Bolted Joint Analysis of a Rocket Engine

ME 274: Advanced Finite Element Method in Engineering
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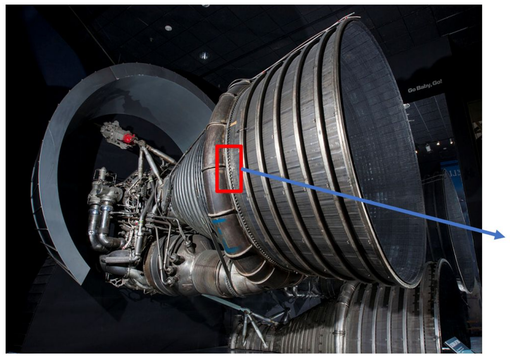
Introduction and Background

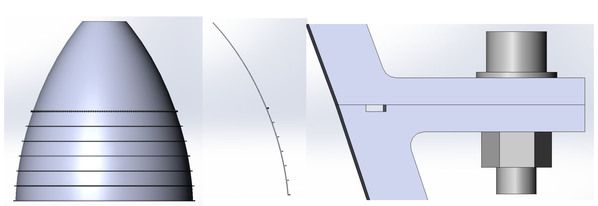
The preloaded bolted joints found in the Rocketdyne F-1 Engine were analyzed. Boundary conditions include thermal strain due to the temperature of the thrust chamber, bolt preload, pressure applied by the gas propellants, and forces induced by the regeneration channels.

The objective is to determine the maximum stresses within the bolted connections made between the top and bottom sections of the engine nozzle and the gap between the bottom and top nozzle at this connection using a simplified model of the engine geometry. Simulations and analyses will be made through the use of ANSYS Workbench.



Geometry and Materials

- Top and bottom sections of nozzle assumed to be bolted together by 200 1⅛” long ⅜”-16 bolts made of A-286 steel, with corresponding nuts and washers
- Nozzle assumed to be made of 300 series stainless steel
- Stiffeners found in lower section of engine modeled with simplified geometry
- 0.9° slice taken of engine geometry, such that half of a bolt is captured
- Corresponding symmetry conditions applied



Pre-Analysis

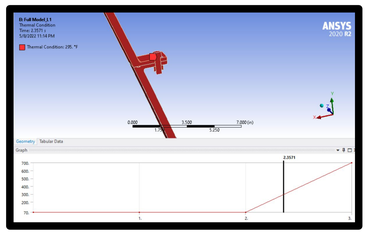
- Thermal strain: temperature of 700°F (cooking temperature of Kerosene)
- Bolt preload: 2320 lbf (50% of ultimate tensile strength)
- Gas pressure: exit pressure of 12.17 psi and entrance pressure of 47.72 psi, based on Mach number

$$\frac{P_t}{P} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{\gamma}{\gamma - 1}}$$

- Force due to regeneration channels: force of 1000 lbf pulling apart connection between upper and lower nozzle assumed

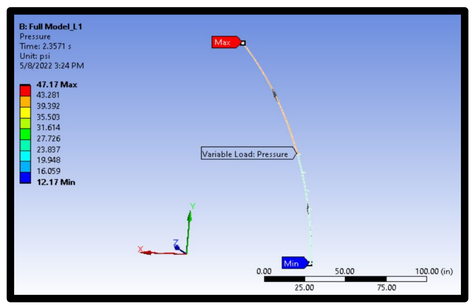
Boundary Conditions

- Thermal Condition

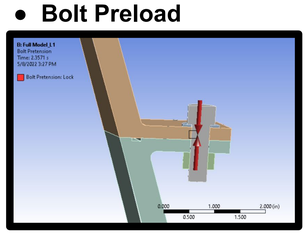


700 °F

- Variable Chamber Pressure

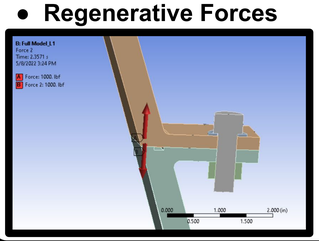


- Bolt Preload



2320 lbf

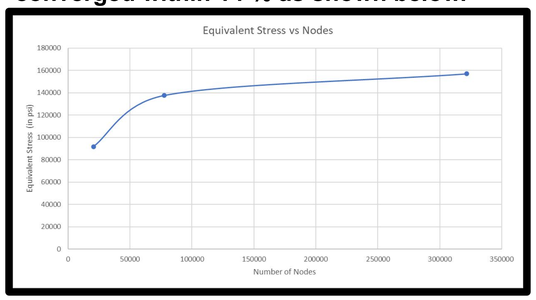
- Regenerative Forces



1000 lbf

Mesh

Tetrahedral and Hexahedral mix mesh was converged within 14 % as shown below.

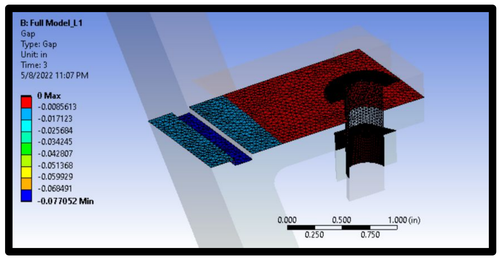


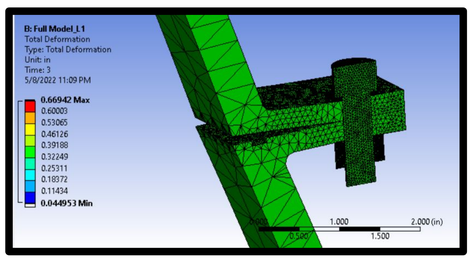
Mesh used refinement near areas of bolt yielding and nozzle gapping.

90% of elements near bolted joint region has skewness close to 0 and aspect ratio close to 1.

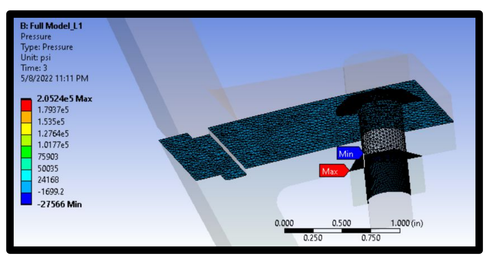
Results - Nozzle Contact

A maximum gaping of .07 in was obtained.



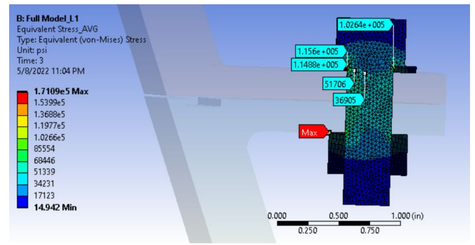


A maximum contact pressure of 205 ksi was obtained.



Results - Bolt Yield Margin

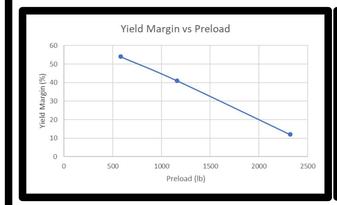
A maximum Von Mises stress of areas most susceptible to yielding is 115 ksi.

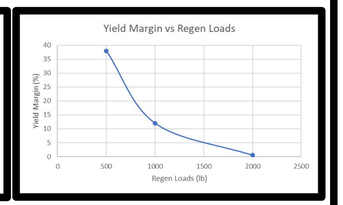


A-286 Bolt has an yield strength of 129 ksi at 700F. This gives an yield margin of 12%

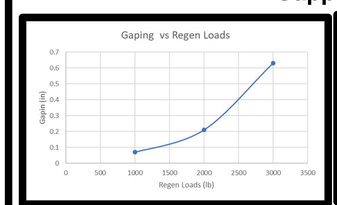
Sensitivity Analysis

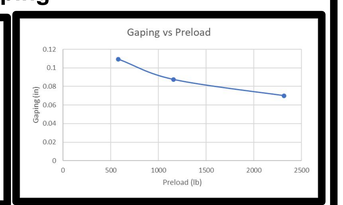
Yield Margins





Gapping





Conclusions

Using ANSYS Static Structural, a Non-Linear analysis of bolted joint of a rocket engine flange was performed. It was concluded that under transient operating conditions, the yield margin of preloaded A-286 bolt is 12% and maximum gaping between flanges is 0.7”. Such low yield margins poses a risk to the A-286 bolts. Sensitivity analysis shows yield margins can be improved with lower preload and lower regen forces.