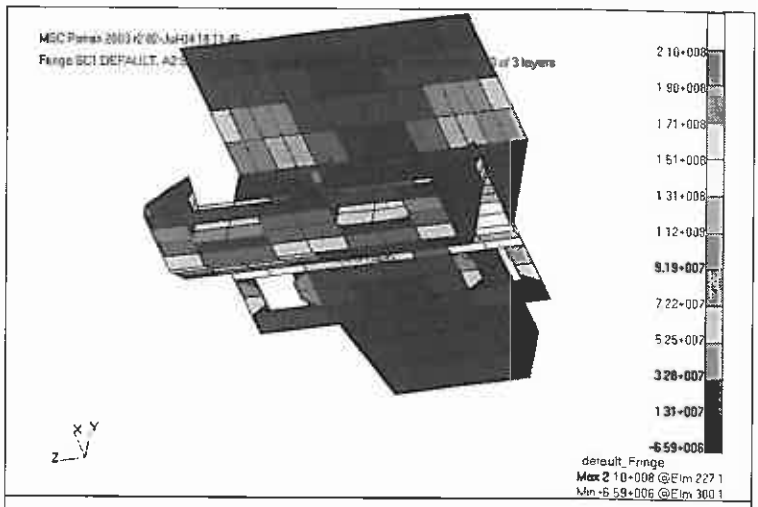

Figure 9-33: Scintillators support Y component, element 1027

The resulting XY component stress for the max τ_{xy} is: τ_{XY} **= 41 MPa**.
Following figure shows the deformation and the stress distribution.

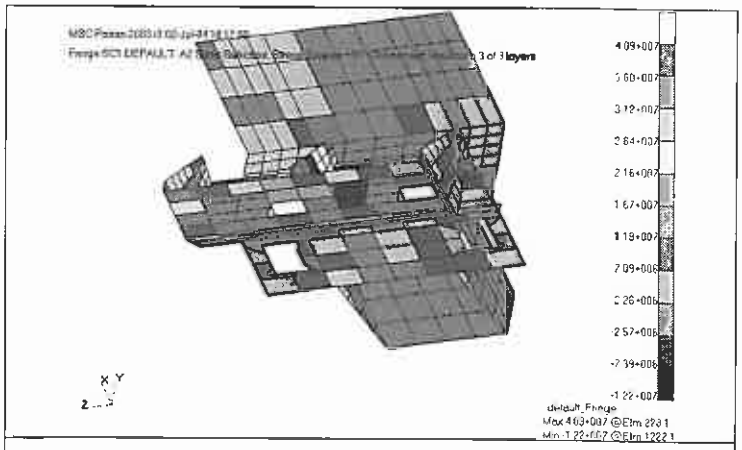

Figure 9-34: Scintillators support X component, element 361

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9.2.18 HONEYCOMB CORE INTERNAL

9.2.18.1 Z COMPONENT

The worst condition is for **ELEMENT 26681** for **Load Case 4041.**
The resulting stress is: σ_Z **= 0.11 MPa**.
Following figure shows stress distribution for this subcase.

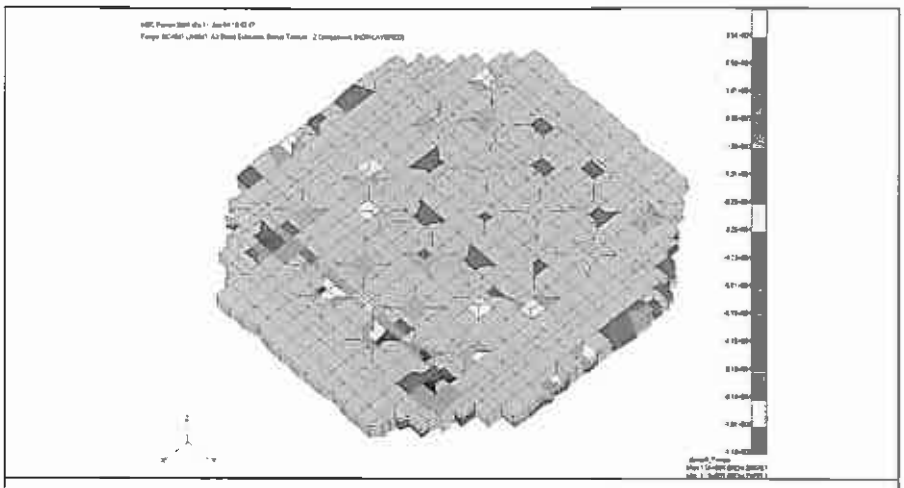

Figure 9-35: Honeycomb core internal Z component, Load Case 4041

9.2.18.2 XZ COMPONENT

The worst condition is for **ELEMENT 26433** for **Load Case 1020.**
The resulting stress is: τ_{XZ} **= 0.0014 MPa**.
Following figure shows stress distribution for this subcase.

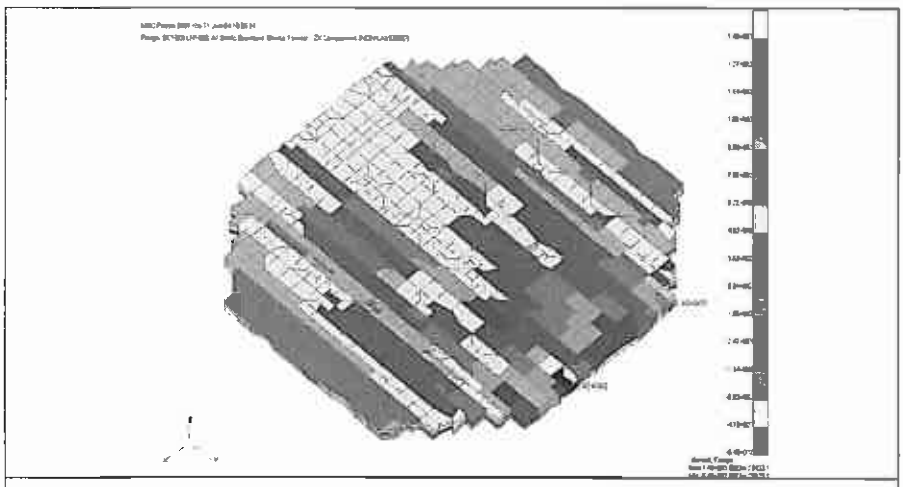

Figure 9-36: Honeycomb core internal XZ component, Load Case 1020

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9.2.18.3 ZY COMPONENT

The worst condition is for **ELEMENT 26683** for **Load Case 4042**
The resulting stress is: τ_{ZY} **= 0.13 MPa**.
Following figure shows stress distribution for this subcase.

Figure 9-37: Honeycomb core internal ZY component, Load Case 4042

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9.2.19 HONEYCOMB CORE EXTERNAL

9.2.19.1 Z COMPONENT

The worst condition is for **ELEMENT 26933** for **Load Case 4045.**
The resulting stress is: σ_Z **= 0.4335 MPa.**
Following figure shows stress distribution for this subcase.

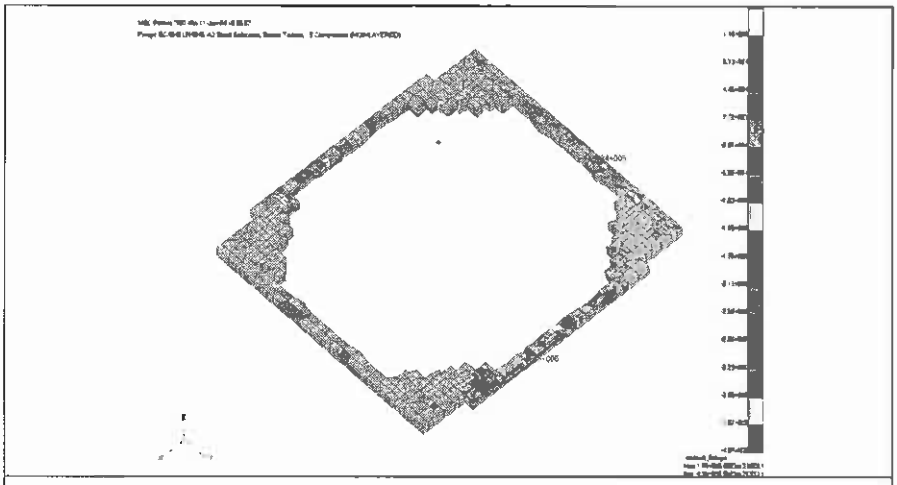

Figure 9-38: Honeycomb core external Z component, Load Case 4045

9.2.19.2 XZ COMPONENT

The worst condition is for **ELEMENT 23819** for **Load Case 1032.**
The resulting stress is: τ_{XZ} **= 0.0030 MPa**.
Following figure shows stress distribution for this subcase.

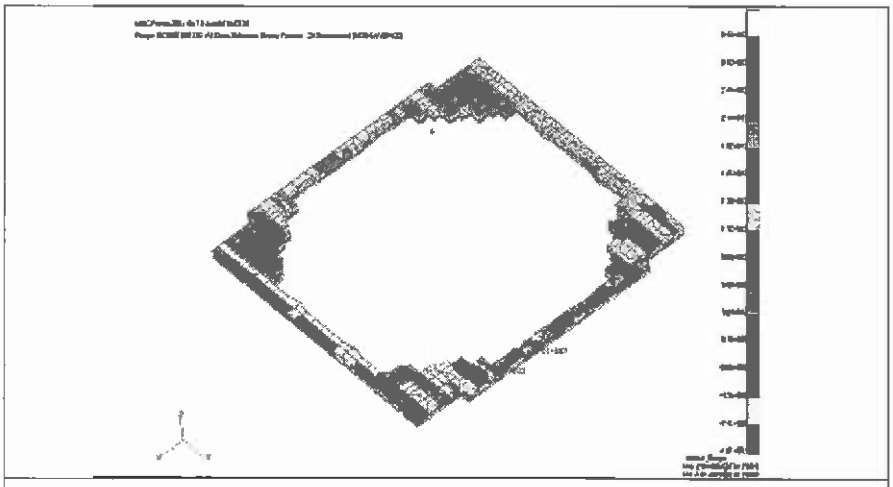

Figure 9-39: Honeycomb core external XZ component, Load Case 1032

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9.2.19.3 ZY COMPONENT

The worst condition is for **ELEMENT 26911** for **Load Case 4058**
The resulting stress is: τ_{ZY} **= 0.32 MPa**.
Following figure shows stress distribution for this subcase.

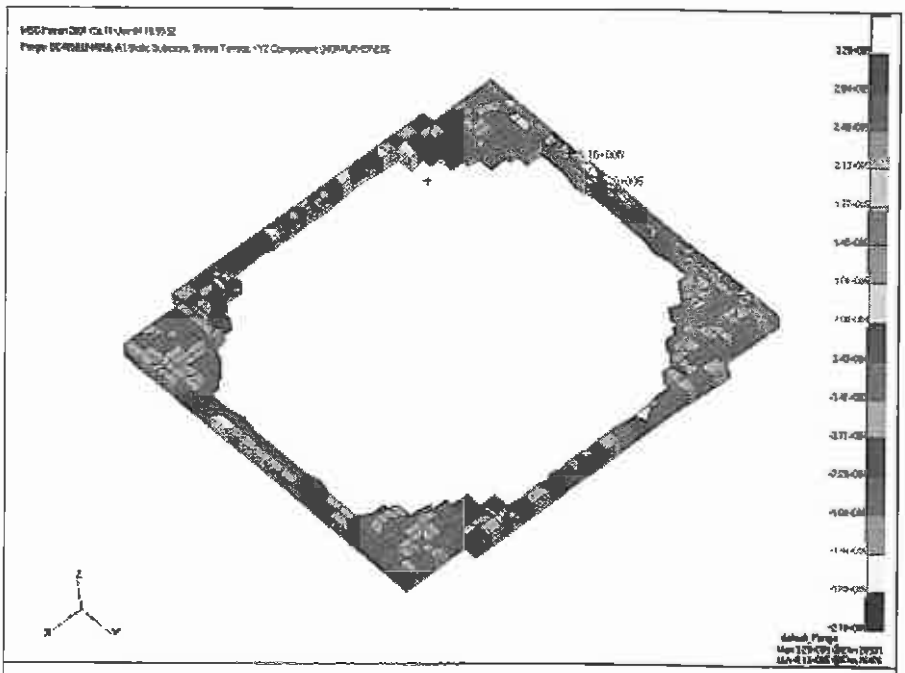

Figure 9-40: Honeycomb core external ZY component, Load Case 4058

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9.2.20 MARGINS OF SAFETY

In the following tables MoS of the entire structure are shown:

MARGINS OF SAFETY FOR STRENGHT FAILURE													
ITEM	PART NUMBER	LC	EID	MATERIAL	F_{ty} [MPa]	F_{tu} [MPa]	Limit stress [MPa]	$S.F._y$	$S.F._u$	MoS_y	MoS_u	REMARKS	REFERENCE PAGE
BEAM A	ams TOF 04-01-001 LT	4061 (Layer Z1)	16293	7075 T7351	369	441	211	1,25	2	**0,40**	**0,05**	VM	52
BEAM B	ams TOF 04-01-002 LT	1056 (Layer Z2)	14903	7075 T7351	369	441	206	1,25	2	**0,43**	**0,07**	VM	53
CORNER BEAM	ams TOF 04-01-003 LT	4015 (Layer Z1)	17785	7075 T7351	369	441	76	1,25	2	**>2**	**1,90**	VM	54
UPPER BRACKET	ams TOF 04-01-021 LT	4031 (Layer Z1)	2446	7075 T7351	369	441	74	1,25	2	**>2**	**1,98**	VM	54
LOWER BRACKET	ams TOF 04-01-020 LT	4045 (Layer Z1)	2111	7075 T7351	369	441	69	1,25	2	**>2**	**>2**	VM	55
INTERNAL BRACKET	ams TOF 04-01-018 LT ams TOF 04-01-019 LT	4028 (Layer Z2)	14819	7075 T7351	369	441	92	1,25	2	**>2**	**1,40**	VM	55
RODS	ams TOF 04-01-01-001 LT ams TOF 04-01-02-001 LT	4031	4798	7075 T7351	369	441	101	1,25	2	**1,93**	**1,18**	MC	56
HONEYCOMB SKINS	ams TOF 04-02-001 LT ams TOF 04-02-002 LT	1017 (Layer Z2)	4982	Al 2024 T81	376	434	45	1,25	2	**>2**	**>2**	VM	58
SENSOR BOXES BRACKETS PLATE	ams TOF 04-01-011 LT ams TOF 04-01-010 LT ams TOF 04-01-009 LT ams TOF 04-01-008 LT ams TOF 04-01-007 LT ams TOF 04-01-006 LT ams TOF 04-01-005 LT ams TOF 04-01-004 LT	4058 (Layer Z2)	21696	7075 T7351	369	441	54	1,25	2	**>2**	**>2**	VM	62
SENSOR BOXES BRACKETS BAR		1028	22632	7075 T7351	369	441	123	1,25	2	**1,40**	**0,79**	MC	62
PMT HORIZ SUPPORT	ams TOF 05-01 UT ams TOF 05-02 UT	4054 (Layer Z1)	21271	MAKROLON	60	NA	28	1.25	NA	**0,71**	**NA**	VM	63

Table 9-1: MOS STRENGTH

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MARGINS OF SAFETY FOR CFRP FAILURE													
ITEM	PART NUMBER	LC	EID	MATERIAL	F_{tu} [MPa]		Limit stress [MPa]	S.F.$_u$	FAILURE INDEX<1	REMARKS		REFERENCE PAGE
SENSOR BOXES	ams TOF 02-001 LT ams TOF 02-002 LT ams TOF 01-001 LT ams TOF 01-01-001 LT	4045(Layer 3)	21043	CFRP	X COMP	799	-67	2	0,39	MAX X Component	TSAI HILL	64
		4032 (Layer 1)	21043		Y COMP	799	68	2		MAX Y Component		
		1015 (Layer 3)	6935		SHEAR COMP	99	27	2		MAX XY Component		
SCINTILLATORS COVERS	TBD	4045 (Layer 1)	10150	CFRP	X COMP	799	-8,4	2	0,004	MAX X Component	TSAI HILL	66
		4032 (Layer 2)	10289		Y COMP	799	8,9	2		MAX Y Component		
		4028 (Layer 5)	10096		SHEAR COMP	99	2,3	2		MAX XY Component		
BOXES/PMT SUPPORT	ams TOF 05-05-001 UT ams TOF 05-05-002 UT ams TOF 05-05-003 UT ams TOF 05-05-004 UT ams TOF 05-05-005 UT ams TOF 05-05-006 UT	4058 (Layer 1)	20967	CFRP	X COMP	799	96	2	0,46	MAX X Component	TSAI HILL	68
		4045 (Layer 3)	21069		Y COMP	799	-120	2		MAX Y Component		
		1024 (Layer 1)	20957		SHEAR COMP	99	-24	2		MAX XY Component		
SCINTILLATORS SUPPORTS	TBD	NA	NA	CFRP	X COMP	799	120	2	0,89	MAX X Component	TSAI HILL	70
		NA	NA		Y COMP	799	210	2		MAX Y Component		
		NA	NA		SHEAR COMP	99	41	2		MAX XY Component		

Table 9-2: MOS CFRP

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COMBINED LOAD STRENGTH INTERNAL

ITEM	SIZE	ALLOWABLE STRESS CORE			APPLIED STRESS CORE			SF	SHEAR [MPa]		AXIAL [MPa]	MOS	
		SHEAR [MPa]		AXIAL [MPa]	SHEAR [MPa]		AXIAL [MPa]						
		F'SL	F'SW	F'C	F'sL	F'sW	F'c		RsL	RsW	Ra	RsL	RsW
HCOMB	1,8-3/4-25	0.74	0.46	0.95	0.0014	0.1309	0.1100	2	0.004	0.569	0.23	3.04	0.54
					LC1020	LC4042	LC4041						

COMBINED LOAD STRENGTH EXTERNAL

ITEM	SIZE	ALLOWABLE STRESS CORE			APPLIED STRESS CORE			SF	SHEAR [MPa]		AXIAL [MPa]	MOS	
		SHEAR [MPa]		AXIAL [MPa]	SHEAR [MPa]		AXIAL [MPa]						
		F'SL	F'SW	F'C	F'sL	F'sW	F'c		RsL	RsW	Ra	RsL	RsW
HCOMB	1,8-3/4-25	2.30	1.50	1.44	0.0030	0.3201	0.4335	2	0.003	0.427	0.60	0.63	0.18
					LC1032	LC4058	LC4045						

INTRACELL BUCKLING (Biaxial and Shear Loading) INTERNAL

ITEM	Ef [MPa]	Fcy [MPa]	tf [m]	s [m]	Sf	LC	EID	APPLIED STRESS FACE SHEET			MOS
								fx [Mpa]	fy [Mpa]	fs [Mpa]	
HCOMB	72400	400	0.00050	0.0190	2	1027	4952	-3.4	26.8	-4.9	3.15

INTRACELL BUCKLING (Biaxial and Shear Loading) EXTERNAL

ITEM	Ef [MPa]	Fcy [MPa]	tf [m]	s [m]	Sf	LC	EID	APPLIED STRESS FACE SHEET			MOS
								fx [Mpa]	fy [Mpa]	fs [Mpa]	
HCOMB	72400	400	0.00125	0.0032	2	4046	28156	-31.7	-10.2	-7.8	5.18

WRINKLING (Biaxial and Shear Loading) INTERNAL

ITEM	Ef [MPa]	G'c [MPa]	E'c [MPa]	Fcy [MPa]	Sf	LC	EID	APPLIED STRESS FACE SHEET			MOS
								fx [Mpa]	fy [Mpa]	fs [Mpa]	
HCOMB	72400	96	215	400	2	4027	27498	-25.0	-9.5	6.9	5.68

WRINKLING (Biaxial and Shear Loading) EXTERNAL

ITEM	Ef [MPa]	G'c [MPa]	E'c [MPa]	Fcy [MPa]	Sf	LC	EID	APPLIED STRESS FACE SHEET			MOS
								fx [Mpa]	fy [Mpa]	fs [Mpa]	
HCOMB	72400	214	1034	400	2	4046	28156	-31.7	-10.2	-7.8	4.92

Table 9-3: SANDWICH VERIFICATION

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9.3 JOINT ANALYSIS

The analysis of the joints shall be divided in five different kinds of connections:

9.3.1 JOINT 1: BRACKET-RING
9.3.2 JOINT 2: USS/U-BKT
9.3.3 JOINT 3: USS/L-BKT
9.3.4 JOINT 4: RING-HCOMB
9.3.5 JOINT 5: SCINTILLATOR SUPPORTS VERIFICATION
9.3.6 JOINT 6: ROD END

Summary of joint analysis results are shown in 9.3.7 (MOS SUMMARY FOR JOINT ANALYSIS).

The value of Fsy is evaluated according to RD. 1, par. 1.4.6.5.

For each joint, bolt separation has been verified using the maximum axial force acting on the bolts .
Other MoS have been calculated using the worst load case for the most loaded bolt (where most loaded means that the forces acting on the selected bolts results in lower MoS, with respect to other bolts).

Used formulas are shown in Annex 1.

Also a Fail Safe analysis of bolts have been made; Summary of joint analysis results for Fail Safe configuration are shown in paragraph 9.3.8 .

The MoS definition for bolts analysis is reported in the next table.

MOS	DESCRIPTION
MoSCombU	Margin of Safety for Combined load (Tension and shear) on bolt Ultimate
MoSsep	Margin of Safety for separation
MoSBRY	Margin of Safety for Bearing Yield
MoSBRU	Margin of Safety for Bearing Ultimate
MoS LugTy	Margin of Safety for Tension failure on Lug Yield
MoS LugTu	Margin of Safety for Tension failure on Lug Ultimate
MoS LugSy	Margin of Safety for Shear out failure on Lug Yield
MoS LugSu	Margin of Safety for Shear out failure on Lug Ultimate

Table 9-4: MoS definition for bolt analysis

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9.3.1 JOINT 1: BRACKET-RING

L-TOF bracket-ring joints are NAS 1351-5 bolts made of stainless steel A286-160 ksi.
In the following figure positions of the bolts are shown:

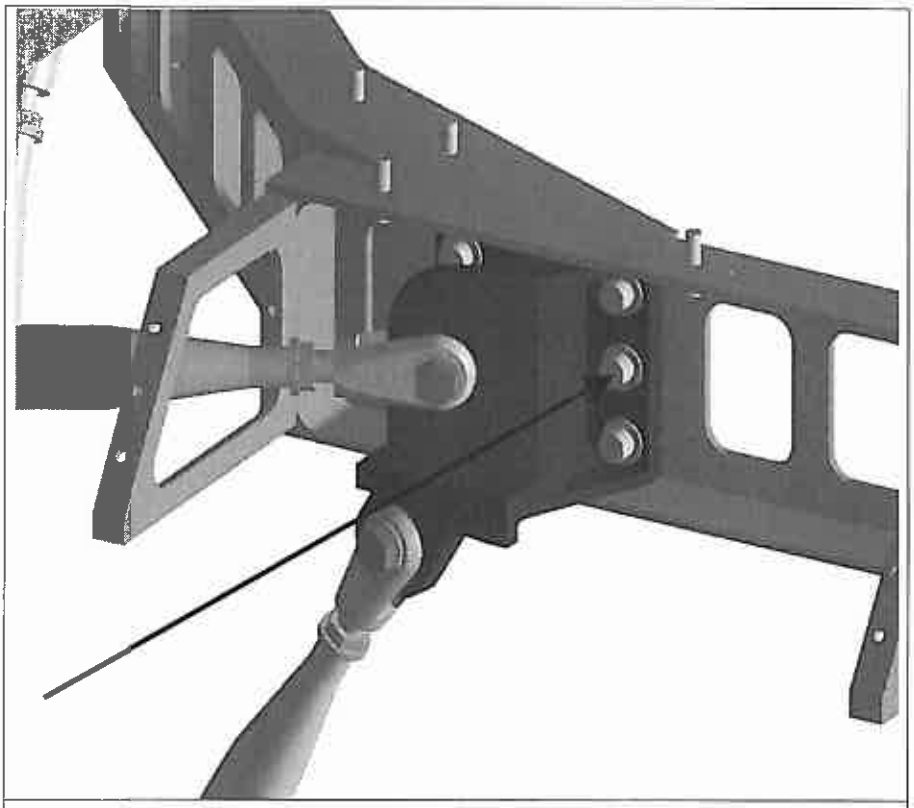

Figure 9-41: JOINT1: Bracket-ring bolts

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In the following figures the forces applied to the joint are shown:

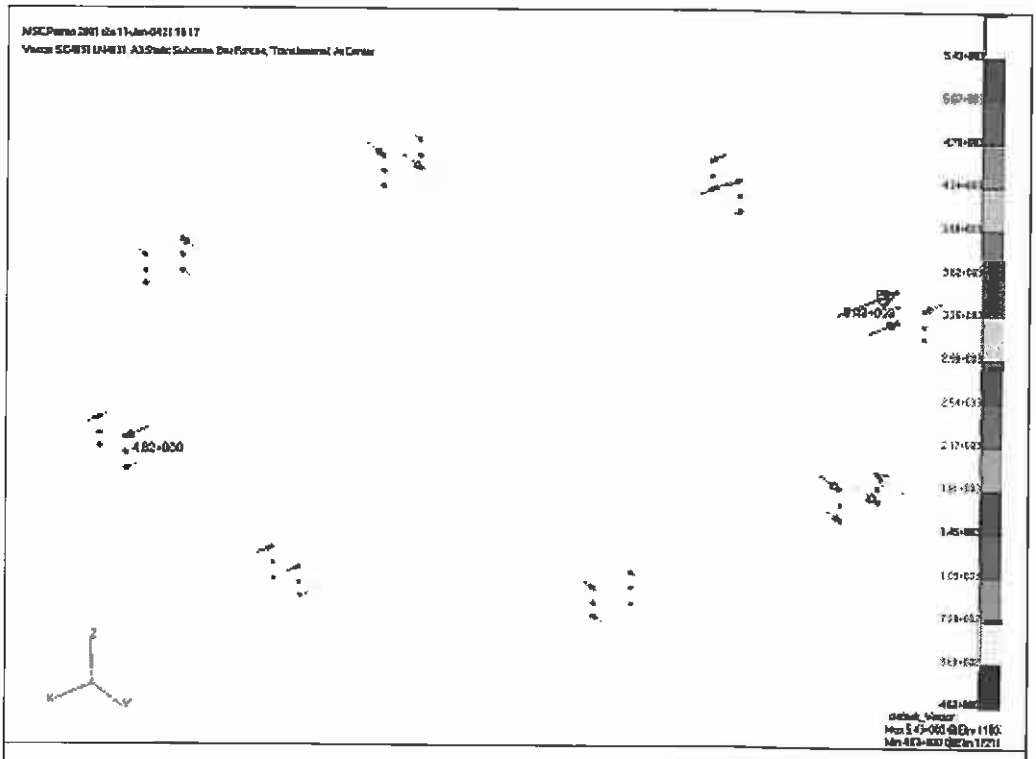

Figure 9-42: JOINT 1: Maximum axial force, element 11807, load case 4031

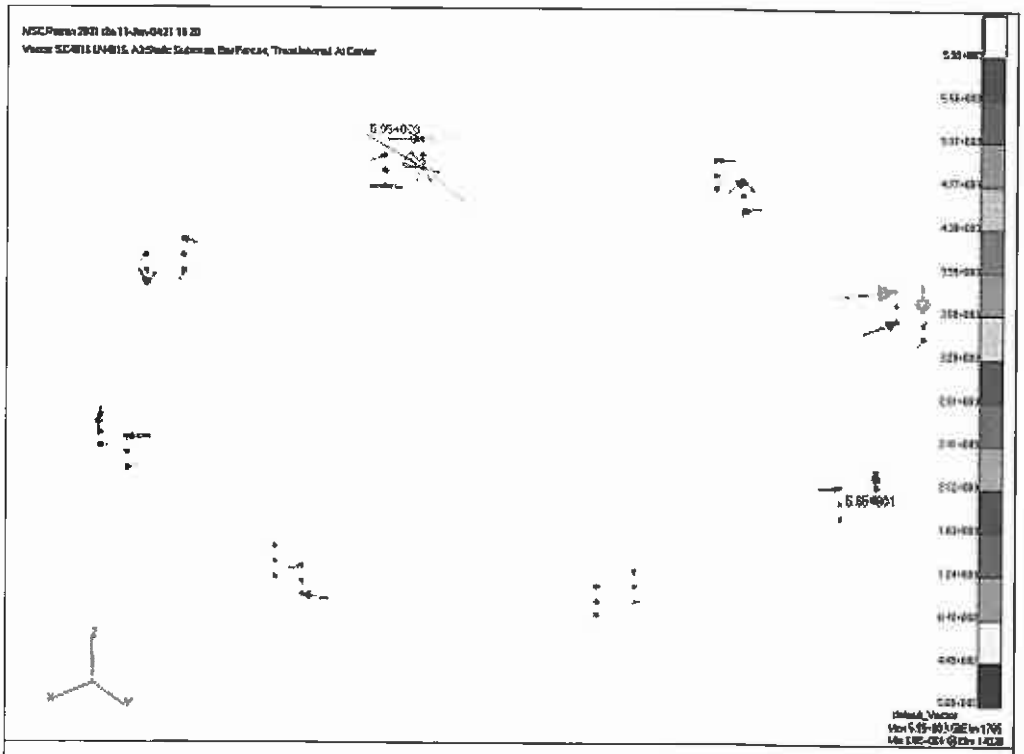

Figure 9-43: JOINT 1: Maximum resultant force, element 1785, load case 4015

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In the following tables input and output data are shown:

BRACKET RING	
JOINT 1	
JOINT DEFINITION	**VALUE**
Bolt size	NAS 1351-5
Nominal diameter [mm]	7.938
Thread pitch [1/in]	24
Bolt Material	A-286 (u:160ksi-y:120ksi)
Bolt Material FTU [MPa]	1103
Bolt Material FTY [MPa]	827
Bolt Material FSU [MPa]	655
Temperature correction factor	0.94
Plastic bending factor for circular cross section	1.7
Fitting-factor	1.15
Dry torque coefficient	0.2
Loading plane factor	0.5
Joint load factor (steel bolt on Alum. plate)	0.266
Plate Material	AL 7075 T7351
Plate Thickness [mm]	4
BEARING AND LUG DATA	**VALUE**
Hole diameter [mm]	7.938
e/D	>1.5
Distance hole-end plate (Lug an. Tension)	12.5
Distance hole-end plate (Lug an. Shear)	12.5
Plate FBRU [MPa]	703.27
Plate FBRY [MPa]	544.69
Lug Ftu [MPa]	468.84
Lug Fty [MPa]	393.00
Lug Fsu [MPa]	262.00
Lug Fsy [MPa]	218.97
WORST CASE LOAD DEFINITION	**VALUE**
LOAD CASE	4015
ELEMENT ID	1785
AXIAL LOAD [N]	2817.04
SHEAR LOAD [N]	5242.78
WORST CASE LOAD DEFINITION FOR SEPARATION (MAX AXIAL LOAD)	**VALUE**
LOAD CASE	4031
ELEMENT ID	11807
AXIAL LOAD [N]	5427.93
SHEAR LOAD [N]	2143.89
RESULTS	**VALUE**
Max Torque [Nm]	36.91
Min Torque [Nm]	31.37
MoS combU	0.26
MoS brY	1.48
MoS brU	1.00
MoS lug t Y	4.64
MoS lug t U	3.20
MoS lug s Y	2.14
MoS lug s U	1.35
MoS Sep	0.71

Table 9-5: JOINT 1

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9.3.2 JOINT 2: USS/U-BKT

L-TOF USS/U-BKT joints are NAS 1351-6 bolts, made of stainless steel A286-160 ksi: in the following figure positions of some bolts are shown.

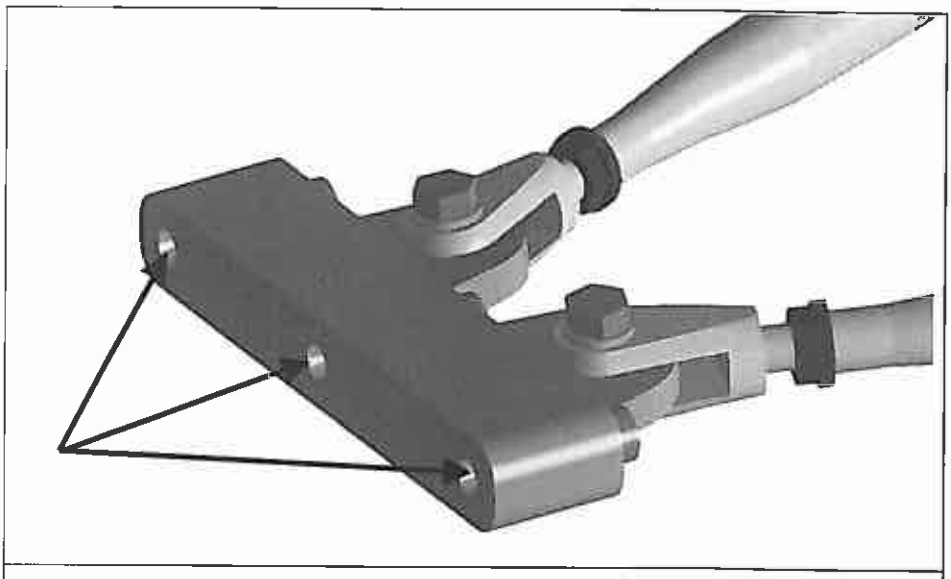

Figure 9-44: JOINT 2: USS/U-BKT bolts

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In the following figures the forces applied to the joint are shown:

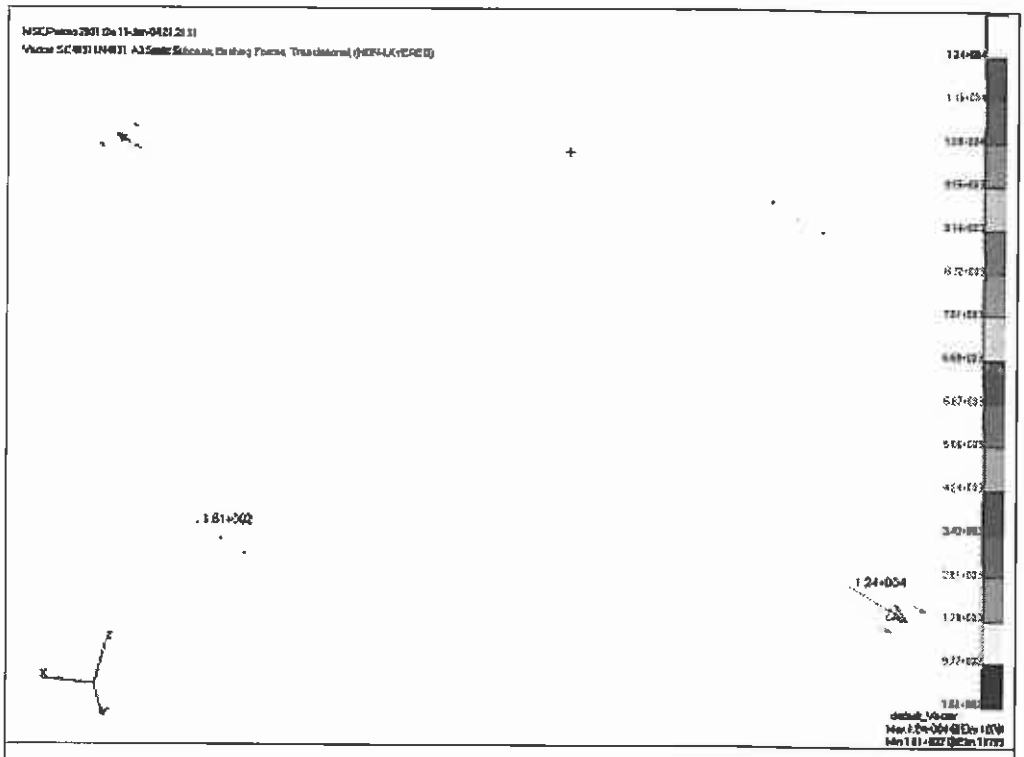

Figure 9-45: JOINT 2: Maximum axial force, node 10788 , load case 4031

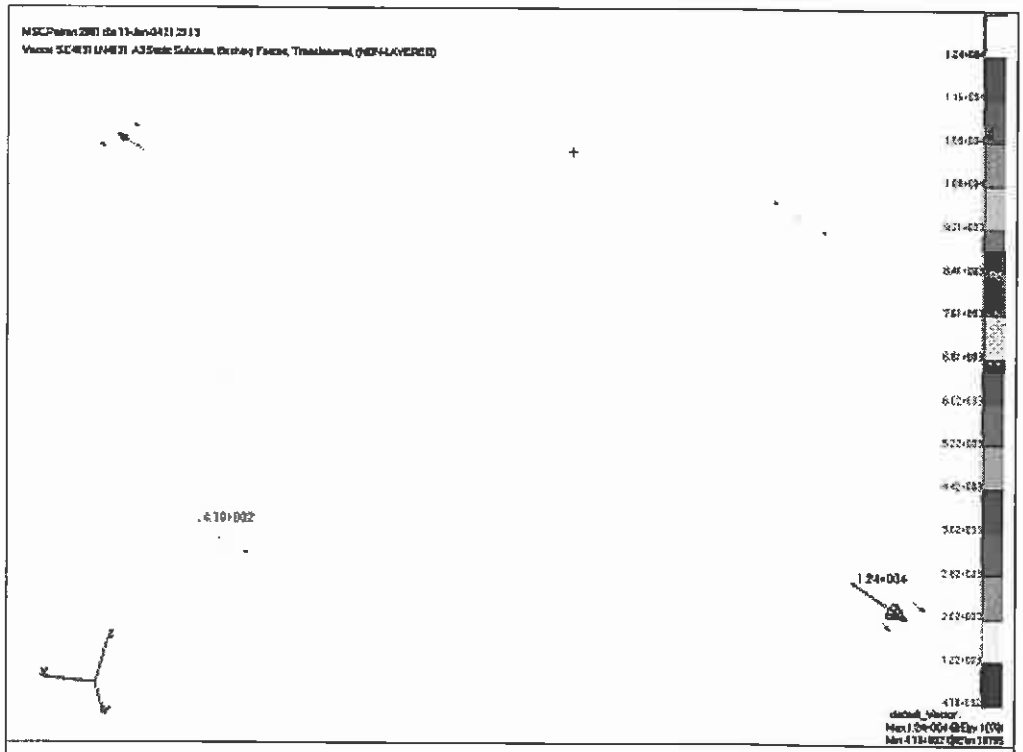

Figure 9-46: JOINT 2: Maximum shear force, node 10788, load case 4031

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In the following tables input and output data are shown:

USS/U-BKT	
JOINT 2	
JOINT DEFINITION	**VALUE**
Bolt size	NAS 1351-6
Nominal diameter [mm]	9.525
Thread pitch [1/in]	24
Bolt Material	A-286 (u:160ksi-y:120ksi)
Bolt Material FTU [MPa]	1103
Bolt Material FTY [MPa]	827.4
Bolt Material FSU [MPa]	662
Temperature correction factor	0.94
Plastic bending factor for circular cross section	1.7
Plate Material	AL 7075 T7351
WORST CASE LOAD DEFINITION	**VALUE**
LOAD CASE	4031
ELEMENT ID	53939
AXIAL LOAD [N]	12401.87
SHEAR LOAD [N]	477.76
WORST CASE LOAD DEFINITION FOR SEPARATION (MAX AXIAL LOAD)	**VALUE**
LOAD CASE	4031
ELEMENT ID	53939
AXIAL LOAD [N]	12401.87
SHEAR LOAD [N]	477.76
RESULTS	**VALUE**
Max Torque [Nm]	63.77
Min Torque [Nm]	54.20
MoS combU	0.51
MoS Sep	0.57

Table 9-6: JOINT 2

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9.3.3 JOINT 3: USS/L-BKT

L.-TOF USS/L-BKT joints are NAS 1351-4 bolts, made of stainless steel A286-160 ksi: in the following figure positions of some of the bolts are shown.

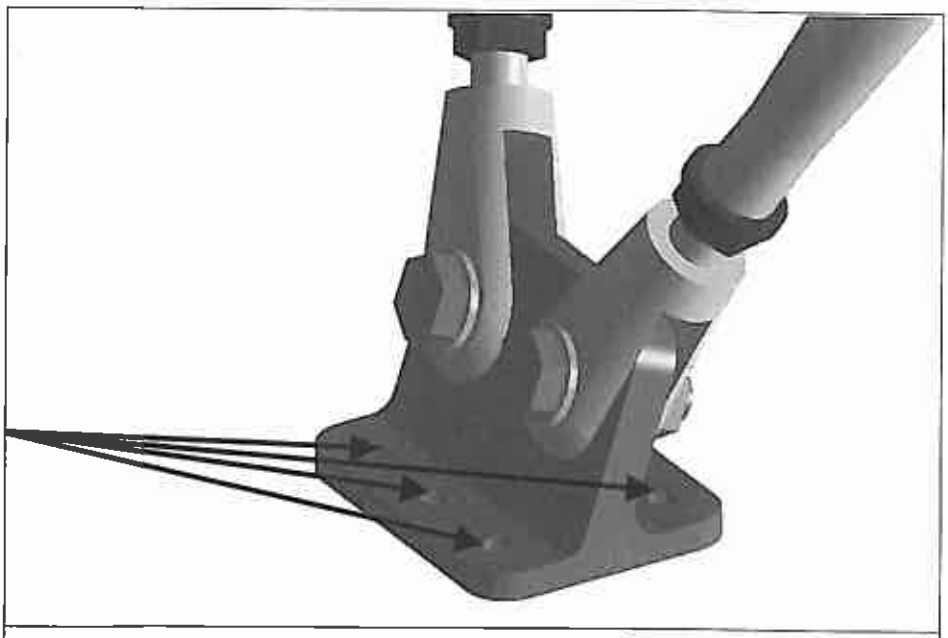

Figure 9-47: JOINT 3: USS/L-BKT bolts

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In the following figures the forces applied to the joint are shown:

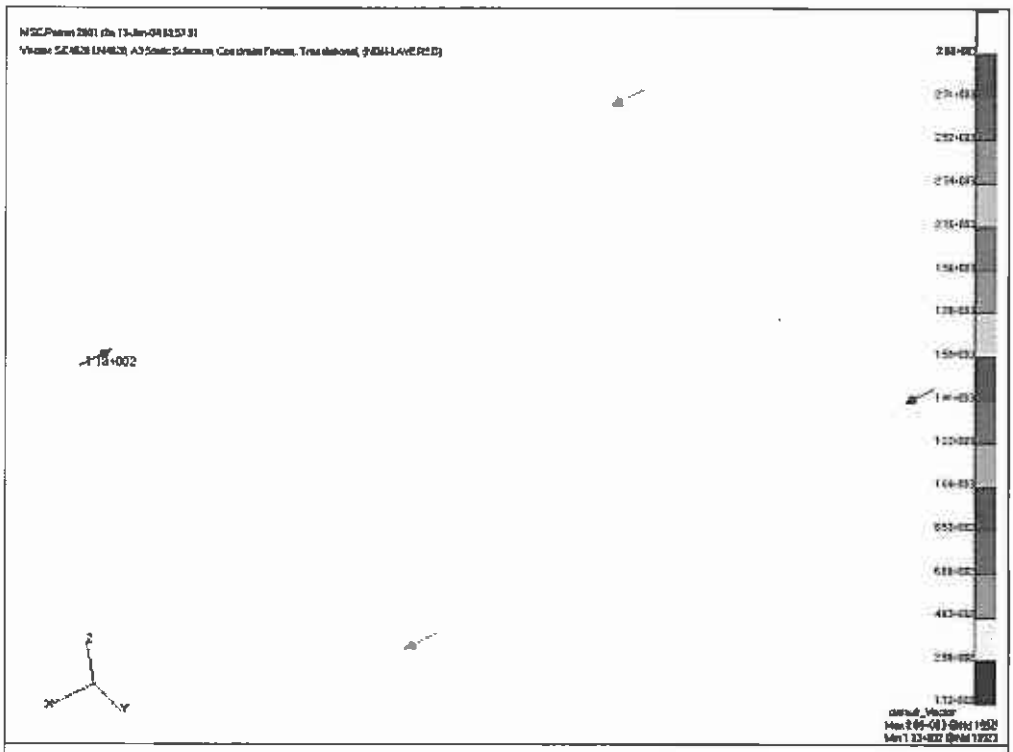

Figure 9-48: JOINT 3: Maximum axial force, node 19925, load case 4028

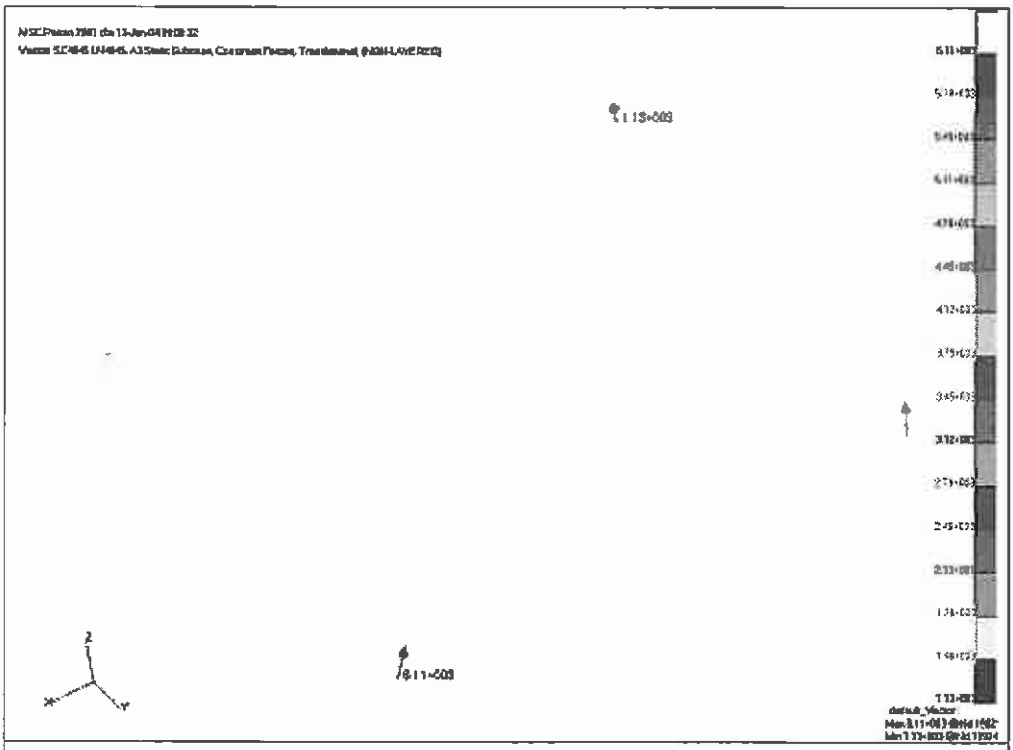

Figure 9-49: JOINT 3: Maximum resultant force, node 19921, load case 4045

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In the following tables input and output data are shown:

USS/L-BKT	
JOINT 3	
JOINT DEFINITION	VALUE
Bolt size	NAS 1351-4
Nominal diameter [mm]	6.35
Thread pitch [1/In]	28
Bolt Material	A-286 (u:160ksi-y:120ksi)
Bolt Material FTU [MPa]	1103
Bolt Material FTY [MPa]	827
Bolt Material FSU [MPa]	655
Temperature correction factor	0.94
Plastic bending factor for circular cross section	1.7
Fitting-factor	1.15
Dry torque coefficient	0.2
Loading plane factor	0.5
Joint load factor (steel bolt on Alum. plate)	0.266
Plate Material	AL 7075 T7351
Plate Thickness [mm]	8
BEARING AND LUG DATA	VALUE
Lug diameter [mm]	6.5
e/D	1.54
Distance hole-end plate (Lug an. Tension)	10
Distance hole-end plate (Lug an. Shear)	10
Plate FBRU [MPa]	703.27
Plate FBRY [MPa]	544.69
Lug Ftu [MPa]	468.84
Lug Fty [MPa]	393.00
Lug Fsu [MPa]	262.00
Lug Fsy [MPa]	218.97
WORST CASE LOAD DEFINITION	VALUE
LOAD CASE	4045
ELEMENT ID	19921
AXIAL LOAD [N]	427.32
SHEAR LOAD [N]	924.27
WORST CASE LOAD DEFINITION FOR SEPARATION (MAX AXIAL LOAD)	VALUE
LOAD CASE	4028
ELEMENT ID	19925
AXIAL LOAD [N]	481.818
SHEAR LOAD [N]	703.25
RESULTS	VALUE
Max Torque [Nm]	18.49
Min Torque [Nm]	15.72
MoS combU	0.64
MoS brY	10.26
MoS brU	8.08
MoS lug t Y	30.98
MoS lug t U	22.84
MoS lug s Y	16.82
MoS lug s U	12.32
MoS Sep	0.96

Table 9-7: JOINT 3

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9.3.4 JOINT 4: RING-HCOMB

L-TOF RING-HCOMB joints are NAS 1351-4 bolts, made of stainless steel A286-160 ksi: in the following figure positions of the bolts are shown.

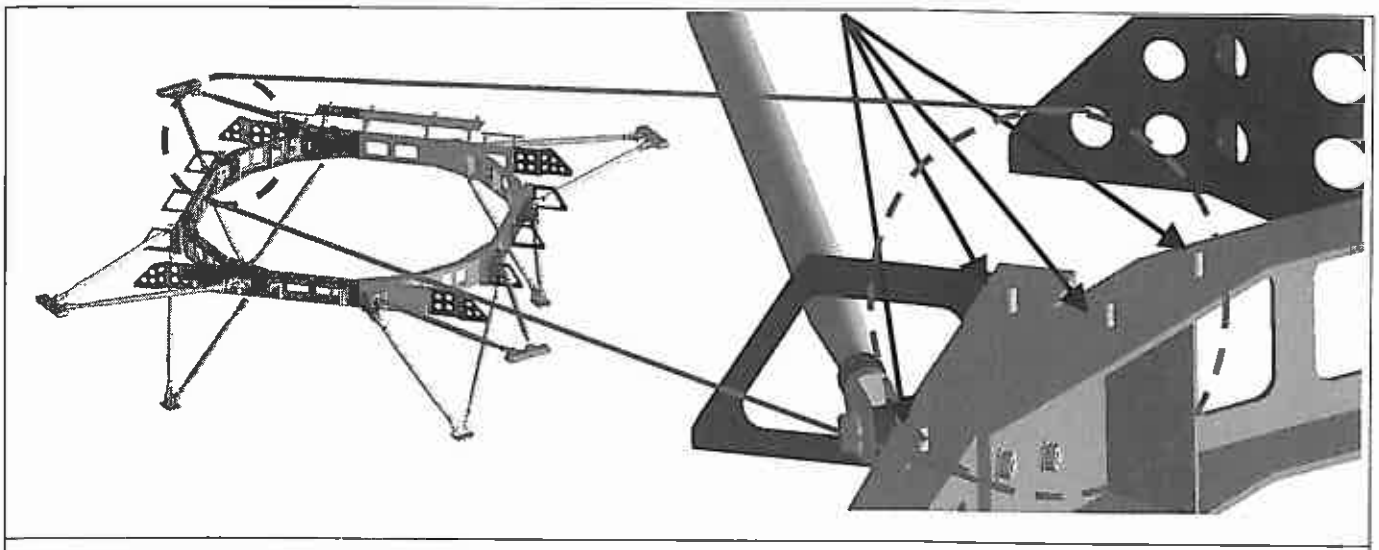

Figure 9-50: JOINT 4: RING-HCOMB

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In the following figures the forces applied to the joint are shown:

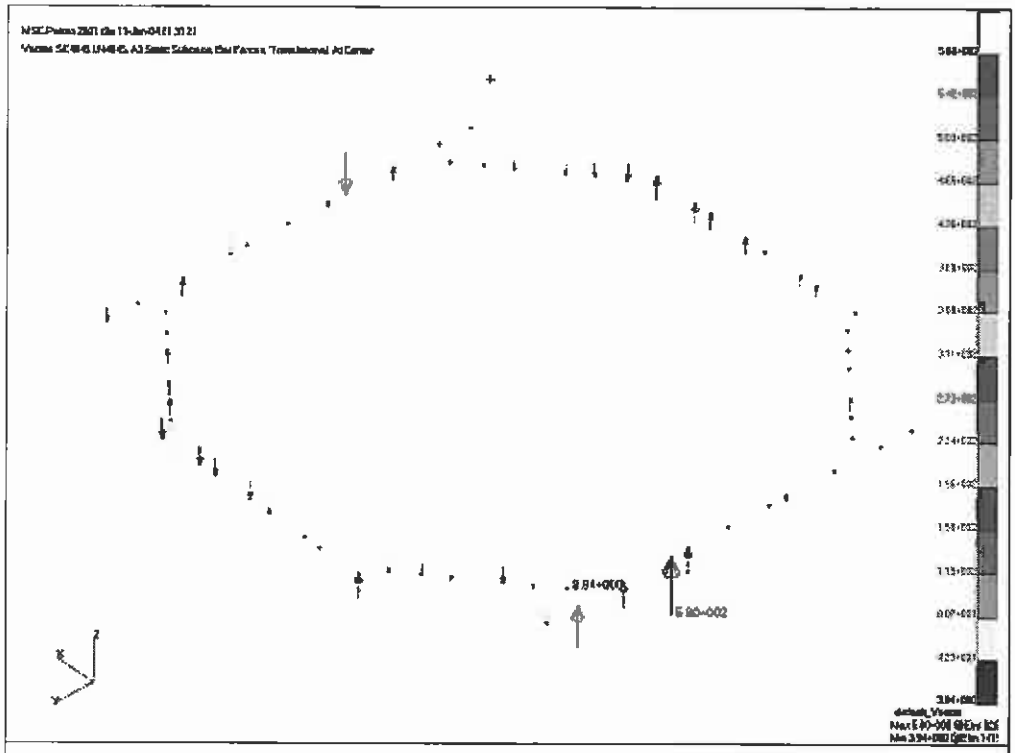

Figure 9-51: JOINT 4: Maximum axial force, element 826, load case 4045

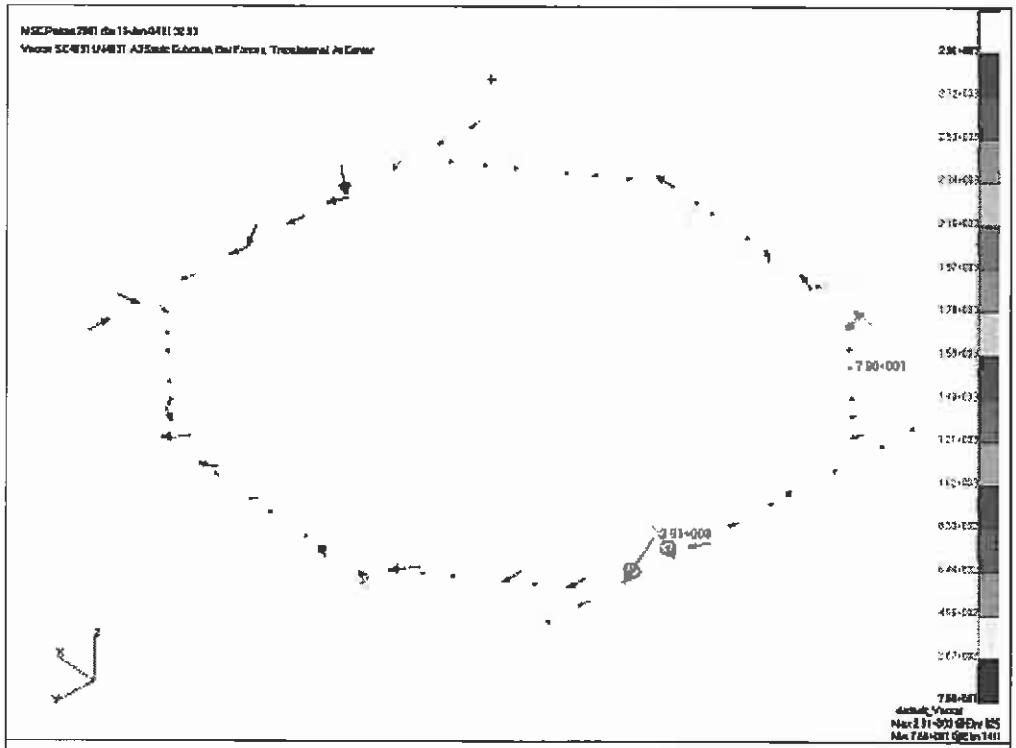

Figure 9-52: JOINT 4: Maximum resultant force, element 825, load case 4031

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9.3.4.1 BOLT ANALYSIS

In the following tables input and output data are shown:

RING-HCOMB	
JOINT 4	
JOINT DEFINITION	VALUE
Bolt size	NAS 1351-4
Nominal diameter [mm]	6.35
Thread pitch [1/in]	28
Bolt Material	A-286 (u:160ksi-y:120ksi)
Bolt Material FTU [MPa]	1103
Bolt Material FTY [MPa]	827
Bolt Material FSU [MPa]	655
Temperature correction factor	0.94
Plastic bending factor for circular cross section	1.7
Fitting-factor	1.15
Dry torque coefficient	0.2
Loading plane factor	0.5
Joint load factor (steel bolt on Alum. plate)	0.266
Plate Material	AL 7075 T7351
Plate Thickness [mm]	4
BEARING AND LUG DATA	VALUE
Hole diameter [mm]	6.35
e/D	>2
Distance hole-end plate (Lug an. Tension)	18
Distance hole-end plate (Lug an. Shear)	18
Plate FBRU [MPa]	903.21
Plate FBRY [MPa]	655.00
Lug Ftu [MPa]	468.84
Lug Fty [MPa]	393.00
Lug Fsu [MPa]	262.00
Lug Fsy [MPa]	218.97
WORST CASE LOAD DEFINITION	VALUE
LOAD CASE	4031
ELEMENT ID	825
AXIAL LOAD [N]	205.2
SHEAR LOAD [N]	2903.05
WORST CASE LOAD DEFINITION FOR SEPARATION (MAX AXIAL LOAD)	VALUE
LOAD CASE	4045
ELEMENT ID	826
AXIAL LOAD [N]	580
SHEAR LOAD [N]	1258
RESULTS	VALUE
Max Torque [Nm]	18.49
Min Torque [Nm]	15.72
MoS combU	0.36
MoS brY	3.31
MoS brU	2.71
MoS lug t Y	9.18
MoS lug t U	6.59
MoS lug s Y	4.67
MoS lug s U	3.24
MoS Sep	0.95

Table 9-8: JOINT 4

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9.3.4.2 INSERTS VERIFICATION

Inserts force is obtained with FEM analysis and its value has been evaluated in

- 205 N in axial direction
- 2903 N in transverse direction

This load is used to calculate MOS for CFRP inserts
RD.3 guidelines are followed.
The results are shown in the table below:

INSERT DATA	INSERT				
	Size	Material	Ext min Diameter [mm]	External height [mm]	Thread lenght [mm]
	NAS 1351 - 04	ALUMINUM	22,5	9	6
	HONEYCOMB FACESHEET				
	Material	F_{ty} [MPa]	Thk [mm]		
	AL 2024 T81	376	1,25		
	HONEYCOMB CORE				
	TYPE	Size cell [mm]	Thk [mm]	Height [mm]	
	4.5-1/8-10	3,175	0,0254	50	
	INSTALLATION				
	a [mm]	a/d	e [mm]	e/d	
	53	4,71	17,6	1,56	
	DERATING FACTOR CALCULATION (ESA PSS-03-1202)				
	der e (Shear)	der e (Axial)	der a (Axial)	SF	
	0,73	0,61	0,74	2	
FORCES ALLOWABLE	SHEAR ALLOWABLE				
	P_{SH}=Thk*Fty*Diameter [N]				
	10561				
	AXIAL ALLOWABLE (ESA PSS-03-1202)				
	P_{AX} FROM TABLE [N]				
	7000				
FORCES APPLIED	FORCES APPLIED				
	AXIAL [N]	SHEAR [N]			
	205	2903			
INSERT VERIFICATION	$R=R_{SH}^2+R_{AX}^2 < 1$				
	R_{SH} = SHEAR / (P_{SH} * der e / SF)		R_{AX} = AXIAL / (P_{AX} * der e * der a / SF)		R
	0,751		0,131		0,58

Table 9-9: Ring/honeycomb inserts verification

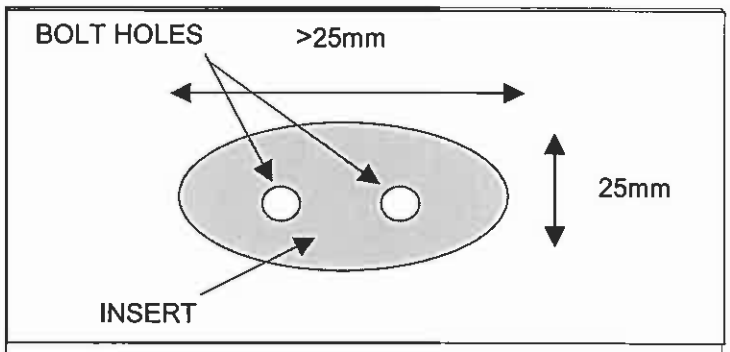

Figure 9-53: Insert Dimensions

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9.3.5 JOINT 5: SCINTILLATOR SUPPORTS VERIFICATION

L-TOF honeycomb joints are M3 bolts, made of aluminum 7075 T7351: in the following figure positions of the bolts are shown.

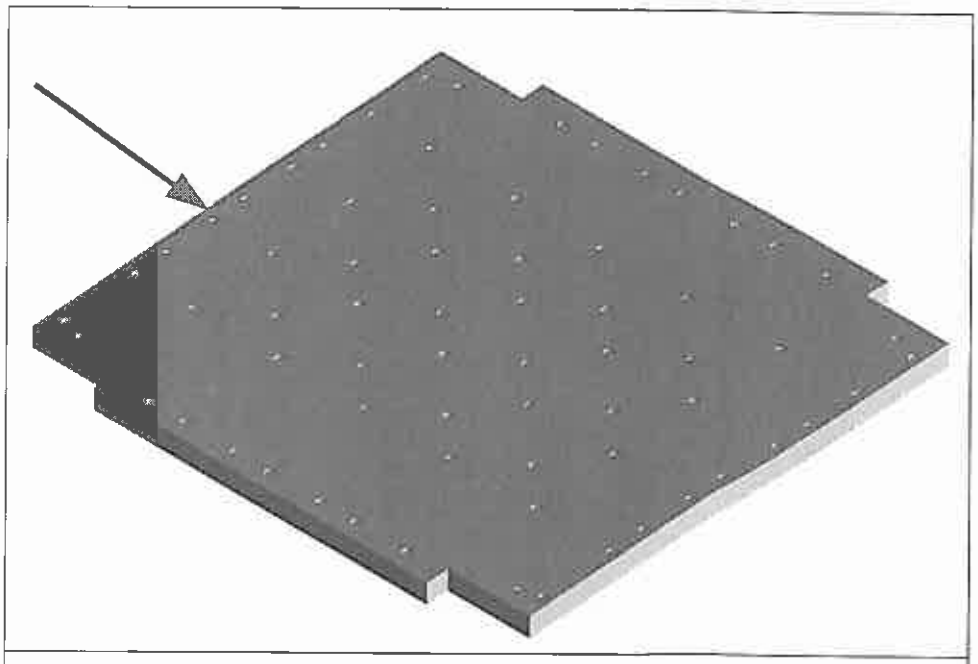

Figure 9-54: JOINT 5: Honeycomb

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In the following figures the forces applied to the joint are shown:

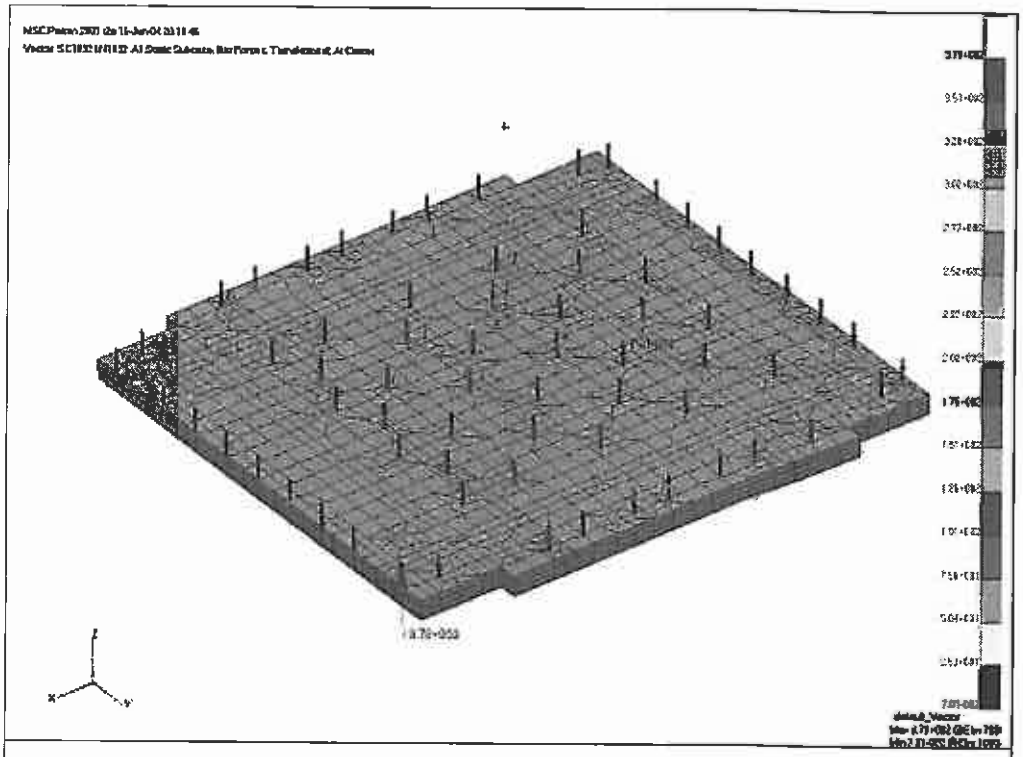

Figure 9-55: JOINT 5: Maximum axial force, element 7080, load case 1033

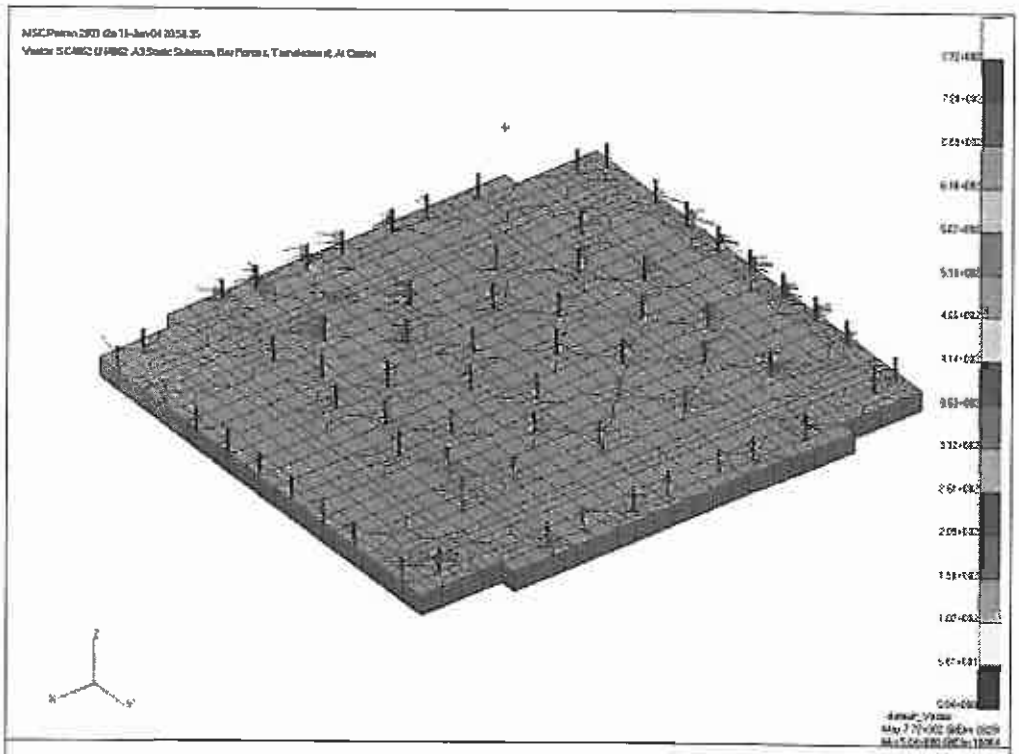

Figure 9-56: JOINT 5: Maximum resultant force, element 28256, load case 4062

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9.3.5.1 BOLT VERIFICATION

In the following tables input and output data are shown:

HONEYCOMB BOLTS	
JOINT 5	
JOINT DEFINITION	**VALUE**
Bolt size	M3
Nominal diameter [mm]	3
Thread pitch [1/In]	48
Bolt Material	Al 7075 T7351
Bolt Material FTU [MPa]	468
Bolt Material FTY [MPa]	393
Bolt Material FSU [MPa]	262
Temperature correction factor	0.94
Plastic bending factor for circular cross section	1.7
Fitting-factor	1.15
Dry torque coefficient	0.2
Loading plane factor	0.5
Joint load factor (steel bolt on Alum. plate)	0.266
WORST CASE LOAD DEFINITION	**VALUE**
LOAD CASE	4062
ELEMENT ID	28256
AXIAL LOAD [N]	106
SHEAR LOAD [N]	371
WORST CASE LOAD DEFINITION FOR SEPARATION (MAX AXIAL LOAD)	**VALUE**
LOAD CASE	1032
ELEMENT ID	7080
AXIAL LOAD [N]	188.955
SHEAR LOAD [N]	106.065
RESULTS	**VALUE**
Max Torque [Nm]	0.73
Min Torque [Nm]	0.63
MoS combU	0.04
MoSsep	0.81

Table 9-10: JOINT 5

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9.3.5.2 INSERTS VERIFICATION

Inserts force is obtained with FEM analysis and its value has been evaluated in

- 212 N in axial direction
- 742 N in transverse direction

This load is used to calculate MOS for CFRP inserts
RD.3 guidelines are followed.
The results are shown in the table below:

SCINTILLATORS/HONEYCOMB					
INSERT DATA	INSERT				
	Size	Material	Ext min Diameter [mm]	External height [mm]	Thread lenght [mm]
	M3	CFRP	25	8	6
	HONEYCOMB FACESHEET				
	Material	F_{ty} [MPa]	Thk [mm]		
	AL 2024 T81	376	0,5		
	HONEYCOMB CORE				
	TYPE	Size cell [mm]	Thk [mm]	Height [mm]	
	1.8-3/4-25	19	0,0635	50	
	INSTALLATION				
	a [mm]	a/d	e [mm]	e/d	
	68	2,72	18	0,72	
	DERATING FACTOR CALCULATION (ESA PSS-03-1202)				
	der e (Shear)	der e (Axial)	der a (Axial)	SF	
	0,71	0,59	0,77	2	
FORCES ALLOWABLE	SHEAR ALLOWABLE				
	P_{SH}=Thk*Fty*Diameter [N]				
	4693,8				
	AXIAL ALLOWABLE (ESA PSS-03-1202)				
	P_{AX} FROM TABLE [N]				
	4000				
FORCES APPLIED	FORCES APPLIED				
	AXIAL [N]	SHEAR [N]			
	212	742			
INSERT VERIFICATION	$R=R_{SH}^2+R_{AX}^2 < 1$				
	R_{SH} = SHEAR / (P_{SH} * der e / SF)		R_{AX} = AXIAL / (P_{AX} * der e * der a / SF)		R
	0,45		0,23		0,26

Table 9-11: Scintillator/honeycomb inserts verification

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9.3.6 JOINT 6: ROD END

9.3.6.1 LUG VERIFICATION

The analysis of the lugs that connect the rods to the USS and to the ring (see the following figure) is performed using the worst condition of load (10143N, see chapter 9.4.1) and geometry:

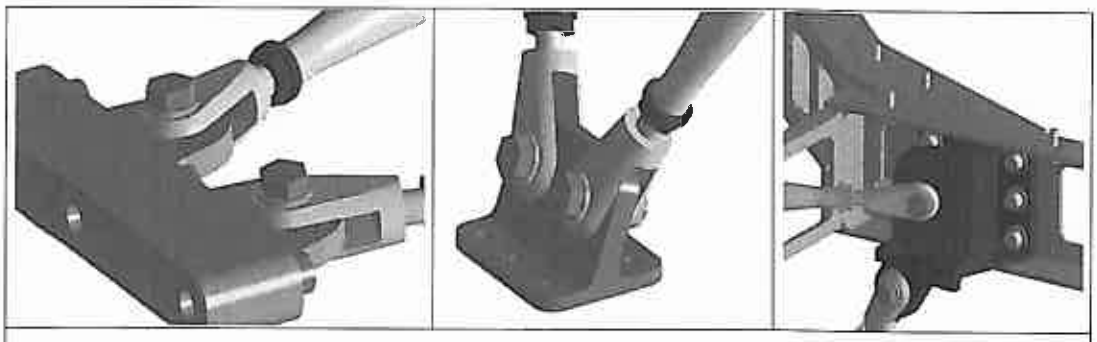

Figure 9-57: Lugs

LUG ANALYSIS											
MARGINS OF SAFETY FOR BEARING FAILURE											
MATERIAL	Fbr_y [MPa]	Fbr_u [MPa]	Limit shear force [N]	thk [mm]	dia [mm]	Bearing area [mm^2]	Limit stress [MPa]	$S.F._y$	$S.F._u$	MoS_y	MoS_u
AL 7075 T7351	512	661	10143	10	21	210	48.300	1.25	2	7.48	5.84
MARGINS OF SAFETY FOR TENSION FAILURE (STRESS)											
MATERIAL	Fty [MPa]	Ftu [MPa]	Limit shear force [N]	thk [mm]	distance hole-end plate [mm]	Tensile area [mm^2]	Limit stress [MPa]	$S.F._y$	$S.F._u$	MoS_y	MoS_u
AL 7075 T7351	369	441	10143	10	20	400	25.358	1.25	2	10.64	7.70
MARGINS OF SAFETY FOR SHEAR FAILURE (STRESS)											
MATERIAL	Fsy [MPa]	Fsu [MPa]	Limit shear force [N]	thk [mm]	distance hole-end plate [mm]	Shear area [mm^2]	Limit stress [MPa]	$S.F._y$	$S.F._u$	MoS_y	MoS_u
AL 7075 T7351	185	246	10143	10	20	400	25.358	1.25	2	4.84	3.86

Table 9-12: LUG verification

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9.3.6.2 ROD-END VERIFICATION

The ends of the RODs are forks with a bearing into the Bracket Lug this verification is performed with the worst load case: 10143N, see chapter 9.4.1 .

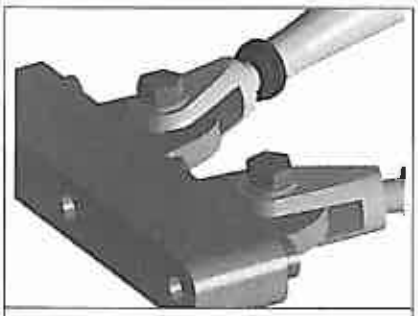

Figure 9-58: Rod-End

	SPECIFICATION	Allowable force	Applied force	MoS
ROD END (FORK)	CEY-6-6J-127	38980N	10143N	0.92
SPHERICAL BEARING	MS14103 (dash 6)	60000N	10143N	1.95

Table 9-13: Rod End verification

9.3.6.3 BOLT VERIFICATION

ROD END BOLT	
JOINT 6	
JOINT DEFINITION	**VALUE**
Bolt size	NAS 1351-6
Nominal diameter [mm]	9.525
Thread pitch [1/in]	24
Bolt Material	A-286 (u:160ksi-y:120ksi)
Bolt Material FTU [MPa]	1103
Bolt Material FTY [MPa]	827
Bolt Material FSU [MPa]	655
Temperature correction factor	0.94
Plastic bending factor for circular cross section	1.7
WORST CASE LOAD DEFINITION	**VALUE**
LOAD CASE	4031
AXIAL LOAD [N]	0
SHEAR LOAD [N]	10143
RESULTS	**VALUE**
Max Torque [Nm]	53.58
Min Torque [Nm]	45.54
MoS combU	0.21

Table 9-14: Rod End Bolt verification

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9.3.7 MOS SUMMARY FOR JOINT ANALYSIS

In the following tables MoS summary for joint analysis is presented.

MOS SUMMARY														
JOINT	BOLT	Fbry [MPa]	Fbru [MPa]	Limit axial force [N]	Limit shear force [N]	MoS sup	MoS COMBu	MoS Bry	MoS Bru	MoS lug Ty	MoS lug Tu	MoS lug Sy	MoS lug Su	INSERT VERIFICATION <1
BRACKET-RING	NAS 1351-5	544.7	703.3	2817.0	5242.78	0.71	0.27	1.46	1.00	>2	>2	>2	1.36	NA
USS/U-BKT	NAS 1351-6	NA	NA	12401.9	477.8	0.57	0.51	NA	NA	NA	NA	NA	NA	NA
USS/L-BKT	NAS 1351-4	544.7	703.3	427.3	924.3	0.86	0.84	>2	>2	>2	>2	>2	>2	NA
RING-HCOMB	NAS 1351-4	655.0	903.2	205.2	2903.1	0.96	0.38	>2	>2	>2	>2	>2	>2	NA
HONEYCOMB	M3	NA	NA	106.1	370.9	0.92	0.54	NA	NA	NA	NA	NA	NA	0.58
ROD END	NAS 1351-6	544.7	703.3	10143.0	0.0	NA	0.21	>2	>2	>2	>2	>2	>2	NA

Table 9-15: Joint analysis MoS summary

9.3.8 FAIL SAFE JOINT ANALYSIS

In order to check the integrity of the joints under failing of the most stressed joints. For such analysis, a new static FEA has been carried out. The four most stressed joint (one for each set, as described from par. 9.3.1 to par. 9.3.5) have been removed from the model. The analyses for each joint set have been newly performed. In the following table the results are reported.

MOS SUMMARY											
JOINT	BOLT	Fbru [MPa]	LC	ID	Limit axial force [N]	Limit shear force [N]	MoS COMBu	MoS Bru	MoS lug Tu	MoS lug Su	INSERT VERIFICATION <1
BRACKET-RING	NAS 1351-5	703.3	4062	1781	2744	5130	0.57	3.09	7.59	3.80	NA
USS/U-BKT	NAS 1351-6	NA	4015	10789	5238	1704	0.63	NA	NA	NA	NA
USS/L-BKT	NAS 1351-4	703.3	4045	19921	515	1104	0.66	14.21	38.93	21.32	NA
RING-HCOMB	NAS 1351-4	903.2	4031	826	211	3460	0.57	5.23	11.74	6.12	NA
HONEYCOMB	M3	NA	4062	28257	212	741	0.54	NA	NA	NA	0.58

Table 9-16: Joint Fail Safe analysis MoS summary

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9.4 BUCKLING ANALYSIS

The buckling analysis shall be performed for the both the rods and the main structure:

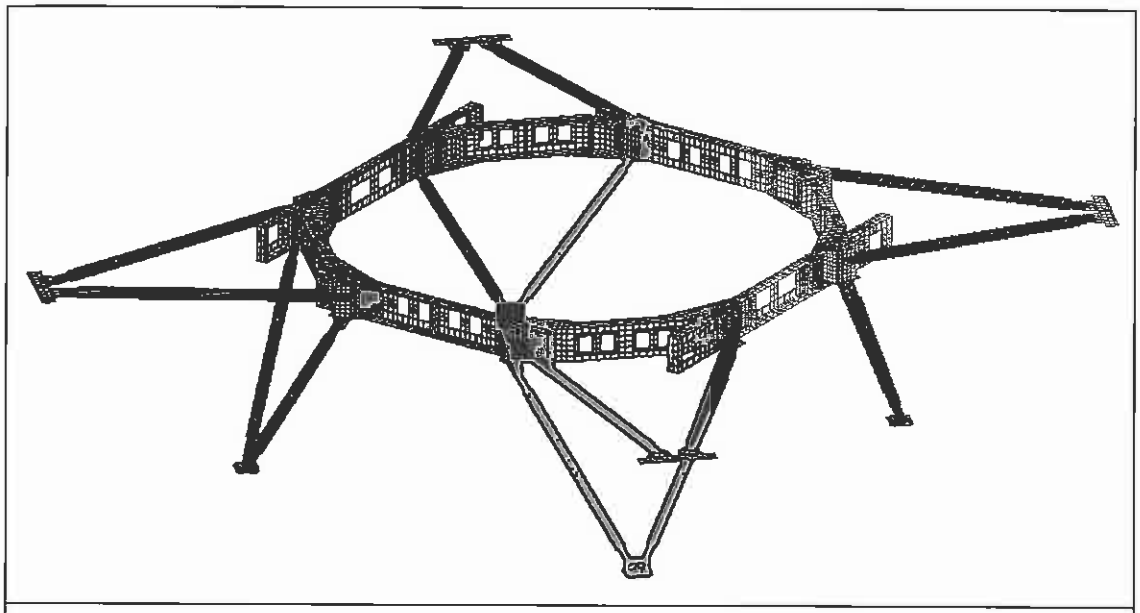

Figure 9-59: Main structure analyzed for buckling

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9.4.1 BUCKLING ANALYSIS FOR THE RODS

For the Rods that constrain the LTOF structure to the USS the compressive axial force calculate is for ELEMENT 4872 for Load Case 1019.
The resulting applied force is 7586N.
The maximum force is 10143N for ELEMENT 4807 for Load Case 4031 but can not be use because is a tension force.

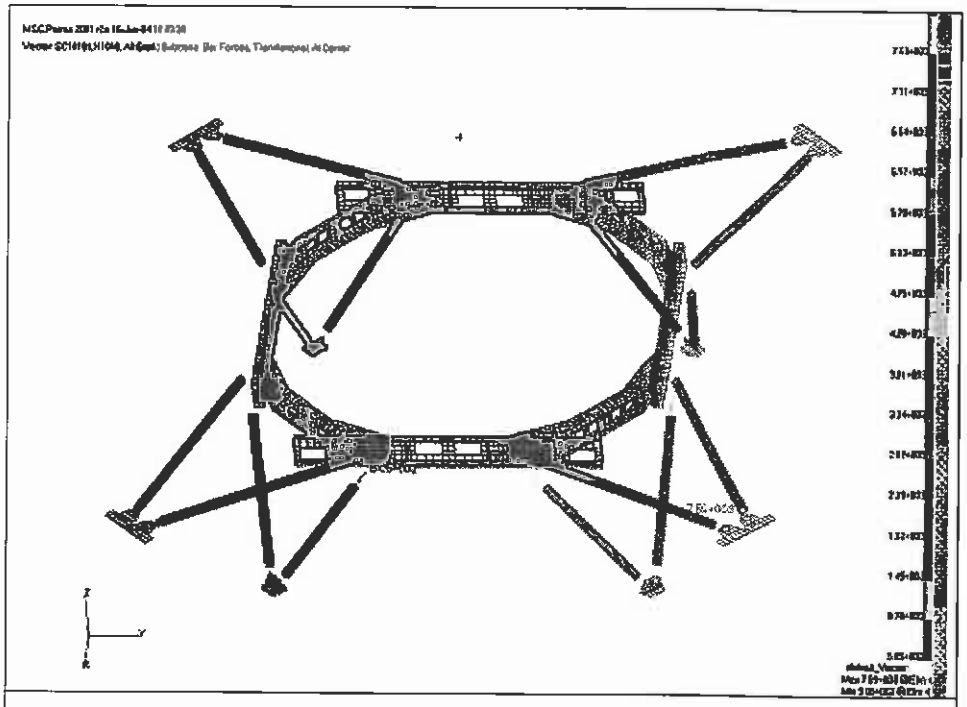

Figure 9-60: Axial force on the rod

This applied force lead to the buckling of the ROD:

MARGINS OF SAFETY FOR INSTABILITY FAILURE												
ITEM	R_{EST} [m]	R_{INT} [m]	Thichness [m]	E [Pa]	L [m]	I [m^4]	A [m^2]	P_{ALL} [N]	P_{APP} [N]	SF	MoS	NOTE
ROD NOMINAL	1,43E-02	1,30E-02	1,25E-03	6,94E+10	0,65	1,0E-08	1,1E-04	16266,1	7586	2	0,072	force from STATIC analysis

Table 9-17: Buckling calculation for the rod (Static Analysis)

The calculated force (7586N) comes from a static analysis based on the result of the transient and assembly sequence of the entire AMS-02; in AD 2 the analysis of the ROD with the forces calculated from the transient and assembly sequence analysis is presented. In this document the maximum compressive force applied to the ROD is 7242N; with this load the MoS of the buckling for the RODs is higher.

MARGINS OF SAFETY FOR INSTABILITY FAILURE												
ITEM	R_{EST} [m]	R_{INT} [m]	Thichness [m]	E [Pa]	L [m]	I [m^4]	A [m^2]	P_{ALL} [N]	P_{APP} [N]	SF	MoS	NOTE
ROD NOMINAL	1,43E-02	1,30E-02	1,25E-03	6,94E+10	0,65	1,0E-08	1,1E-04	16266,1	7242	2	0,123	force from TRANSIENT analysis

Table 9-18: buckling calculation for the rod (Static Analysis)

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9.4.2 BUCKLING ANALYSIS FOR THE MAIN STRUCTURE

For main structure of the LTOF buckling verification, the following equation is used:

$$\sigma_{CR} = \frac{\pi^2 k_c E}{12\left(1-\nu^2\right)} \cdot \left(\frac{t}{b}\right)^2 \quad \text{(RD 6 chp. C.6.2)}$$

Where:

k_c: buckling coefficient;
E: material Young modulus in compression;
ν: material elastic Poisson's ratio;
b: short dimension of plate or loaded edge
t: sheet thickness

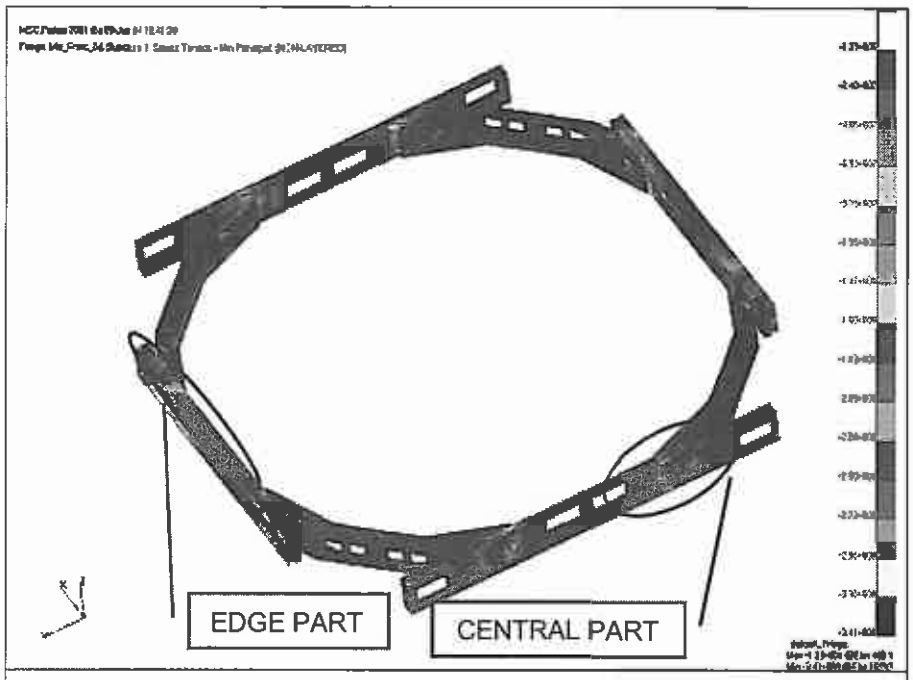

Table 9-19: Buckling verification, main structure

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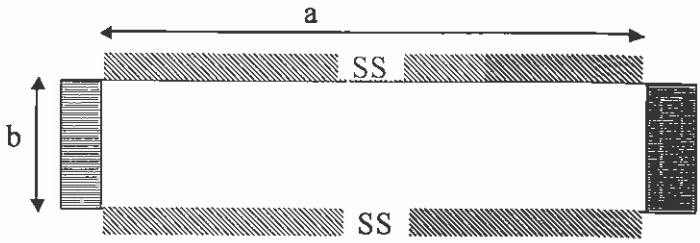
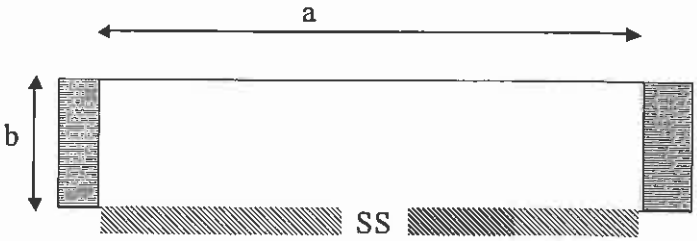
For the Central Part the equivalent beam is:



for this equivalent section the k_c defined in RD6 Chapter C5.3 is used:

k_c=4

For the Edge Part the equivalent beam is:



for this equivalent section the k_c defined in RD6 Chapter C6.1 is used:

k_c=0.43

In the following table MoS of buckling verification are shown:

MOS SUMMARY FOR BUCKLING VERIFICATION								
ITEM	k_c	b	t	MATERIAL	F_{cr} [MPa]	Limit stress [MPa]	$S.F._u$	MoS_u
CENTRAL PART	4	0.1	0.004	Al 7075 T7351	419	160	2	0.31
EDGE PART	0.43	0.036	0.004	Al 7075 T7351	348	137	2	0.27

Table 9-20: Buckling verification MoS summary

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10.CONCLUSIONS AND COMMENTS

The performed analyses show the following results:

- the 1st natural frequency of the assembly is 53.08Hz (see chapter 8.1)

- all MoS are positive for all applied loads; see chapters 9.2.20 for the stress verification, chapters 9.3.7 for joints verification and 9.4 for buckling analysis.

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ANNEX 1. BOLTS VERIFICATION EXAMPLE

JOINT 1 "BRACKET/RING":

(NAS 1351 - 5 Material 160Ksi)

FACTORS of SAFETY Ultimate: $FSu := 2.0$ Yield: $FSy := 1.25$ Separation: $FSsep := 1.2$

Nominal diameter: $D := 7.938 \cdot mm$ Thread pitch: $N := 24 \cdot \frac{1}{in}$

$D = 0.313\,in$

Temperature correction factor: $\alpha c := .94$

Tensile allowable, ultimate: $Ftu := 160000 \cdot psi$ Shear allowable: $Fsu := 95000psi$

$Ftu = 1.103 \times 10^9\,Pa$ $Fsu = 6.55 \times 10^8\,Pa$

Tensile allowable, yield: $Fty := 120000psi$

$Fty = 8.274 \times 10^8\,Pa$

Tensile area: $At := \pi \cdot \left(\frac{D - 0.9743 \cdot \frac{1}{N}}{2} \right)^2$ $At = 0.0581\,in^2$ $At = 3.747 \times 10^{-5}\,m^2$

Equations for areas from Machinery's Handbook

Shear area. $As := \pi \cdot \left(\frac{D - 1.299038 \cdot \frac{1}{N}}{2} \right)^2$ $As = 0.0524\,in^2$ $As = 3.747 \times 10^{-5}\,m^2$

Moment of inertia of bolt cross section: $I := \frac{\pi \cdot D^4}{64}$ $I = 0.0005\,in^4$ $I = 1.949 \times 10^{-10}\,m^4$

distance to outer fiber: $c := \frac{D}{2}$ $c = 0.156\,in$ $c = 3.969 \times 10^{-3}\,m$

Tensile ultimate strength: $ftu := Ftu \cdot At$ $ftu = 9.292 \times 10^3\,lbf$ $ftu = 4.133 \times 10^4\,newton$

Tensile yield strength: $fty := Fty \cdot At$ $fty = 6.969 \times 10^3\,lbf$ $fty = 3.1 \times 10^4\,newton$

Shear strength: $fsu := Fsu \cdot As$ $fsu = 4.982 \times 10^3\,lbf$ $fsu = 2.216 \times 10^4\,newton$

Bending allowable: $fbu := Ftu \cdot \frac{I}{c}$ $fbu = 479.459\,in \cdot lbf$ $fbu = 54.172\,m \cdot newton$

Plastic bending factor for circular cross section: $Ky := 1.7$

Fitting-factor: $FF := 1.15$

Forces at the Bolts:

Bolt tensile force (N) : $Ften := 2817.04newton$

Bolt tensile force (lbf) : $Ften = 633.296\,lbf$

Bolt shear force (N) : $Fshear := 5242.78newton$

Bolt shear force: $Fshear = 1.179 \times 10^3\,lbf$

Bolt bending moment (N*m) : $Fbend := 0newton \cdot m$

Bolt bending moment (in*lbf) : $Fbend = 0\,in \cdot lbf$

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Preload on the Bolt:

Dry torque coef.: $k := 0.2$

Bolt preload: $Fpmax := .75 \cdot At \cdot Fty$ $\quad Fpmax = 5.227 \times 10^3\,lbf$ $\quad Fpmax = 2.325 \times 10^4\,newton$

Tightening torque: $Tmax := Fpmax \cdot k \cdot D$

Tightening torque: $Tmax = 326.689\,in \cdot lbf$ $\quad Tmax = 36.911\,m \cdot newton$

$Tmin := .85 \cdot Tmax$

$Tmin = 277.685\,in \cdot lbf$ $\quad Tmin = 31.374\,m \cdot newton$

$Fpmin := \frac{Tmin}{k \cdot D}$ $\quad Fpmin = 4443\,lbf$ $\quad Fpmin = 1.976 \times 10^4\,newton$

Preload ratio: $\frac{Fpmax}{fty} = 0.75$

Loading plane factor: $n := .5$

Joint load factor (steel bolt on Alum. plate): $\phi := 0.266$

Calculate joint seperation load: $Wjs := \frac{Fpmin}{(1 - n \cdot \phi)}$ $\quad Wjs = 5124\,lbf$ $\quad Wjs = 2.279 \times 10^4\,newton$

Check for joint seperation (if ratio is > 1.0, separation occurs)

$\frac{Ften \cdot FSsep}{Wjs} = 0.148$ $\quad MoSsep := \left(1 - \frac{Ften \cdot FSsep}{Wjs}\right)$ $\quad MoSsep = 0.852$

Tensile, shear and bending ratios

$Fa := if[(Ften < Wjs), Fpmax + \phi \cdot n \cdot (FSu \cdot FF \cdot Ften), FF \cdot FSu \cdot Ften]$

Axial load:

If statement determines if joint separation occurs

$Fa = 5.42 \times 10^3\,lbf$ $\quad Fa = 2.411 \times 10^4\,newton$

Tensile ratio: $Rt := \frac{Fa}{ftu \cdot \alpha c}$ $\quad Rt = 0.621$

Note: Temperature correction factor is applied to the bolt allowables here.

Bending ratio: $Rb := \frac{FF \cdot FSu \cdot Fbend}{fbu \cdot \alpha c}$ $\quad Rb = 0$

Shear ratio: $Rs := \frac{FF \cdot FSu \cdot Fshear}{fsu \cdot \alpha c}$ $\quad Rs = 0.579$

Calculate Margins of safety:

Guess K $\quad K := 1.0$

Given

$(K \cdot Rs)^3 + [K \cdot (Rt + Ky \cdot Rb)]^2 = 1$ $\quad K := Find(K)$

Margin of safety: $MoScombU := K - 1$ $\quad MoScombU = 0.26$

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For the bearing, tension and shear out verification the lug formulas from Bruhn "Analysis and design of flight vehicle structures" are used.

Calculate Margins of safety for Bearing:

Fbry(plate) [Pa] : $Fbry := 544E6 \cdot Pa$

Fbru(plate) [Pa] : $Fbru := 703E6 \cdot Pa$

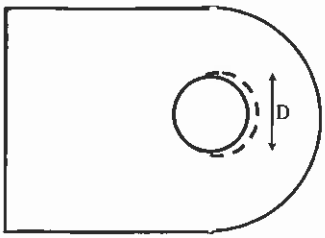


Plate Thickness [mm] : $Thk := 4mm$ $Thk = 4 \times 10^{-3}\,m$

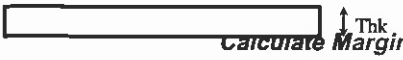
Nominal Diameter [mm] : $D = 7.938mm$

Limit Shear Force [N] : $Shear := Fshear$

Limit Stress [Pa] : $Sh := \frac{Shear}{(Thk \cdot D)}$ $Sh = 1.651 \times 10^{8}\,Pa$

MoS bry : $MoSbry := \left(\frac{Fbry \cdot \alpha c}{Sh \cdot FSy}\right) - 1$ $MoSbry = 1.478$

MoS bru : $MoSbru := \left(\frac{Fbru \cdot \alpha c}{Sh \cdot FSu}\right) - 1$ $MoSbru = 1.001$



Calculate Margins of safety for tension failure:

Fty(plate) [Pa] :

Ftu(plate) [Pa] : $Fty := 393E6 \cdot Pa$ $Ftu := 468E6 \cdot Pa$

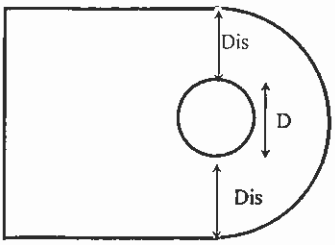


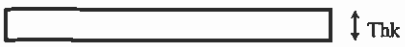
Plate Thickness [mm] : $Thk := 4mm$ $Thk = 4 \times 10^{-3}\,m$

Distance hole-end plate [mm] : $Dis := 12.5mm$ $Dis = 0.013m$

Limit Shear Force [N] : $Shear := Fshear$

Limit Stress [Pa] : $Sh := \frac{Shear}{(Thk \cdot Dis \cdot 2)}$ $Sh = 5.243 \times 10^{7}\,Pa$

MoS lug ty : $MoSlugty := \left(\frac{Fty \cdot \alpha c}{Sh \cdot FSy}\right) - 1$ $MoSlugty = 4.637$



MoS lug tu : $MoSlugtu := \left(\frac{Ftu \cdot \alpha c}{Sh \cdot FSu}\right) - 1$ $MoSlugtu = 3.195$

Calculate Margins of safety for shear out failure:

Fsy(plate) [Pa] : $Fsy := 219000000Pa$

Fsu(plate) [Pa] : $Fsu := 262E6 \cdot Pa$

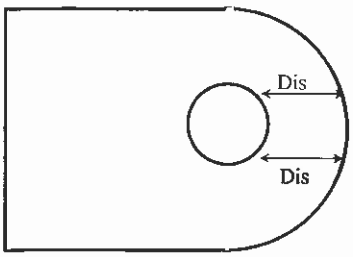


Plate Thickness [mm] : $Thk := 4mm$ $Thk = 4 \times 10^{-3}\,m$

Distance hole-end plate [mm] : $Dis := 12.5mm$ $Dis = 0.013m$

Limit Shear Force [N] : $Shear := Fshear$

Limit Stress [Pa] : $Sh := \frac{Shear}{(Thk \cdot Dis \cdot 2)}$ $Sh = 5.243 \times 10^{7}\,Pa$

MoS lug sy : $MoSlugsy := \left(\frac{Fsy \cdot \alpha c}{Sh \cdot FSy}\right) - 1$ $MoSlugsy = 2.141$

MoS lug su : $MoSlugsu := \left(\frac{Fsu \cdot \alpha c}{Sh \cdot FSu}\right) - 1$ $MoSlugsu = 1.349$

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ANNEX 2. HONEYCOMB VERIFICATION EXAMPLE

HONEYCOMB LTOF VERIFICATION

(HEXCEL 1.8-3/4-25)

COMBINED LOAD STRENGTH VERIFICATION

ACCORDING TO RD 6 CHP C12.4.8

INPUT HONEYCOMB ALLOWABLE

$F1sl := 2300000Pa$

$F1sw := 1500000Pa$

$F1c := 1440000Pa$

Safety factor $SF := 2$

INPUT STRESS APPLIED ON HONEYCOMB CORE

$f1sl := 30000Pa$

$f1sw := 320000Pa$

$f1c := 430000Pa$

INTERACTION EQUATION CALCULATION

VERIFICATION

$Rsl := SF \cdot \frac{f1sl}{F1sl}$ $Rsl = 0.026$

$Rsw := SF \cdot \frac{f1sw}{F1sw}$ $Rsw = 0.427$

$Ra := SF \cdot \frac{f1c}{F1c}$ $Ra = 0.597$

$VER := \max\left(Rsl + Ra^2, Rsw + Ra^2\right)$

$\boxed{VER = 0.783}$ <1 OK

$Rx := \min(Rsl, Rsw)$ $Rx = 0.026$

Guess K $K := 1.0$

Given

$(K \cdot Rx) + [K \cdot (Ra)]^2 = 1$ $K := Find(K)$

Margin of safety: $MoScombU := K - 1$ $MoScombU = 0.638$

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INTRACELL BUCKLING VERIFICATION

ACCORDING TO RD 6 CHP C12.5.2

INPUT HONEYCOMB ALLOWABLE

$Ef := 72395E6Pa$

$Fcy := 400E6Pa$

Face thickness $tf := 1.25mm$

Core cell size $S2 := 3.2 \cdot mm$

INPUT APPLIED STRESS ON HONEYCOMB FACE SHEET

$fx := 31.7E6Pa$

$fy := 10.2E6Pa$

$fxy := 7.8E6 \cdot Pa$

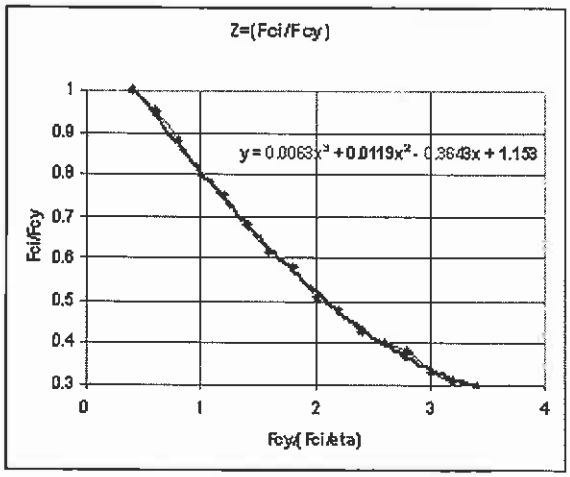
VERIFICATION

COMPRESSION CONTRIBUTION

$$F2ci\_\eta := 0.75 \cdot Ef \cdot \left(\frac{tf}{S2}\right)^{\left(\frac{3}{2}\right)} \qquad F2ci\_\eta = 1.326 \times 10^{10} Pa$$

$$\frac{Fcy}{F2ci\_\eta} = 0.03$$

Graph to determine Fci and Fi value



Z1 = F2ci/Fcy

Z2 = F2i/Fcy

$$Z1 := 0.0065 \cdot \left(\frac{Fcy}{F2ci\_\eta}\right)^3 + 0.0114 \cdot \left(\frac{Fcy}{F2ci\_\eta}\right)^2 - 0.3654 \cdot \left(\frac{Fcy}{F2ci\_\eta}\right) + 1.1539 \qquad Z1 = 1.143$$

$$F2ci := Z1 \cdot Fcy \qquad F2ci = 4.572 \times 10^8 Pa$$

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BIAXIAL CONTRIBUTION

PARAMETER N IF doesnt work properly, please input **n value** manually

$$\text{if}\left[\left(\frac{S2}{tf} < 15.63\right), n := 2 + \left(15.63 \cdot \frac{tf}{S2}\right)^2, n := 3\right] \qquad n := 3$$

$$\gamma := \frac{fy}{fx} \qquad \gamma = 0.322$$

$$F2cix := \frac{F2ci}{\left(1 + \gamma^n\right)^{\frac{1}{n}}} \qquad F2cix = 4.522 \times 10^8\,Pa$$

SHEAR CONTRIBUTION

$$F2si\_\eta := 0.6 \cdot Ef \cdot \left(\frac{tf}{S2}\right)^{\left(\frac{3}{2}\right)} \qquad F2si\_\eta = 1.06 \times 10^{10}\,Pa$$

$$F2i\_\eta := F2si\_\eta \cdot \sqrt{3} \qquad F2i\_\eta = 1.837 \times 10^{10}\,Pa$$

$Z2 = F2i/F2cy$

$$Z2 := 0.0065 \cdot \left(\frac{Fcy}{F2i\_\eta}\right)^3 + 0.0114 \cdot \left(\frac{Fcy}{F2i\_\eta}\right)^2 - 0.3654 \cdot \left(\frac{Fcy}{F2i\_\eta}\right) + 1.1539 \qquad Z2 = 1.146$$

$$F2i := Z2 \cdot Fcy \qquad F2i = 4.584 \times 10^8\,Pa$$

BIAXIAL AND SHEAR CONTRIBUTION

$$F2si := \frac{F2i}{\sqrt{3}}$$

$$Ra2 := \frac{fx \cdot SF}{F2cix} \qquad Rs2 := \frac{fxy \cdot SF}{F2si}$$

$$\boxed{Ra2 + Rs2^2 = 0.144} \qquad <1\ OK$$

Guess Y $\quad Y := 1.0$

Given

$$(Y \cdot Ra2) + [Y \cdot (Rs2)]^2 = 1 \qquad Y := \text{Find}(Y)$$

Margin of safety: $\quad MoScombU := Y - 1 \qquad MoScombU = 5.184$

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WRINKLING VERIFICATION

ACCORDING TO RD 6 CHP C12.5.3

INPUT HONEYCOMB ALLOWABLE

Core compression modulus $Ec := 215E6Pa$

$Gc := 214E6Pa$

Safety factor $SF := 2$

INPUT APPLIED STRESS ON HONEYCOMB FACE SHEET

$fx := 31.7E6Pa$

$fy := 10.2E6Pa$

$fxy := 7.8E6Pa$

VERIFICATION

COMPRESSION CONTRIBUTION

$\gamma := \frac{fy}{fx}$ $\gamma = 0.322$

$\gamma i := \sqrt{1 - \gamma + \gamma^2}$ $\gamma i = 0.884$

$Fcwx\_\eta 2 := 0.43 \cdot \frac{\sqrt[3]{Ef \cdot Ec \cdot Gc}}{\sqrt[3]{1 + \gamma^3}}$ $Fcwx\_\eta 2 = 6.352 \times 10^8 Pa$

$F3i\_\eta := Fcwx\_\eta 2 \cdot \gamma i$ $F3i\_\eta = 5.616 \times 10^8 Pa$

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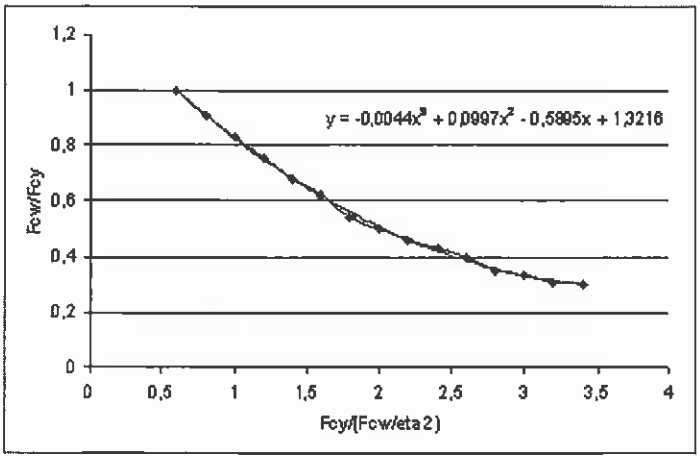
Graph to determine Fcw and F4i value



Z3 = Fcw/Fcy

Z4 = F4i/Fcy

$Z3 := -0.0044\cdot\left(\frac{Fcy}{F3i\_\eta}\right)^3 + 0.0997\cdot\left(\frac{Fcy}{F3i\_\eta}\right)^2 - 0.5895\cdot\left(\frac{Fcy}{F3i\_\eta}\right) + 1.3216$ $\quad Z3 = 0.951$

$Fcw := Z3\cdot Fcy$ $\quad Fcw = 3.803\times10^8\,Pa$

$Fcwx := \frac{Fcw}{\gamma i}$ $\quad Fcwx = 4.301\times10^8\,Pa$

SHEAR CONTRIBUTION

$Fsw3\_\eta2 := 0.43\cdot\sqrt[3]{Ef\cdot Ec\cdot Gc}$ $\quad Fsw3\_\eta2 = 6.422\times10^8\,Pa$

$F4i\_\eta := Fsw3\_\eta2\cdot\sqrt{3}$ $\quad F4i\_\eta = 1.112\times10^9\,Pa$

$Z4 := -0.0044\cdot\left(\frac{Fcy}{F4i\_\eta}\right)^3 + 0.0997\cdot\left(\frac{Fcy}{F4i\_\eta}\right)^2 - 0.5895\cdot\left(\frac{Fcy}{F4i\_\eta}\right) + 1.3216$ $\quad Z4 = 1.122$

$F4i := Z4\cdot Fcy$ $\quad F4i = 4.489\times10^9\,Pa$

$Fsw4 := \frac{F4i}{\sqrt{3}}$ $\quad Fsw4 = 2.592\times10^8\,Pa$

SHEAR CONTRIBUTION

$Ra4 := fx\cdot\frac{SF}{Fcwx}$ $\quad Ra4 = 0.147$

$Rs4 := fxy\cdot\frac{SF}{Fsw4}$ $\quad Rs4 = 0.06$

$\boxed{Ra4 + Rs4^2 = 0.151}$

Guess Z $\quad Z := 1.0$

Given

$(Z\cdot Ra4) + [Z\cdot(Rs4)]^2 = 1 \quad Z := Find(Z)$

Margin of safety: $\quad MoScombU := Z - 1 \quad MoScombU = 4.922$

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ANNEX 3. TABLE FOR SAFETY REVIEW FOR MAIN STRUCTURE

ITEM	Drawing Number	Material and Temper	Max Tensile Stress [Ksi]	Ratio of applied limit stress to allowable stress	Margin of Safety (ultimate) SF = 2	Fracture classification	Rationale	Comments
BEAM A	ams TOF 04-01-001 LT	Al 7075 T7351	30.60	0.45	0.11			Near bolts
BEAM B	ams TOF 04-01-002 LT	Al 7075 T7351	29.88	0.44	0.14			Near bolts
CORNER BEAM	ams TOF 04-01-003 LT	Al 7075 T7351	11.02	0.16	>2			Near bolts
SKIN 1 HONEYCOMB	ams TOF 04-02-001 LT	Al 7075 T7351	4.52	0.07	>2			Near insert
SKIN 2 HONEYCOMB	ams TOF 04-02-002 LT	Al 7075 T7351	6.49	0.10	>2			Near insert
ROD L 450	ams TOF 04-01-01-001 LT	Al 7075 T7351	7.14	0.11	>2			Axial force
ROD L 605	ams TOF 04-01-02-001 LT	Al 7075 T7351	14.65	0.22	1.32			Axial force
USS BRACKET LOWER TOF Z-Strut	ams TOF 04-01-020 LT	Al 7075 T7351	10.01	0.15	>2			Near bolts
USS UPPER BRACKET LOWER TOF	ams TOF 04-01-021 LT	Al 7075 T7351	10.73	0.16	>2			Near bolts
INTERNAL BRACKET DX	ams TOF 04-01-018 LT	Al 7075 T7351	11.89	0.17	1.86			Near bolts
INTERNAL BRACKET SX	ams TOF 04-01-019 LT	Al 7075 T7351	13.34	0.20	1.55			Near bolts

ITEM	Material	Ftu [Ksi]	Fty [Ksi]	Fsu [Ksi]	Margin of Safety (ultimate) SF = 2	Fracture classification	Rationale	Comments
JOINT 1	A-286	160	120	95	0.27	Fail Safe		Bracket ring
JOINT 2	A-286	160	120	95	0.51	Fail Safe		USS/U-BKT
JOINT 3	A-286	160	120	95	0.64	Fail Safe		USS/L-BKT
JOINT 4	A-286	160	120	95	0.36	Fail Safe		RING-HCOMB
JOINT 5	Al 7075 T7351	68	57	38	0.04	Fail Safe		HONEYCOMB BOLT
JOINT 6	A-286	160	120	95	0.21	Safe Life		ROD END BOLT

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