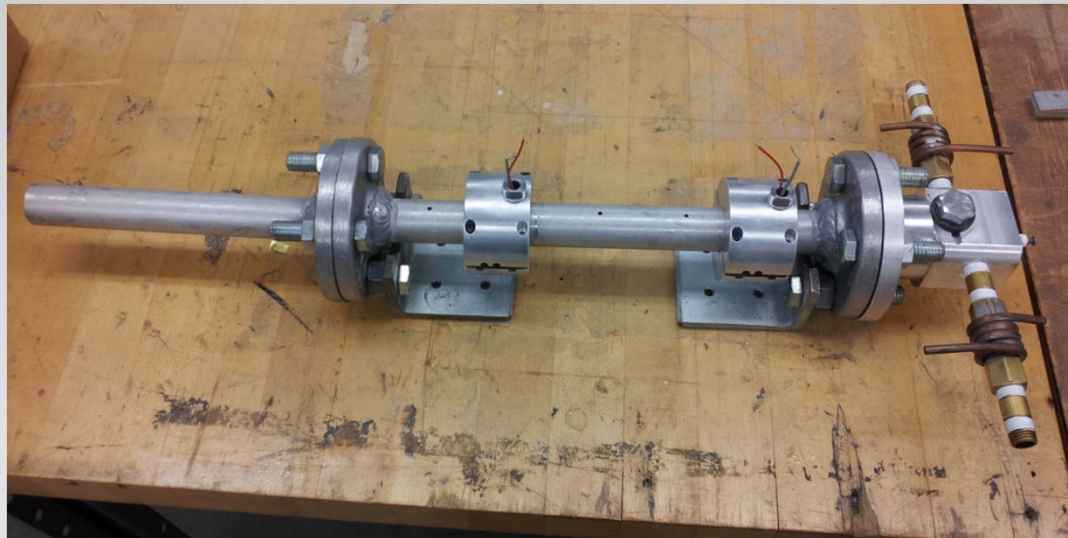


MAE 656 – Advanced Computer Aided Design

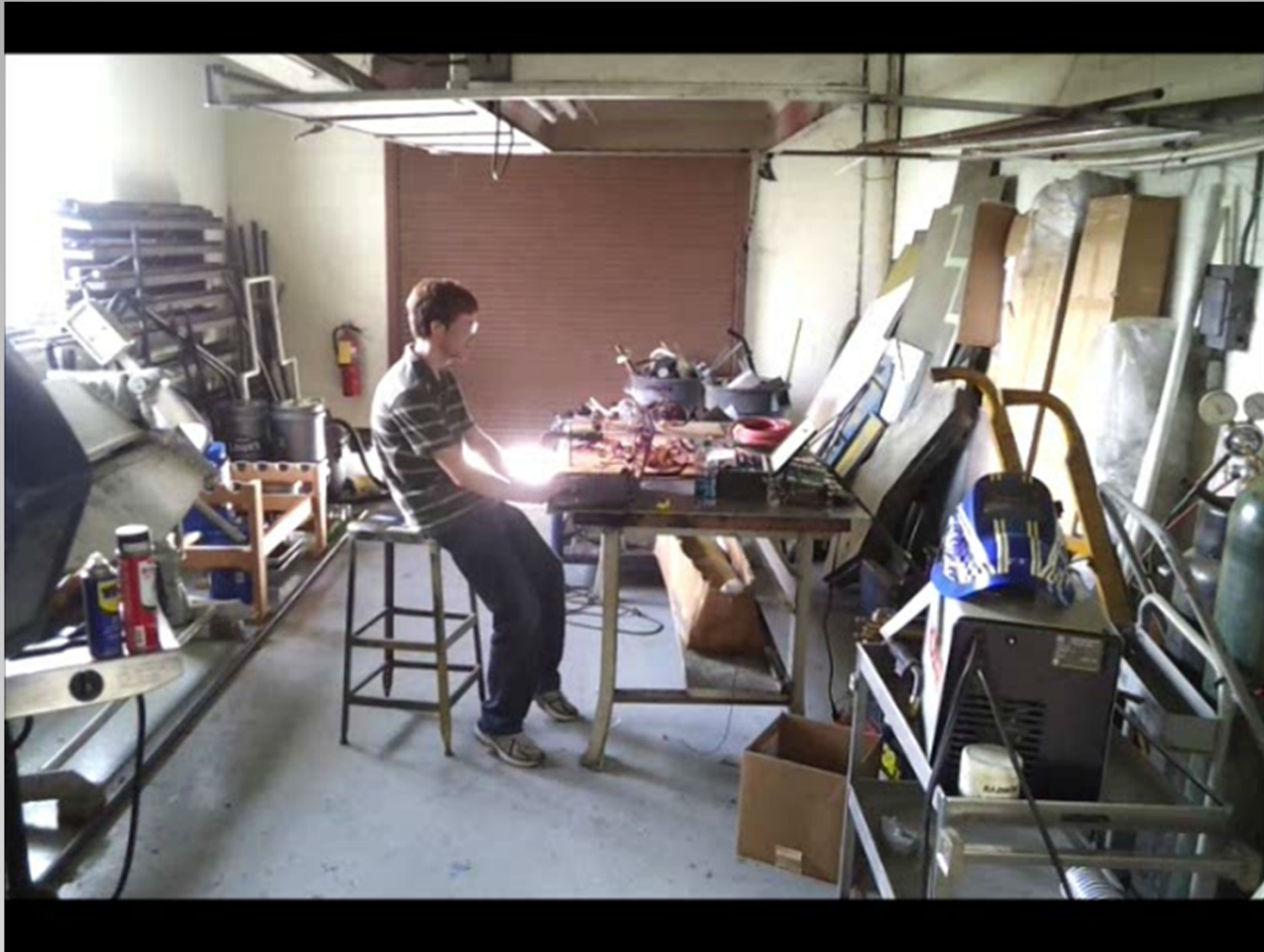
Richard Cain

Load Analysis on Pulse Detonation Engine Mixing
Chamber

- Pulse detonation engines, or PDE's, are a propulsion design theorized over 50 years ago that has become a popular research topic in the last decade due to high thermal efficiency
- The PDE detonates fuel rather than burning it through conventional deflagration. The detonation process involves immense pressures which leads to higher thermal efficiency.
- High pressure and thermal stress lead to a high chance of failure in the PDE components.



Pulse Detonation Engine



Video

- The Mixing Chamber of the PDE is where the fuel (acetylene, ethylene, or hydrogen) is mixed with the oxidizer (air or oxygen) and ignited by the sparkplug
- The mixing chamber is the part with the most complex geometry that is exposed to the combusting gasses and was custom built for the PDE; therefore, it is one of the more interesting and complex parts to examine.



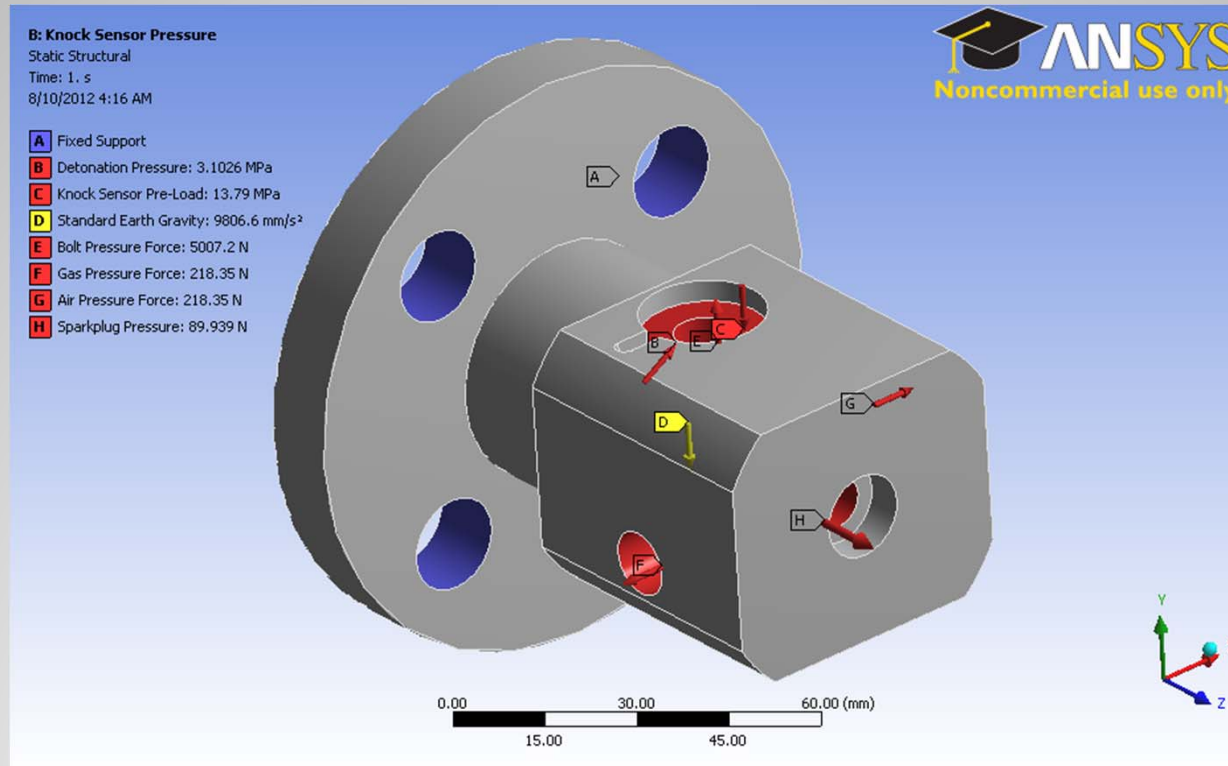
Aluminum 6160		
Material Properties		
Density	2.7	g/cm ³
Young's Modulus	69	GPa
Poisson's Ratio	0.33	
Yield Strength	276	MPa
Melting Temperature	582	°C

Mixing Chamber

- The mixing chamber is put under a considerable amount of stress from both fuel detonation and various component attachments.
- The part was overbuilt for room temperature conditions.
- During operation the engine will heat up and change the yield strength of the Aluminum 6160.
- The problem was broken down into a series of steps to be solved:
 1. Isolate the major forces acting on the Mixing Chamber
 2. Solve for the maximum stress, shear, and deformation that the part is likely to experience
 3. Find the temperature at which the part will begin to deform. This was previously assumed to be the melting point of AL 6160.

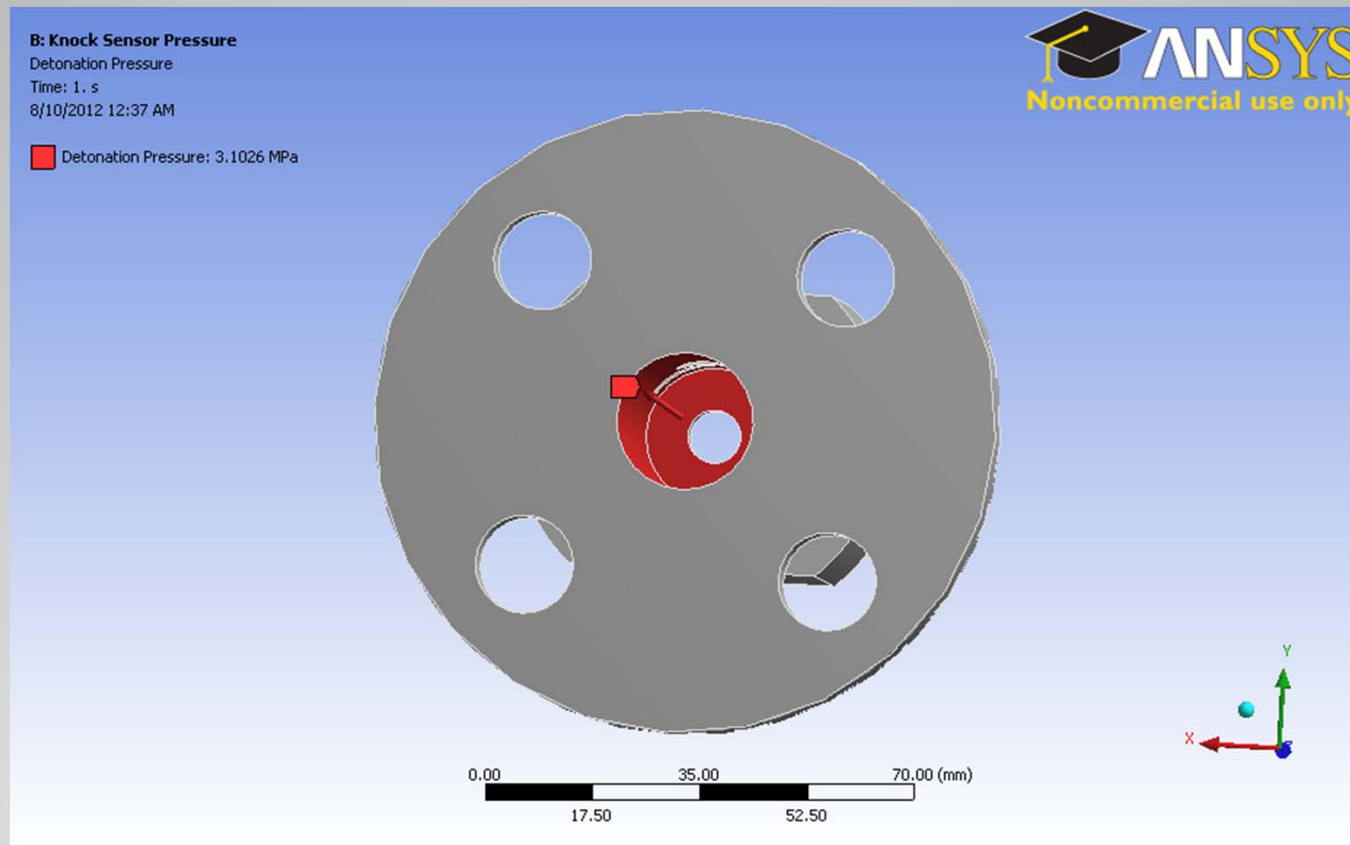
Description of Problem

- The part was generated in Ansys using Workbench's modeling tool
- Attempts were made to import the design from SolidWorks to no avail.
- The Mixing Chamber is fixed by four bolts to the frame of the engine.



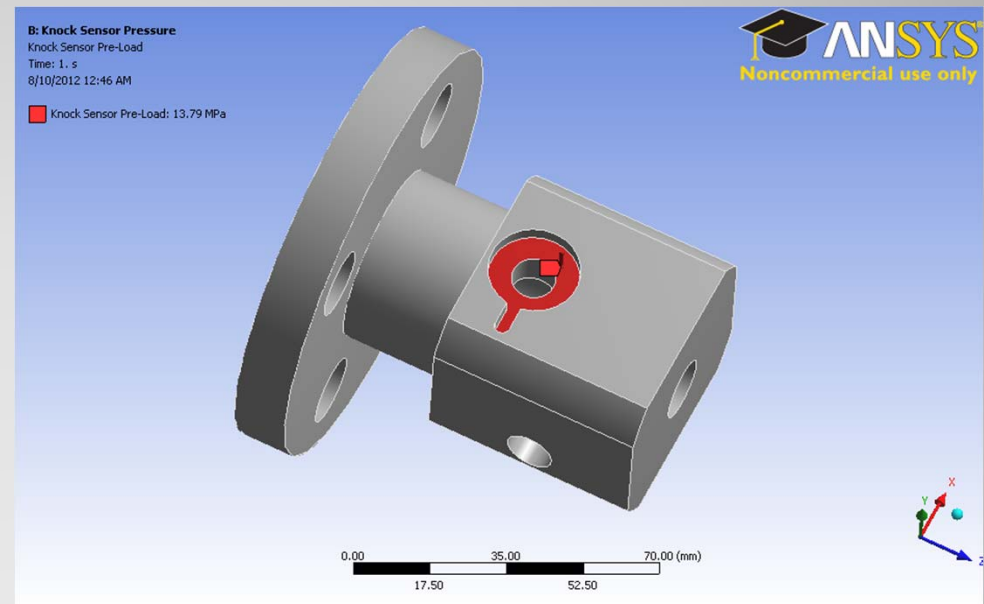
Model

- Pressure loads up to 3.1026 MPa (450psi) are anticipated in the mixing chamber when detonation is initiated.
- In addition, there are a number of external loads including gravity that are acting on the structure.



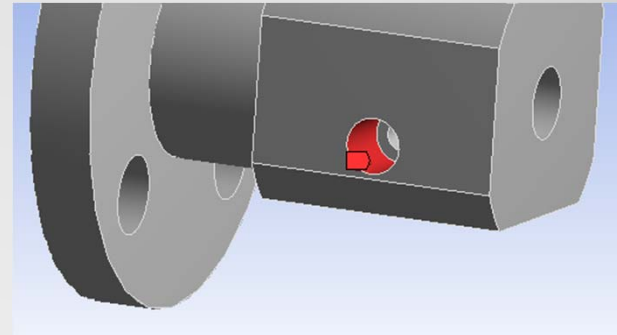
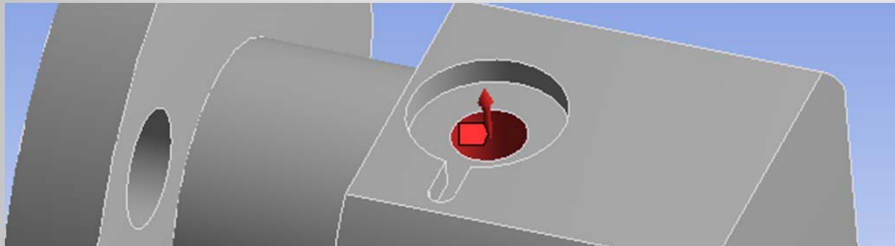
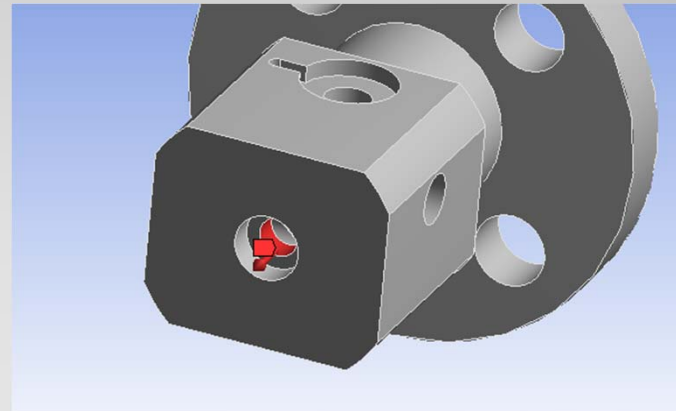
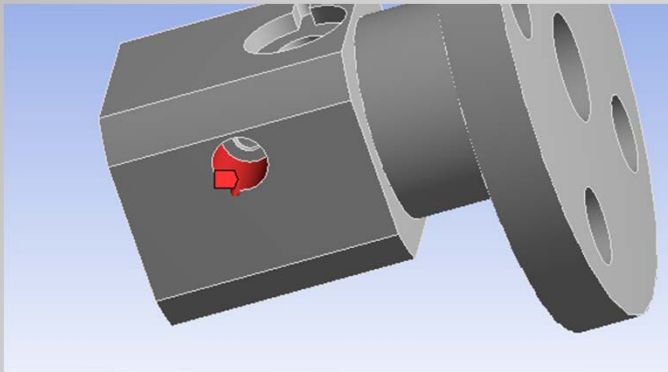
Pressure Load

- A knock sensor is used to identify the moment of detonation. This sensor is pre-torqued by 1000lbf. The torque applies a pressure load on the mixing chamber; however, this load varies due to friction and without experimentation there is no way to accurately correlate torque load to pressure. Instead a back-of-the-envelope equation was used to obtain an estimated pressure of 13.79MPa.



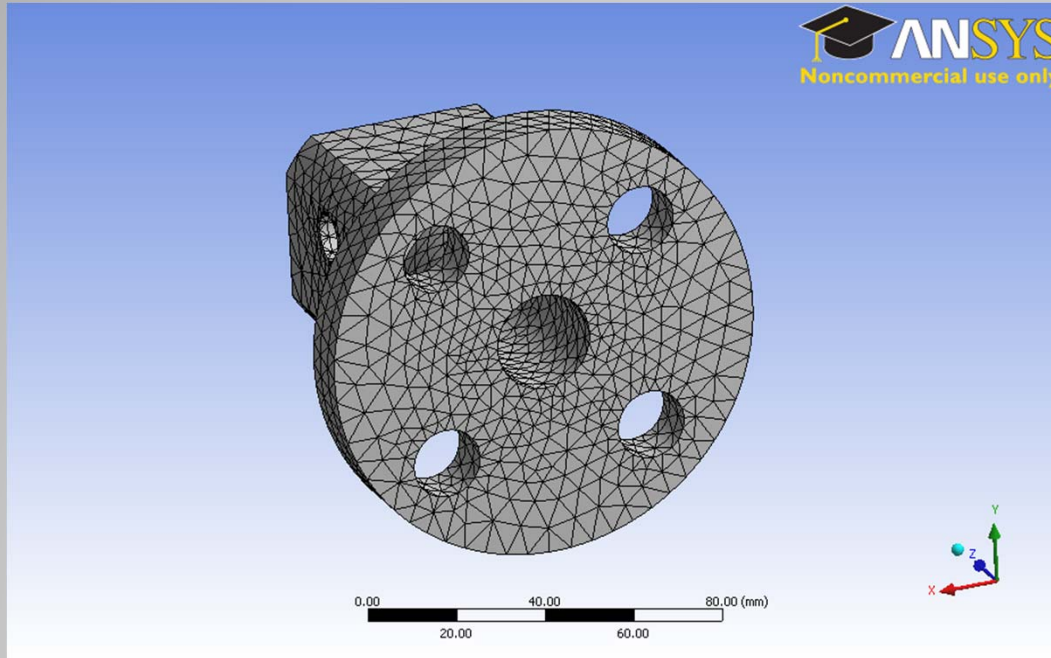
External Loads

- In addition to the internal pressure applied to the inner surface of the mixing chamber, the detonation pressure also acts on the components attached to the part. This is translated as a force to the threading where the various components are attached to.
- The air and gas lines are self supported and the weight of the NK-6 Micro Sparkplug was deemed negligible compared to the other forces.



External Loads

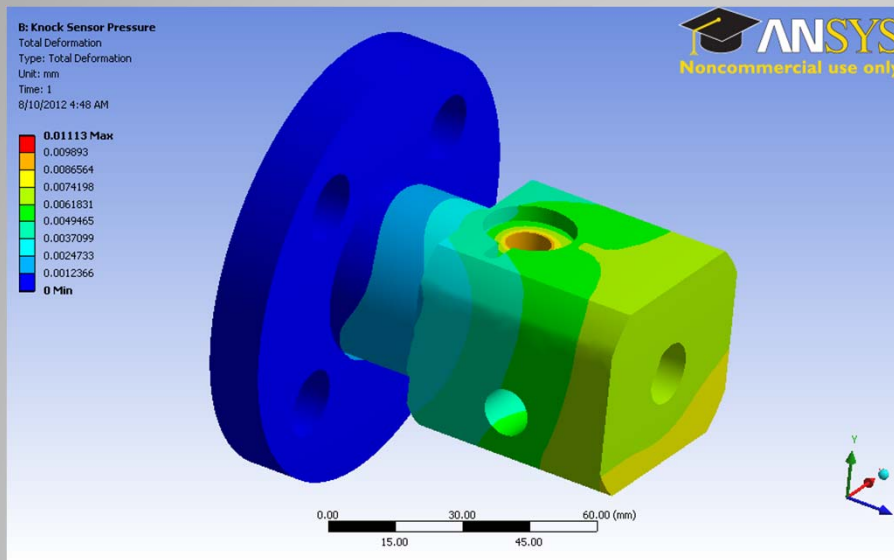
- Due to the blocky geometric features, the part was modeled as a 3D solid.
- This was the most detailed mesh obtained before Ansys began crashing.



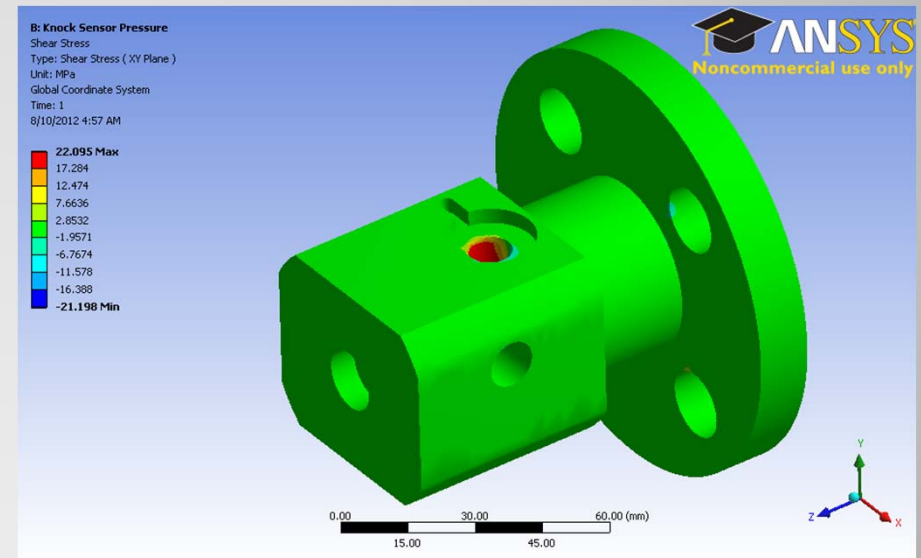
Defaults	
Physics Preference	Mechanical
Relevance	100
Sizing	
Use Advanced Size Function	Off
Relevance Center	Coarse
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Medium
Minimum Edge Length	1.93540 mm
Statistics	
Nodes	28702
Elements	17217
Mesh Metric	None

Mesh

- Neither the shear nor the deformation proved significant to the part; the max shear being half the max stress and the deformation was just over a hundredth of a millimeter. The main concern was the yield stress, especially at higher temperatures.

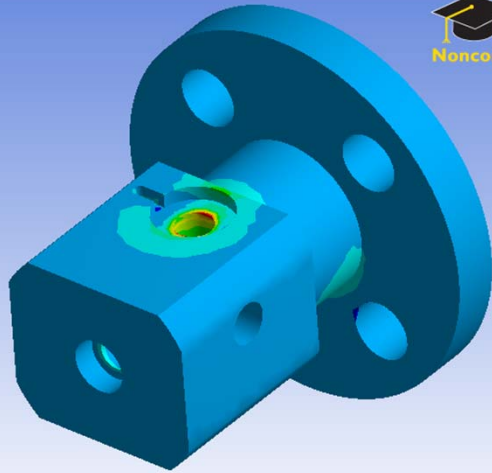


Tabulated Results		
Total Deformation	0.01113	mm
Shear	22.095	MPa
Maximum Principle Stress	43.173	MPa
Normal Stress X-Axis	42.473	MPa
Normal Stress Y-Axis	16.985	MPa
Normal Stress Z-Axis	29.823	MPa



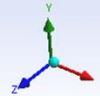
Results

B: Knock Sensor Pressure
Maximum Principal Stress
Type: Maximum Principal Stress
Unit: MPa
Time: 1
8/10/2012 12:13 AM

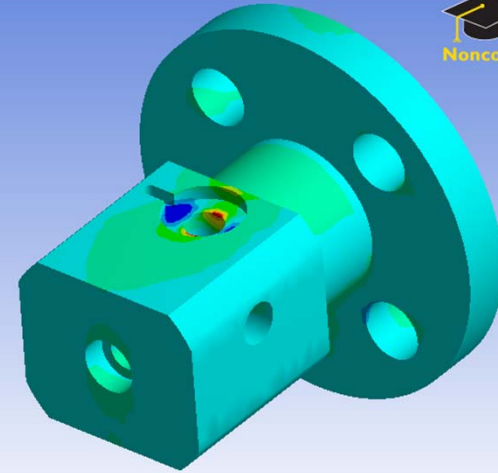


43.173 Max
37.503
31.833
26.162
20.492
14.822
9.1513
3.481
-2.1893
-7.8597 Min

0.00 35.00 70.00 (mm)
17.50 52.50

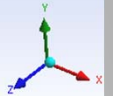


B: Knock Sensor Pressure
Normal Stress X
Type: Normal Stress (X Axis)
Unit: MPa
Global Coordinate System
Time: 1
8/10/2012 12:14 AM

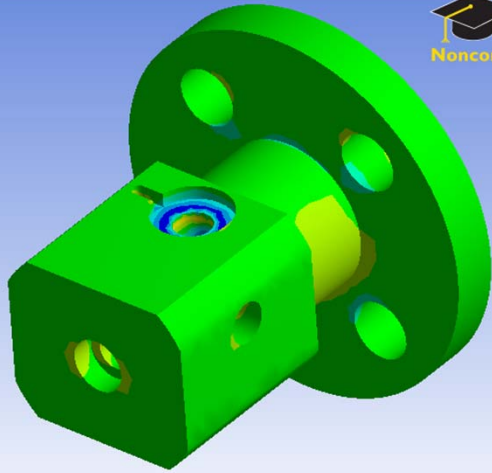


42.473 Max
35.473
28.474
21.475
14.476
7.4763
0.47702
-6.5223
-13.522
-20.521 Min

0.00 35.00 70.00 (mm)
17.50 52.50

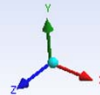


B: Knock Sensor Pressure
Normal Stress Y
Type: Normal Stress (Y Axis)
Unit: MPa
Global Coordinate System
Time: 1
8/10/2012 12:15 AM

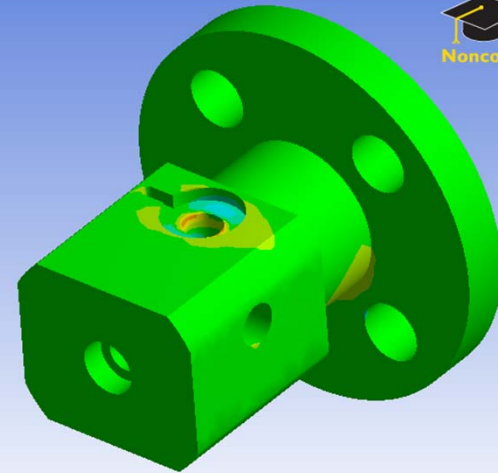


16.985 Max
12.992
8.9997
5.007
1.0143
-2.9784
-6.9711
-10.964
-14.957
-18.949 Min

0.00 35.00 70.00 (mm)
17.50 52.50

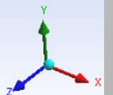


B: Knock Sensor Pressure
Normal Stress Z
Type: Normal Stress (Z Axis)
Unit: MPa
Global Coordinate System
Time: 1
8/10/2012 12:17 AM



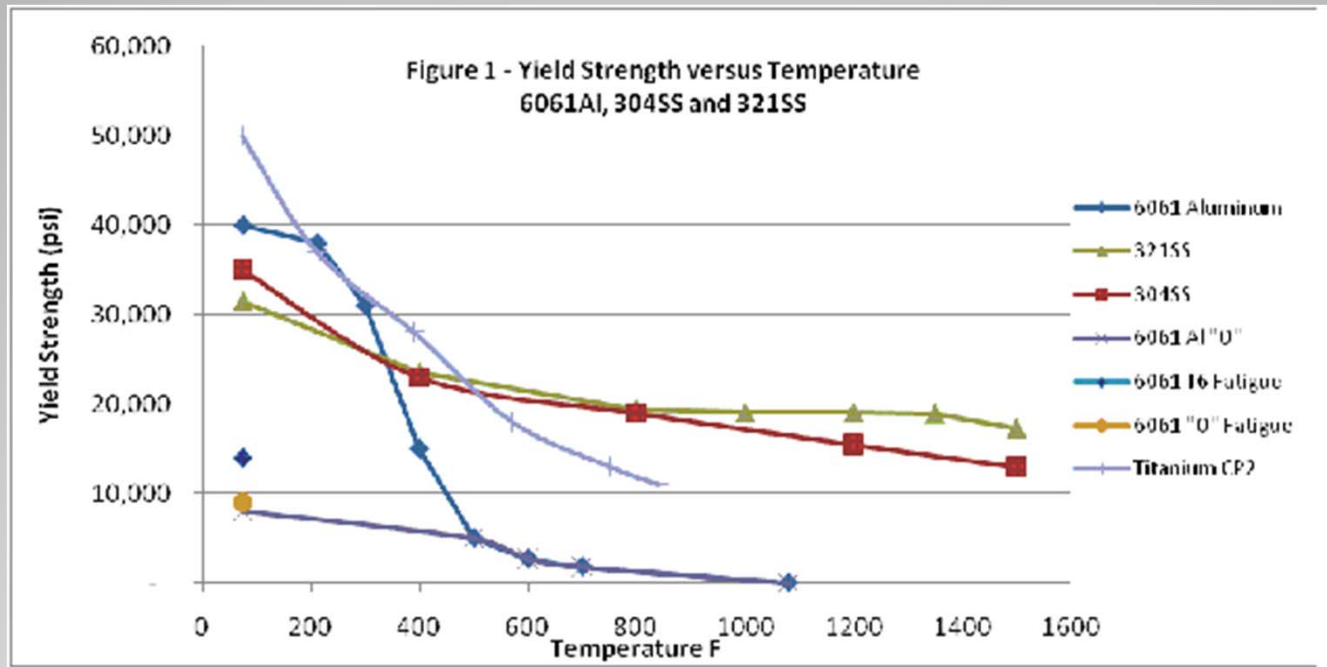
29.823 Max
22.962
16.1
9.239
2.3777
-4.4837
-11.345
-18.206
-25.068
-31.929 Min

0.00 35.00 70.00 (mm)
17.50 52.50



Results

- Running the PDE continuously rapidly increases the engine's temperature. As the temperature increases, the yield strength of the aluminum drops rapidly.



- A maximum principal stress of 43.117 MPa (6253.6 psi) or 53.896 MPa (7817.5 psi) with an 80% yield strength factor of safety.
- Based off the displayed table, the part will begin yielding at around 500°F (260°C).

Temperature

- The Mixing Chamber is more than capable of withstanding the forces applied to it during detonation which is congruent with experimentation.
- However, during extended runs, if the engine temperature climbs above 260°C the mixing chamber will begin to deform near the knock sensor. This is well before the 582°C melting point of aluminum 6160; which had previously been considered the failure point of the engine.
- Design Considerations:
 - The deformation around the knock sensor could lead to leaks or fatigue in the surrounding material and reduce the life of the engine.
 - Without the pre-torque around the knock sensor the mixing chamber would be capable of functioning at much higher temperatures without risk of failure.

Conclusion

- "Yield Strength." *Network Solutions E-Commerce Web Site*. N.p., n.d. Web. 07 Aug. 2012. <<http://www.burnsstainless.com/yieldstrength.aspx>>.
- "6061 (AlMg1SiCu) Aluminum." - *Material Properties Data*. N.p., n.d. Web. 09 Aug. 2012. <<http://www.makeitfrom.com/material-data/?for=6061-AlMg1SiCu-Aluminum>>.

References