



# ECAR-6589 Reflector Support Structure Analysis

October 2023

*Changing the World's Energy Future*

Brandon L Moon



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# **ECAR-6589 Reflector Support Structure Analysis**

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**October 2023**

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**<http://www.inl.gov>**

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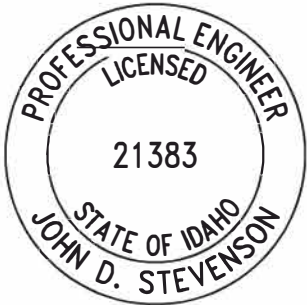
**Walsh Engineering Services**

## **Reflector Support Structure Analysis**

**Project # 33526**





1. Effective Date	10/03/23	<b>Professional Engineer's Stamp</b>  
2. Does this ECAR involve a Safety SSC (see def. LWP-10200)?	YES	
3. Safety SSC Determination Document ID	TBD	
4. SSC ID	N/A	
5. Project No.	33526	
6. Engineering Job (EJ) or Engineering Change (EC) No.	EC 1755	
7. Building	720	
8. Site Area	MFC	
<b>9. Objective / Purpose</b>  <p>The purpose of this ECAR is to document compliance with best engineering practices, ANSI/AISC N690 and the seismic requirements of IBC-2015 for the Reflector Support Structure of the MARVEL microreactor.</p>		
<b>10. If revision, please state the reason and list sections and/or page being affected.</b>  <p>N/A</p>		
<b>11. Conclusion / Recommendations</b>  <p>A frequency analysis was performed to show that there were no natural frequencies near 60 Hz to ensure there would be no amplification of the Stirling Engine vibration. The design is capable of meeting the requirements of being able to maintain the reflectors in the correct position for the duration of the reactor operation and surviving a seismic event.</p>		

John Stevenson  
Walsh Engineering Services  
2023.09.28 15:47:46-06'00'

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Appendix C Modal Analysis

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## 1. PROJECT ROLES AND RESPONSIBILITIES

Project Role	Name	Organization	Pages Covered (if applicable)
Performer	John Stevenson	Walsh Engineering Services (WES)	See DCR 704405
Checker <sup>a</sup>	Luke Andrew	WES	See DCR 704405
Independent Reviewer <sup>b</sup>	Ben Coryell	U710	See DCR 704405
CUI Reviewer <sup>c</sup>	MW Patterson	C120	See DCR 704405
Manager <sup>d</sup>	Nathan Seaver	WES	See DCR 704405
Requestor <sup>ef</sup>	Yasir Arafat	C120	See DCR 704405
Nuclear Safety <sup>f</sup>	Doug Gerstner	U023	See DCR 704405
Document Owner <sup>f</sup>	Brandon Moon	U022	See DCR 704405
Reviewer <sup>f</sup>	N/A	N/A	-----

### Responsibilities:

- Confirmation of completeness, mathematical accuracy, and correctness of data and appropriateness of assumptions.
- Concurrence of method or approach. See definition, LWP-10106.
- Concurrence with the document's markings in accordance with LWP-11202.
- Concurrence of procedure compliance. Concurrence with method/approach and conclusion.
- Authorizes the commencement of work of the engineering deliverable.
- Concurrence with the document's assumptions and input information. See definition of Acceptance, LWP-10200.

**NOTE:** Delete or mark "N/A" for project roles not engaged. Include ALL personnel and their roles listed above in the DCR system. The list of the roles above is not all inclusive. If needed, the list can be extended or reduced.

## 2. SCOPE AND BRIEF DESCRIPTION

Under the auspices of the DOE Microreactor Program, INL is developing a nuclear microreactor applications test bed to perform research and development on various operational features of microreactors and enable improved integration of microreactors with end-user applications.

Development of the MARVEL testbed provides an opportunity to establish and exercise key capabilities to support future microreactor demonstrations by addressing:

1. The need identified in engagements with potential end-users of microreactor systems wanting more information about how microreactors meet their application needs.
2. Development of a small-scale reactor for R&D purposes for the first time in nearly 50 years.
3. Engagement and outreach with end-users and stakeholders to perform research and development on the integration of microreactors with a range of anticipated applications, such as load-following electricity demand, process heat, hydrogen production, and water purification.
4. Research and development to investigate and address issues and challenges related to the fabrication, assembly, rapid installation, deployment, authorization, and operation of microreactors to facilitate end-user adoption.

The MARVEL microreactor consists of five main systems: MRS (MARVEL Reactor Structure), PGS (Power Generation System), FCS (Fuel Core System), RCS (Reactivity Control System), and ICS (Instrument Control System). The RSS (Reflector Control System) is a sub system of the MRS which contains the upper and lower reflector support plates which support and locate the stationary core reflector and provide vertical support for the control drums. They are suspended from the Primary Coolant System by bolted structural straps which utilize a turnbuckle to allow for adjustment and leveling of the support plates. The stainless-steel support plates are each formed from four quarter circle segments which are bolted together around the lower core barrel. Bearing plates of non-galling Nitronic 60 alloy are fitted to the inner diameter of the support plates to prevent adhesive wear between the plates and the core barrel as the barrel expands and contracts due to changes in the temperature of the reactor.

### 2.1 SCOPE

This ECAR documents the calculations performed to ensure the reflector support assemblies are capable of safely holding the reflectors in a suspended position for the duration of the reactor operation and have the ability to survive a seismic event. The calculations performed for the reflector support assemblies consist of strength calculations for the support plates, support straps, and fasteners as well as tolerance

calculations. Additional calculations were performed to ensure that seismic forces would not cause the reflector plates to shift. The seismic analysis was performed using finite element analysis.

## DESIGN OR TECHNICAL PARAMETER INPUT AND SOURCES

### **2.2 TECHNICAL AND FUNCTIONAL REQUIREMENTS PER REF 5**

- The RSS shall be designed to the seismic criteria of IBC-2015, using the response coefficients in Table 3-1 of DOE-STD-1020.
  - The MARVEL reactor is categorized as NDC-2 per SDS-119. Per DOE-STD-1020, SDC-2 SSCs shall be designed according to the criteria of IBC-2015, for Risk Category IV facilities.
- The RSS shall be designed to allow access to the reactor core area.
  - The core area will need to be accessed for the installation of fuel elements prior to operation, and for removal of those elements at end-of-life.
- The RSS shall be designed to support the Drum and Rod Neutronics Subsystem.
  - The Drum and Rod Neutronics Subsystem needs to be properly supported to ensure that it's components are able to perform as designed to control the operation of the reactor.

### **2.3 FUNCTIONAL GUIDELINES**

- Support the reflectors in the correct position for reactor operation.
- Provide a means for leveling the reflectors.

## **3. RESULTS OF LITERATURE SEARCHES AND OTHER BACKGROUND DATA**

The position of the reflector plates affects the overall reactivity, so it is necessary to maintain the position of the reflector plates during the operation of the reactor.

## **4. ASSUMPTIONS**

Mechanical properties of 316H at elevated temperatures are assumed to be the same as the mechanical properties of 316 at elevated temperatures per AISC DG-27.

## **5. COMPUTER CODE VALIDATION**

- A. Computer type: Blackbird: 64-bit Windows 10 Pro, AMD Ryzen 9 5950X 16-Core Processor 3.40 GHz
- B. Operating System and Version: Windows 10 Pro
- C. Computer program name and revision: Abaqus 2021, SolidWorks 2022 SP4, MathCAD Prime 8
- D. Inputs (may refer to an appendix): Appendix B & C
- E. Outputs (may refer to an appendix): Appendix B & C
- F. Evidence of, or reference to, computer program validation: V&V in process
- G. Bases supporting application of the computer program to the specific physical problem: N/A

## **6. DISCUSSION/ANALYSIS**

Each component of the Reflector Support Structure was analyzed individually to common machine design practice and ANSI/AISC N690 to ensure they are capable of performing as designed to meet the requirements. Formulas typically used in hand calculations were entered into Mathcad. FEA Seismic Analysis is performed at 650° C, since the thermal stresses and reduced material strength will be considerably more bounding than at cold conditions.

An extreme load of 10 times the expected axial shield weight was used in the static finite element analysis.

The max principal stress is compared to the tensile allowable as specified in N690.

The stress intensity divided by 2 is compared to the shear allowable as specified in N690.

A frequency analysis was performed to show that there were no natural frequencies near 60 Hz ensure there would be no amplification of the Stirling Engine vibration.

The stationary Core Reflector stacks were analyzed to ensure the friction forces are sufficient to prevent the plates from shifting during a seismic event.

The torque required for the Alignment Ring bolts was calculated so the Alignment Rings will have sufficient bolt pretension to hold any seismic forces but will slide due to the differential temperature between the Core Barrel, Support Blocks, and Alignment Rings.

Artificially high stresses are observed on the edges of bolt holes in the seismic analysis. These stresses do not penetrate beyond the surface and the surrounding stresses are low, they are the result of an artificial stress amplification and do not represent real stresses. Since these stresses will not be present in the real parts, they will not affect the performance of the Reflector Support Structure. This stress area is shown in figure 1 below.

Reflector Support Structure Analysis

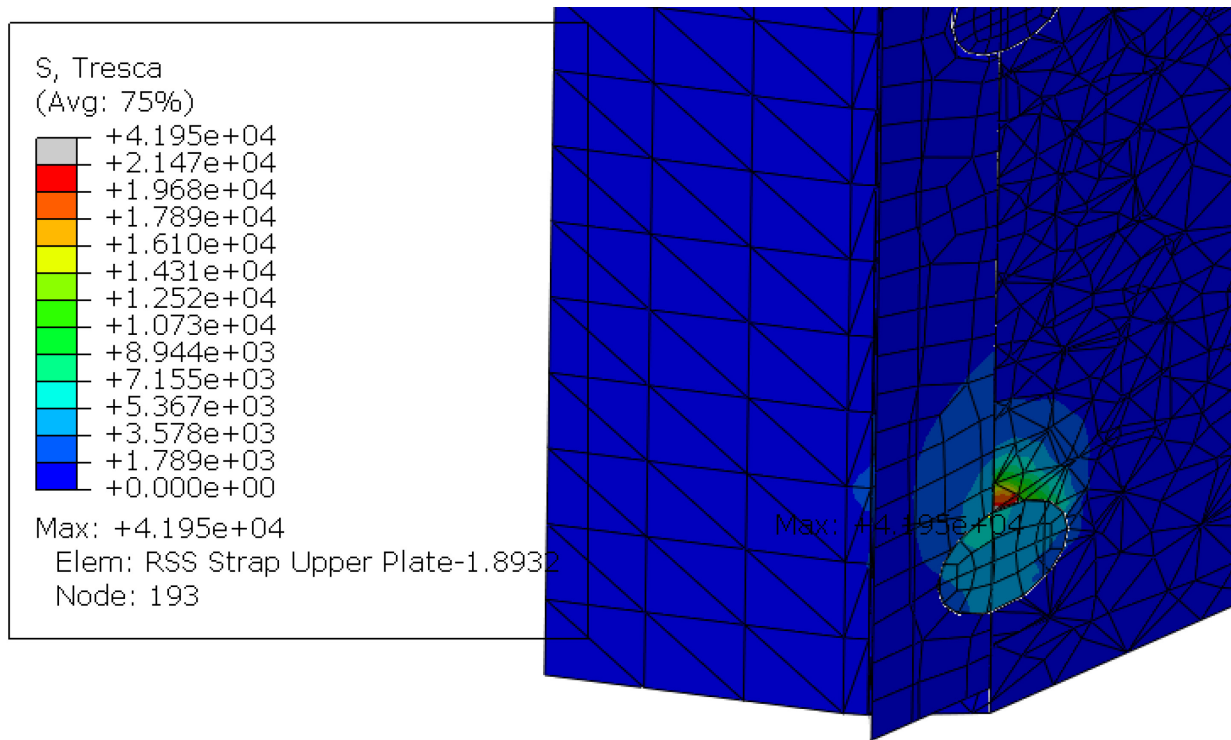


Figure 1. Artificial High Stress Area

## 7. RESULTS

The RSS Seismic FEA principal stress results are shown in figure 2 below.

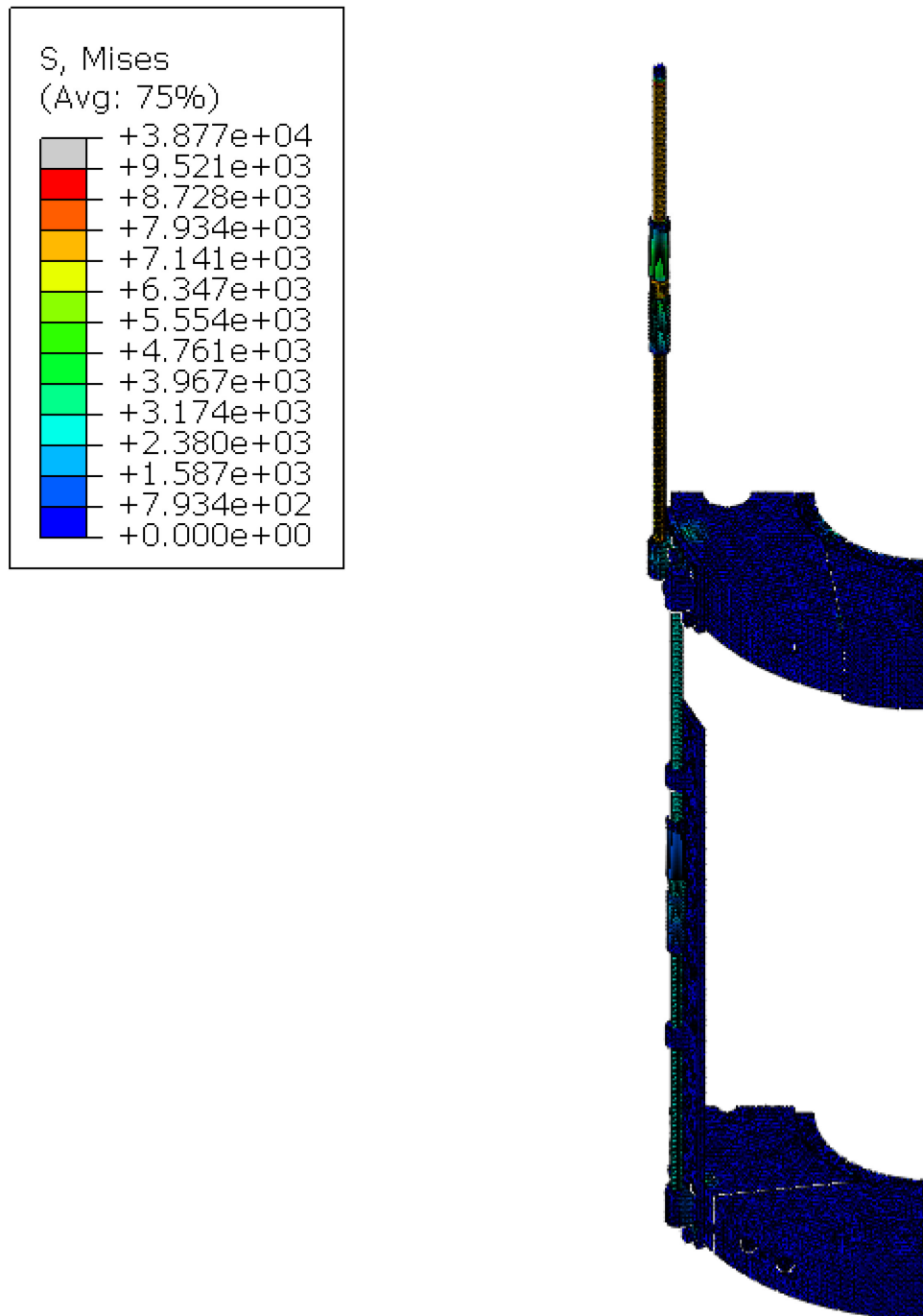


Figure 2. Max Principal Stress

The allowable stress for tension as calculated in Appendix A is: 9.521 ksi



Reflector Support Structure Analysis

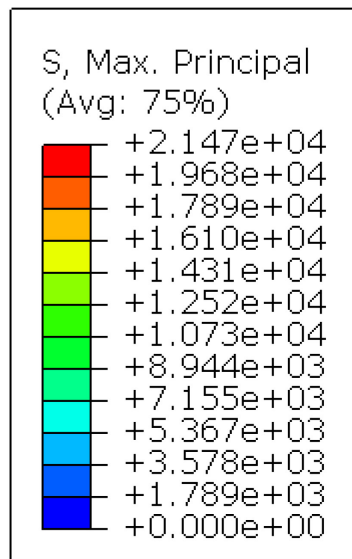


Figure 3. Elements over 9.521 ksi

The RSS Seismic FEA stress intensity results are shown in figure 3 below.

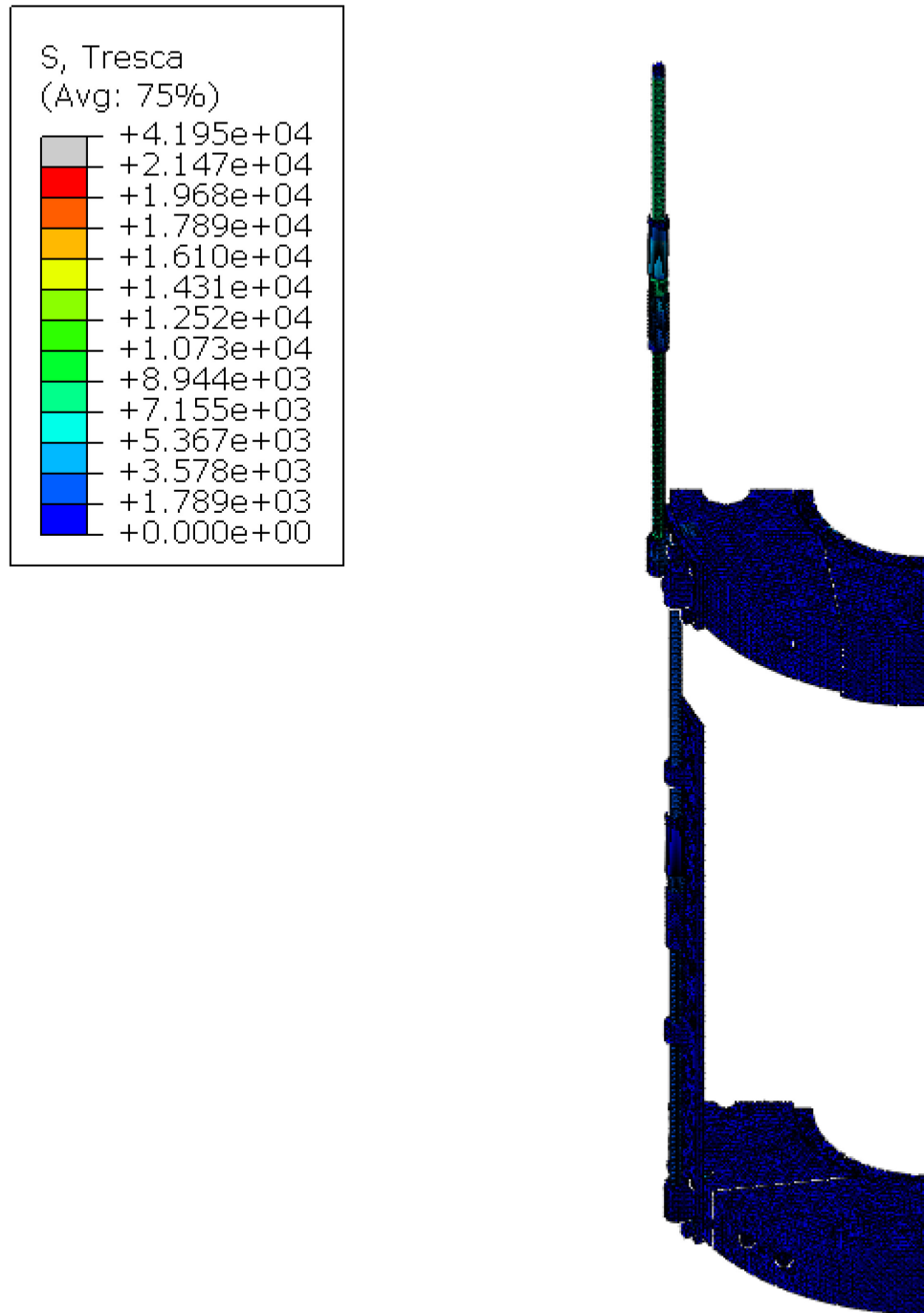


Figure 4. Stress Intensity

The allowable stress for shear as calculated in Appendix A is: 10.733 ksi

This equates to an allowable stress intensity of: 21.466 ksi

Reflector Support Structure Analysis

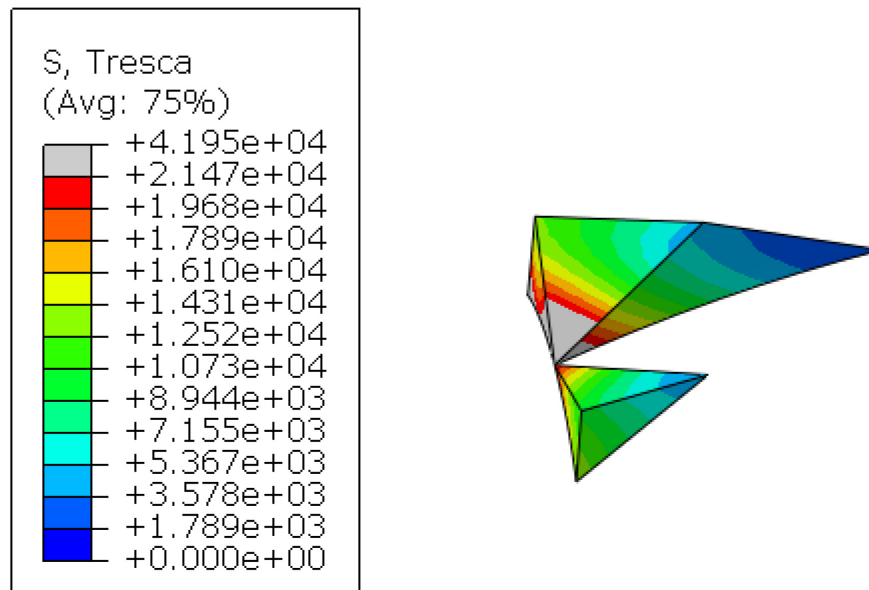


Figure 5. Elements over 21.466 ksi

Reflector Support Structure Analysis

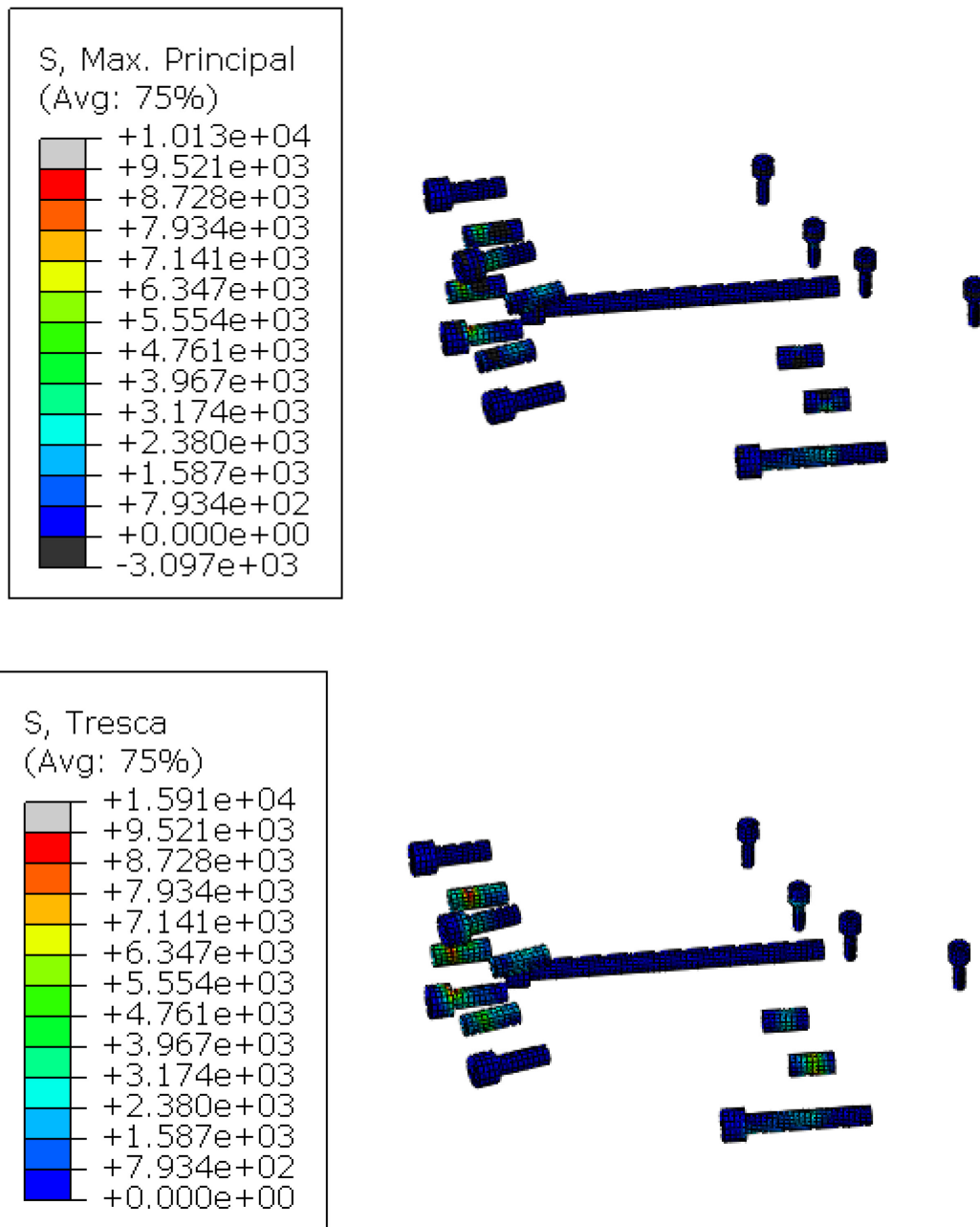


Figure 6. Upper Fasteners

Reflector Support Structure Analysis

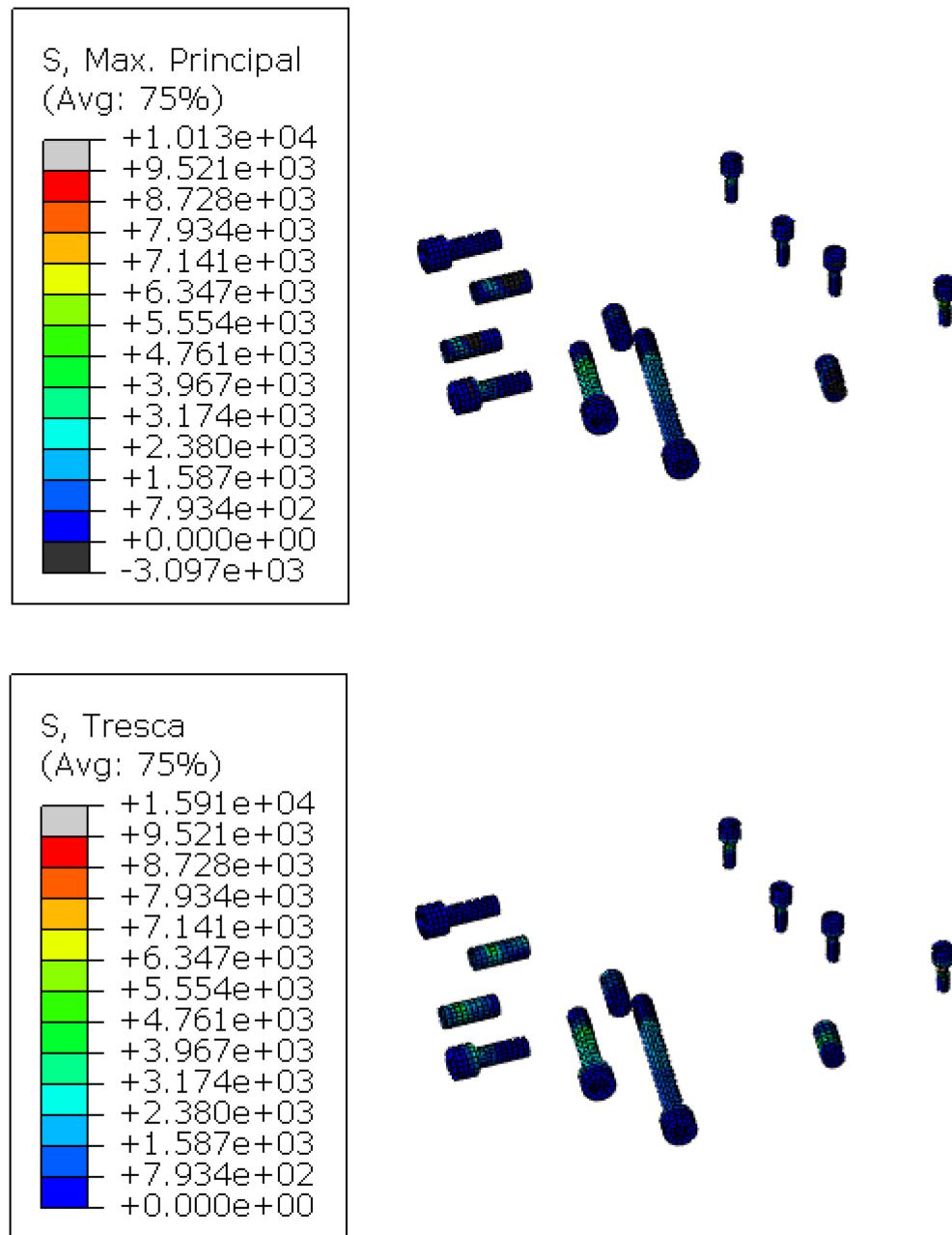


Figure 7. Lower Fasteners

The allowable stress for fastener tension as calculated in Appendix A is: 24.975 ksi

The allowable stress for fastener shear as calculated in Appendix A is: 14.985 ksi

This equates to an allowable stress intensity of: 29.970 ksi

The results of the Modal analysis showing the first five frequencies are shown in the figures below.

Frequency Number	Rad/sec	Hertz	Seconds
1	13.153	2.0934	0.47769
2	13.343	2.1235	0.47091
3	19.781	3.1482	0.31764
4	563	89.604	0.01116
5	563.41	89.669	0.011152

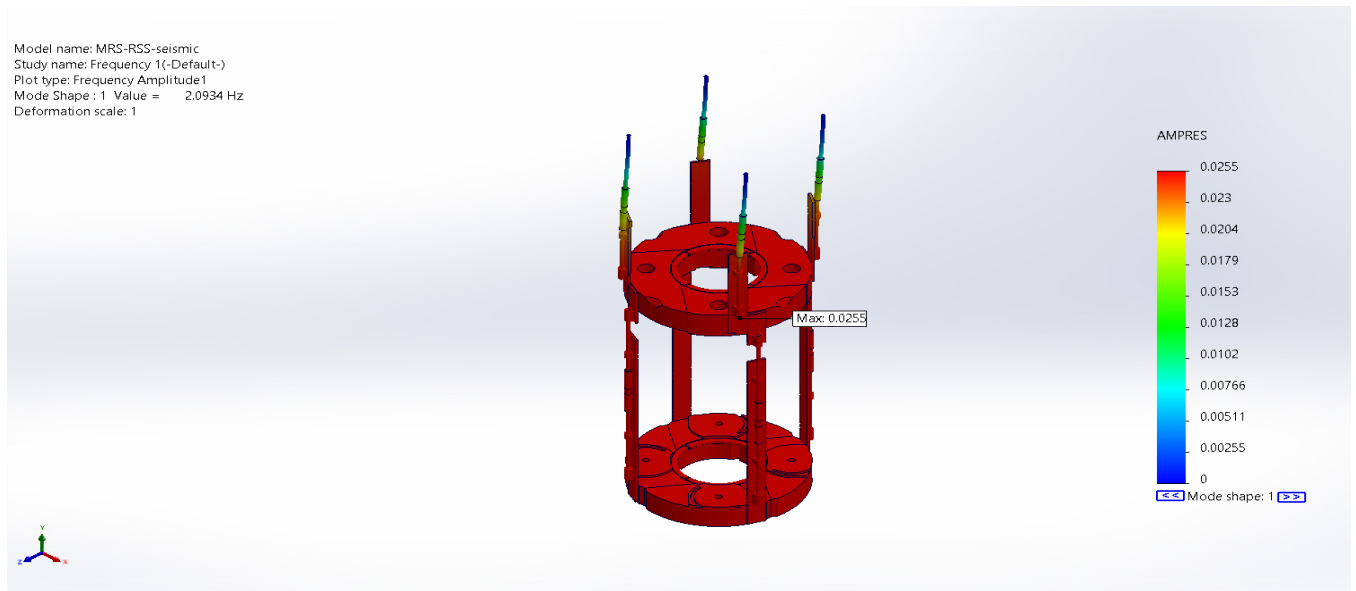


Figure 8. Mode 1

Reflector Support Structure Analysis

Model name: MRS-RSS-seismic  
Study name: Frequency 1(-Default-)  
Plot type: Frequency Amplitude2  
Mode Shape : 2 Value = 2.1235 Hz  
Deformation scale: 1

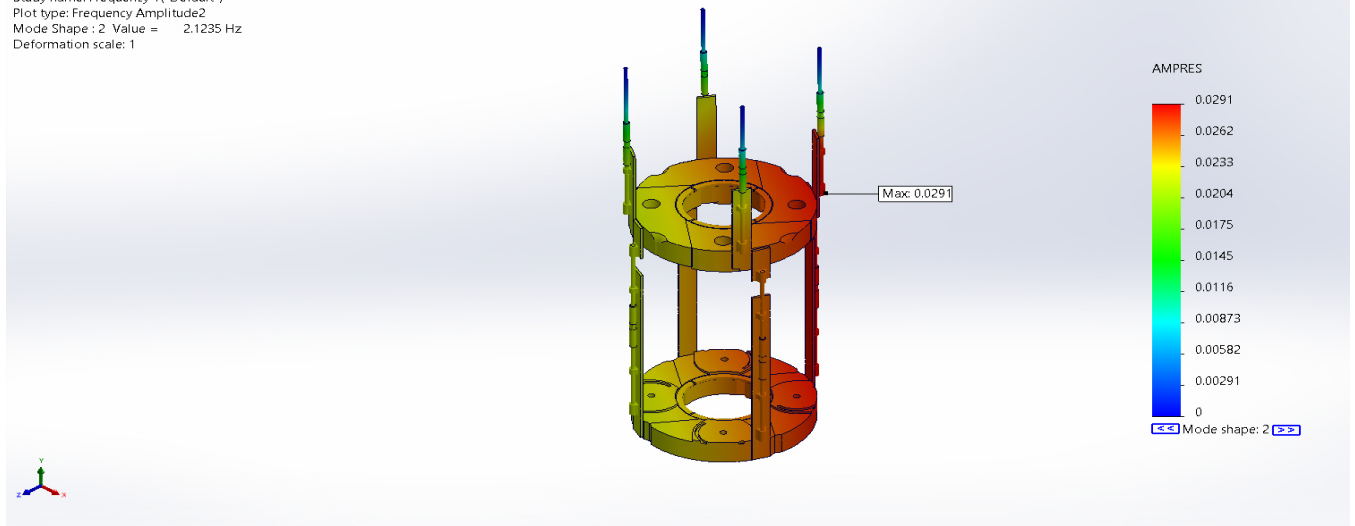


Figure 9. Mode 2

Model name: MRS-RSS-seismic  
Study name: Frequency 1(-Default-)  
Plot type: Frequency Amplitude3  
Mode Shape : 3 Value = 3.1482 Hz  
Deformation scale: 1

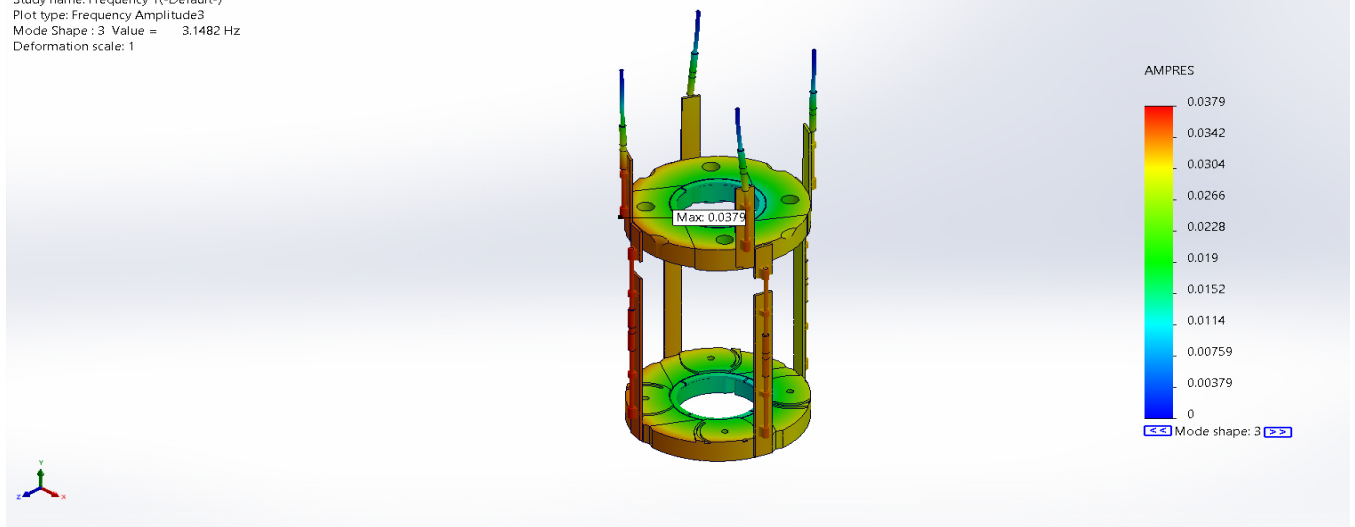


Figure 10. Mode 3

Reflector Support Structure Analysis

Model name: MRS-RSS-seismic  
Study name: Frequency 1(-Default-)  
Plot type: Frequency Amplitude4  
Mode Shape : 4 Value = 89.604 Hz  
Deformation scale: 1

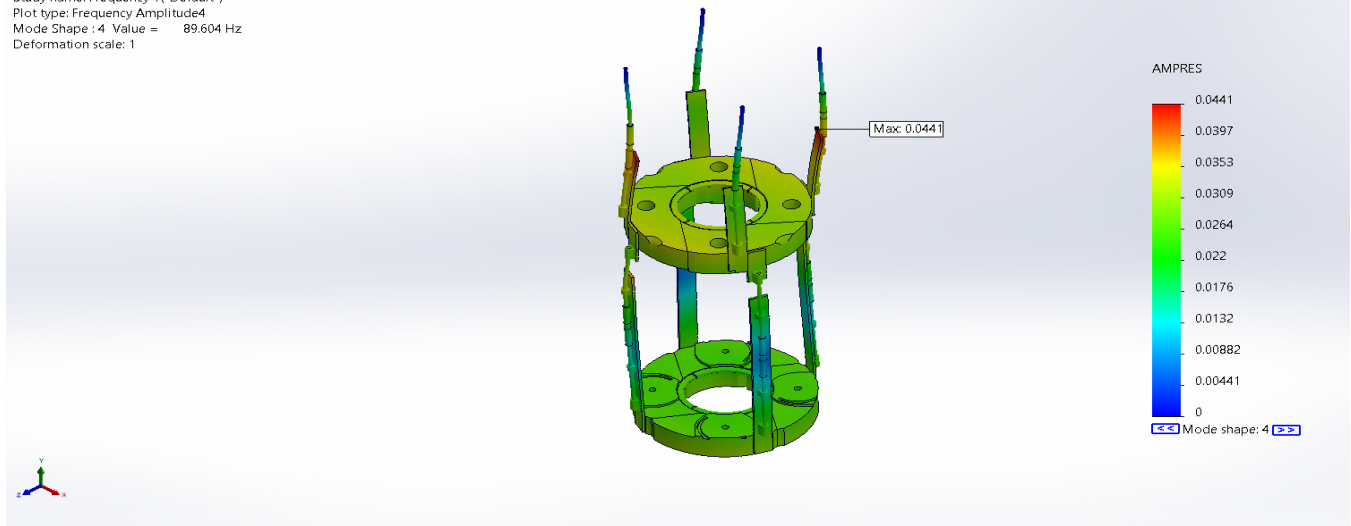


Figure 11. Mode 4

Model name: MRS-RSS-seismic  
Study name: Frequency 1(-Default-)  
Plot type: Frequency Amplitude5  
Mode Shape : 5 Value = 89.669 Hz  
Deformation scale: 1

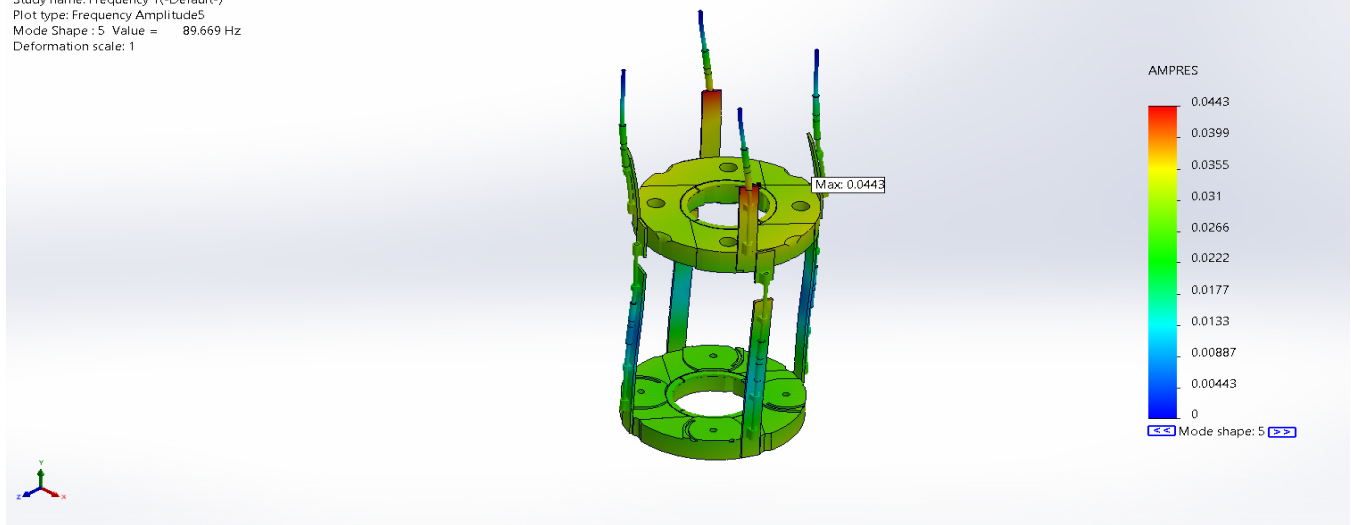


Figure 12. Mode 5

## 8. CONCLUSION

The modal analysis shows that there were no natural frequencies near 60 Hz. The analyses show that the design is capable of meeting the requirements of being able to maintain the reflectors in the correct position for the duration of the reactor operation and surviving a seismic event.



## 9. REFERENCES

1. Oberg, Erik, Jones, Franklin D., Horton, Holbrook L. and Ryffel, Henry H. 2020. *Machinery's Handbook*. 31st. New York: Industrial Press.
2. Avallone, Eugene A., Baumeister III, Theodore and Sadegh, Ali M. 2007. *Marks' Standard Handbook for Mechanical Engineers*. 11th. New York: McGraw-Hill.
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7. HPAIloy. 2017. *The Nitronic 60 Book*. Windfall: HPAIloy
8. Walsh Engineering Services. 2023. *MARVEL INL Drawings*. Idaho Falls: Walsh Engineering Services.
  - a. 1014616 - REFLECTOR SUPPORT STRUCTURE ASSEMBLY - Rev 000B
  - b. 1014618 - REFLECTOR SUPPORT STRAP ASSEMBLIES - Rev 000B
  - c. 1014619 - SUPPORT PLATE ALIGNMENT RING - Rev 000A
  - d. 1014672 - LOWER REFLECTOR PLATE - Rev 000B
  - e. 1014673 - UPPER REFLECTOR SUPPORT PLATE - Rev 000B

## 10. APPENDICES

## Appendix A

### Calculations

#### Summary

$\sigma_d = 3.125 \text{ ksi}$	$C.D._{\sigma_d} = 7.992$	Tensile shear stress in threaded rod
$\sigma_D = 2.875 \text{ ksi}$	$C.D._{\sigma_D} = 3.312$	Tensile shear stress in turnbuckle
$\sigma_{DS} = 3.958 \text{ ksi}$	$C.D._{\sigma_{DS}} = 2.405$	Tensile stress in turnbuckle with seismic
$\sigma_{dS} = 4.303 \text{ ksi}$	$C.D._{\sigma_{dS}} = 7.992$	Tensile stress in threaded rod with seismic
$LE_{req} = 0.564 \text{ in}$		Minimum length of thread engagement required
$\tau_J = 1.16 \text{ ksi}$	$C.D._{\tau_J} = 12.923$	Shear stress in joint
$\tau_{w_1} = 1.138 \text{ ksi}$	$C.D._{\tau_{w_1}} = 9.375$	Shear in weld
$\sigma_S = 0.776 \text{ ksi}$	$C.D._{\sigma_S} = 12.273$	Tensile stress in strap
$\tau_B = 0.815 \text{ ksi}$	$C.D._{\tau_B} = 18.395$	Shear stress in bolts and pins
$\tau_{Bm} = 2.35 \text{ ksi}$	$C.D._{\tau_{Bm}} = 6.378$	Shear stress in bolts and pins due to moment (lower)
$\tau_{Bmu} = 2.811 \text{ ksi}$	$C.D._{\tau_{Bmu}} = 5.331$	Shear stress in bolts and pins due to moment (upper)
$\sigma_B = 7.029 \text{ ksi}$	$C.D._{\sigma_B} = 3.553$	Tensile stress in bolt (lower)
$\sigma_{Bu} = 3.035 \text{ ksi}$	$C.D._{\sigma_{Bu}} = 8.228$	Tensile stress in bolt (upper)

## Turnbuckle Design

$d := 0.6250 \text{ in}$

5/8-18 UNF basic major diameter - Ref 1 - pg 1950 - table 2

$$r_g := \frac{d}{2} = 0.313 \text{ in}$$

5/8-18 UNF design hole radius per B4.3a of AISC 360-16 (gross)

$$r_n := \frac{d + \frac{1}{16} \text{ in}}{2} = 0.344 \text{ in}$$

5/8-18 UNF design hole radius per B4.3b of AISC 360-16 (net)

$$a := 0.256 \text{ in}^2$$

5/8-18 UNF Threaded rod tensile area - Ref 1 - pg 1979 - table 4b

$D := 1$  in

Turnbuckle diameter - Item 12 - 1014618 Rev 000B

$$R := \frac{D}{2} = 0.5 \text{ in}$$

Turnbuckle radius

$$TPI := \frac{18}{in}$$

Threads per inch - turnbuckle & threaded rod

$$n_s := 4$$

Number of support straps per 1014616 Rev 000B

	Component	Quantity	Weight (ea)	Weight (all)
<b>LSB</b> := 440 <b>lbf</b>	Lower Support Block	4	110	440
<b>USB</b> := 440 <b>lbf</b>	Upper Support Block	4	110	440
<b>CD</b> := 860 <b>lbf</b>	Control Drum	4	215	860
<b>SCR</b> := 744 <b>lbf</b>	Stationary Core Reflector	124	6	744
<b>PP</b> := 120 <b>lbf</b>	Preload Plate	4	30	120
<b>SP</b> := 72 <b>lbf</b>	Support Plate	4	18	72
<b>LSS</b> := 80 <b>lbf</b>	Lower Support Strap	4	20	80
<b>USS</b> := 40 <b>lbf</b>	Upper Support Strap	4	10	40
<b>GB</b> := 140 <b>lbf</b>	Gamma Block	4	35	140
<b>NC</b> := 120 <b>lbf</b>	Neutron Can	4	30	120
<b>B4C</b> := 120 <b>lbf</b>	B4C Fill	4	30	120
<b>C</b> := 24 <b>lbf</b>				
				<b>Total Weight</b>
				3176

$$W := LSB + USB + CD + SCR + PP + SP + LSS + USS + GB + NC + BAC + C = 3200 \text{ lbf}$$

Total weight of RSS Assembly  
(rounded up for conservatism)

$$F_{u316} := 30 \text{ ksi}$$

Yield stress of 316H SS from ASTM A479 Table 2

$$F_{u316} := 75 \text{ ksi}$$

Tensile strength of 316H SS from ASTM A479 Table 2

$$F_{u316@1200F} = F_{u316} \cdot 0.53 = 15.9 \text{ ksi}$$

Elevated temperature correction for 1200. F per Table 10-3 of AISC DG-27 - assumes properties for 316 apply to 316H

$$F_{u316@1200F} := F_{u316} \cdot 0.59 = 44.25 \text{ ksi}$$

Reflector Support Structure Analysis

$$F_{yBSS@1200F} := 28.1 \text{ ksi}$$

Yield stress of Nitronic 60 at 1200° F from Nitronic 60 Book

$$F_{uBSS@1200F} := 66.6 \text{ ksi}$$

Tensile strength of Nitronic 60 at 1200° F from Nitronic 60 Book

$$A_g := \pi \cdot (R^2 - r_g^2) - 6 \cdot \left( \frac{1}{2} R^2 \cdot \left( \frac{360^\circ}{6} - \sin \left( \frac{360^\circ}{6} \right) \right) \right) = 0.343 \text{ in}^2$$

Gross Turnbuckle tensile area -  
(OD - ID - 6 circular segment  
cuts - Ref 2 - pg 2-8) per B4.3a  
of AISC 360-16

$$A_n := \pi \cdot (R^2 - r_n^2) - 6 \cdot \left( \frac{1}{2} R^2 \cdot \left( \frac{360^\circ}{6} - \sin \left( \frac{360^\circ}{6} \right) \right) \right) = 0.278 \text{ in}^2$$

Net Turnbuckle tensile area -  
(OD - ID - 6 circular segment  
cuts - Ref 2 - pg 2-8) per B4.3b  
of AISC 360-16

Design for tension in Turnbuckle per AISC DG-27

$$\Omega_{ty} := 1.67$$

ASD safety factor for yielding in tension specified in AISC DG-27 Section 4.1

$$\Omega_{tu} := 2.00$$

ASD safety factor for rupture in tension specified in AISC DG-27 Section 4.1

$$\Omega_b := 2.00$$

ASD safety factor for bolts specified in AISC DG-27 Section 9.3.4

$$U := 1.0$$

Defined in Table D3.1 of AISC 360-16 (Case 1)

$$A_e := A_n \cdot U = 0.278 \text{ in}^2$$

Equation D3-1 of AISC 360-16 (Case 1)

$$P_{ny} := F_{y316@1200F} \cdot A_g = 5.449 \text{ kip}$$

Tensile yielding strength in gross cross section, Eq. D2-1

$$P_{nu} := F_{u316@1200F} \cdot A_e = 12.315 \text{ kip}$$

Ultimate tensile strength in net section, Eq. D2-2

$$P_{nt} := \frac{\min(P_{ny}, P_{nu})}{\Omega_{ty}} = 3.263 \text{ kip}$$

Allowable tensile strength using minimum between  
Eq. D2-1 and D2-2

$$\sigma_t := \frac{P_{nt}}{A_g} = 9.521 \text{ ksi}$$

Allowable tensile stress

$$\sigma_D := \frac{W}{n_s \cdot A_e} = 2.875 \text{ ksi}$$

Tensile stress in turnbuckle

$$C.D._{\sigma_D} := \frac{\sigma_t}{\sigma_D} = 3.312$$

$$SF := 0.377$$

Seismic factor - ECAR-6601

$$\sigma_{DS} := \frac{W + W \cdot SF}{n_s \cdot A_e} = 3.958 \text{ ksi}$$

Tensile stress in turnbuckle with seismic

$$C.D._{\sigma_{DS}} := \frac{\sigma_t}{\sigma_{DS}} = 2.405$$

Reflector Support Structure Analysis

$$F_{nt} := 0.75 \cdot F_{uBSS@1200F} = 49.95 \text{ ksi}$$

Nominal tensile stress per AISC DG-27 Section 9.3.4

$$\sigma_{aB} := \frac{F_{nt}}{\Omega_b} = 24.975 \text{ ksi}$$

Allowable tensile stress for bolted connection per AISC DG-27 Section 9.3.4

$$\sigma_d := \frac{W}{n_s \cdot a} = 3.125 \text{ ksi}$$

Tensile stress in threaded rod

$$C.D._{\sigma d} := \frac{\sigma_{aB}}{\sigma_d} = 7.992$$

$$\sigma_{dS} := \frac{W + W \cdot SF}{n_s \cdot a} = 4.303 \text{ ksi}$$

Tensile stress in threaded rod with seismic

$$C.D._{\sigma dS} := \frac{\sigma_{aB}}{\sigma_d} = 7.992$$

Turnbuckle Thread Strength

$$E_s := 0.5828 \text{ in}$$

Minimum pitch diameter of external thread - Ref 1 - pg 1956 - table 3

$$D_s := 0.6149 \text{ in}$$

Minimum major diameter of external thread - Ref 1 - pg 1956 - table 3

$$E_n := 0.5949 \text{ in}$$

Maximum pitch diameter of internal thread - Ref 1 - pg 1956 - table 3

$$K_n := 0.578 \text{ in}$$

Maximum minor diameter of internal thread - Ref 1 - pg 1956 - table 3

$$L_e := \frac{2 \cdot a}{\pi \cdot K_n \cdot \left( \frac{1}{2} + 0.57735 \cdot TPI \cdot (E_s - K_n) \right)} = 0.513 \text{ in}$$

Minimum thread length engagement  
Ref 1 - pg 1668 - (1)

$$A_{ext} := \pi \cdot TPI \cdot L_e \cdot K_n \cdot \left( \frac{1}{2 \cdot TPI} + 0.57735 \cdot (E_s - K_n) \right) = 0.512 \text{ in}^2$$

External thread shear area  
Ref 1 - pg 1669 - (5)

$$A_{int} := \pi \cdot TPI \cdot L_e \cdot D_s \cdot \left( \frac{1}{2 \cdot TPI} + 0.57735 \cdot (D_s - E_n) \right) = 0.701 \text{ in}^2$$

Internal thread shear area  
Ref 1 - pg 1669 - (6)

$$J := \frac{A_{ext} \cdot F_{uBSS@1200F}}{A_{int} \cdot F_{u316@1200F}} = 1.099$$

Minimum thread length engagement multiplier  
Ref 1 - pg 1668 - (1)

$$LE_{req} := L_e \cdot J = 0.564 \text{ in}$$

Minimum length of thread engagement required

Design of bolted connection at support strap to support plate connection per AISC DG-27 Section 9.3.4

$$D_B := 0.5 \text{ in}$$

Bolt diameter - Item 14 - 1014616 Rev 000B

$$A_{B\sigma} := 0.1599 \text{ in}^2$$

Bolt tensile area - 1/2-20 Fine Thread - Ref 1 - pg 1979 - table 4b

Reflector Support Structure Analysis

$$A_{Br} := 0.1486 \text{ in}^2 \quad \text{Bolt shear area - 1/2-20 Fine Thread - Ref 1 - pg 1979 -table 4b}$$

$$D_p := 0.5 \text{ in} \quad \text{Pin diameter - Item 5 - 1014616 Rev 000B}$$

$$A_p := \pi \cdot \left( \frac{D_p}{2} \right)^2 = 0.196 \text{ in}^2 \quad \text{Pin stress area}$$

$$P := \frac{1}{20} \text{ in} \quad \text{Thread pitch - Item 13 - 1014616 Rev 000B}$$

$$\mu := .1 \quad \text{Coefficient of friction - Loctite 771 Product Description Sheet}$$

$$N_p := 2 \quad \text{Number of pins}$$

$$N_b := 2 \quad \text{Number of bolts}$$

$$N_s := 4 \quad \text{Number of straps}$$

$$F_{nv} := 0.45 \cdot F_{uB8S@1200F} = 29.97 \text{ ksi} \quad \text{Nominal shear stress per AISC DG-27 Section 9.3.4}$$

$$\tau_{ab} := \frac{F_{nv}}{\Omega_b} = 14.985 \text{ ksi} \quad \text{Allowable shear stress for bolted connection per AISC DG-27 Section 9.3.4}$$

$$\tau_J := \frac{W}{N_s \cdot (N_b \cdot A_{Br} + N_p \cdot A_p)} = 1.16 \text{ ksi} \quad \text{Shear stress in joint}$$

$$C.D._{\tau_J} := \frac{\tau_{ab}}{\tau_J} = 12.923$$

$$P_B := 0.9 A_{Br} \cdot 0.85 \cdot F_{yB8S@1200F} = 3437.29 \text{ lbf} \quad \text{Bolt preload - Ref 1 - pg 1653}$$

$$T := P_B \cdot (0.159 \cdot P + 1.156 \cdot \mu \cdot D_B) = 18.833 \text{ ft} \cdot \text{lbf} \quad \text{Torque - Ref 1 - pg 1665 - (24)}$$

Design of Strap Welded Connection - Dimensions per 1014618 Rev 000B

$$L := 2.75 \text{ in} \quad \text{Strap width}$$

$$t := 0.375 \text{ in} \quad \text{Strap thickness}$$

$$A_S := L \cdot t = 1.031 \text{ in}^2 \quad \text{Strap stress area}$$

$$\Omega_w := 2.70 \quad \text{ASD safety factor for shear per AISC DG-27 Section 9.2}$$

$$R_w := \frac{1.125 \text{ in}}{2} = 0.563 \text{ in} \quad \text{Radius of joint surface per AISC 360-16 Table J2.2}$$

$$FG_t := \frac{5}{8} \cdot R_w = 0.352 \text{ in} \quad \text{Flare bevel groove effective throat per AISC 360-16 Table J2.2}$$

Reflector Support Structure Analysis

$$\begin{aligned}
 F_{1682} &:= 80 \text{ ksi} && \text{Tensile strength of E16-8-2 electrodes} \\
 l_w &:= 2 \text{ in} && \text{Length of weld on 1014618 Rev 000B} \\
 N_w &:= 2 && \text{Number of welds} \\
 L_w &:= l_w \cdot N_w = 4 \text{ in} && \text{Effective weld length} \\
 A_{BM} &:= L_w \cdot R_w = 2.25 \text{ in}^2 && \text{Cross sectional area of base metal in contact with weld metal} \\
 V_{nBM} &:= 0.6 \cdot F_{y316} \cdot A_{BM} = 40.5 \text{ kip} && \text{Shear strength of base metal per AISC 360-16 Section G} \\
 F_{nBM} &:= \frac{V_{nBM}}{A_{BM}} = 18 \text{ ksi} && \text{Allowable shear stress governed by AISC 360-16 Section G} \\
 A_{we} &:= L_w \cdot FG_t = 1.406 \text{ in}^2 && \text{Effective area of weld per Eq. J2-3} \\
 F_{nw} &:= 0.6 \cdot F_{1682} = 48 \text{ ksi} && \text{Nominal shear stress of the weld metal per AISC 360-16 Table J2.5} \\
 R_{nBM} &:= F_{nBM} \cdot A_{BM} = 40.5 \text{ kip} && \text{Shear strength of base metal} \\
 R_{nw} &:= F_{nw} \cdot A_{we} = 67.5 \text{ kip} && \text{Shear strength of weld} \\
 R_{n,a} &:= \frac{\min(R_{nBM}, R_{nw})}{\Omega_w} = 15 \text{ kip} && \text{Allowable shear strength of welded connection} \\
 \tau_{w,a} &:= \frac{R_{n,a}}{A_{we}} = 10.667 \text{ ksi} && \text{Shear stress allowable for welded connection} \\
 \tau_{w,1} &:= \frac{W}{2 \cdot A_{we}} = 1.138 \text{ ksi} && \text{Shear stress in welded connection} \\
 C.D._{\tau_{w,1}} &:= \frac{\tau_{w,a}}{\tau_{w,1}} = 9.375 \\
 \sigma_s &:= \frac{F_{y316@1200F}}{\Omega_{ty}} = 9.521 \text{ ksi} && \text{Allowable tensile stress - AISC DG-27 Section 4.1} \\
 \sigma_S &:= \frac{W}{4 \cdot A_S} = 0.776 \text{ ksi} && \text{Tensile stress in strap} \\
 C.D._{\sigma_S} &:= \frac{\sigma_s}{\sigma_S} = 12.273
 \end{aligned}$$

Reflector Support Structure Analysis

Support Block Bolts - Refer to 1614616 Rev 000B View F and H

$$D_{Pin} := 0.5 \text{ in} \quad \text{Pin diameter}$$

$$A_{Pin} := \pi \cdot \left( \frac{D_{Pin}}{2} \right)^2 = 0.196 \text{ in}^2 \quad \text{Pin area}$$

$$N_c := 4 \quad \text{Number of bolted connections}$$

$$x := 7.5 \text{ in} \quad \text{Distance from bolted connection to strap}$$

$$y := 1.75 \text{ in} \quad \text{Distance from bolted connection to edge}$$

$$z := 7.0 \text{ in} \quad \text{Distance from strap to radius}$$

$$p_1 := -1.1 \text{ in} \quad \text{Distance from pin 1 to radius}$$

$$p_2 := 3.8 \text{ in} \quad \text{Distance from pin 2 to radius}$$

$$b_1 := 3.1 \text{ in} \quad \text{Distance from bolt 1 to radius}$$

$$b_2 := 4.6 \text{ in} \quad \text{Distance from bolt 2 to radius}$$



$$w_l := LSB + CD + SCR + PP + SP + 0.5 \cdot C = 2248 \text{ lbf} \quad \text{Weight of Lower Components} \\ + 1/2 \text{ Conservatism}$$

$$M := \frac{w_l}{N_s} \cdot z = 327.833 \text{ ft} \cdot \text{lbf} \quad \text{Longitudinal bending moment due to weight}$$

$$\sigma_{ab} := \frac{0.75 \cdot F_{uBSS@1200F}}{\Omega_b} = 24.975 \text{ ksi} \quad \text{Allowable tensile stress in bolted connections per AISC} \\ \text{DG-27 Section 9.3.4}$$

$$F := \frac{M}{y} = 2248 \text{ lbf} \quad \text{Resultant tensile force on bolts}$$

$$\sigma_B := \frac{F}{N_b \cdot A_{B\sigma}} = 7.029 \text{ ksi} \quad \text{Tensile stress in bolts from block separation}$$

$$C.D._{\sigma B} := \frac{\sigma_{ab}}{\sigma_B} = 3.553$$

$$\tau_B := \frac{w_l}{N_c \cdot (N_b \cdot A_{B\tau} + N_p \cdot A_{Pin})} = 0.815 \text{ ksi} \quad \text{Shear stress in bolts and pins from weight on support} \\ \text{blocks}$$

$$C.D._{\tau B} := \frac{\tau_{ab}}{\tau_B} = 18.395$$



Reflector Support Structure Analysis

$$\tau_{Bm} := \frac{M}{b_1 \cdot A_{Br} + b_2 \cdot A_{Br} + p_1 \cdot A_{Pin} + p_2 \cdot A_{Pin}} = 2.35 \text{ ksi}$$

$$C.D. \tau_{Bm} := \frac{\tau_{ab}}{\tau_{Bm}} = 6.378$$

Shear stress in bolts and pins  
between support blocks due  
to moment

$$b_{3v} := 1.75 \text{ in} \quad \text{Distance from bolt 3 to edge}$$

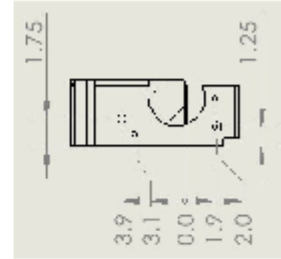
$$b_{3h} := 3.9 \text{ in} \quad \text{Distance from bolt 3 to radius}$$

$$b_{4v} := 1.25 \text{ in} \quad \text{Distance from bolt 4 to edge}$$

$$b_{4h} := -2.0 \text{ in} \quad \text{Distance from bolt 4 to radius}$$

$$p_3 := 3.1 \text{ in} \quad \text{Distance from pin 3 to radius}$$

$$p_4 := -1.9 \text{ in} \quad \text{Distance from pin 4 to radius}$$



$$w_u := USB + GB + NC + BAC + 0.5 \cdot C = 832 \text{ lbf}$$

Weight of Upper Components  
+ 1/2 Conservatism

$$M_u := \frac{w_u}{N_s} \cdot z = 121.333 \text{ ft} \cdot \text{lbf} \quad \text{Longitudinal bending moment due to weight}$$

$$\tau_{Bmu} := \frac{M_u}{b_{3h} \cdot A_{Br} + b_{4h} \cdot A_{Br} + p_3 \cdot A_{Pin} + p_4 \cdot A_{Pin}} = 2.811 \text{ ksi}$$

$$C.D. \tau_{Bmu} := \frac{\tau_{ab}}{\tau_{Bmu}} = 5.331$$

Shear stress in bolts and  
pins due to moment

$$F_{up} := \frac{M_u}{\frac{b_{3v} + b_{4v}}{2}} = 970.667 \text{ lbf} \quad \text{Resultant tensile force on bolts between support blocks}$$

$$\sigma_{Bu} := \frac{F_{up}}{N_b \cdot A_{B\sigma}} = 3.035 \text{ ksi} \quad \text{Tensile stress in bolts from block separation}$$

$$C.D. \sigma_{Bu} := \frac{\sigma_{ab}}{\sigma_{Bu}} = 8.228$$

Reflector Support Structure Analysis

Alignment Ring Bolt Torque

$$D_B := 0.313 \text{ in}$$

Bolt diameter - Item 16 - 1014616 Rev 000B

$$P := \frac{1}{18} \text{ in}$$

Thread pitch - Item 16 - 1014616 Rev 000B

$$\mu_t := .1$$

Coefficient of friction - threads - Loctite 771 Product Description Sheet

$$\mu_f := .3$$

Coefficient of friction - sliding - faces - Ref 2 - Table 3.2.4

$$n := 4$$

Number of bolts

$$W := 3200 \text{ lbf}$$

Total weight

$$SA := 0.377$$

Seismic factor - ECAR-6601

$$F_s := \sqrt{2 \cdot (W \cdot SA)^2} = 1706.107 \text{ lbf}$$

Seismic force (2X total weight)

$$F_{Ns} := \frac{F_s}{\mu_f} = 5687.024 \text{ lbf}$$

Normal force required

$$BL_s := \frac{F_{Ns}}{n} = 1421.756 \text{ lbf}$$

Bolt load - Ref 1 - pg 1653

$$T_{min} := BL_s \cdot (0.159 \cdot P + 1.156 \cdot \mu_t \cdot D_B) = 5.333 \text{ ft} \cdot \text{lbf}$$

Torque - Ref 1 - pg 1665 - (24)

Reflector Support Structure Analysis

Reflector Plate Seismic Stability

$$k := 35 \frac{\text{lb}f}{\text{in}}$$

Spring constant - Century Spring

$$l_f := 1.91 \text{ in}$$

Spring free length - Century Spring

$$l_c := 1.6 \text{ in}$$

Spring compressed length -  
SolidWorks model 1014613

$$m := 5.644 \text{ lb}$$

Mass of BeO plate - SolidWorks model  
for DWG 1014557 Rev. 000A

$$f := 0.35$$

Friction between BeO plates -  
Minimum value on Alumina graph

$$sf := 0.377$$

Seismic factor - ECAR-6601 Rev. 0

$$n_p := [1 \ 10 \ 20 \ 30]$$

Plate number from top

$$n_s := 4$$

Number of springs - SolidWorks  
model for DWG 1014613 Rev. 000B

$$S := n_s \cdot k \cdot (l_f - l_c) = 43.4 \text{ lb}f$$

Spring Force

$$F_f := (n_p^T \cdot m \cdot (g - sf \cdot g) + (n_p^T - 1) \cdot m \cdot (g - sf \cdot g) + S) \cdot f = \begin{bmatrix} 16.421 \\ 38.573 \\ 63.186 \\ 87.8 \end{bmatrix} \text{ lb}f$$

Friction force on plates

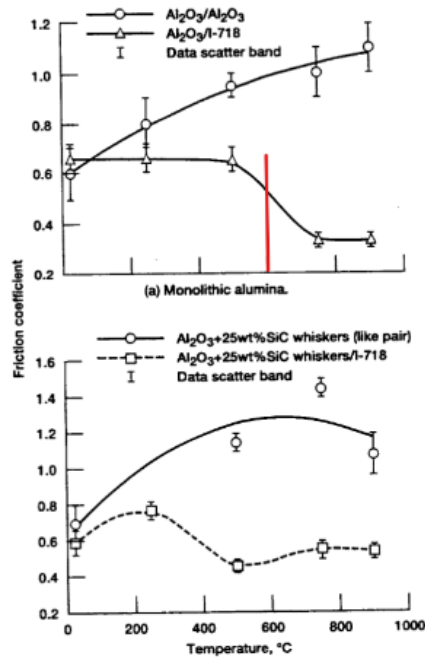
$$F_s := m \cdot sf \cdot g = 2.128 \text{ lb}f$$

Seismic force per plate

$$\frac{F_f}{F_s} = \begin{bmatrix} 7.717 \\ 18.128 \\ 29.696 \\ 41.263 \end{bmatrix}$$

Safety factor

Reflector Support Structure Analysis



The supplier Materion, did not have a coefficient of friction available for the BeO disks. However, the following figure was provided by one of their Technical Experts as a valid approximation.

Reflector Support Structure Analysis

Tolerance (Straps)

ASME Y14.5 - App B - B-3 & B-4

$$D_{B,max} := 0.4987 \text{ in} \quad D_{B,min} := 0.4906 \text{ in}$$

Ref 1 - pg 1955 - table 3

$$D_{BH,max} := 0.56 \text{ in} \quad D_{BH,min} := 0.53 \text{ in}$$

Hole size - 1014618 Rev 000B

$$D_{BH,min} - D_{B,max} = 0.031 \text{ in}$$

Total tolerance available at MMC

$$2 \ t = t_1 + t_2$$

$$D_{BH,max} - D_{B,min} = 0.069 \text{ in}$$

Bonus tolerance available for hole

$$D_{P,max} := 0.3753 \text{ in} \quad D_{P,min} := 0.3751 \text{ in}$$

Pin size - 1014618 Rev 000B

$$D_{PH,max} := 0.385 \text{ in} \quad D_{PH,min} := 0.381 \text{ in}$$

Hole size - 1014618 Rev 000B

$$D_{PH,min} - D_{P,max} = 0.0057 \text{ in}$$

Total tolerance available at MMC

$$2 \ t = t_1 + t_2$$

$$D_{PH,max} - D_{P,min} = 0.0099 \text{ in}$$

Bonus tolerance available for hole

Tolerance (Blocks)

$$D_{b,max} := 0.4987 \text{ in} \quad D_{b,min} := 0.4906 \text{ in}$$

Ref 1 - pg 1955 - table 3

$$D_{bH,max} := 0.526 \text{ in} \quad D_{bH,min} := 0.506 \text{ in}$$

Hole size - 1014672 Rev 000B  
1014673 Rev 000B

$$D_{bH,min} - D_{b,max} = 0.007 \text{ in}$$

Total tolerance available at MMC

$$2 \ t = t_1 + t_2$$

$$D_{bH,max} - D_{b,min} = 0.035 \text{ in}$$

Bonus tolerance available for hole

$$D_{p,max} := 0.2503 \text{ in} \quad D_{p,min} := 0.2501 \text{ in}$$

Ref 1 - pg 1882 - table 1

$$D_{pH,max} := 0.265 \text{ in} \quad D_{pH,min} := 0.260 \text{ in}$$

Hole size - 1014672 Rev 000B  
1014673 Rev 000B

$$D_{pH,min} - D_{p,max} = 0.0097 \text{ in}$$

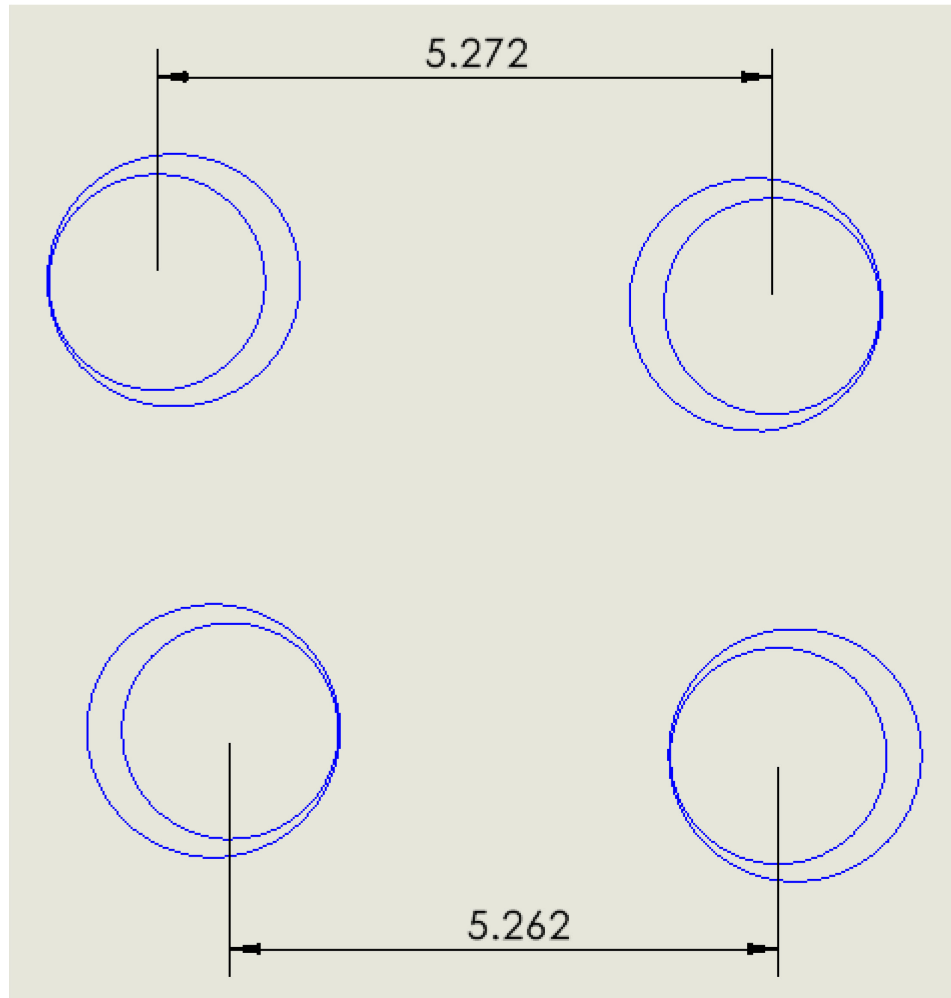
Tolerance available at MMC

$$2 \ t = t_1 + t_2$$

$$D_{pH,max} - D_{p,min} = 0.0149 \text{ in}$$

Bonus tolerance available for hole

Reflector Support Structure Analysis



✓	Nominal:	5.267
✗	Min:	5.262
✗	Max:	5.272

Single Support Block Pin tolerance.

Reflector Support Structure Analysis

**Study Name**

**Analysis Parameters**

Orientation tolerances

Normal to origin feature

Float fasteners and pins

**TolAnalyst Measurement**

Nominal Value

Minimum Value

Maximum Value

RSS Minimum

RSS Maximum

**Minimum Contributors**

Feature

Simple Hole8@1014672-tol-2

Simple Hole7@1014672-tol-2

**Maximum Contributors**

Feature

Simple Hole8@1014672-tol-2

Simple Hole7@1014672-tol-2

**Measurement**

From

To

Direction

**Assembly**

1014616-tol-2@1014613-tol/1014672-tol-2@1014616-tol

1014616-tol-2@1014613-tol/1014616\_1\_4 x 1 dowel pin-tol-34@1014616-tol

1014616-tol-2@1014613-tol/1014672-tol-1@1014616-tol

1014616-tol-2@1014613-tol/1014616\_1\_4 x 1 dowel pin-tol-38@1014616-tol

Reflector Support Structure Analysis

Study1

OFF  
NO  
OFF

(in)  
5.267  
5.262  
5.272  
5.263  
5.271

Percentage

74.35%

Gtols

Position6@Hole Pattern2@1014672-tol-2

25.65%

Gtols

Position6@Hole Pattern2@1014672-tol-2

Type

Position

Type

Position

Percentage

88.74%

Gtols

Position6@Hole Pattern2@1014672-tol-2

11.26%

Gtols

Position6@Hole Pattern2@1014672-tol-2

Type

Position

Type

Position

Feature

Simple Hole7@1014672-tol-2

Simple Hole8@1014672-tol-2

Location

Center

Center

Constraints

Source

Primary

Boss1@1014616\_1\_4 x 1 dowel pin-tol-34

Primary

Plane16@1014672-tol-1

Primary

Boss1@1014616\_1\_4 x 1 dowel pin-tol-38



Reflector Support Structure Analysis

Tolerance 1      Tolerance 2    Primary   Secondary   Tertiary

Tolerance 1      Tolerance 2    Primary   Secondary   Tertiary

Tolerance 1      Tolerance 2    Primary   Secondary   Tertiary

Tolerance 1      Tolerance 2    Primary   Secondary   Tertiary

X	Y	Z
0.531	-0.38	-0.758
Target		

Simple Hole7@1014672-tol-2

Plane15@1014672-tol-2

Simple Hole8@1014672-tol-2

✓	Nominal:	5.267
✗	Min:	5.262
✗	Max:	5.272

Pin tolerance including connections at all four Support Blocks.

Reflector Support Structure Analysis

**Study Name**

**Analysis Parameters**

Orientation tolerances

Normal to origin feature

Float fasteners and pins

**TolAnalyst Measurement**

Nominal Value

Minimum Value

Maximum Value

RSS Minimum

RSS Maximum

**Minimum Contributors**

Feature

Simple Hole8@1014672-tol-2

Simple Hole7@1014672-tol-2

**Maximum Contributors**

Feature

Simple Hole8@1014672-tol-2

Simple Hole7@1014672-tol-2

**Measurement**

From

To

Direction

**Assembly**

1014616-tol-2@1014613-tol/1014672-tol-2@1014616-tol

1014616-tol-2@1014613-tol/1014616\_1\_4 x 1 dowel pin-tol-34@1014616-tol

1014616-tol-2@1014613-tol/1014616\_1\_2-13\_UNC\_x\_2-1\_4\_LG\_bolt-tol-4@1014616-tol

1014616-tol-2@1014613-tol/1014616\_1\_2-13\_UNC\_x\_4-1\_2\_LG\_bolt-tol-5@1014616-tol

1014616-tol-2@1014613-tol/1014672-tol-1@1014616-tol

1014616-tol-2@1014613-tol/1014616\_1\_4 x 1 dowel pin-tol-38@1014616-tol

Reflector Support Structure Analysis

Study2

OFF  
NO  
OFF

(in)  
5.267  
5.262  
5.272  
5.263  
5.271

Percentage

74.35%

Gtols

Position6@Hole Pattern2@1014672-tol-2

25.65%

Gtols

Position6@Hole Pattern2@1014672-tol-2

Type

Position

Type

Position

Percentage

88.74%

Gtols

Position6@Hole Pattern2@1014672-tol-2

11.26%

Gtols

Position6@Hole Pattern2@1014672-tol-2

Type

Position

Type

Position

Feature

Simple Hole7@1014672-tol-2

Simple Hole8@1014672-tol-2

Location

Center

Center

Constraints

Source

Primary

Boss1@1014616\_1\_4 x 1 dowel pin-tol-34

Primary

Boss1@1014616\_1\_2-13\_UNC\_x\_2-1\_4\_LG\_bolt-tol-4

Primary

Boss1@1014616\_1\_2-13\_UNC\_x\_4-1\_2\_LG\_bolt-tol-5

Primary

Plane16@1014672-tol-1

**Primary**

**Boss1@1014616\_1\_4 x 1 dowel pin-tol-38**

Reflector Support Structure Analysis

Tolerance 1	Tolerance 2	Primary	Secondary	Tertiary
-------------	-------------	---------	-----------	----------

Tolerance 1	Tolerance 2	Primary	Secondary	Tertiary
-------------	-------------	---------	-----------	----------

Tolerance 1	Tolerance 2	Primary	Secondary	Tertiary
-------------	-------------	---------	-----------	----------

Tolerance 1	Tolerance 2	Primary	Secondary	Tertiary
-------------	-------------	---------	-----------	----------

X	Y	Z
---	---	---

0.531	-0.38	-0.758
-------	-------	--------

Target
--------

Simple Hole7@1014672-tol-2

Width13@1014672-tol-2

Width5@1014672-tol-2

Plane15@1014672-tol-2

Simple Hole8@1014672-tol-2

Reflector Support Structure Analysis

**RSS FEA inputs**

Seismic inputs

$$g = 386.089 \frac{\text{in}}{\text{s}^2}$$

Acceleration due to gravity

$$HA := 145.362 \frac{\text{in}}{\text{s}^2}$$

Horizontal Seismic Acceleration - ECAR-6601 Rev. C

$$VA := 145.362 \frac{\text{in}}{\text{s}^2}$$

Vertical Seismic Acceleration - ECAR-6601 Rev. C

$$g + VA = 531.451 \frac{\text{in}}{\text{s}^2}$$

Vertical Acceleration (down)

$$g - VA = 240.727 \frac{\text{in}}{\text{s}^2}$$

Vertical Acceleration (up)

Control Drum Inputs

$$W_{CD} := 225 \text{ lbf}$$

Round up from 212 lb reported in INL DWG 1014540 Rev E

Axial Shielding Mass

$$W_{GS} := 35 \text{ lbf}$$

INL DWG 1014706 Rev 000B

$$\rho_{B4C} := 2.48 \frac{\text{gm}}{\text{cm}^3} \cdot g$$

Density of Boron carbide (B4C) which is the neutron shield material from Boron Carbide Properties and Information - Appendix D

$$\alpha_{B4C} := 0.50$$

Packing density of B4C powder based on WES test report - Appendix D

$$V_{B4C} := 556.835 \text{ in}^3$$

Volume of neutron shield - SolidWorks model for DWG 1014577 Rev. 000A

$$W_{NS} := \rho_{B4C} \cdot \alpha_{B4C} \cdot V_{B4C} = 24.945 \text{ lbf}$$

Weight of the B4C powder in the neutron shield



Reflector Support Structure Analysis

$$W_{NS\_ext} := 30 \text{ lbf}$$

Weight of neutron shield exterior metal per INL  
DWG 1014707 Rev. 000A

$$W_{AX\_SH} := 4 \cdot (W_{GS} + (W_{NS} + W_{NS\_ext})) = 359.78 \text{ lbf}$$

Weight of axial shielding

Fixed Reflectors Mass

$$\rho_{BeO} := 2.9 \frac{\text{gm}}{\text{cm}^3} \cdot g = 0.105 \frac{\text{lbf}}{\text{in}^3}$$

Material datasheet - Appendix D

$$V_{SCR} := 53.751 \text{ in}^3$$

Volume of SCR - SolidWorks model for DWG  
1014613 Rev. 000A

$$W_{SCR} := \rho_{BeO} \cdot V_{SCR} = 5.631 \text{ lbf}$$

Weight of SCR

$$W_{SCR\_tot} := 31 \cdot 4 \cdot W_{SCR} = 698.299 \text{ lbf}$$

INL DWG 1014613 Rev 00A

## Appendix B

### Seismic Analysis

Firefox

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# RSS Seismic

## I. Overview

*This report was generated by user on 2023-09-28 07:36:46 Mountain Daylight Time from output database file C:/Users/john.stevenson/Documents/Models/Marvel/RSS Seismic - KBF/RSS-ZSeismic.odt.*

The information included in this report reflects the options selected in the HTML Report Generator plug-in when the report was generated. Therefore, the report does not necessarily include all of the model and results data available in the output database (.odb) file. In addition, this report may include information in 3D XML format; to view the 3D XML content properly, you must use Internet Explorer as your browser.

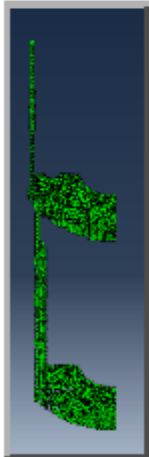
You can distribute this report by copying all of the files listed in the [File Summary](#).

This report is organized into sections that match the organization of modules in Abaqus/CAE:

### Table of Contents

- [Material Information](#)
- [Step Data](#)
- [Job Diagnostics](#)
- [Results](#)
- [File Summary](#)

### Basic Model Information



User's name

Output database C:/Users/john.stevenson/Documents/Models/Marvel/RSS Seismic - KBF/RSS-ZSeismic.odt

Time created Wed Sep 27 16:12:57 Mountain Daylight Time 2023

Firefox

file:///C:/Users/john.stevenson/Documents/Models/Marvel/RSS%20Seis...

Solver Abaqus/Standard 2021.HF6  
Precision SINGLE\_PRECISION  
Work directory C:/SIMULIA/WorkingDirectory  
HTML directory C:/SIMULIA/WorkingDirectory/htmlReport  
Image directory C:/SIMULIA/WorkingDirectory/htmlReport/images

## 2. Material Information

This section includes figures that display the material information in the model. The default view orientations are provided, along with any user-defined views requested, and these figures are color coded according to the material definitions. A key to material definitions and their corresponding colors is provided after the figures. Hyperelastic material properties are included in the figures, if they are available.

- [Material Color Table](#)
- [Elastic Behaviour](#)
- [Density Table](#)
- [3DXML for material data](#)
- [Figures Containing Material Information](#)

**Table 2.1 Material Color Table**

Material	Color
NITRONIC-60	
SA240-316H	

**Table 2.2 Elastic Behaviour**

Material	dependencies	moduli	noCompression	noTension	temperatureDependency	type
NITRONIC-60	0	LONG_TERM	OFF	OFF	ON	ISOTROPIC
SA240-316H	0	LONG_TERM	OFF	OFF	ON	ISOTROPIC

[^ back](#)

**Table 2.3 Elastic Table**

Material	Young's modulus	Poisson's ratio	Temp
NITRONIC-60	25800000.0	0.298	70.0
NITRONIC-60	25100000.0	0.298	200.0
NITRONIC-60	24600000.0	0.298	300.0
NITRONIC-60	24100000.0	0.298	400.0
NITRONIC-60	23600000.0	0.298	500.0
NITRONIC-60	23100000.0	0.298	600.0
NITRONIC-60	22600000.0	0.298	700.0
NITRONIC-60	22100000.0	0.298	800.0
NITRONIC-60	21600000.0	0.298	900.0

Reflector Support Structure Analysis

Firefox

file:///C:/Users/john.stevenson/Documents/Models/Marvel/RSS%20Seis...

NITRONIC-60	21100000.0	0.298	1000.0
NITRONIC-60	20600000.0	0.298	1100.0
NITRONIC-60	20100000.0	0.298	1200.0
NITRONIC-60	19600000.0	0.298	1300.0
NITRONIC-60	19100000.0	0.298	1400.0
NITRONIC-60	18600000.0	0.298	1500.0
SA240-316H	28300000.0	0.28	70.0
SA240-316H	27500000.0	0.28	200.0
SA240-316H	27000000.0	0.28	300.0
SA240-316H	26400000.0	0.28	400.0
SA240-316H	25900000.0	0.28	500.0
SA240-316H	25300000.0	0.28	600.0
SA240-316H	24800000.0	0.28	700.0
SA240-316H	24100000.0	0.28	800.0
SA240-316H	23500000.0	0.28	900.0
SA240-316H	22800000.0	0.28	1000.0
SA240-316H	22000000.0	0.28	1100.0
SA240-316H	21200000.0	0.28	1200.0
SA240-316H	20300000.0	0.28	1300.0
SA240-316H	19200000.0	0.28	1400.0
SA240-316H	18100000.0	0.28	1500.0

[^ back](#)

Table 2.4 Density Table

Material	Density	Temperature
NITRONIC-60	0.000712	#
SA240-316H	0.000751388	#

3DXML for material data in the model

Note: The "artificial ground" in the 3DXML is a visual artifact and not part of the model

Figures Containing Material Information

Reflector Support Structure Analysis

Firefox

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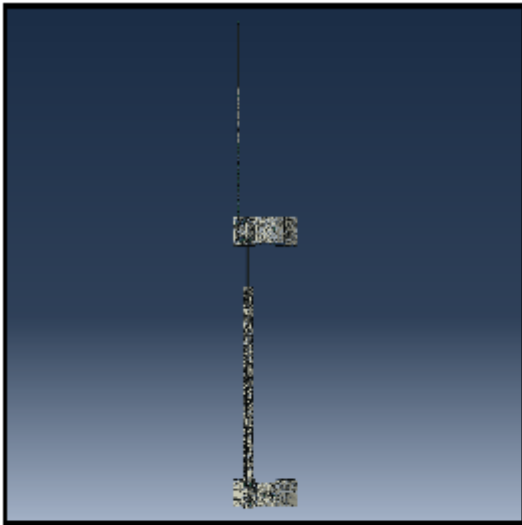


Figure 2.1 Figures Containing Material Information Front view

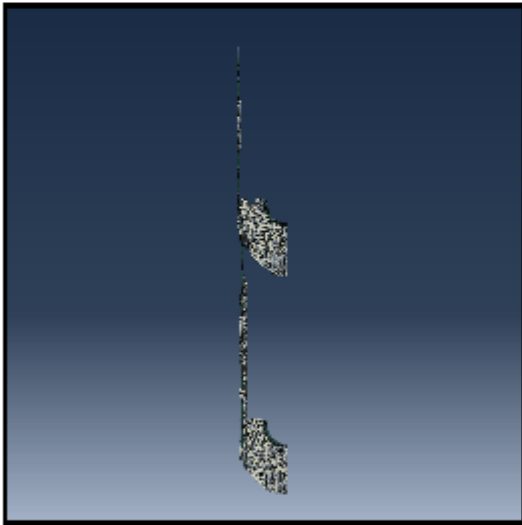


Figure 2.2 Figures Containing Material Information Iso view

Firefox

file:///C:/Users/john.stevenson/Documents/Models/Marvel/RSS%20Seis...

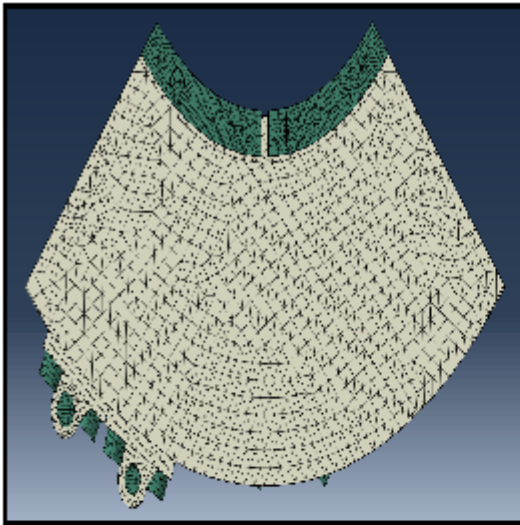


Figure 2.3 Figures Containing Material Information Top view

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---

### 3. Step Information

This section gives details about steps used in this analysis. NLGeom controls whether nonlinear geometric aspects are taken into consideration in the analysis.

Table 3.1 Step Information

#	Step Name	Procedure	Step Time	Total Time	Nlgeom
1	Static	STATIC,GENERAL	1.000	1.000	ON

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---

### 4. Data Diagnostics Information

This section includes the following information about the analysis data:

- [Warnings](#)
- [Job time Table](#)
- [Numerical problem summary Table](#)
- [Step Data](#)

#### Warnings

Flux is zero everywhere 26

Negative eigenvalues 25

Reflector Support Structure Analysis

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**Table 4.1 Job time  
(currently unavailable)**

System time	3561.84
User time	12799.02
Wallclock time	5795.0

[^ back](#)

**Table 4.2 Numerical problem summary**

Number of zero pivots	0
Number of numerical singularities	0
Number of negative eigenvalues	100
Converged zero pivots	OFF
Converged numerical singularities	OFF
Converged negative eigenvalues	OFF

[^ back](#)

**Table 4.3 Step Data**

Step	
Perturbation	OFF
Characteristic element length	1.1057E-01
Increments completed	0
Minimum time increment	1e-15
Step time completed	0.0
Analysis type	Standard
Maximum time increment	1.0
Initial time increment	0.01
Riks	OFF
Matrix solver	DIRECT_SOLVER
Time Period	1.0
Stabilization	OFF
Maximum number of increments	100000
Unsymmetric Solver	ON
Stabilization Factor	0.0
Number of contact diagnostics	2

[^ back](#)

Converged zero pivots: Whether any increment of the analysis converged on a zero pivot.

Converged numerical singularities: Whether any increment of the analysis converged on a numerical singularity.

Converged negative eigenvalues: Whether any increment of the analysis converged on a negative eigenvalue.

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Firefox

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## 5. Results

This section displays results data requested from the output database file, including the maximum and minimum values for selected output variables. This section also includes any X-Y plots saved to the output database and requested for inclusion in the report.

- [U Magnitude results step = Static increment = 18](#)
- [S Mises results step = Static increment = 18](#)
- [S Max. Principal results step = Static increment = 18](#)
- [S Mid. Principal results step = Static increment = 18](#)

### 3DXML for U Magnitude results

**Note:** The "artificial ground" in the 3DXML is a visual artifact and not part of the model

[^ back](#)

Figures containing U Magnitude Results step=Static  
increment=18

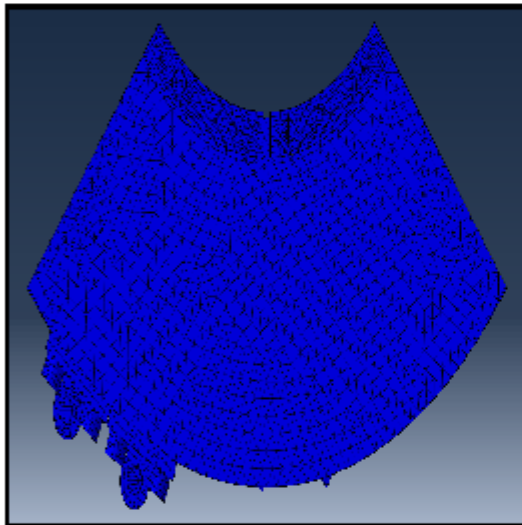


Figure 5.1 Figures containing U Magnitude Results Top  
view

Firefox

file:///C:/Users/john.stevenson/Documents/Models/Marvel/RSS%20Seis...

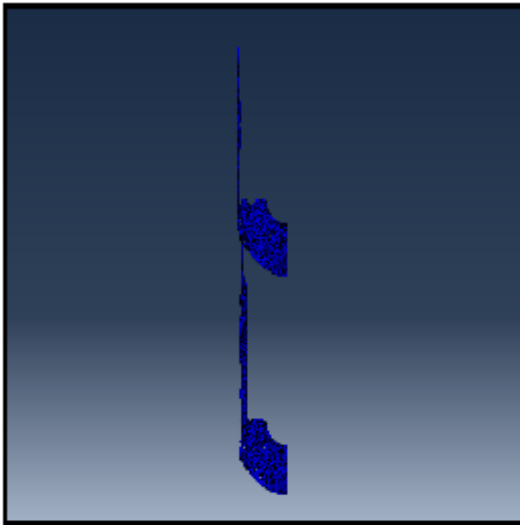


Figure 5.2 Figures containing U Magnitude Results Iso view

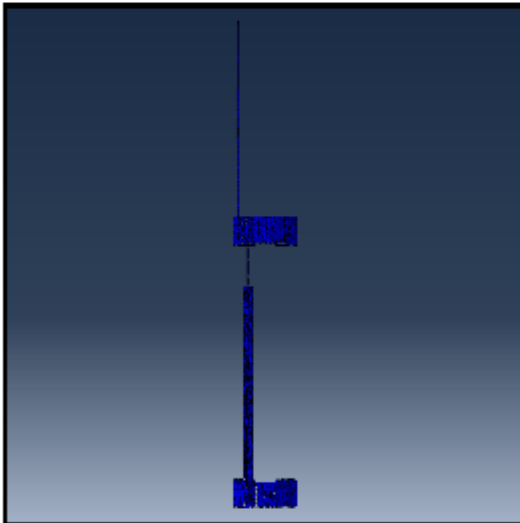


Figure 5.3 Figures containing U Magnitude Results Front view

[^ back](#)

3DXML for S Mises results

Note: The "artificial ground" in the 3DXML is a visual artifact and not part of the model

[^ back](#)

Figures containing S Mises Results step=Static increment=18

Reflector Support Structure Analysis

Firefox

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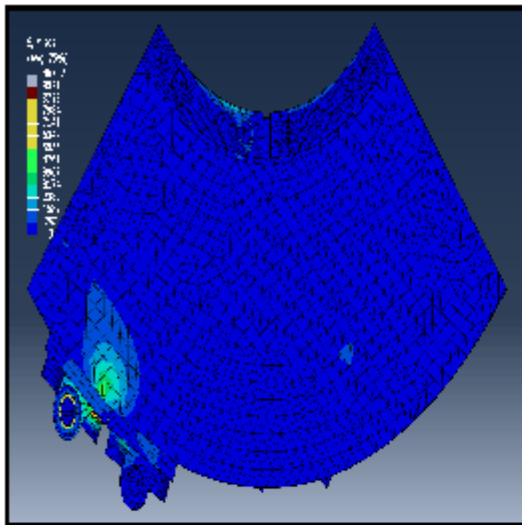


Figure 5.4 Figures containing S Mises Results Top view

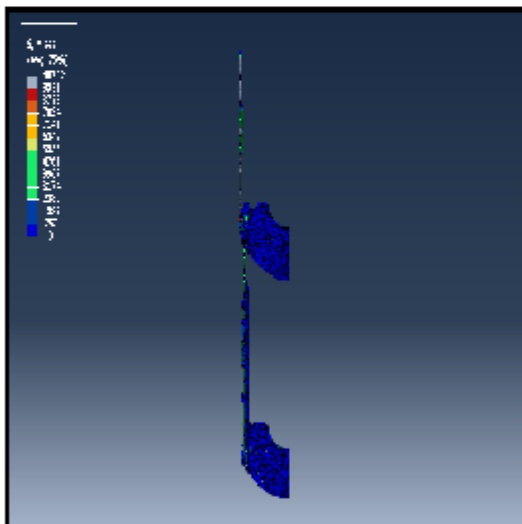


Figure 5.5 Figures containing S Mises Results Iso view

Reflector Support Structure Analysis

Firefox

file:///C:/Users/john.stevenson/Documents/Models/Marvel/RSS%20Seis...

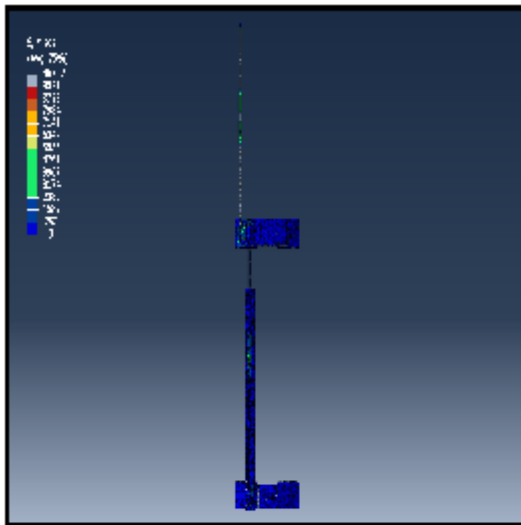


Figure 5.6 Figures containing S Mises Results Front view

[^ back](#)

3DXML for S Max. Principal results

Note: The "artificial ground" in the 3DXML is a visual artifact and not part of the model

[^ back](#)

Figures containing S Max\_principal Results step=Static  
increment=18

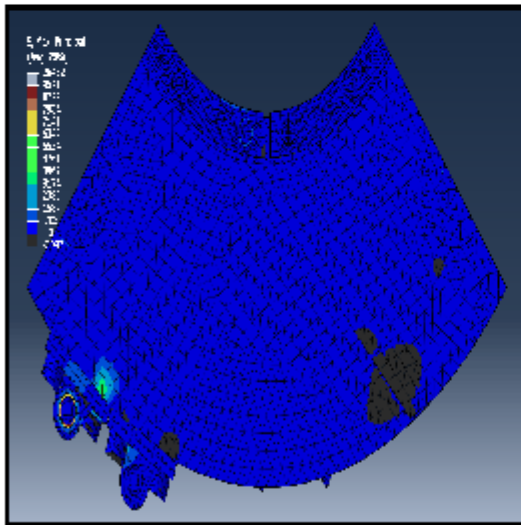


Figure 5.7 Figures containing S Max\_principal Results Top  
view

Reflector Support Structure Analysis

Firefox

file:///C:/Users/john.stevenson/Documents/Models/Marvel/RSS%20Seis...

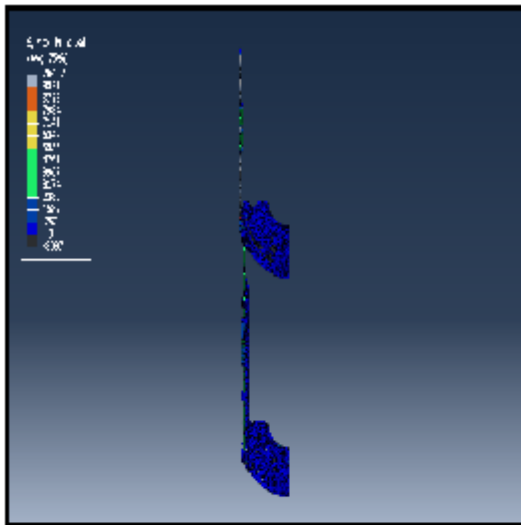


Figure 5.8 Figures containing S Max\_principal Results Iso view

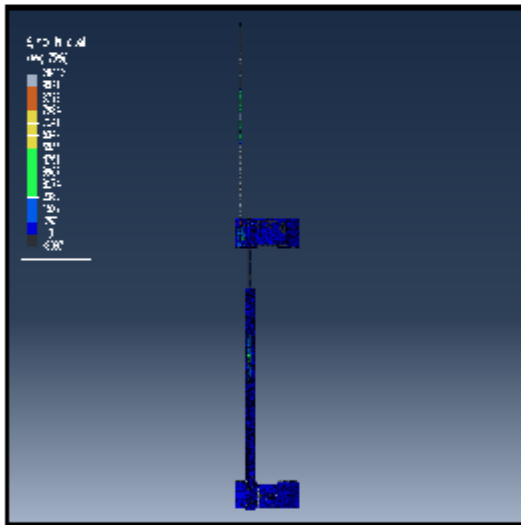


Figure 5.9 Figures containing S Max\_principal Results Front view

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3DXML for S Mid. Principal results

Note: The "artificial ground" in the 3DXML is a visual artifact and not part of the model

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Figures containing S Mid\_principal Results step=Static  
increment=18

Reflector Support Structure Analysis

Firefox

file:///C:/Users/john.stevenson/Documents/Models/Marvel/RSS%20Seis...

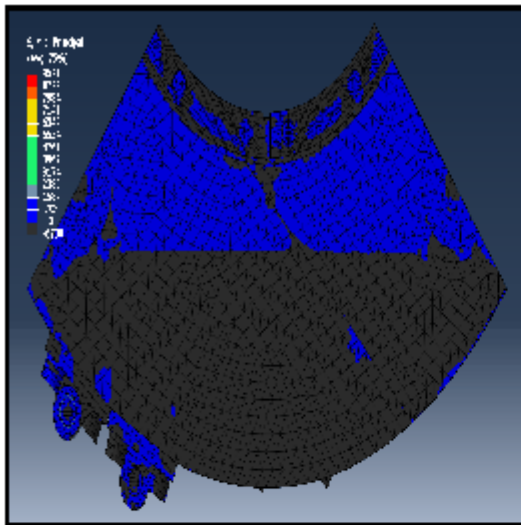


Figure 5.10 Figures containing S Mid\_principal Results Top view

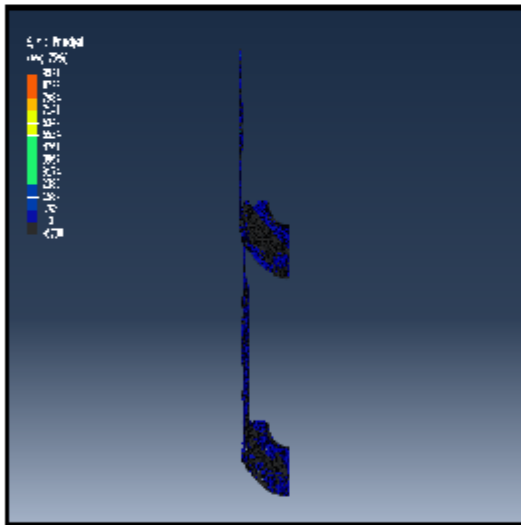


Figure 5.11 Figures containing S Mid\_principal Results Iso view

Firefox

file:///C:/Users/john.stevenson/Documents/Models/Marvel/RSS%20Seis...

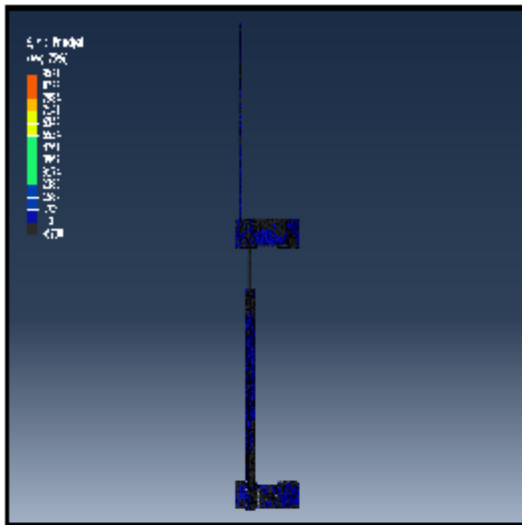


Figure 5.12 Figures containing S Mid\_principal Results  
Front view

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## 6. File Summary

To transfer this report, following files and directories must be copied:

- htmlReport\image
- htmlReport\additionalImages
- htmlReport\additionalFiles
- htmlReport\abaqus.css
- htmlReport\htmlReport.html

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The logo for DS SIMULIA, featuring a stylized 'DS' in a large, bold, sans-serif font, followed by the word 'SIMULIA' in a smaller, all-caps, sans-serif font.

Firefox

file:///C:/Users/john.stevenson/Documents/Models/Marvel/RSS%20Seis...

# RSS Static

## I. Overview

*This report was generated by user on 2023-09-28 07:41:52 Mountain Daylight Time from output database file C:/Users/john.stevenson/Documents/Models/Marvel/RSS Seismic - KBF/RSS-Static-Frictionless.odb.*

The information included in this report reflects the options selected in the HTML Report Generator plug-in when the report was generated. Therefore, the report does not necessarily include all of the model and results data available in the output database (.odb) file. In addition, this report may include information in 3D XML format; to view the 3D XML content properly, you must use Internet Explorer as your browser.

You can distribute this report by copying all of the files listed in the [File Summary](#).

This report is organized into sections that match the organization of modules in Abaqus/CAE:

### Table of Contents

- [Material Information](#)
- [Step Data](#)
- [Job Diagnostics](#)
- [Results](#)
- [File Summary](#)

### Basic Model Information



User's name

Output database C:/Users/john.stevenson/Documents/Models/Marvel/RSS Seismic - KBF/RSS-Static-Frictionless.odb

Time created Wed Sep 27 20:43:48 Mountain Daylight Time 2023



Firefox

file:///C:/Users/john.stevenson/Documents/Models/Marvel/RSS%20Seis...

Solver Abaqus/Standard 2021.HF6  
Precision SINGLE\_PRECISION  
Work directory C:/SIMULIA/WorkingDirectory  
HTML directory C:/SIMULIA/WorkingDirectory/htmlReport  
Image directory C:/SIMULIA/WorkingDirectory/htmlReport/images

## 2. Material Information

This section includes figures that display the material information in the model. The default view orientations are provided, along with any user-defined views requested, and these figures are color coded according to the material definitions. A key to material definitions and their corresponding colors is provided after the figures. Hyperelastic material properties are included in the figures, if they are available.

- [Material Color Table](#)
- [Elastic Behaviour](#)
- [Density Table](#)
- [3DXML for material data](#)
- [Figures Containing Material Information](#)

**Table 2.1 Material Color Table**

Material	Color
NITRONIC-60	
SA240-316H	

**Table 2.2 Elastic Behaviour**

Material	dependencies	moduli	noCompression	noTension	temperatureDependency	type
NITRONIC-60	0	LONG_TERM	OFF	OFF	ON	ISOTROPIC
SA240-316H	0	LONG_TERM	OFF	OFF	ON	ISOTROPIC

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**Table 2.3 Elastic Table**

Material	Young's modulus	Poisson's ratio	Temp
NITRONIC-60	25800000.0	0.298	70.0
NITRONIC-60	25100000.0	0.298	200.0
NITRONIC-60	24600000.0	0.298	300.0
NITRONIC-60	24100000.0	0.298	400.0
NITRONIC-60	23600000.0	0.298	500.0
NITRONIC-60	23100000.0	0.298	600.0
NITRONIC-60	22600000.0	0.298	700.0
NITRONIC-60	22100000.0	0.298	800.0
NITRONIC-60	21600000.0	0.298	900.0

Reflector Support Structure Analysis

Firefox

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NITRONIC-60	21100000.0	0.298	1000.0
NITRONIC-60	20600000.0	0.298	1100.0
NITRONIC-60	20100000.0	0.298	1200.0
NITRONIC-60	19600000.0	0.298	1300.0
NITRONIC-60	19100000.0	0.298	1400.0
NITRONIC-60	18600000.0	0.298	1500.0
SA240-316H	28300000.0	0.28	70.0
SA240-316H	27500000.0	0.28	200.0
SA240-316H	27000000.0	0.28	300.0
SA240-316H	26400000.0	0.28	400.0
SA240-316H	25900000.0	0.28	500.0
SA240-316H	25300000.0	0.28	600.0
SA240-316H	24800000.0	0.28	700.0
SA240-316H	24100000.0	0.28	800.0
SA240-316H	23500000.0	0.28	900.0
SA240-316H	22800000.0	0.28	1000.0
SA240-316H	22000000.0	0.28	1100.0
SA240-316H	21200000.0	0.28	1200.0
SA240-316H	20300000.0	0.28	1300.0
SA240-316H	19200000.0	0.28	1400.0
SA240-316H	18100000.0	0.28	1500.0

[^ back](#)

Table 2.4 Density Table

Material	Density	Temperature
NITRONIC-60	0.000712	#
SA240-316H	0.000751388	#

3DXML for material data in the model

Note: The "artificial ground" in the 3DXML is a visual artifact and not part of the model

Figures Containing Material Information

Firefox

file:///C:/Users/john.stevenson/Documents/Models/Marvel/RSS%20Seis...

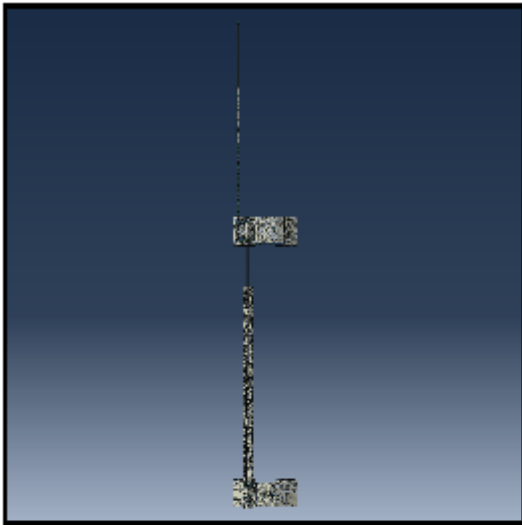


Figure 2.1 Figures Containing Material Information Front view

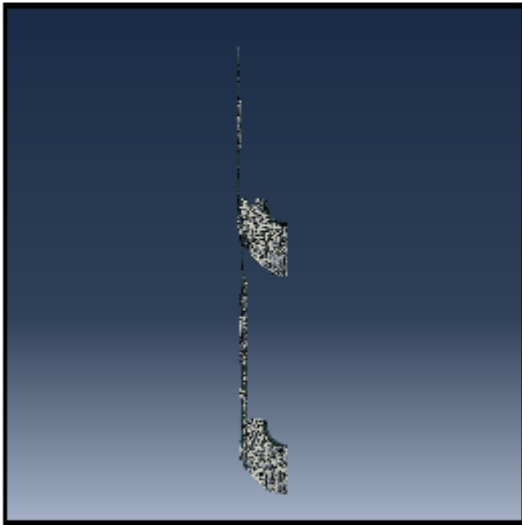


Figure 2.2 Figures Containing Material Information Iso view

Firefox

file:///C:/Users/john.stevenson/Documents/Models/Marvel/RSS%20Seis...

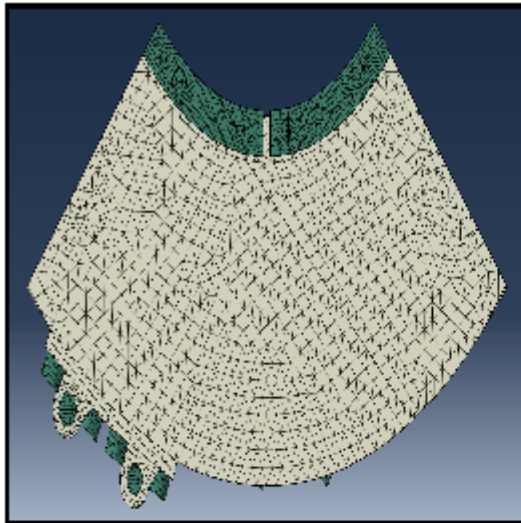


Figure 2.3 Figures Containing Material Information Top view

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### 3. Step Information

This section gives details about steps used in this analysis. NLGeom controls whether nonlinear geometric aspects are taken into consideration in the analysis.

Table 3.1 Step Information

#	Step Name	Procedure	Step Time	Total Time	Nlgeom
1	Static	STATIC,GENERAL	1.000	1.000	ON

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### 4. Data Diagnostics Information

This section includes the following information about the analysis data:

- [Warnings](#)
- [Job time Table](#)
- [Numerical problem summary Table](#)
- [Step Data](#)

#### Warnings

Flux is zero everywhere 60

Negative eigenvalues 25

Reflector Support Structure Analysis

Firefox

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**Table 4.1 Job time  
(currently unavailable)**

System time	1692.21
User time	9646.74
Wallclock time	2683.0

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**Table 4.2 Numerical problem summary**

Number of zero pivots	0
Number of numerical singularities	0
Number of negative eigenvalues	100
Converged zero pivots	OFF
Converged numerical singularities	OFF
Converged negative eigenvalues	OFF

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**Table 4.3 Step Data**

Step	
Perturbation	OFF
Characteristic element length	1.1057E-01
Increments completed	0
Minimum time increment	1e-15
Step time completed	0.0
Analysis type	Standard
Maximum time increment	1.0
Initial time increment	0.01
Riks	OFF
Matrix solver	DIRECT_SOLVER
Time Period	1.0
Stabilization	OFF
Maximum number of increments	100000
Unsymmetric Solver	OFF
Stabilization Factor	0.0
Number of contact diagnostics	2

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Converged zero pivots: Whether any increment of the analysis converged on a zero pivot.

Converged numerical singularities: Whether any increment of the analysis converged on a numerical singularity.

Converged negative eigenvalues: Whether any increment of the analysis converged on a negative eigenvalue.

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## 5. Results

This section displays results data requested from the output database file, including the maximum and minimum values for selected output variables. This section also includes any X-Y plots saved to the output database and requested for inclusion in the report.

- [U Magnitude results step = Static increment = 18](#)
- [S Mises results step = Static increment = 18](#)
- [S Max. Principal results step = Static increment = 18](#)
- [S Mid. Principal results step = Static increment = 18](#)
- [U Magnitude results step = Static increment = 28](#)
- [S Mises results step = Static increment = 28](#)
- [S Max. Principal results step = Static increment = 28](#)
- [S Mid. Principal results step = Static increment = 28](#)

### 3DXML for U Magnitude results

Note: The "artificial ground" in the 3DXML is a visual artifact and not part of the model

[^ back](#)

Figures containing U Magnitude Results step=Static  
increment=18

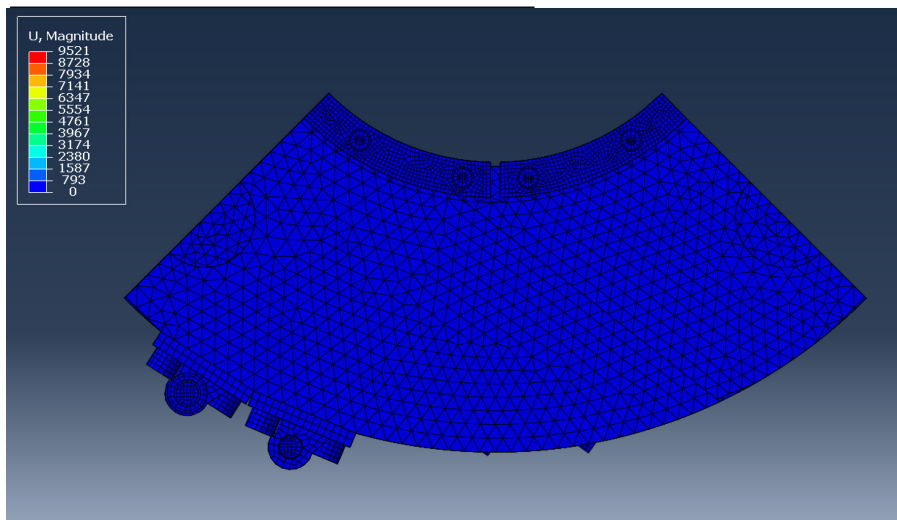


Figure 5.1 Figures containing U Magnitude Results Top  
view

Reflector Support Structure Analysis

Firefox

file:///C:/Users/john.stevenson/Documents/Models/Marvel/RSS%20Seis...

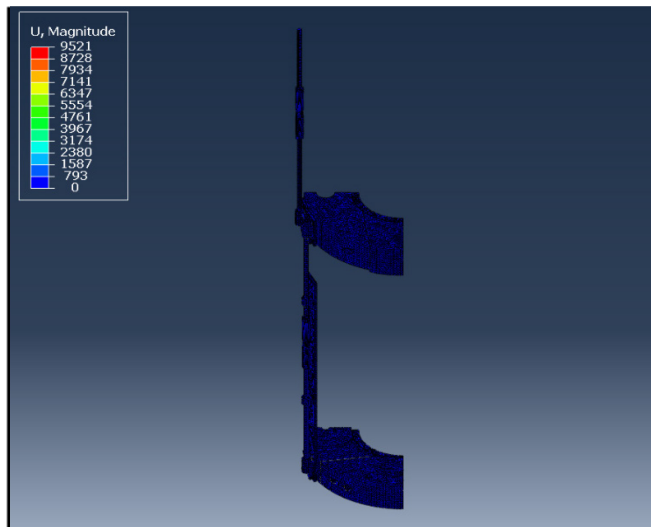


Figure 5.2 Figures containing U Magnitude Results Iso view

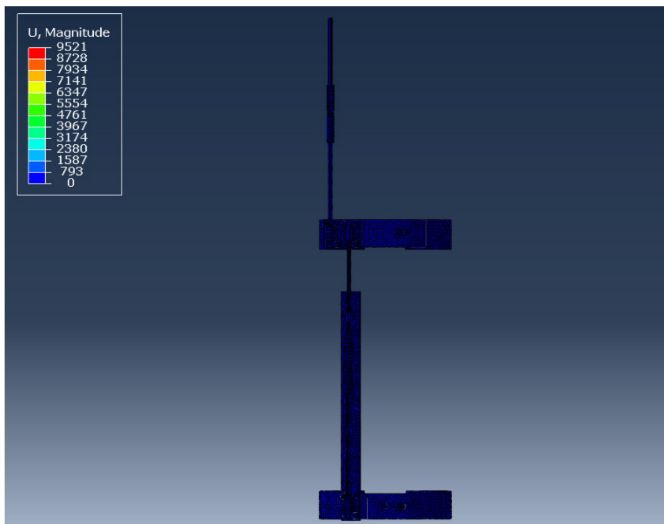


Figure 5.3 Figures containing U Magnitude Results Front view

[^ back](#)

3DXML for S Mises results

Note: The "artificial ground" in the 3DXML is a visual artifact and not part of the model

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Figures containing S Mises Results step=Static increment=18

Reflector Support Structure Analysis

Firefox

file:///C:/Users/john.stevenson/Documents/Models/Marvel/RSS%20Seis...

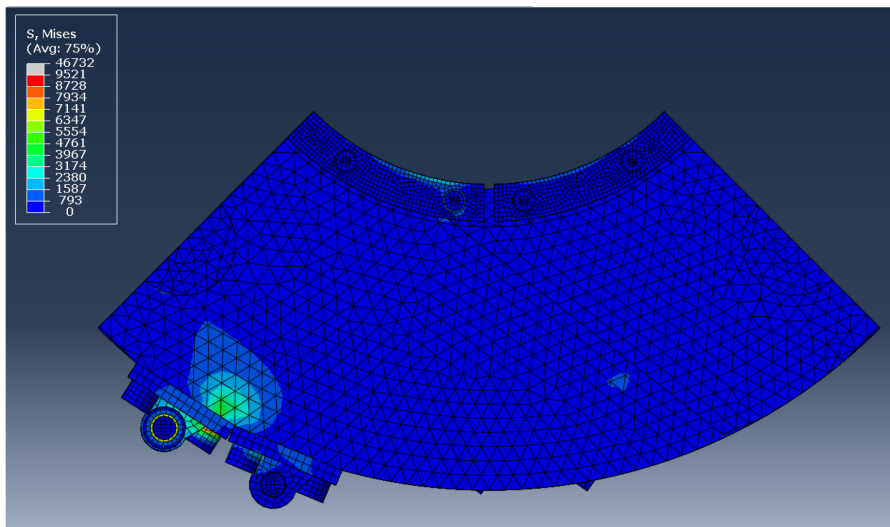


Figure 5.4 Figures containing S Mises Results Top view

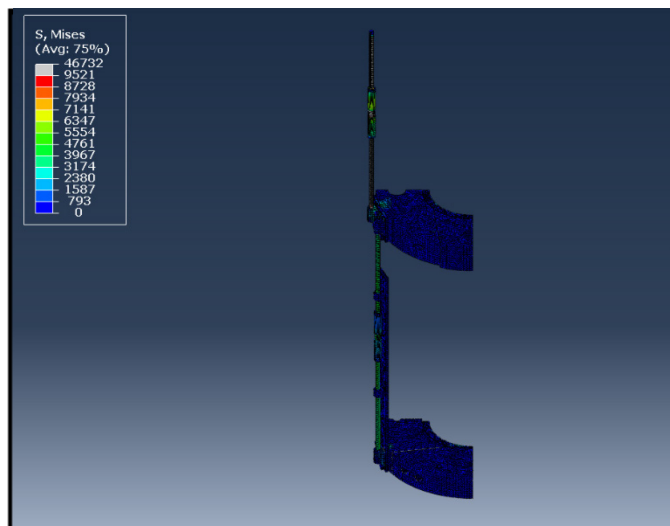


Figure 5.5 Figures containing S Mises Results Iso view



Reflector Support Structure Analysis

Firefox

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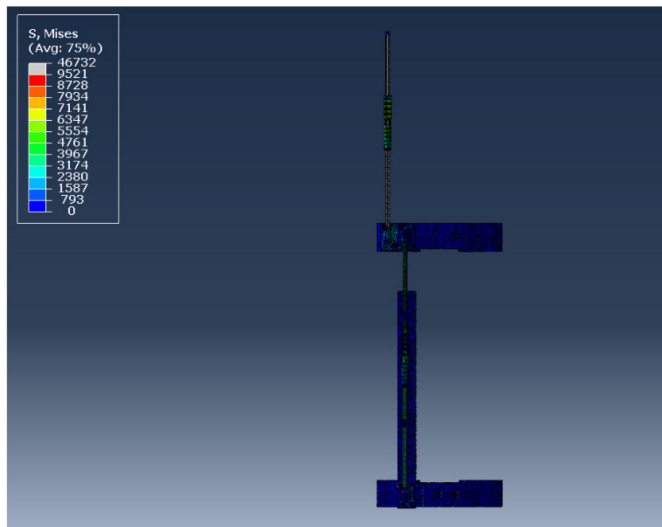


Figure 5.6 Figures containing S Mises Results Front view

[^ back](#)

3DXML for S Max. Principal results

Note: The "artificial ground" in the 3DXML is a visual artifact and not part of the model

[^ back](#)

Figures containing S Max\_principal Results step=Static  
increment=18

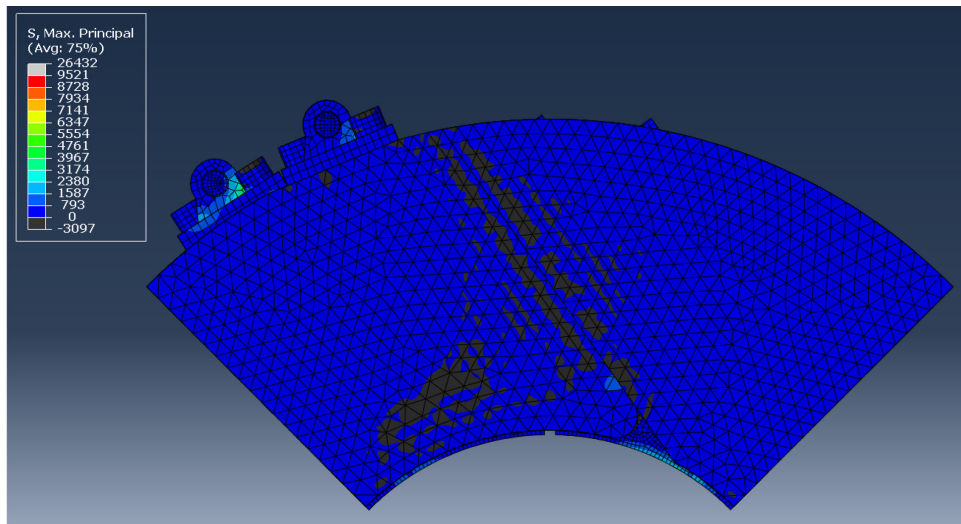


Figure 5.7 Figures containing S Max\_principal Results Top  
view

Reflector Support Structure Analysis

Firefox

file:///C:/Users/john.stevenson/Documents/Models/Marvel/RSS%20Seis...

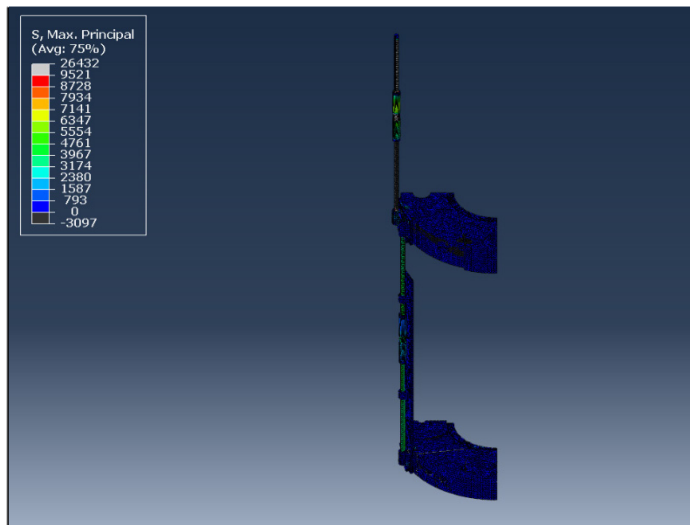


Figure 5.8 Figures containing S Max\_principal Results Iso  
view

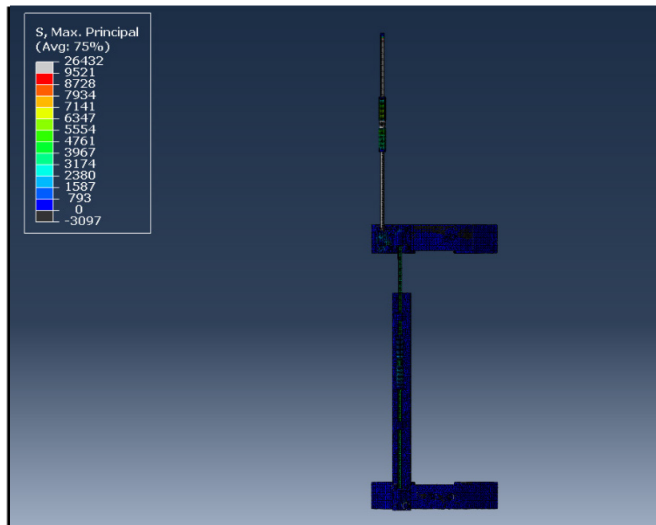


Figure 5.9 Figures containing S Max\_principal Results  
Front view

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3DXML for S Mid. Principal results

Note: The "artificial ground" in the 3DXML is a visual artifact and not part of the model

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Figures containing S Mid\_principal Results step=Static  
increment=18

Reflector Support Structure Analysis

Firefox

file:///C:/Users/john.stevenson/Documents/Models/Marvel/RSS%20Seis...

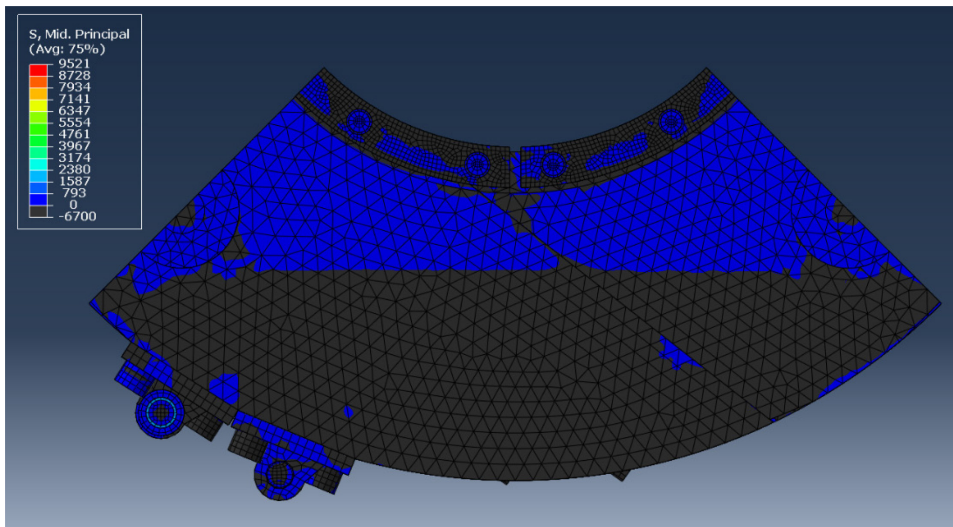


Figure 5.10 Figures containing S Mid\_principal Results Top view

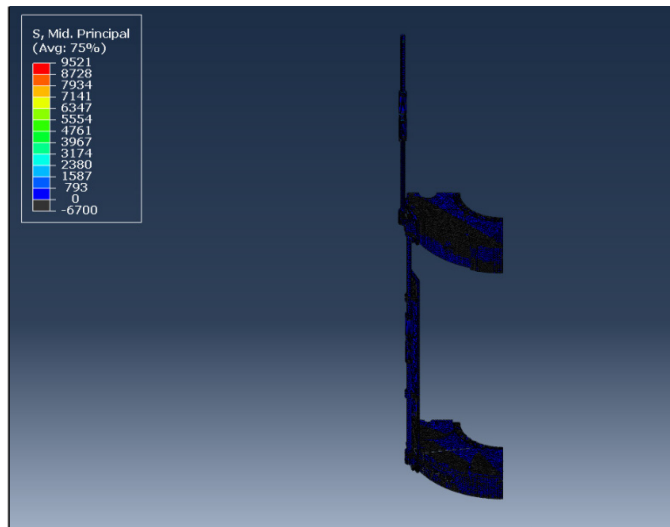


Figure 5.11 Figures containing S Mid\_principal Results Iso view

Reflector Support Structure Analysis

Firefox

file:///C:/Users/john.stevenson/Documents/Models/Marvel/RSS%20Seis...

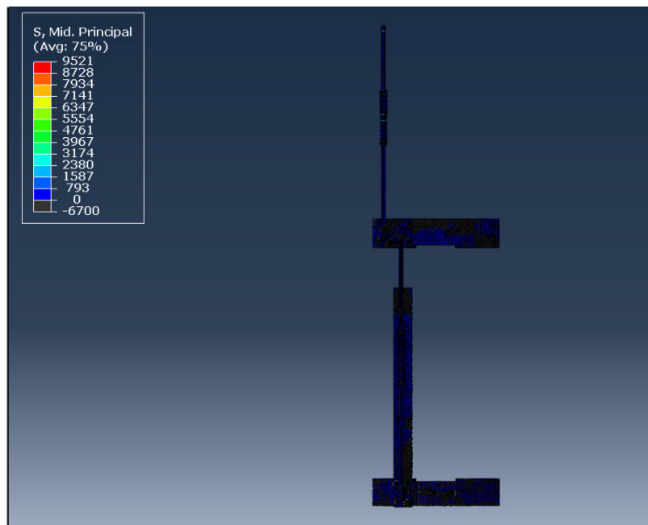


Figure 5.12 Figures containing S Mid\_principal Results  
Front view

[^ back](#)

3DXML for U Magnitude results

Note: The "artificial ground" in the 3DXML is a visual artifact and not part of the model

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Figures containing U Magnitude Results step=Static  
increment=28

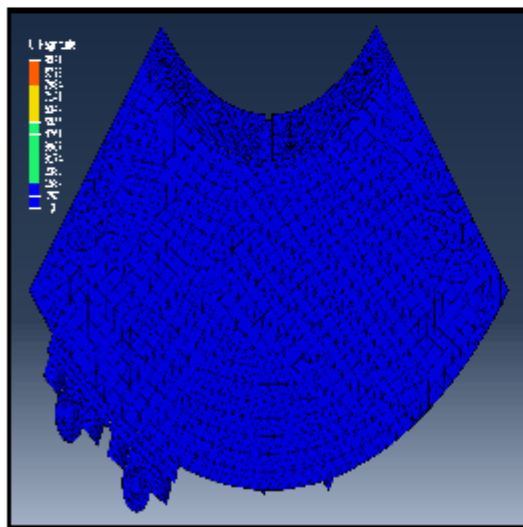


Figure 5.13 Figures containing U Magnitude Results Top  
view

Reflector Support Structure Analysis

Firefox

file:///C:/Users/john.stevenson/Documents/Models/Marvel/RSS%20Seis...

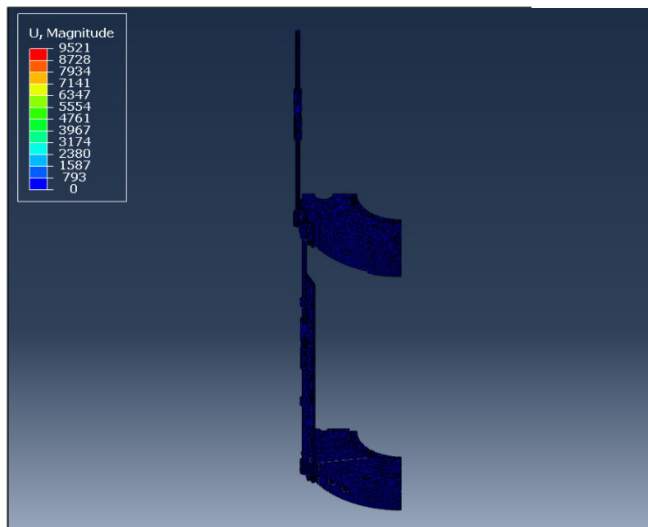


Figure 5.14 Figures containing U Magnitude Results Iso view

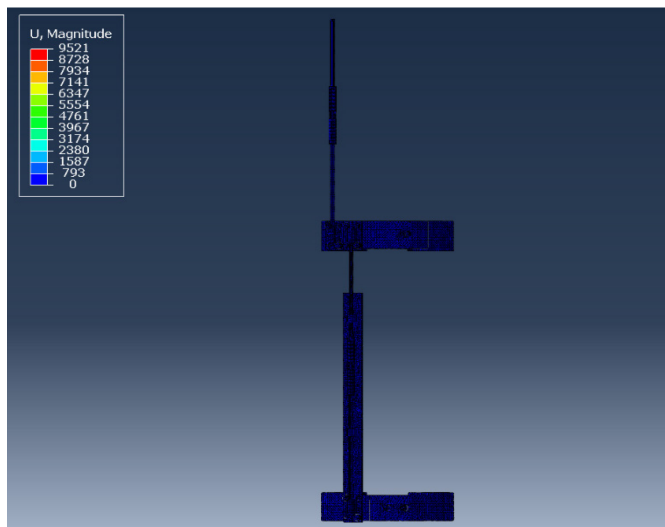


Figure 5.15 Figures containing U Magnitude Results Front view

[^ back](#)

3DXML for S Mises results

Note: The "artificial ground" in the 3DXML is a visual artifact and not part of the model

[^ back](#)

Figures containing S Mises Results step=Static increment=28

Reflector Support Structure Analysis

Firefox

file:///C:/Users/john.stevenson/Documents/Models/Marvel/RSS%20Seis...

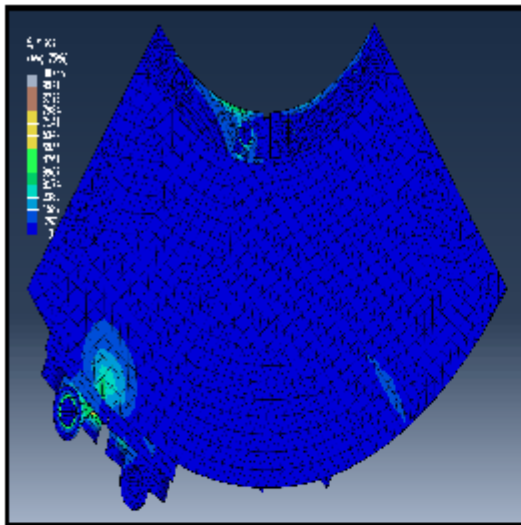


Figure 5.16 Figures containing S Mises Results Top view

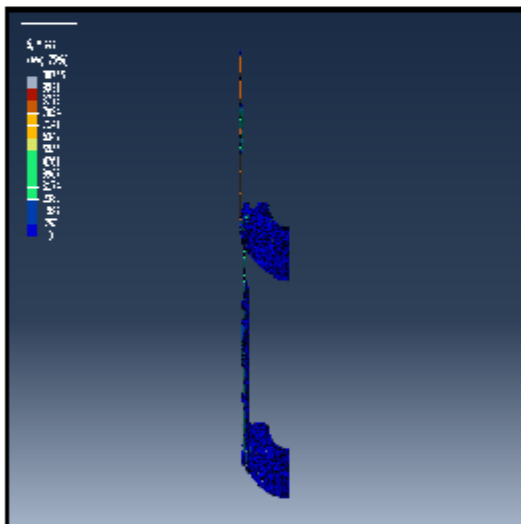


Figure 5.17 Figures containing S Mises Results Iso view

Reflector Support Structure Analysis

Firefox

file:///C:/Users/john.stevenson/Documents/Models/Marvel/RSS%20Seis...

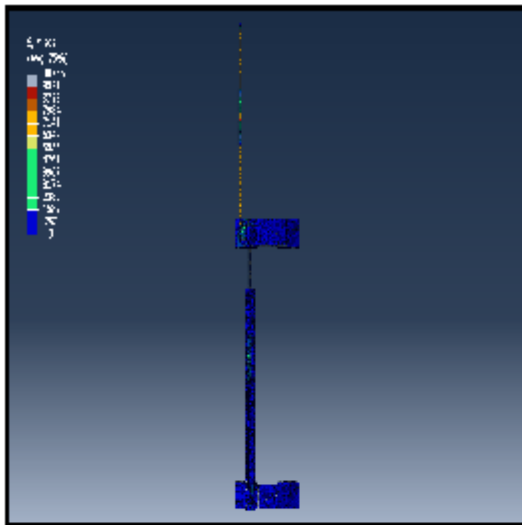


Figure 5.18 Figures containing S Mises Results Front view

[^ back](#)

3DXML for S Max. Principal results

Note: The "artificial ground" in the 3DXML is a visual artifact and not part of the model

[^ back](#)

Figures containing S Max\_principal Results step=Static  
increment=28

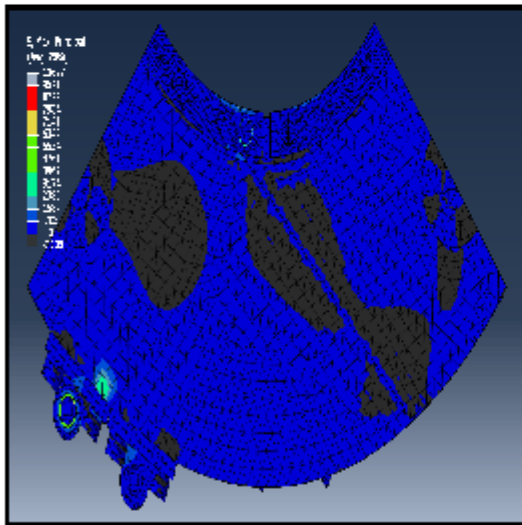


Figure 5.19 Figures containing S Max\_principal Results  
Top view

Reflector Support Structure Analysis

Firefox

file:///C:/Users/john.stevenson/Documents/Models/Marvel/RSS%20Seis...

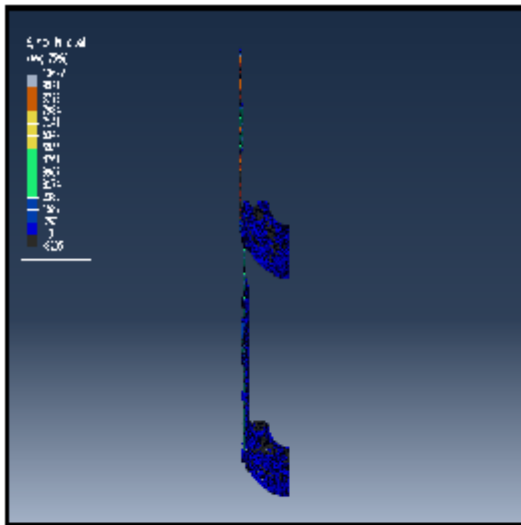


Figure 5.20 Figures containing S Max\_principal Results Iso view

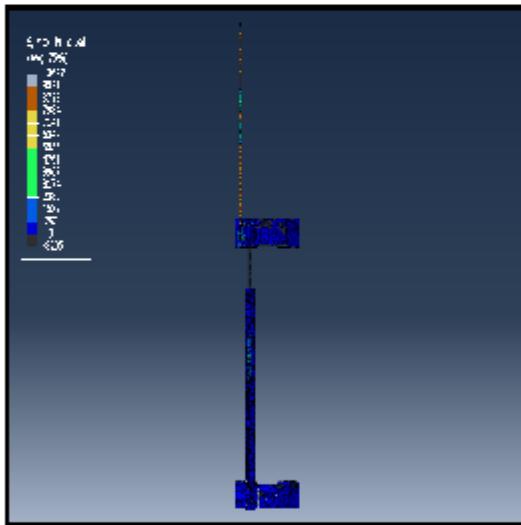


Figure 5.21 Figures containing S Max\_principal Results Front view

[^ back](#)

3DXML for S Mid. Principal results

Note: The "artificial ground" in the 3DXML is a visual artifact and not part of the model

[^ back](#)

Figures containing S Mid\_principal Results step=Static  
increment=28



Reflector Support Structure Analysis

Firefox

file:///C:/Users/john.stevenson/Documents/Models/Marvel/RSS%20Seis...

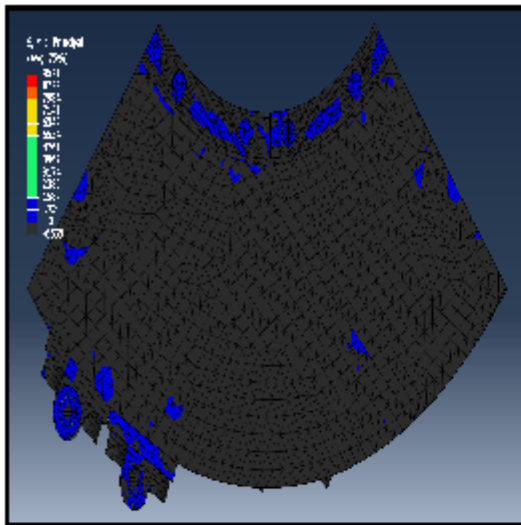


Figure 5.22 Figures containing S Mid\_principal Results Top view

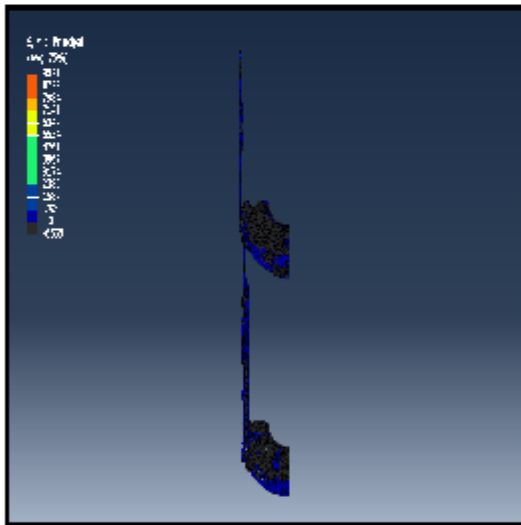


Figure 5.23 Figures containing S Mid\_principal Results Iso view

Firefox

file:///C:/Users/john.stevenson/Documents/Models/Marvel/RSS%20Seis...

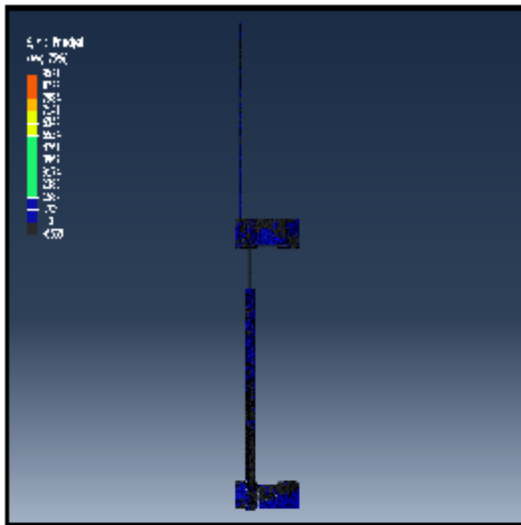


Figure 5.24 Figures containing S Mid\_principal Results  
Front view

[^ back](#)

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## 6. File Summary

To transfer this report, following files and directories must be copied:

- htmlReport/image
- htmlReport/additionalImages
- htmlReport/additionalFiles
- htmlReport/abaqus.css
- htmlReport/htmlReport.html

[Back to Table of Contents](#)

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## Appendix C

### Modal Analysis



## Simulation of MRS-RSS-seismic

Date: Tuesday, April 25, 2023

Designer: Solidworks

Study name: Frequency 1

Analysis type: Frequency

### Table of Contents

Study Properties.....	2
Units .....	2
Material Properties .....	3
Loads and Fixtures .....	4
Interaction Information .....	6
Mesh information.....	6
Study Results .....	7



SOLIDWORKS

Analyzed with SOLIDWORKS Simulation

Simulation of MRS-RSS-seismic 1

### Study Properties

Study name	Frequency 1
Analysis type	Frequency
Mesh type	Solid Mesh
Number of frequencies	5
Solver type	FFEPlus
Soft Spring:	Off
Incompatible bonding options	Automatic
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Result folder	SOLIDWORKS document (C:\Users\john.stevenson\Documents\Models\Marvel\RSS Seismic)



### Units

Unit system:	English (IPS)
Length/Displacement	in
Temperature	Celsius
Angular velocity	Hertz
Pressure/Stress	ksi



Reflector Support Structure Analysis



Material Properties

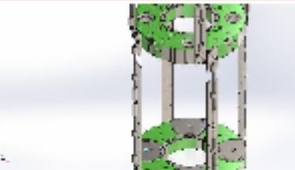

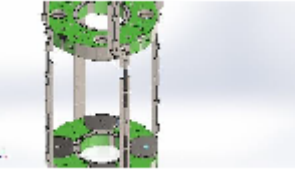
Model Reference	Properties	Components
	<b>Name:</b> AISI 316 Annealed Stainless Steel Bar (SS) <b>Model type:</b> Linear Elastic Isotropic <b>Default failure criterion:</b> Unknown <b>Yield strength:</b> 137.895 N/mm <sup>2</sup> <b>Tensile strength:</b> 550 N/mm <sup>2</sup> <b>Mass density:</b> 8 g/cm <sup>3</sup> <b>Elastic modulus:</b> 193,000 N/mm <sup>2</sup> <b>Poisson's ratio:</b> 0.3 <b>Thermal expansion coefficient:</b> 1.6e-05 /Kelvin	All Components except rings
Curve Data: N/A		
	<b>Name:</b> A286 Iron Base Superalloy <b>Model type:</b> Linear Elastic Isotropic <b>Default failure criterion:</b> Unknown <b>Yield strength:</b> 275 N/mm <sup>2</sup> <b>Tensile strength:</b> 620 N/mm <sup>2</sup> <b>Mass density:</b> 7.92 g/cm <sup>3</sup> <b>Elastic modulus:</b> 201,000 N/mm <sup>2</sup> <b>Poisson's ratio:</b> 0.31 <b>Thermal expansion coefficient:</b> 1.7e-05 /Kelvin	Rings
Curve Data: N/A		



Reflector Support Structure Analysis

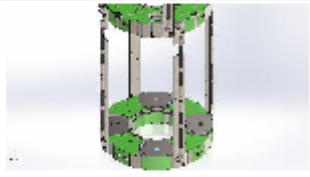
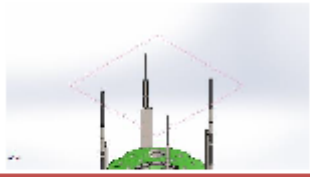
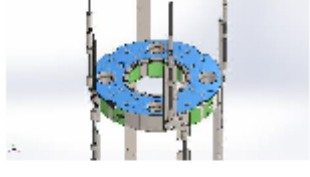
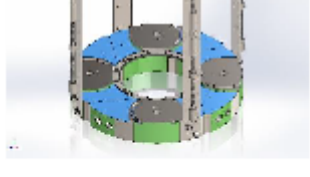
Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		Entities: 4 face(s) Type: Fixed Geometry
Roller/Slider-1		Entities: 8 face(s) Type: Roller/Slider

Load name	Load Image	Load Details
Control Drum 1		Entities: 2 face(s) Type: Load/Mass (Rigid connection) Coordinate System: Global cartesian coordinates Force Values: ---, ---, --- lbf Moment Values: ---, ---, --- N.m Reference coordinates: -7.25 -48 7.25 in Remote Mass: 215 lb Moment of Inertia: 0,0,0,0,0 lb.in^2 Components transferred: NA
Control Drum 2		Entities: 2 face(s) Type: Load/Mass (Rigid connection) Coordinate System: Global cartesian coordinates Force Values: ---, ---, --- lbf Moment Values: ---, ---, --- N.m Reference coordinates: -7.25 -48 -7.25 in Remote Mass: 215 lb Moment of Inertia: 0,0,0,0,0 lb.in^2 Components transferred: NA
Control Drum 3		Entities: 2 face(s) Type: Load/Mass (Rigid connection) Coordinate System: Global cartesian coordinates Force Values: ---, ---, --- lbf Moment Values: ---, ---, --- N.m Reference coordinates: 7.25 -48 -7.25 in Remote Mass: 215 lb




Reflector Support Structure Analysis

		<b>Moment of Inertia:</b> 0,0,0,0,0 lb.in <sup>2</sup> <b>Components transferred:</b> NA
Control Drum 4		<b>Entities:</b> 2 face(s) <b>Type:</b> Load/Mass (Rigid connection) <b>Coordinate System:</b> Global cartesian coordinates <b>Force Values:</b> ---, ---, --- lbf <b>Moment Values:</b> ---, ---, --- N.m <b>Reference coordinates:</b> 7.25 -48 7.25 in <b>Remote Mass:</b> 215 lb <b>Moment of Inertia:</b> 0,0,0,0,0 lb.in <sup>2</sup> <b>Components transferred:</b> NA
Gravity-1		<b>Reference:</b> Top Plane <b>Values:</b> 0 0 -386.22 <b>Units:</b> in/s <sup>2</sup>
Axial Shielding		<b>Entities:</b> 4 face(s) <b>Type:</b> Displacement (Direct transfer) <b>Coordinate System:</b> Global cartesian coordinates <b>Translation Values:</b> ---, ---, --- cm <b>Rotation Values:</b> ---, ---, --- deg <b>Reference coordinates:</b> 0 0 0 in <b>Remote Mass:</b> 640 lb <b>Moment of Inertia:</b> 0,0,0,0,0 lb.in <sup>2</sup> <b>Components transferred:</b> NA
Fixed Reflectors		<b>Entities:</b> 8 face(s) <b>Type:</b> Displacement (Direct transfer) <b>Coordinate System:</b> Global cartesian coordinates <b>Translation Values:</b> ---, ---, --- cm <b>Rotation Values:</b> ---, ---, --- deg <b>Reference coordinates:</b> 0 0 0 in <b>Remote Mass:</b> 900 lb <b>Moment of Inertia:</b> 0,0,0,0,0 lb.in <sup>2</sup> <b>Components transferred:</b> NA





### Interaction Information

Interaction	Interaction Image	Interaction Properties
Global Interaction		Type: Bonded Components: 1 component(s) Options: Independent mesh

### Mesh information

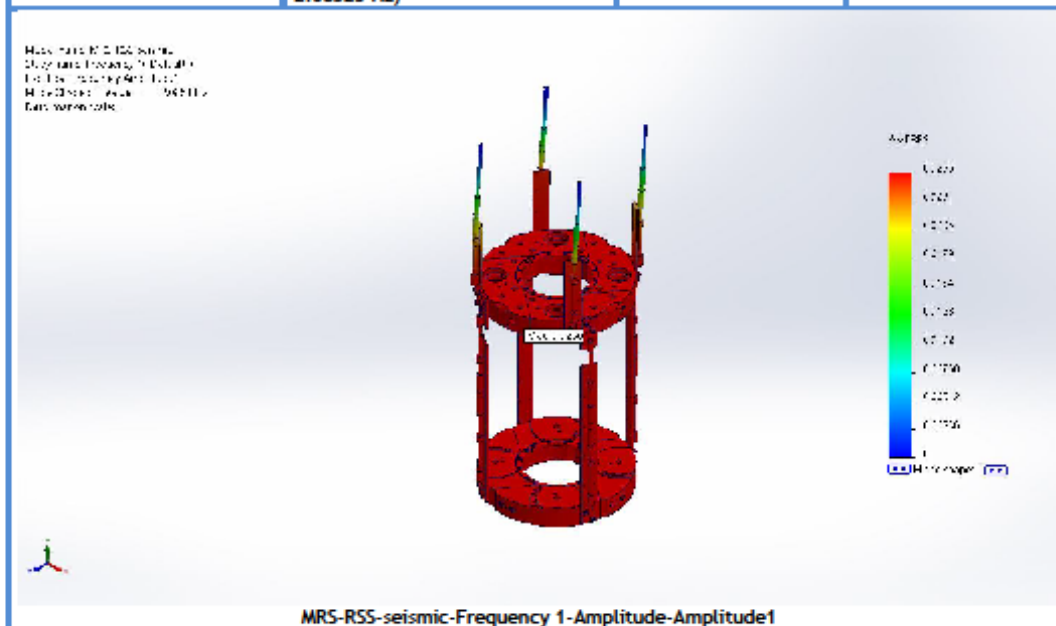
Mesh type	Solid Mesh
Mesher Used:	Blended curvature-based mesh
Jacobian points for High quality mesh	16 Points
Maximum element size	2 in
Minimum element size	0.01 in
Mesh Quality	High
Remesh failed parts independently	Off

### Mesh information - Details

Total Nodes	2561134
Total Elements	1592805
Maximum Aspect Ratio	137.64
% of elements with Aspect Ratio < 3	97.5
Percentage of elements with Aspect Ratio > 10	0.054
Percentage of distorted elements	0
Time to complete mesh(hh:mm:ss):	00:01:59
Computer name:	CRESTLINE



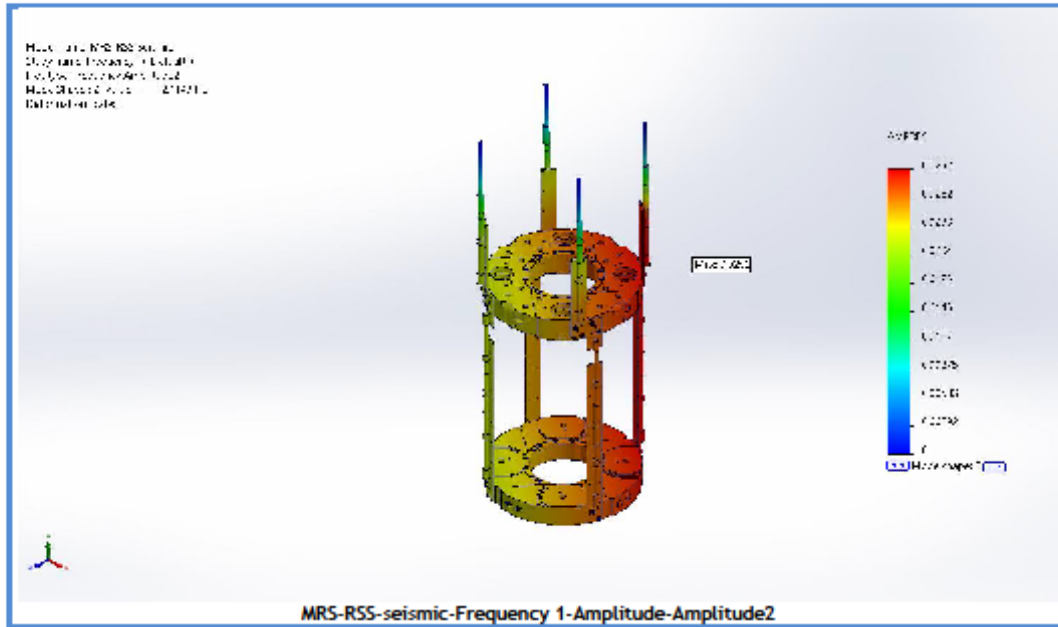
Name	Type	Min	Max
Amplitude1	AMPRES: Resultant Amplitude Plot for Mode Shape: 1(Value = 2.08525 Hz)	0 Node: 283755	0.0256 Node: 94237



MRS-RSS-seismic-Frequency 1-Amplitude-Amplitude1

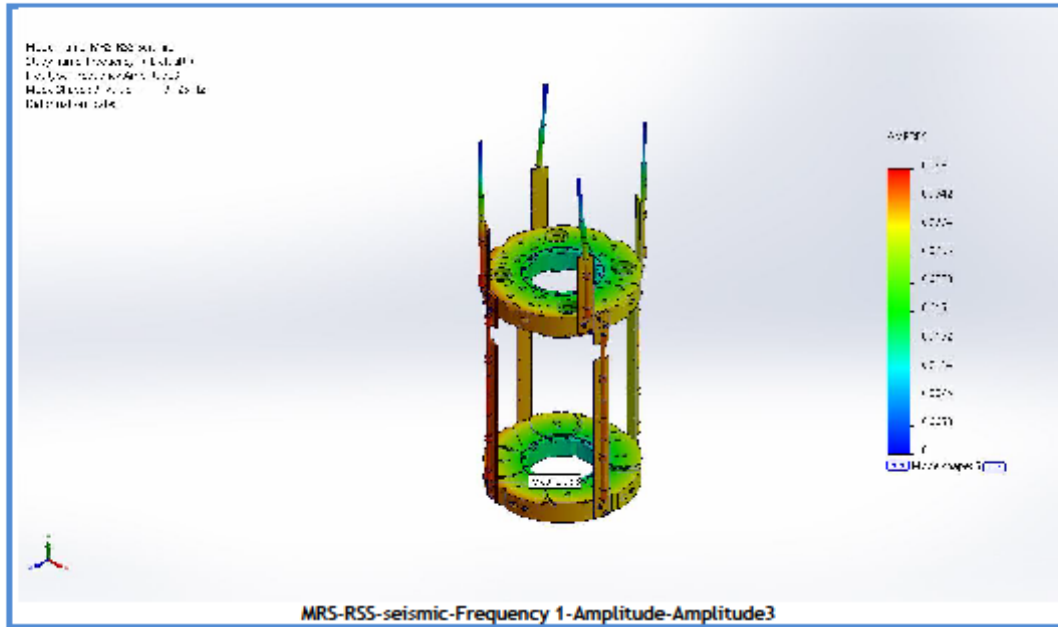
Name	Type	Min	Max
Amplitude2	AMPRES: Resultant Amplitude Plot for Mode Shape: 2(Value = 2.11427 Hz)	0 Node: 283755	0.0292 Node: 298571

Reflector Support Structure Analysis



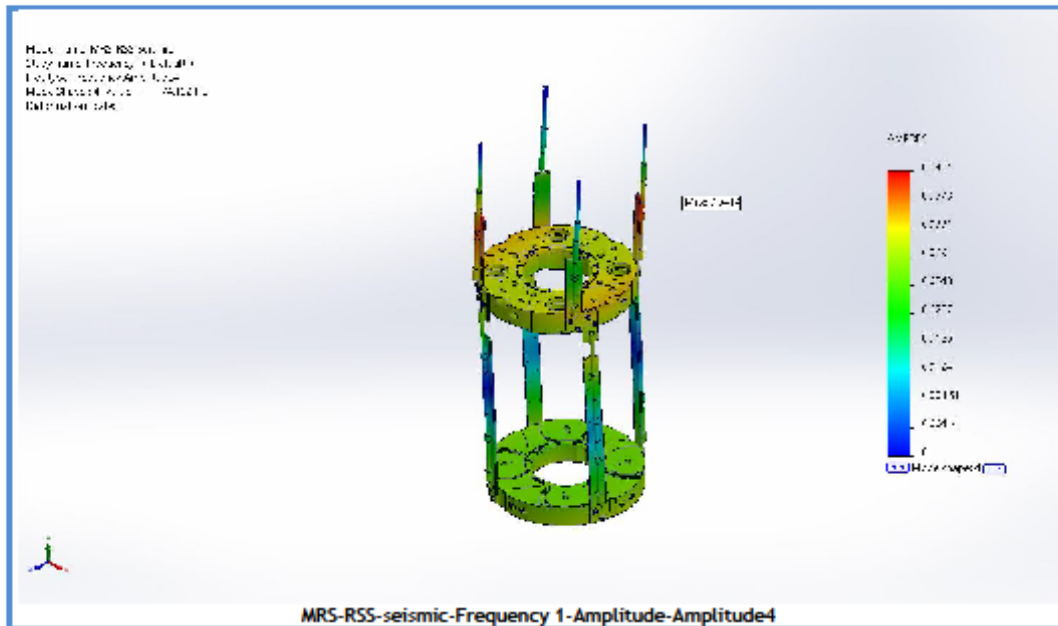
Name	Type	Min	Max
Amplitude3	AMPRES: Resultant Amplitude Plot for Mode Shape: 3(Value = 3.12505 Hz)	0 Node: 283755	0.038 Node: 92332

Reflector Support Structure Analysis



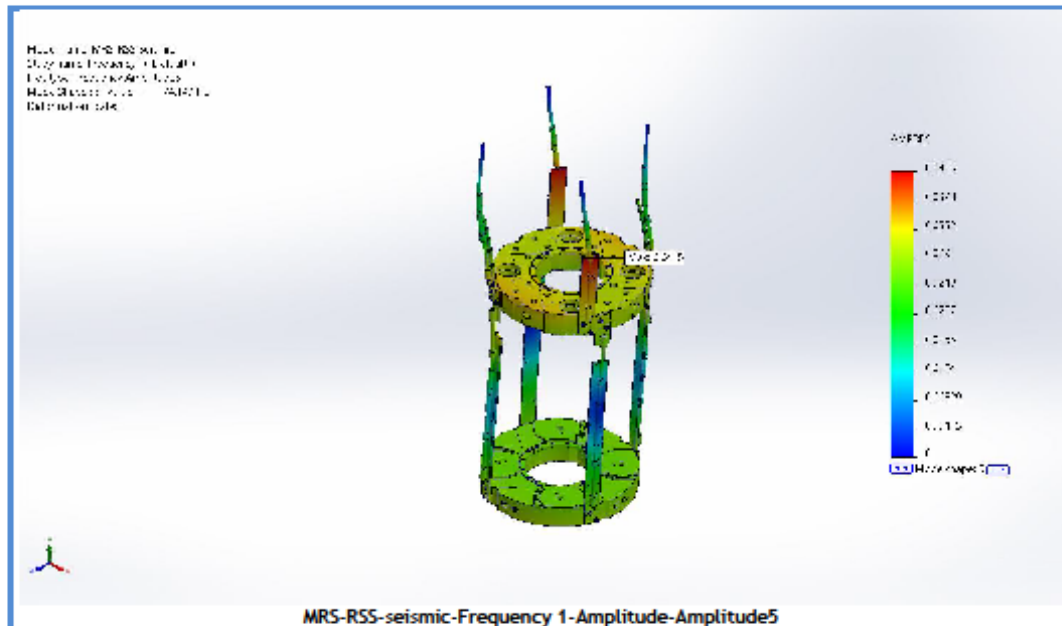
Name	Type	Min	Max
Amplitude4	AMPRES: Resultant Amplitude Plot for Mode Shape: 4(Value = 74.1222 Hz)	0 Node: 283755	0.0414 Node: 287536

Reflector Support Structure Analysis



Name	Type	Min	Max
Amplitude5	AMPRES: Resultant Amplitude Plot for Mode Shape: 5(Value = 74.1465 Hz)	0 Node: 283755	0.0415 Node: 378123

Reflector Support Structure Analysis



Mode List

Frequency Number	Rad/sec	Hertz	Seconds
1	13.102	2.0853	0.47956
2	13.284	2.1143	0.47298
3	19.635	3.125	0.32
4	465.72	74.122	0.013491
5	465.88	74.147	0.013487

Mass Participation (Normalized)

Mode Number	Frequency(Hertz)	X direction	Y direction	Z direction
1	2.0853	0.30798	2.7443e-10	0.69479
2	2.1143	0.68724	3.3751e-14	0.30465
3	3.125	0.0075562	2.4215e-10	0.0033382
4	74.122	2.045e-07	1.3231e-09	2.3212e-10
5	74.147	9.2002e-08	1.6e-10	6.0409e-08
		Sum X = 1.0028	Sum Y = 1.9997e-09	Sum Z = 1.0028



## Appendix D

## References



### Material Properties Chart

		Thermalox® NRG
Property		Units
PHYSICAL	Color	-
	Density	g/cc
	Grain Size ave.	microns (typical)
	Hardness	Rockwell 45N
		Min. 99.0% BeO
		varies
		2.800 - 2.900
		20 - 40
		60
THERMAL	Thermal Conductivity ave.	W/m <sup>2</sup> K (@ RT)
	Coefficient of Thermal Expansion ave.	(200- 1600 degC) ppm
	Specific Heat	cal/g <sup>o</sup> C
		280
		8.5
		0.25
MECHANICAL	Flexural Strength (MOR)	Mpa
	Elastic Modulus	Gpa
	Tensile Strength	Mpa
	Compressive Strength	Mpa
	Poisson's Ratio	
	Fracture Toughness (K <sub>IC</sub> )	Mpa·m <sup>1/2</sup>
		172
		345
		124
		1551
		0.26
		3.5
ELECTRICAL	Dielectric Constant	1 MHz @ RT
	Dielectric Constant	10 GHz @ RT
	Dissipation Factor	1 MHz @ RT
	Dissipation Factor	10 GHz @ RT
	Volume Resistivity	ohm-cm @ RT
	Dielectric Strength	ac-volts/mil (6.35 mm)
		6.76
		6.67
		0.0004
		0.0040
		> 10 <sup>15</sup>
		230

MATERION CORPORATION

Thermalox® NRG is a registered trademark of Materion Brush Inc.



PRODUCT DATA SHEET

BORON CARBIDE

Chemical

	Total B	Total C	B4C
F4 – F150	77-81%	17-21%	96-98%
F180 – F400	77-81%	17-21%	96-98%
F500 – F800	76-81%	17-21%	95-98%
F1000 – F1500	76-81%	17-21%	95-98%
-10µ or -25µ	76-81%	17-21%	95-98%
-100, -200, -300 mesh	76-81%	17-21%	95-98%
-60 + 150 mesh	76-81%	17-21%	95-98%
B <sub>2</sub> O <sub>3</sub>	max 0.5 %		
Fe <sub>2</sub> O <sub>3</sub>	max 0.5%		

Physical

Density	>2.48g/cm <sup>3</sup> hot pressed and sintered
Hardness (Knoop 100g)	2900-3580
Fracture Toughness	2.9-3.7 MPa.m <sup>1/2</sup>
Young's Modulus	450-470 GPa
Electrical Conductivity (25°C)	140 S
Thermal Conductivity (25°C)	30-42 W/m.K
Thermal Expansion Coefficient	5 x 10 <sup>-6</sup> /°C

Appearance

Black Powder

Material can also be supplied as hot pressed and sintered pieces up to 400 x 400 mm<sup>2</sup>

Applications

Refractory, Wear Resistant and Structural Ceramics  
Metal matrix Composites  
Nuclear Shielding  
Grinding, Polishing and Lapping  
Ballistic armour

CAS Number

12069-32-8

REACH

01-2119497788-10-XXXX

Transport

Non Hazardous

Tariff No

28499010





January 26, 2022

Yasir Arafat  
MARVEL Project Lead, DOE Microreactor Program  
Idaho National Laboratory  
Idaho Falls, ID 83402

Re: B4C Powder Density

Dear Yasir:

The results of density measurements for B4C powder, with measurement standard deviation was as follows:

Unsettled\*:  $1.11 \pm 0.023$  g/ml  
Settled\*:  $1.25 \pm 0.0093$  g/ml

\*"Unsettled" = as poured, "Settled" = filled container tapped on counter 4 minutes, topped off at the end of each minute.

Some bridging was encountered during emptying of the container after settled sample measurements, but tapping on the sides of the container would restore flow and the container would eventually empty completely.

Details are provided in the attached appendix. Please feel free to contact me with any concerns or questions.

Best Regards,

A handwritten signature in black ink, appearing to read "Jeff Jones".

Jeff Jones  
Senior Consulting Engineer

WALSH ENGINEERING SERVICES  
330 SHOUP AVENUE, SUITE 300  
IDAHO FALLS, ID 83402  
208-524-2286





### APPENDIX – MEASUREMENT DETAILS

Material:

Boron Carbide 100, Washington Mills Electro Minerals Corporation

Equipment:

OHAUS(R) Gold Series balance 500g x 0.1 g Model YA501

Measurements:

2 densities (unpacked and settled) x 2 volumetric flask sizes (50 +/-0.05 ml and 100 ml +/-0.1 ml) x 3 measurements each

	Empty Container	
	50 ml flask	100 ml flask
w1	45.7	66.7
w2	45.8	66.6
w3	45.7	66.7
Avg. weight	45.73	66.67
Weight Stdev	0.0577	0.0577

	Filled to line - unpacked	
	50 ml flask	100 ml flask
w1	101.2	177.1
w2	103.6	178
w3	101.4	174.4
w4		174.4
Avg. weight	102.07	175.98
Weight Stdev	1.33	1.86
Net weight	56.33	109.31
Density	1.1267	1.0931
Mean Density	1.110	
Mean stdev	0.023	

	Filled to line - packed	
	50 ml flask	100 ml flask
w1	107.3	194.8
w2	108.4	191.1
w3	107.8	190.2
w4	107.7	192.4
Avg. weight	107.80	192.13
Weight Stdev	0.379	1.106
Net weight	62.067	125.458
Density	1.241	1.255
Mean Density	1.25	
Mean stdev	0.0093	

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IDAHO FALLS, ID 83402  
208-524-2286



Reflector Support Structure Analysis



Figure 1 - B4C Container

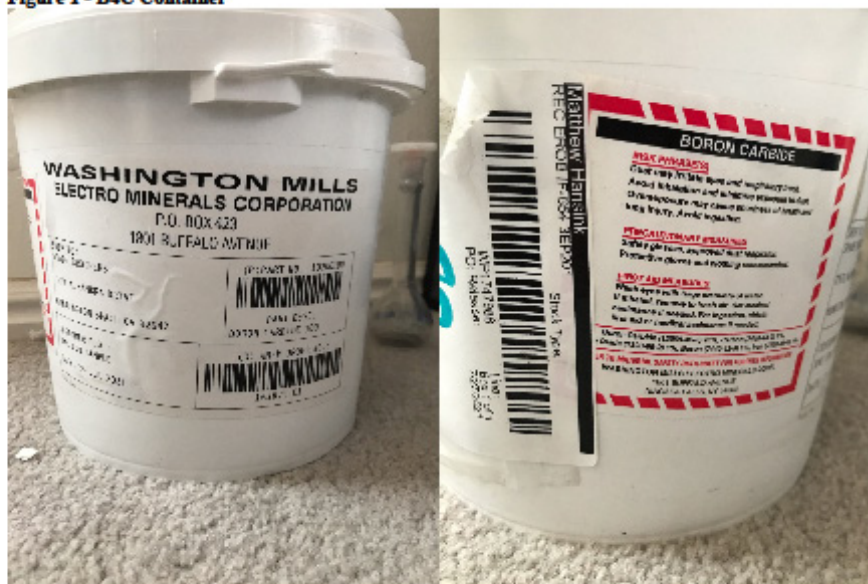
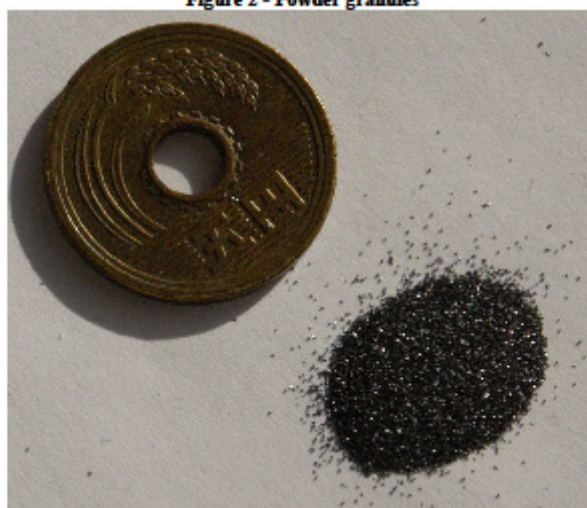


Figure 2 - Powder granules



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Figure 3 - Bridging encountered during emptying



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