VEX-U Online CAD Challenge

Part Title:
Reinforced Standoff Coupler

Due Date:
1/13/2016

Team:
FLTCH – Florida Institute of Technology

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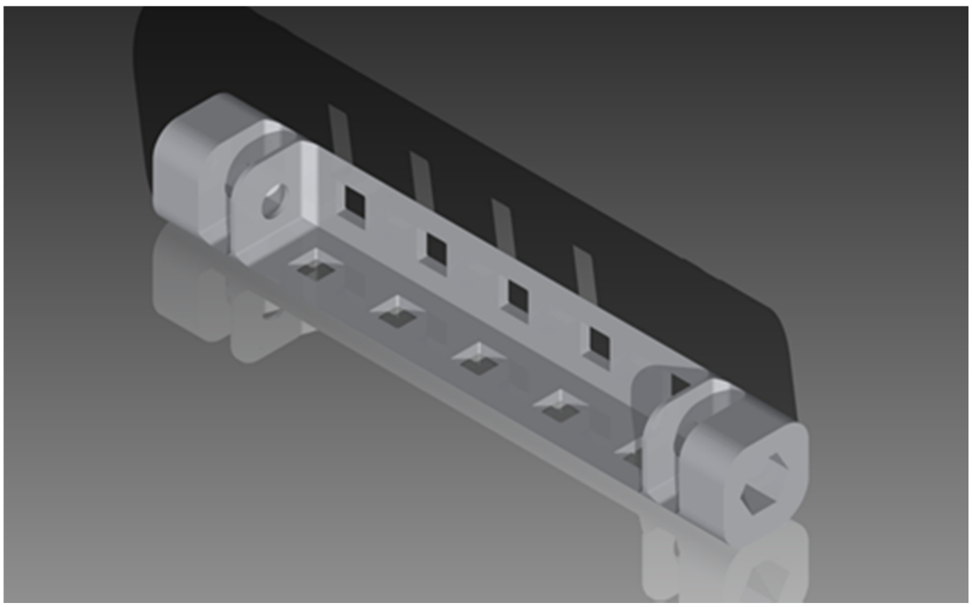
Introduction

In the world of Vex Robotics, it's not a matter of whether you can perform a task. It's a question of how quickly can it be done. Because of this, teams worldwide push the limits of engineering by making robots as light, precise, and as rigid as possible. Aluminum vex pieces are the closest answer to their needs, however they almost



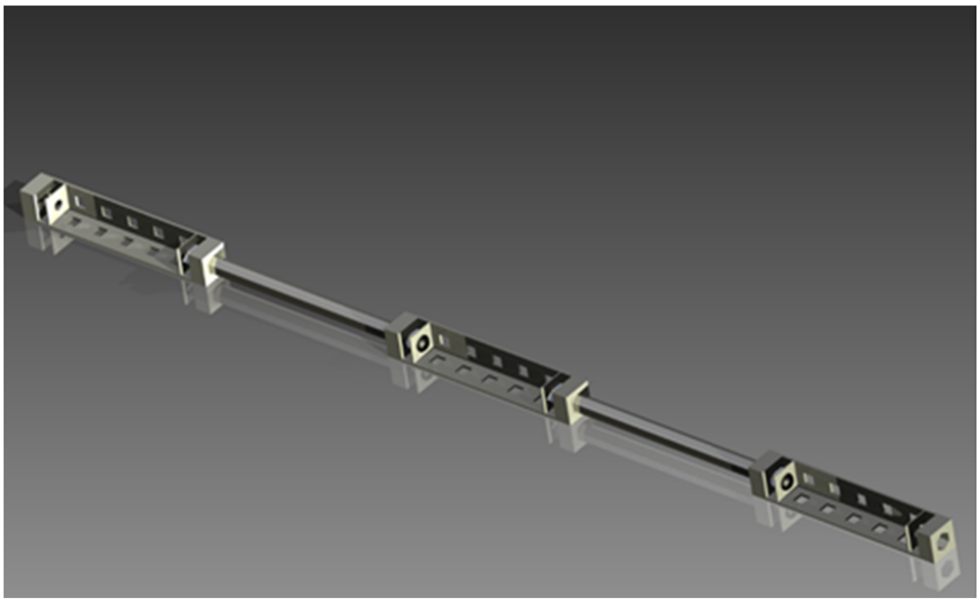
require cutting to remain customizable and lightweight.

This part however allows teams to push past the present limitations of vex metal to make superior robots.

Above: Reinforced Standoff Coupler version 3

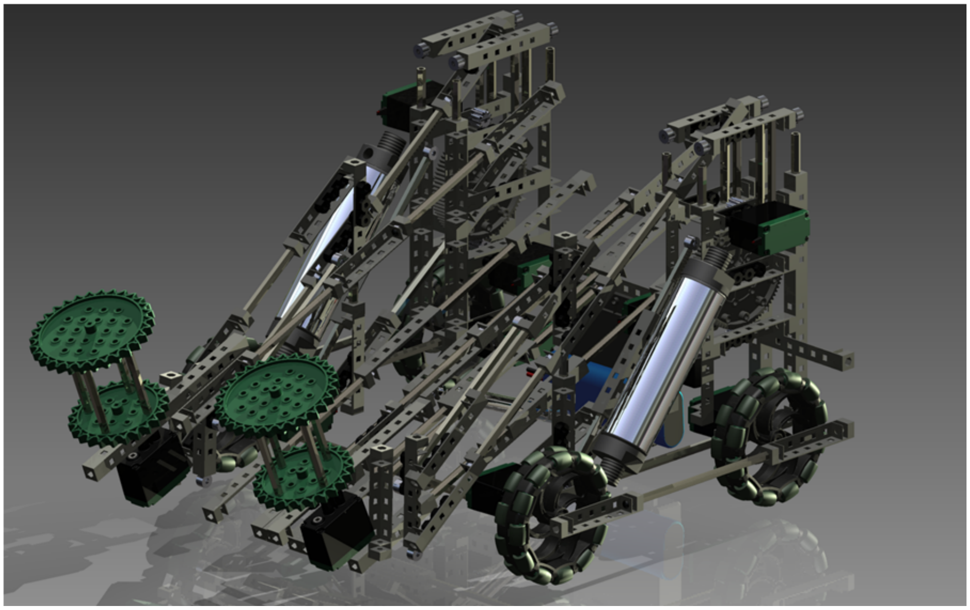
Explanation of Part

This part allows teams to build robots that are lighter, more precise, and remain just as rigid as before; all without cutting. This part takes advantages of the various lengths and popularity of standoffs and washers to replace the current uses of present vex metal.



Above: Reinforced Standoff Coupler extended to 17.5”

The reinforced standoff coupler is an aluminum coupler that allows teams to connect standoffs and build off of them. This follows the same 5 hole pattern, shape, and 0.5 inch increments as standard vex metal, allowing this part to be fully compatible with current vex parts. Standoffs are inserted at either end of the coupler and screwed down. A niche is also inserted so teams can apply locknuts to avoid retightening the robot after every match. If teams want distances in between 0.5 inch increments, teams can also insert washers between the reinforced standoff coupler and standoff, allowing them to get increments of 0.03 inches. For comparison a 12.5 inch standoff beam would be 7% lighter than a 12.5 inch aluminum rail and about 33% lighter than a 12.5 inch channel. However, since different standoffs can be used, it is also possible to make 7.5 and 8 inch beams which are drastically lighter than the 7.5 inch steel channel and 8 inch steel rail, or even smaller pieces without cutting. Likewise, it is also possible to make



long pieces like the 17.5 inch channel or rail or any size longer or shorter, making this a useful piece not only for high school and middle school students, but also for university students in Vex U. Due to the adjustability of this piece, it's very easy to create triangular braces to increase the rigidity of robot designs.

Above: A complete redesign of the common Toss Up design with reinforced standoff couplers

This design above is the standard design at the world championships for the Toss Up season. It has the ability to grab bucky balls, large balls, shoot large balls, and hang. That year, robots were somewhere between 12 to 25 pounds. This robot however weighs less than 10 pounds with no cut pieces that are completely reusable. This was easily achieved through using reinforced standoff couplers and standoffs without the use of vex structural components

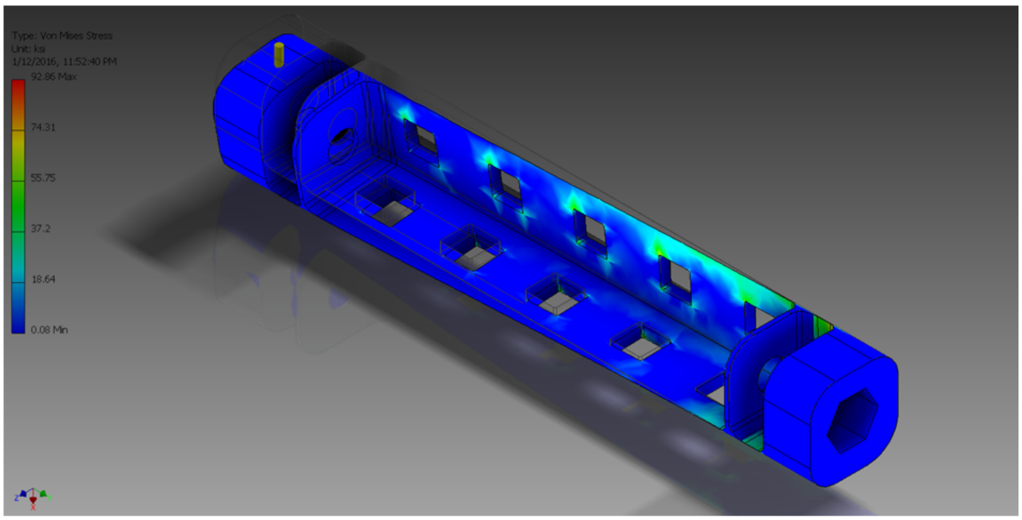
Use of Autodesk Inventor / Fusion

A block was first sketched and extruded to a rectangular block. Once the block was made, cuts were made to get the grooves. After the grooves were made, a standard vex hole was made. Once the hole was made, the hole was patterned to quickly get 3 holes. These features were then carried over to the other side. An assembly was then used to create an entire robot to prove the versatility of this part. However, it was found that the first version with 3 holes only provided limited motor placement. Because of this, I enlarged the block to fit 5 holes to what you see now. With this, the part gained much more flexibility with motor placement, allowing teams to create more flexible designs. As a competitor, I also realized that teams want a robot which requires minimal maintenance. Because of this, I inserted grooves inside the block where locknuts can be inserted. Using this, this prevents both the standoff and screw from wiggling free. Once the part was finalized, I ran a stress analysis on the part and compared it to the stress on channels and aluminum rails. With this, I found that the part was weaker than I expected. So, I then thickened the walls of the part and added fillets to increase the torsional and shear rigidity to what we have now.

Finite Element Analysis

The analysis performed was a basic beam analysis of 25 pounds of force on one end while the other end was fixed. The same analysis was performed on standard vex L angled bar and C-channel cut to the same length as the proposed part to confirm that the data was correct.

Inventor was used to do initial stress analysis using the stress analysis tool. The Inventor files were exported as an IGES file format to be imported into the ANSYS Workbench analysis software for a more accurate analysis. ANSYS and Inventor Stress Analysis allowed the part to be meshed with 21448 nodes and 11512 elements.



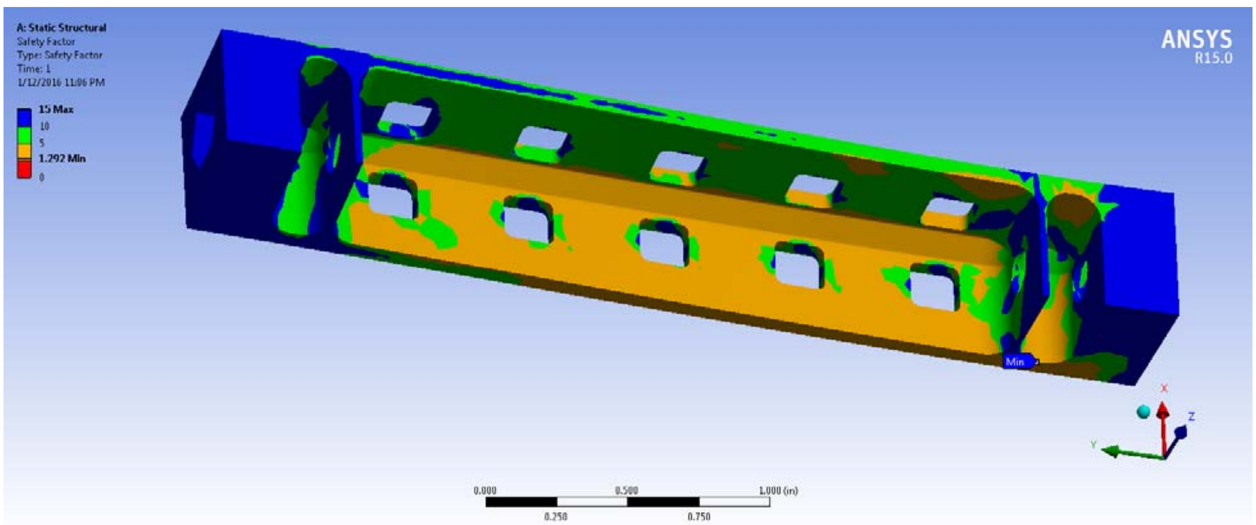
Above: Inventor Stress Analysis on final proposed part.

25 pounds of force was used as a maximum experienced force on any single point of the reinforced standoff coupler. Usually the forces in the vex competition are distributed enough to where the part should never reach that maximum design force under any circumstances.

Total Deformation for proposed part is 0.05414 inches with a maximum stress of 31,431 psi and a factor of safety of 1.292. The part material is the same aluminum used by vex (5052-H32 alloy). The final weight of the part is 0.028 pounds which is far lighter than the same length of L angled bar (0.0349 lbm) and C-channel (0.0372 lbm).

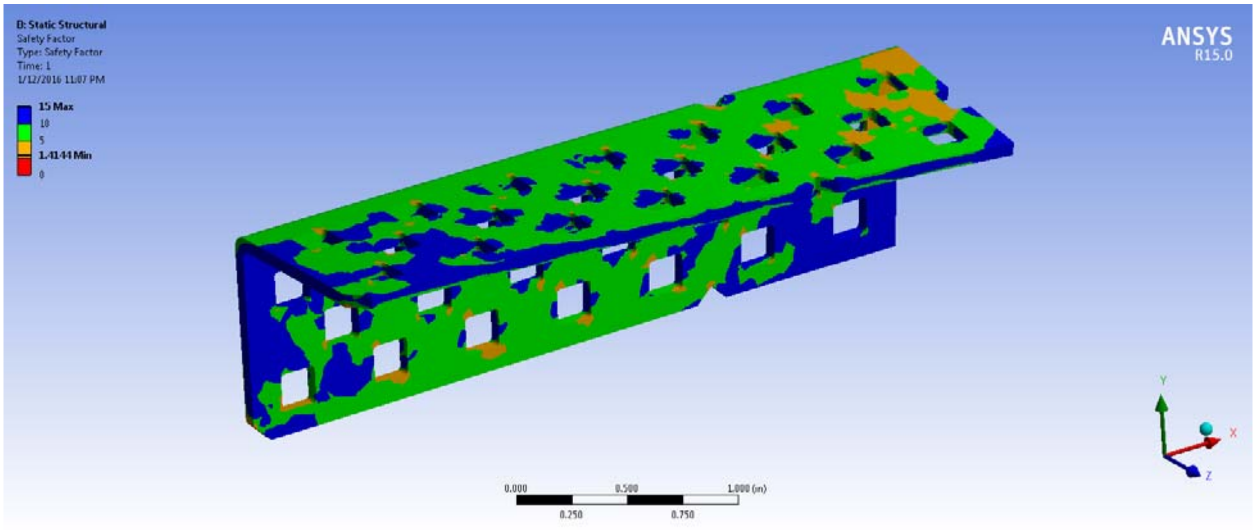
Based on the analysis, the part will not deform plastically, only elastically, showing that the part will withstand any forces that can be encountered at the VEX competition.

The factor of safety of the proposed part is almost matching the factor of safety of the L angled bar which was the goal. The C-channel was used as a baseline to make sure that all of the analysis made sense. The C-channel is stronger due to its additional supporting wall which doubled the factor of safety. Matching the L angled bar factor of safety and being less than the C-channel factor of safety meant that the proper analysis was performed on the proposed part.



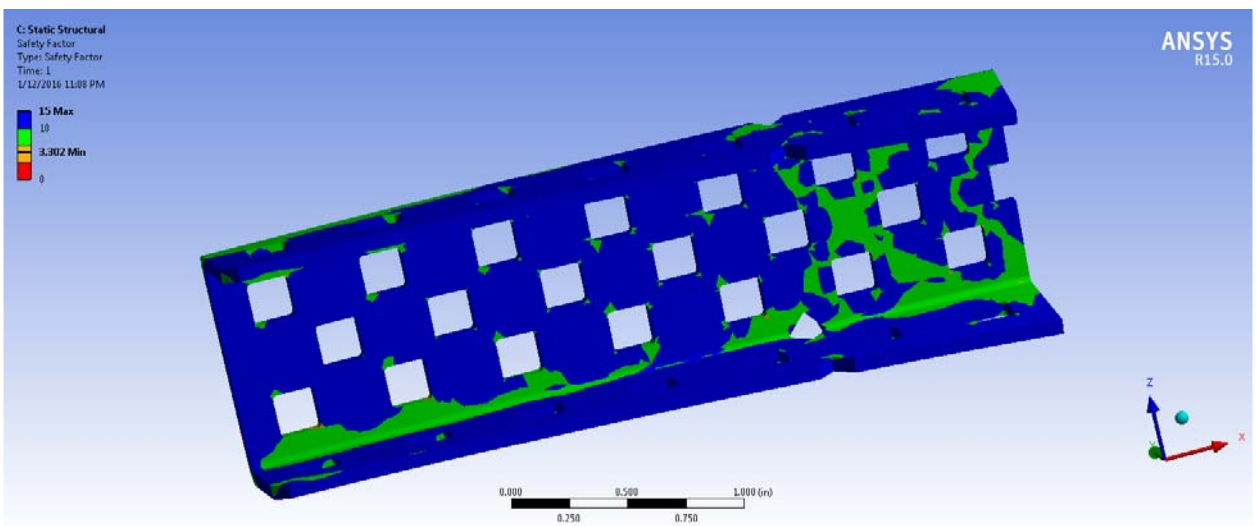
Above: ANSYS Workbench analysis on proposed part. Figure representing the forces traveling through the reinforced standoff coupler with the analysis scenario

Previous versions of the model moved the forces unevenly and would create pressure points in the nodes at the corners of the universal mounting holes. To alleviate this issue a ridge was extruded through the corner of the coupler to transfer most of the forces through a generic beam fashion. This, based on the analysis proved to work very well bringing the factor of safety of the 1 row [of mounting holes] coupler to match the factor of safety of the 3 row [of mounting holes], larger, L angled bar. This concluded the final version of the coupler.



Above: Analysis of the 3 row [of mounting holes] coupler. This was used as the baseline for the factor of safety for the proposed reinforced standoff coupler

For reference to the results of the reinforced standoff coupler, the L angled bar had the following results: 28712 psi max stress, 0.0534 in max deformation, 1.414 FOS.



Above: Analysis of the standard C-channel. The results, as previously stated, were used to ensure that the results of the L angled bar and proposed reinforced standoff coupler are within range of correct results

For reference to the results of the reinforced standoff coupler, the L angled bar had the following results: 12299 psi max stress, 0.0182 in max deformation, 3.302 FOS.

Full tabulated results of all three tests are attached as appendices.

3D Printed Part

The reinforced standoff coupler was 3D printed and pictures are below.

Conclusion

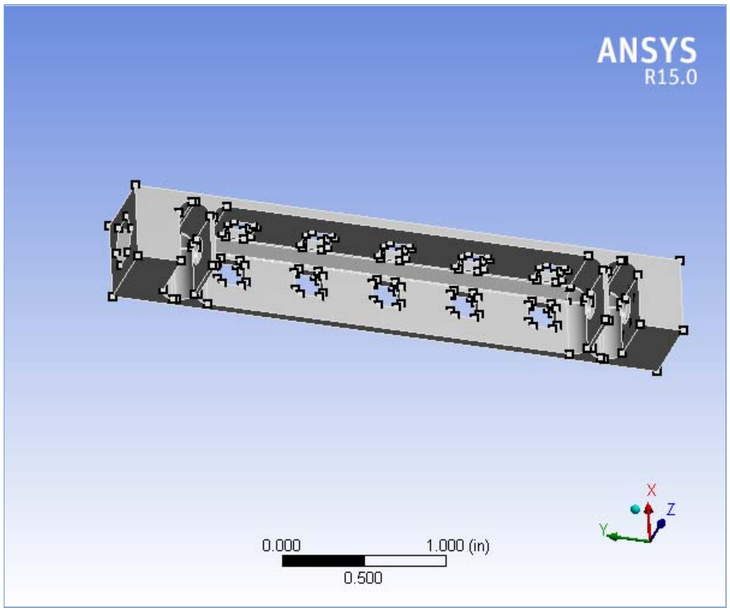
With this project, I learned how to use stress analysis tools, the physics behind stress analysis, and how to render designs. Stress analysis tools are important for determining the strength of a component, ensuring that components do not fail under forces. In addition to this, learning the physics of stress analysis allows parts to be designed with higher strength and safety. Together, these two tools allows me to develop more sophisticated and useful components. However, rendering allows me to better showcase my designs, catching the eye of stakeholders business partners, and possibly even customers in the future.

I would definitely use Fusion and Inventor in the future. Inventor allows me to model assemblies and parts and identify problems before I develop a final design. In the long run, this would save the team money and time with designs. On the other hand, Fusion makes it easier for multiple people to work on a single design or part, increasing collaboration among the teams.

Learning 3D design software would definitely help me on my career path. I am currently majoring in Biomedical Engineering. With this major, I would like to pursue 3D Bioprinting. With knowledge of CAD software, I could model organs and bones within the human body and run stress analyses on various components. By doing this, I can predict whether a design would be successful, saving money in the long run and reduce risk within patients.

Project

First Saved	Monday, January 11, 2016
Last Saved	Tuesday, January 12, 2016
Product Version	15.0.7 Release
Save Project Before Solution	No
Save Project After Solution	No



Contents

- **Units**
- **Model (A4)**
  - Geometry
    - Part 1
  - Coordinate Systems
  - Mesh
  - **Static Structural (A5)**
    - Analysis Settings
    - Loads
    - Solution (A6)
      - Solution Information
      - Results
      - Stress Tool
        - Safety Factor
- **Material Data**
  - Aluminum Alloy

Units

TABLE 1

Unit System	U.S. Customary (in, lbm, lbf, s, V, A) Degrees rad/s Fahrenheit
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Fahrenheit

Model (A4)

Geometry

TABLE 2
Model (A4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\Paul Kepinski\Desktop\VEX PARTS\rons\Reinforced Standoff Coupler v3.8.igs
Type	Iges
Length Unit	Meters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Length X	0.5 in
Length Y	3.5 in
Length Z	0.5 in
Properties	
Volume	0.28269 in³
Mass	2.829e-002 lbm
Scale Factor Value	1.
Statistics	
Bodies	1
Active Bodies	1
Nodes	21448
Elements	11514
Mesh Metric	None
Basic Geometry Options	
Solid Bodies	Yes
Surface Bodies	Yes
Line Bodies	No
Parameters	Yes
Parameter Key	DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	No
Compare Parts On Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\Paul Kepinski\AppData\Local\Temp
Analysis Type	3-D
Mixed Import Resolution	None
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (A4) > Geometry > Parts

Object Name	*Part 1*
State	Meshed
Graphics Properties	

Visible	Yes
Transparency	1
Definition	
Suppressed	No
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Material	
Assignment	Aluminum Alloy
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Length X	0.5 in
Length Y	3.5 in
Length Z	0.5 in
Properties	
Volume	0.28269 in³
Mass	2.829e-002 lbm
Centroid X	-0.19256 in
Centroid Y	1.75 in
Centroid Z	0.18922 in
Moment of Inertia Ip1	4.3346e-002 lbm·in²
Moment of Inertia Ip2	1.5099e-003 lbm·in²
Moment of Inertia Ip3	4.3627e-002 lbm·in²
Statistics	
Nodes	21448
Elements	11514
Mesh Metric	None

Coordinate Systems

TABLE 4
Model (A4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Coordinate System ID	0.
Origin	
Origin X	0. in
Origin Y	0. in
Origin Z	0. in
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Mesh

TABLE 5
Model (A4) > Mesh

Object Name	*Mesh*
State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	9.8124e-003 in
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Patch Independent Options	
Topology Checking	Yes
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Extra Retries For Assembly	Yes
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Defeaturing	

Pinch Tolerance	Please Define
Generate Pinch on Refresh	No
Automatic Mesh Based Defeaturing	On
Defeaturing Tolerance	Default
Statistics	
Nodes	21448
Elements	11514
Mesh Metric	None

Static Structural (A5)

TABLE 6
Model (A4) > Analysis

Object Name	*Static Structural (A5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	Mechanical APDL
Options	
Environment Temperature	71.6 °F
Generate Input Only	No

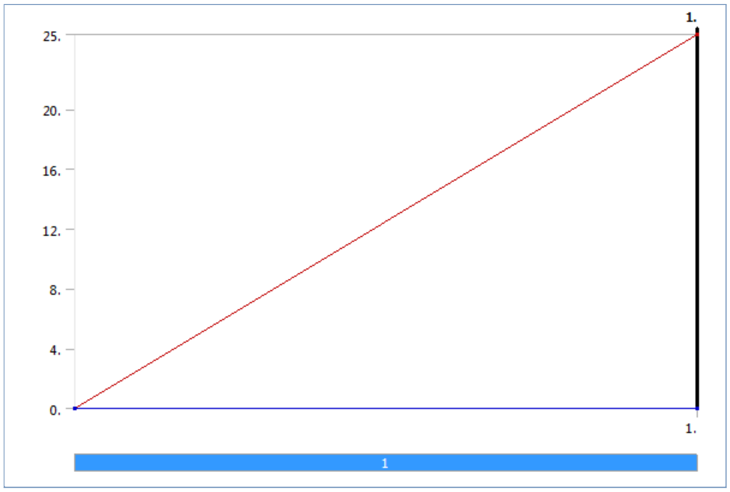
TABLE 7
Model (A4) > Static Structural (A5) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Restart Controls	
Generate Restart Points	Program Controlled
Retain Files After Full Solve	No
Nonlinear Controls	
Newton-Raphson Option	Program Controlled
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Stabilization	Off
Output Controls	
Stress	Yes
Strain	Yes
Nodal Forces	No
Contact Miscellaneous	No
General Miscellaneous	No
Store Results At	All Time Points
Analysis Data Management	
Solver Files Directory	C:\Users\Paul Kepinski\Desktop\VEX PART ANSYS\RONPART_files\dp0\SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save MAPDL db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	Bin

TABLE 8
Model (A4) > Static Structural (A5) > Loads

Object Name	*Fixed Support*	*Force*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	6 Faces	1 Face
Definition		
Type	Fixed Support	Force
Suppressed	No	
Define By		Components
Coordinate System		Global Coordinate System
X Component		25. lbf (ramped)
Y Component		0. lbf (ramped)
Z Component		0. lbf (ramped)

FIGURE 1
Model (A4) > Static Structural (A5) > Force



Solution (A6)

TABLE 9
Model (A4) > Static Structural (A5) > Solution

Object Name	*Solution (A6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.
Information	
Status	Done

TABLE 10
Model (A4) > Static Structural (A5) > Solution (A6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All
FE Connection Visibility	
Activate Visibility	Yes
Display	All FE Connectors
Draw Connections Attached To	All Nodes
Line Color	Connection Type
Visible on Results	No
Line Thickness	Single
Display Type	Lines

TABLE 11
Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Total Deformation*	*Equivalent Elastic Strain*	*Equivalent Stress*
State	Solved		
Scope			
Scoping Method	Geometry Selection		
Geometry	All Bodies		
Definition			
Type	Total Deformation	Equivalent Elastic Strain	Equivalent (von-Mises) Stress
By	Time		
Display Time	Last		
Calculate Time History	Yes		
Identifier			
Suppressed	No		
Results			
Minimum	0. in	1.6915e-006 in/in	7.2211 psi
Maximum	5.414e-002 in	3.0549e-003 in/in	31431 psi
Minimum Value Over Time			
Minimum	0. in	1.6915e-006 in/in	7.2211 psi
Maximum	0. in	1.6915e-006 in/in	7.2211 psi
Maximum Value Over Time			
Minimum	5.414e-002 in	3.0549e-003 in/in	31431 psi
Maximum	5.414e-002 in	3.0549e-003 in/in	31431 psi
Information			
Time	1. s		
Load Step	1		
Substep	1		
Iteration Number	1		
Integration Point Results			
Display Option		Averaged	
Average Across Bodies		No	

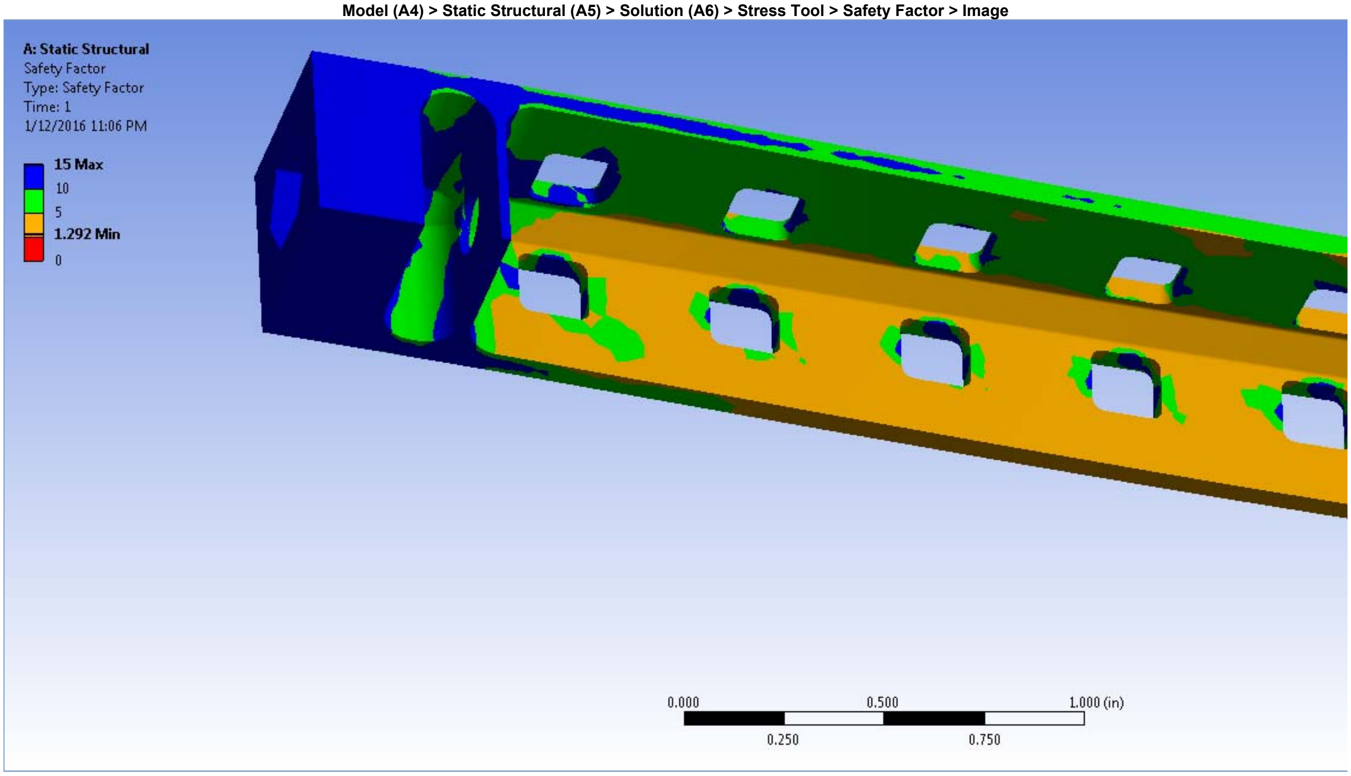
TABLE 12
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Safety Tools

Object Name	*Stress Tool*
State	Solved
Definition	
Theory	Max Equivalent Stress
Stress Limit Type	Tensile Yield Per Material

TABLE 13
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Tool > Results

Object Name	*Safety Factor*
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Safety Factor
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Suppressed	No
Integration Point Results	
Display Option	Averaged
Average Across Bodies	No
Results	
Minimum	1.292
Minimum Value Over Time	
Minimum	1.292
Maximum	1.292
Maximum Value Over Time	
Minimum	15.
Maximum	15.
Information	
Time	1. s
Load Step	1
Substep	1
Iteration Number	1

FIGURE 2
Model (A4) > Static Structural (A5) > Solution (A6) > Stress Tool > Safety Factor > Image



Material Data

Aluminum Alloy

TABLE 14
Aluminum Alloy > Constants

Density	0.10007 lbm in^-3
Coefficient of Thermal Expansion	1.2778e-005 F^-1
Specific Heat	0.20899 BTU lbm^-1 F^-1

TABLE 15

Aluminum Alloy > Compressive Ultimate Strength

Compressive Ultimate Strength psi
0

TABLE 16
Aluminum Alloy > Compressive Yield Strength

Compressive Yield Strength psi
40611

TABLE 17
Aluminum Alloy > Tensile Yield Strength

Tensile Yield Strength psi
40611

TABLE 18
Aluminum Alloy > Tensile Ultimate Strength

Tensile Ultimate Strength psi
44962

TABLE 19
Aluminum Alloy > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature F
71.6

TABLE 20
Aluminum Alloy > Isotropic Thermal Conductivity

Thermal Conductivity BTU s^-1 in^-1 F^-1	Temperature F
1.5247e-003	-148
1.926e-003	32
2.2068e-003	212
2.3406e-003	392

TABLE 21
Aluminum Alloy > Alternating Stress R-Ratio

Alternating Stress psi	Cycles	R-Ratio
40001	1700	-1
34998	5000	-1
29994	34000	-1
25004	1.4e+005	-1
20001	8.e+005	-1
16998	2.4e+006	-1
13000	5.5e+007	-1
12000	1.e+008	-1
24743	50000	-0.5
20247	3.5e+005	-0.5
15751	3.7e+006	-0.5
12750	1.4e+007	-0.5
11251	5.e+007	-0.5
10499	1.e+008	-0.5
21001	50000	0
17506	1.9e+005	0
14997	1.3e+006	0
13500	4.4e+006	0
12499	1.2e+007	0
10499	1.e+008	0
10750	3.e+005	0.5
10250	1.5e+006	0.5
9624.7	1.2e+007	0.5
8999.6	1.e+008	0.5

TABLE 22
Aluminum Alloy > Isotropic Resistivity

Resistivity ohm cmil in^-1	Temperature F
1.2184	32
1.3387	68
1.82	212

TABLE 23
Aluminum Alloy > Isotropic Elasticity

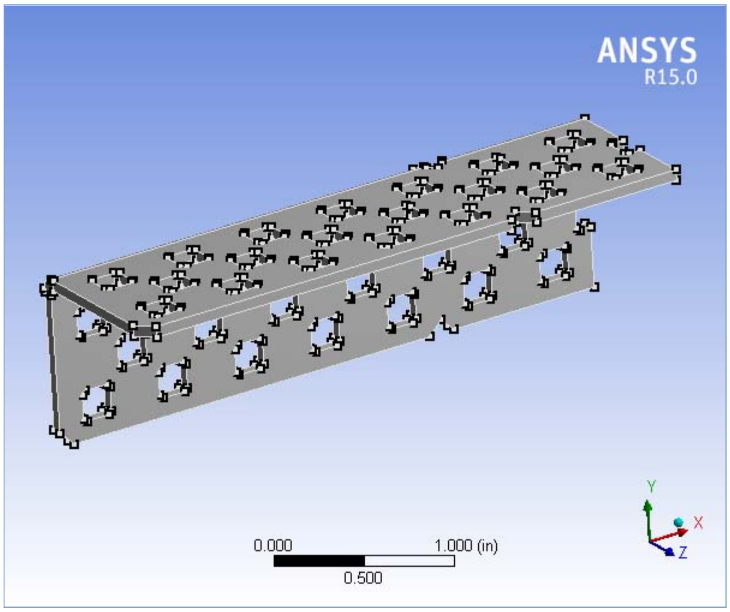
Temperature F	Young's Modulus psi	Poisson's Ratio	Bulk Modulus psi	Shear Modulus psi
	1.0298e+007	0.33	1.0096e+007	3.8713e+006

TABLE 24
Aluminum Alloy > Isotropic Relative Permeability

Relative Permeability
1

Project

First Saved	Monday, January 11, 2016
Last Saved	Monday, January 11, 2016
Product Version	15.0.7 Release
Save Project Before Solution	No
Save Project After Solution	No



Contents

- Units
- Model (B4)
  - Geometry
    - Part 1
  - Coordinate Systems
  - Mesh
  - Static Structural (B5)
    - Analysis Settings
    - Loads
    - Solution (B6)
      - Solution Information
      - Results
      - Stress Tool
        - Safety Factor
- Material Data
  - Aluminum Alloy

Units

TABLE 1

Unit System	U.S. Customary (in, lbm, lbf, s, V, A) Degrees rad/s Fahrenheit
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Fahrenheit

Model (B4)

Geometry

TABLE 2
Model (B4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\Paul Kepinski\Desktop\VEX PARTS\Aluminum Angle 2x2x25 short.igs
Type	Iges
Length Unit	Meters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Length X	3.5 in
Length Y	1.018 in
Length Z	1.018 in
Properties	
Volume	0.34925 in³
Mass	3.4951e-002 lbm
Scale Factor Value	1.
Statistics	
Bodies	1
Active Bodies	1
Nodes	30669
Elements	15392
Mesh Metric	None
Basic Geometry Options	
Solid Bodies	Yes
Surface Bodies	Yes
Line Bodies	No
Parameters	Yes
Parameter Key	DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	No
Compare Parts On Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\Paul Kepinski\AppData\Local\Temp
Analysis Type	3-D
Mixed Import Resolution	None
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (B4) > Geometry > Parts

Object Name	*Part 1*
State	Meshed
Graphics Properties	

Visible	Yes
Transparency	1
Definition	
Suppressed	No
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Material	
Assignment	Aluminum Alloy
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Length X	3.5 in
Length Y	1.018 in
Length Z	1.018 in
Properties	
Volume	0.34925 in³
Mass	3.4951e-002 lbm
Centroid X	-8.5648 in
Centroid Y	-0.21239 in
Centroid Z	-2.5873 in
Moment of Inertia Ip1	7.2145e-003 lbm·in²
Moment of Inertia Ip2	3.762e-002 lbm·in²
Moment of Inertia Ip3	4.1793e-002 lbm·in²
Statistics	
Nodes	30669
Elements	15392
Mesh Metric	None

Coordinate Systems

TABLE 4
Model (B4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Coordinate System ID	0.
Origin	
Origin X	0. in
Origin Y	0. in
Origin Z	0. in
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Mesh

TABLE 5
Model (B4) > Mesh

Object Name	*Mesh*
State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	1.8e-002 in
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Patch Independent Options	
Topology Checking	Yes
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Extra Retries For Assembly	Yes
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Defeaturing	

Pinch Tolerance	Please Define
Generate Pinch on Refresh	No
Automatic Mesh Based Defeaturing	On
Defeaturing Tolerance	Default
Statistics	
Nodes	30669
Elements	15392
Mesh Metric	None

Static Structural (B5)

TABLE 6
Model (B4) > Analysis

Object Name	*Static Structural (B5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	Mechanical APDL
Options	
Environment Temperature	71.6 °F
Generate Input Only	No

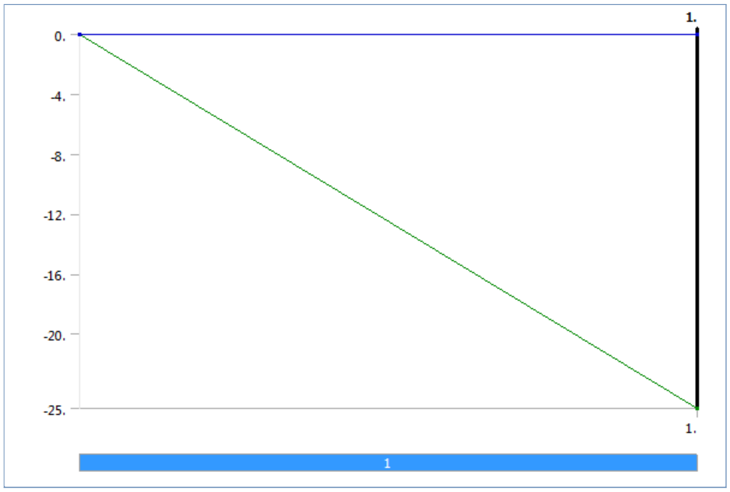
TABLE 7
Model (B4) > Static Structural (B5) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Restart Controls	
Generate Restart Points	Program Controlled
Retain Files After Full Solve	No
Nonlinear Controls	
Newton-Raphson Option	Program Controlled
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Stabilization	Off
Output Controls	
Stress	Yes
Strain	Yes
Nodal Forces	No
Contact Miscellaneous	No
General Miscellaneous	No
Store Results At	All Time Points
Analysis Data Management	
Solver Files Directory	C:\Users\Paul Kepinski\Desktop\VEX PART ANSYS\RONPART_files\dp0\SYS-1\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save MAPDL db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	Bin

TABLE 8
Model (B4) > Static Structural (B5) > Loads

Object Name	*Fixed Support*	*Force*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	3 Faces	
Definition		
Type	Fixed Support	Force
Suppressed	No	
Define By		Components
Coordinate System		Global Coordinate System
X Component		0. lbf (ramped)
Y Component		-25. lbf (ramped)
Z Component		0. lbf (ramped)

FIGURE 1
Model (B4) > Static Structural (B5) > Force



Solution (B6)

TABLE 9
Model (B4) > Static Structural (B5) > Solution

Object Name	*Solution (B6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.
Information	
Status	Done

TABLE 10
Model (B4) > Static Structural (B5) > Solution (B6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All
FE Connection Visibility	
Activate Visibility	Yes
Display	All FE Connectors
Draw Connections Attached To	All Nodes
Line Color	Connection Type
Visible on Results	No
Line Thickness	Single
Display Type	Lines

TABLE 11
Model (B4) > Static Structural (B5) > Solution (B6) > Results

Object Name	*Total Deformation*	*Equivalent Elastic Strain*	*Equivalent Stress*
State	Solved		
Scope			
Scoping Method	Geometry Selection		
Geometry	All Bodies		
Definition			
Type	Total Deformation	Equivalent Elastic Strain	Equivalent (von-Mises) Stress
By	Time		
Display Time	Last		
Calculate Time History	Yes		
Identifier			
Suppressed	No		
Results			
Minimum	0. in	2.367e-005 in/in	139.35 psi
Maximum	5.3431e-002 in	3.1366e-003 in/in	28712 psi
Minimum Value Over Time			
Minimum	0. in	2.367e-005 in/in	139.35 psi
Maximum	0. in	2.367e-005 in/in	139.35 psi
Maximum Value Over Time			
Minimum	5.3431e-002 in	3.1366e-003 in/in	28712 psi
Maximum	5.3431e-002 in	3.1366e-003 in/in	28712 psi
Information			
Time	1. s		
Load Step	1		
Substep	1		
Iteration Number	1		
Integration Point Results			
Display Option		Averaged	
Average Across Bodies		No	

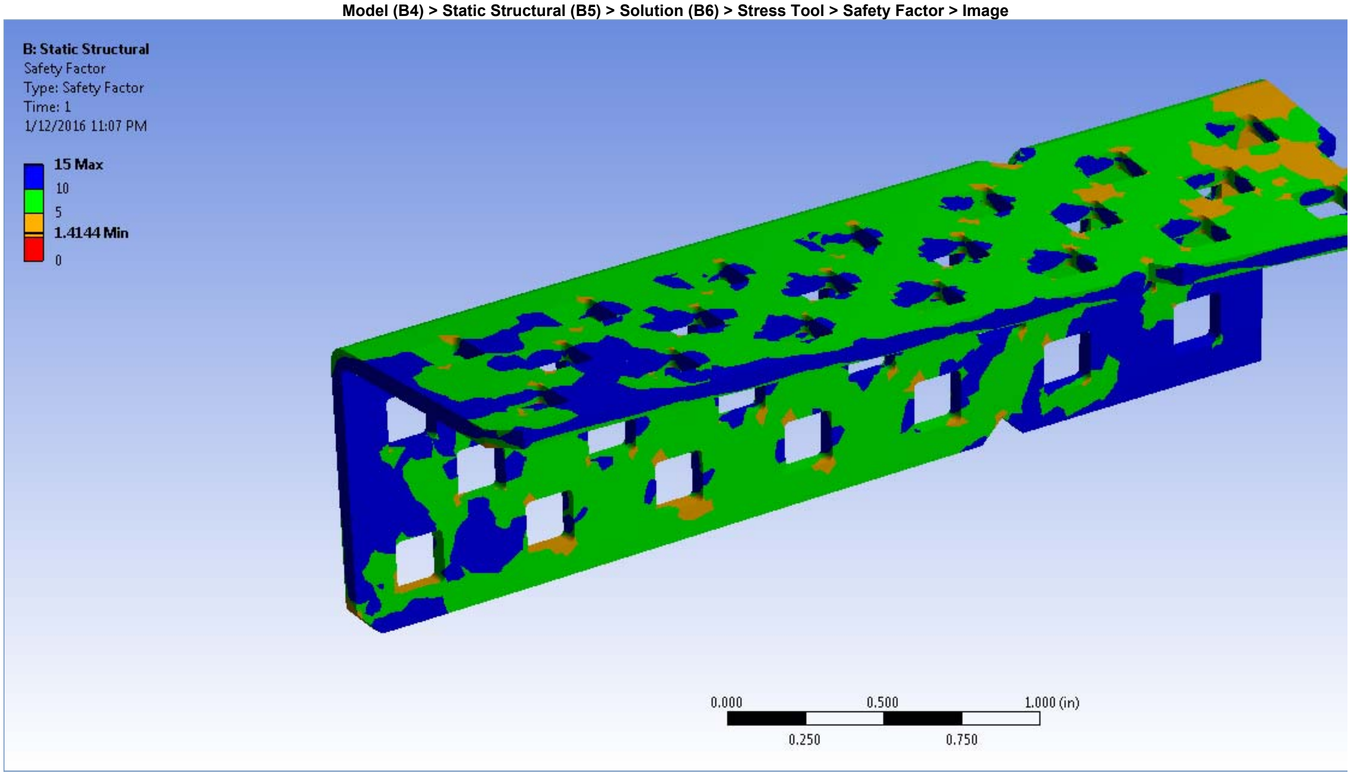
TABLE 12
Model (B4) > Static Structural (B5) > Solution (B6) > Stress Safety Tools

Object Name	*Stress Tool*
State	Solved
Definition	
Theory	Max Equivalent Stress
Stress Limit Type	Tensile Yield Per Material

TABLE 13
Model (B4) > Static Structural (B5) > Solution (B6) > Stress Tool > Results

Object Name	*Safety Factor*
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Safety Factor
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Suppressed	No
Integration Point Results	
Display Option	Averaged
Average Across Bodies	No
Results	
Minimum	1.4144
Minimum Value Over Time	
Minimum	1.4144
Maximum	1.4144
Maximum Value Over Time	
Minimum	15.
Maximum	15.
Information	
Time	1. s
Load Step	1
Substep	1
Iteration Number	1

FIGURE 2
Model (B4) > Static Structural (B5) > Solution (B6) > Stress Tool > Safety Factor > Image



Material Data

Aluminum Alloy

TABLE 14
Aluminum Alloy > Constants

Density	0.10007 lbm in^-3
Coefficient of Thermal Expansion	1.2778e-005 F^-1
Specific Heat	0.20899 BTU lbm^-1 F^-1

TABLE 15

Aluminum Alloy > Compressive Ultimate Strength

Compressive Ultimate Strength psi
0

TABLE 16
Aluminum Alloy > Compressive Yield Strength

Compressive Yield Strength psi
40611

TABLE 17
Aluminum Alloy > Tensile Yield Strength

Tensile Yield Strength psi
40611

TABLE 18
Aluminum Alloy > Tensile Ultimate Strength

Tensile Ultimate Strength psi
44962

TABLE 19
Aluminum Alloy > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature F
71.6

TABLE 20
Aluminum Alloy > Isotropic Thermal Conductivity

Thermal Conductivity BTU s^-1 in^-1 F^-1	Temperature F
1.5247e-003	-148
1.926e-003	32
2.2068e-003	212
2.3406e-003	392

TABLE 21
Aluminum Alloy > Alternating Stress R-Ratio

Alternating Stress psi	Cycles	R-Ratio
40001	1700	-1
34998	5000	-1
29994	34000	-1
25004	1.4e+005	-1
20001	8.e+005	-1
16998	2.4e+006	-1
13000	5.5e+007	-1
12000	1.e+008	-1
24743	50000	-0.5
20247	3.5e+005	-0.5
15751	3.7e+006	-0.5
12750	1.4e+007	-0.5
11251	5.e+007	-0.5
10499	1.e+008	-0.5
21001	50000	0
17506	1.9e+005	0
14997	1.3e+006	0
13500	4.4e+006	0
12499	1.2e+007	0
10499	1.e+008	0
10750	3.e+005	0.5
10250	1.5e+006	0.5
9624.7	1.2e+007	0.5
8999.6	1.e+008	0.5

TABLE 22
Aluminum Alloy > Isotropic Resistivity

Resistivity ohm cmil in^-1	Temperature F
1.2184	32
1.3387	68
1.82	212

TABLE 23
Aluminum Alloy > Isotropic Elasticity

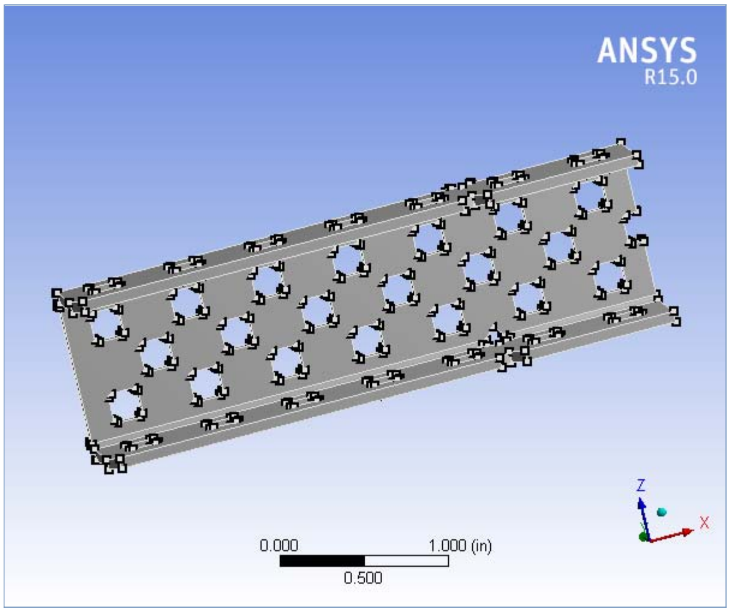
Temperature F	Young's Modulus psi	Poisson's Ratio	Bulk Modulus psi	Shear Modulus psi
	1.0298e+007	0.33	1.0096e+007	3.8713e+006

TABLE 24
Aluminum Alloy > Isotropic Relative Permeability

Relative Permeability
1

Project

First Saved	Monday, January 11, 2016
Last Saved	Monday, January 11, 2016
Product Version	15.0.7 Release
Save Project Before Solution	No
Save Project After Solution	No



Contents

- Units
- Model (C4)
  - Geometry
    - Part 1
  - Coordinate Systems
  - Mesh
  - Static Structural (C5)
    - Analysis Settings
    - Loads
    - Solution (C6)
      - Solution Information
      - Results
      - Stress Tool
        - Safety Factor
- Material Data
  - Aluminum Alloy

Units

TABLE 1

Unit System	U.S. Customary (in, lbm, lbf, s, V, A) Degrees rad/s Fahrenheit
Angle	Degrees
Rotational Velocity	rad/s
Temperature	Fahrenheit

Model (C4)

Geometry

TABLE 2
Model (C4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	C:\Users\Paul Kepinski\Desktop\VEX PARTS\Aluminum C-Channel 1x2x1x25 short.igs
Type	Iges
Length Unit	Meters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Length X	3.5 in
Length Y	0.564 in
Length Z	1.036 in
Properties	
Volume	0.37201 in³
Mass	3.7228e-002 lbm
Scale Factor Value	1.
Statistics	
Bodies	1
Active Bodies	1
Nodes	32232
Elements	16594
Mesh Metric	None
Basic Geometry Options	
Solid Bodies	Yes
Surface Bodies	Yes
Line Bodies	No
Parameters	Yes
Parameter Key	DS
Attributes	No
Named Selections	No
Material Properties	No
Advanced Geometry Options	
Use Associativity	Yes
Coordinate Systems	No
Reader Mode Saves Updated File	No
Use Instances	Yes
Smart CAD Update	No
Compare Parts On Update	No
Attach File Via Temp File	Yes
Temporary Directory	C:\Users\Paul Kepinski\AppData\Local\Temp
Analysis Type	3-D
Mixed Import Resolution	None
Decompose Disjoint Geometry	Yes
Enclosure and Symmetry Processing	Yes

TABLE 3
Model (C4) > Geometry > Parts

Object Name	*Part 1*
State	Meshed
Graphics Properties	

Visible	Yes
Transparency	1
Definition	
Suppressed	No
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Material	
Assignment	Aluminum Alloy
Nonlinear Effects	Yes
Thermal Strain Effects	Yes
Bounding Box	
Length X	3.5 in
Length Y	0.564 in
Length Z	1.036 in
Properties	
Volume	0.37201 in³
Mass	3.7228e-002 lbm
Centroid X	0.69678 in
Centroid Y	-0.1145 in
Centroid Z	-0.11419 in
Moment of Inertia Ip1	7.3818e-003 lbm·in²
Moment of Inertia Ip2	4.4563e-002 lbm·in²
Moment of Inertia Ip3	3.9557e-002 lbm·in²
Statistics	
Nodes	32232
Elements	16594
Mesh Metric	None

Coordinate Systems

TABLE 4
Model (C4) > Coordinate Systems > Coordinate System

Object Name	*Global Coordinate System*
State	Fully Defined
Definition	
Type	Cartesian
Coordinate System ID	0.
Origin	
Origin X	0. in
Origin Y	0. in
Origin Z	0. in
Directional Vectors	
X Axis Data	[1. 0. 0.]
Y Axis Data	[0. 1. 0.]
Z Axis Data	[0. 0. 1.]

Mesh

TABLE 5
Model (C4) > Mesh

Object Name	*Mesh*
State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	6.1968e-003 in
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Patch Independent Options	
Topology Checking	Yes
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Extra Retries For Assembly	Yes
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Defeaturing	

Pinch Tolerance	Please Define
Generate Pinch on Refresh	No
Automatic Mesh Based Defeaturing	On
Defeaturing Tolerance	Default
Statistics	
Nodes	32232
Elements	16594
Mesh Metric	None

Static Structural (C5)

TABLE 6
Model (C4) > Analysis

Object Name	*Static Structural (C5)*
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	Mechanical APDL
Options	
Environment Temperature	71.6 °F
Generate Input Only	No

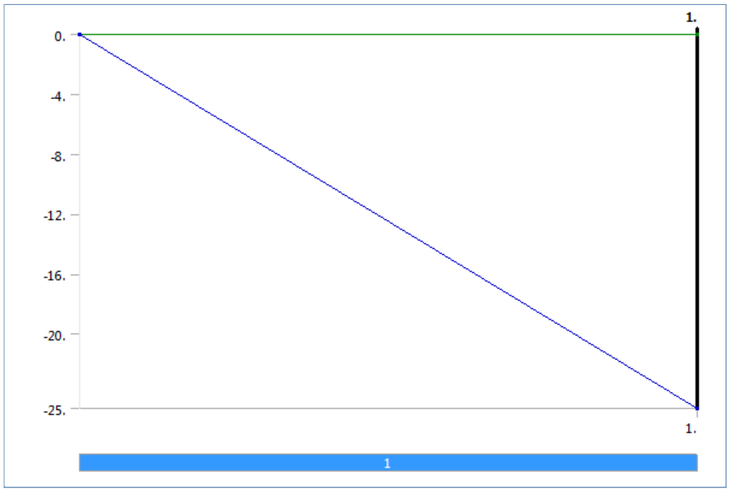
TABLE 7
Model (C4) > Static Structural (C5) > Analysis Settings

Object Name	*Analysis Settings*
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Restart Controls	
Generate Restart Points	Program Controlled
Retain Files After Full Solve	No
Nonlinear Controls	
Newton-Raphson Option	Program Controlled
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Stabilization	Off
Output Controls	
Stress	Yes
Strain	Yes
Nodal Forces	No
Contact Miscellaneous	No
General Miscellaneous	No
Store Results At	All Time Points
Analysis Data Management	
Solver Files Directory	C:\Users\Paul Kepinski\Desktop\VEX PART ANSYS\RONPART_files\dp0\SYS-2\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save MAPDL db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	Bin

TABLE 8
Model (C4) > Static Structural (C5) > Loads

Object Name	*Fixed Support*	*Force*
State	Fully Defined	
Scope		
Scoping Method	Geometry Selection	
Geometry	5 Faces	2 Faces
Definition		
Type	Fixed Support	Force
Suppressed	No	
Define By		Components
Coordinate System		Global Coordinate System
X Component		0. lbf (ramped)
Y Component		0. lbf (ramped)
Z Component		-25. lbf (ramped)

FIGURE 1
Model (C4) > Static Structural (C5) > Force



Solution (C6)

TABLE 9
Model (C4) > Static Structural (C5) > Solution

Object Name	*Solution (C6)*
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.
Information	
Status	Done

TABLE 10
Model (C4) > Static Structural (C5) > Solution (C6) > Solution Information

Object Name	*Solution Information*
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All
FE Connection Visibility	
Activate Visibility	Yes
Display	All FE Connectors
Draw Connections Attached To	All Nodes
Line Color	Connection Type
Visible on Results	No
Line Thickness	Single
Display Type	Lines

TABLE 11
Model (C4) > Static Structural (C5) > Solution (C6) > Results

Object Name	*Total Deformation*	*Equivalent Elastic Strain*	*Equivalent Stress*
State	Solved		
Scope			
Scoping Method	Geometry Selection		
Geometry	All Bodies		
Definition			
Type	Total Deformation	Equivalent Elastic Strain	Equivalent (von-Mises) Stress
By	Time		
Display Time	Last		
Calculate Time History	Yes		
Identifier			
Suppressed	No		
Results			
Minimum	0. in	8.5116e-006 in/in	29.302 psi
Maximum	1.8289e-002 in	1.2008e-003 in/in	12299 psi
Minimum Value Over Time			
Minimum	0. in	8.5116e-006 in/in	29.302 psi
Maximum	0. in	8.5116e-006 in/in	29.302 psi
Maximum Value Over Time			
Minimum	1.8289e-002 in	1.2008e-003 in/in	12299 psi
Maximum	1.8289e-002 in	1.2008e-003 in/in	12299 psi
Information			
Time	1. s		
Load Step	1		
Substep	1		
Iteration Number	1		
Integration Point Results			
Display Option		Averaged	
Average Across Bodies		No	

TABLE 12
Model (C4) > Static Structural (C5) > Solution (C6) > Stress Safety Tools

Object Name	*Stress Tool*
State	Solved
Definition	
Theory	Max Equivalent Stress
Stress Limit Type	Tensile Yield Per Material

TABLE 13
Model (C4) > Static Structural (C5) > Solution (C6) > Stress Tool > Results

Object Name	*Safety Factor*
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Safety Factor
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Suppressed	No
Integration Point Results	
Display Option	Averaged
Average Across Bodies	No
Results	
Minimum	3.302
Minimum Value Over Time	
Minimum	3.302
Maximum	3.302
Maximum Value Over Time	
Minimum	15.
Maximum	15.
Information	
Time	1. s
Load Step	1
Substep	1
Iteration Number	1

FIGURE 2
Model (C4) > Static Structural (C5) > Solution (C6) > Stress Tool > Safety Factor > Figure

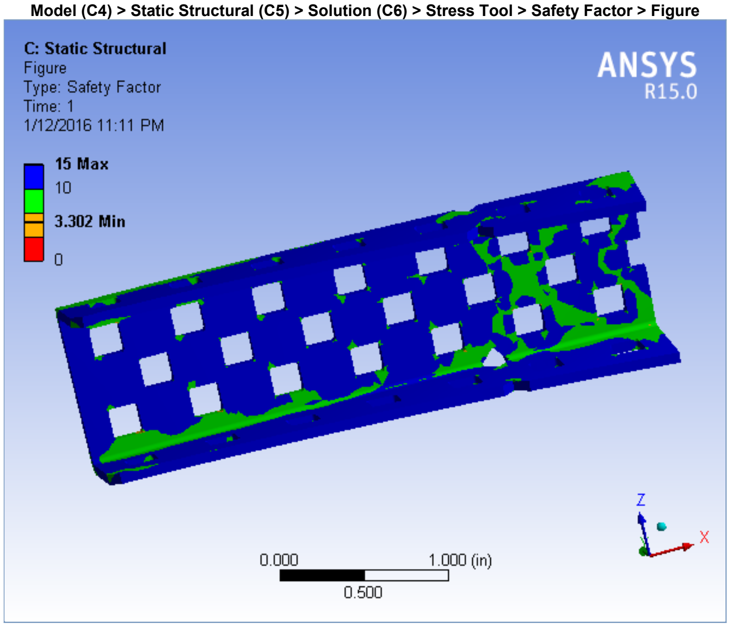
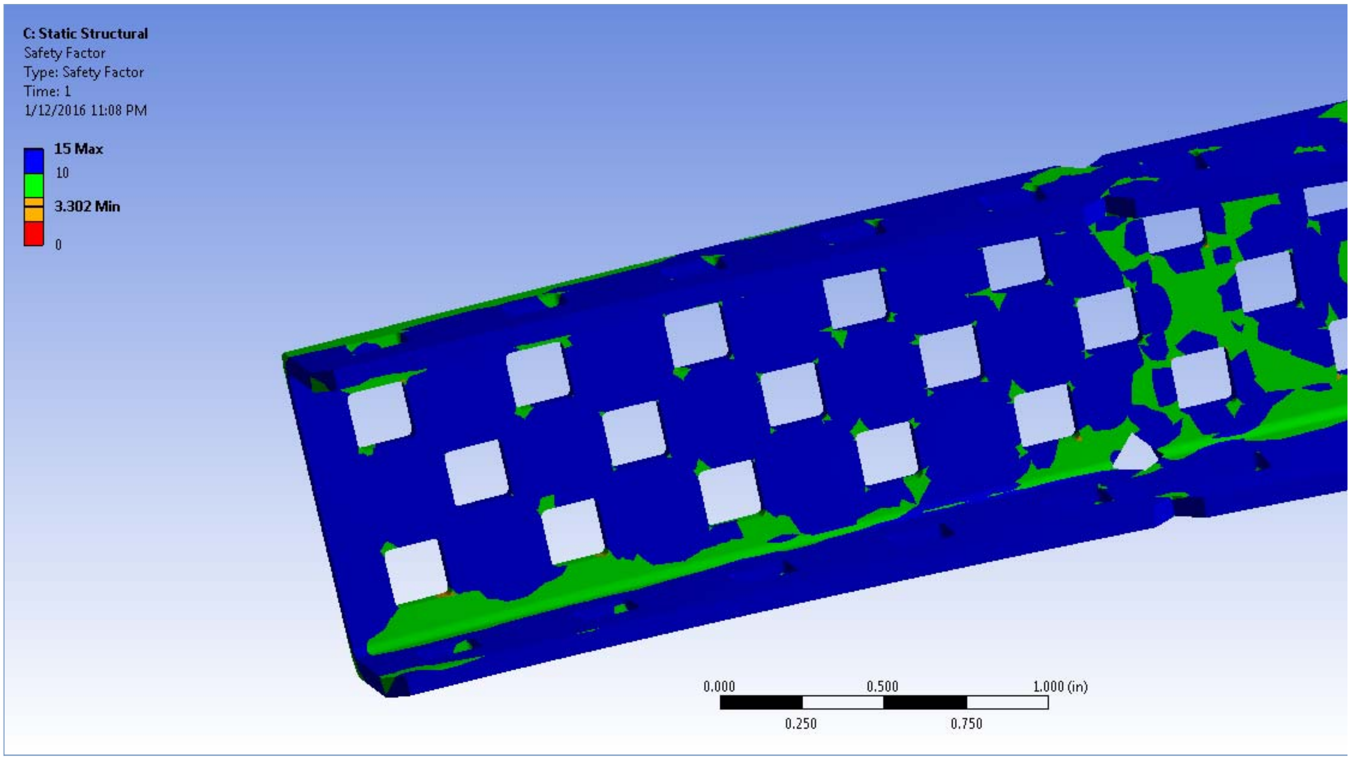


FIGURE 3
Model (C4) > Static Structural (C5) > Solution (C6) > Stress Tool > Safety Factor > Image



Material Data

Aluminum Alloy

TABLE 14
Aluminum Alloy > Constants

Density	0.10007 lbm in^-3
Coefficient of Thermal Expansion	1.2778e-005 F^-1
Specific Heat	0.20899 BTU lbm^-1 F^-1

TABLE 15
Aluminum Alloy > Compressive Ultimate Strength

Compressive Ultimate Strength psi
0

TABLE 16
Aluminum Alloy > Compressive Yield Strength

Compressive Yield Strength psi
40611

TABLE 17
Aluminum Alloy > Tensile Yield Strength

Tensile Yield Strength psi
40611

TABLE 18
Aluminum Alloy > Tensile Ultimate Strength

Tensile Ultimate Strength psi
44962

TABLE 19
Aluminum Alloy > Isotropic Secant Coefficient of Thermal Expansion

Reference Temperature F
71.6

TABLE 20
Aluminum Alloy > Isotropic Thermal Conductivity

Thermal Conductivity BTU s^-1 in^-1 F^-1	Temperature F
1.5247e-003	-148
1.926e-003	32
2.2068e-003	212
2.3406e-003	392

TABLE 21
Aluminum Alloy > Alternating Stress R-Ratio

Alternating Stress psi	Cycles	R-Ratio
40001	1700	-1
34998	5000	-1
29994	34000	-1
25004	1.4e+005	-1

20001	8.e+005	-1
16998	2.4e+006	-1
13000	5.5e+007	-1
12000	1.e+008	-1
24743	50000	-0.5
20247	3.5e+005	-0.5
15751	3.7e+006	-0.5
12750	1.4e+007	-0.5
11251	5.e+007	-0.5
10499	1.e+008	-0.5
21001	50000	0
17506	1.9e+005	0
14997	1.3e+006	0
13500	4.4e+006	0
12499	1.2e+007	0
10499	1.e+008	0
10750	3.e+005	0.5
10250	1.5e+006	0.5
9624.7	1.2e+007	0.5
8999.6	1.e+008	0.5

TABLE 22
Aluminum Alloy > Isotropic Resistivity

Resistivity ohm cmil in^-1	Temperature F
1.2184	32
1.3387	68
1.82	212

TABLE 23
Aluminum Alloy > Isotropic Elasticity

Temperature F	Young's Modulus psi	Poisson's Ratio	Bulk Modulus psi	Shear Modulus psi
	1.0298e+007	0.33	1.0096e+007	3.8713e+006

TABLE 24
Aluminum Alloy > Isotropic Relative Permeability

Relative Permeability
1