Nonlinear finite-element model to analyze a bolted assembly

A study on the F1 Engine

Marco Nanni

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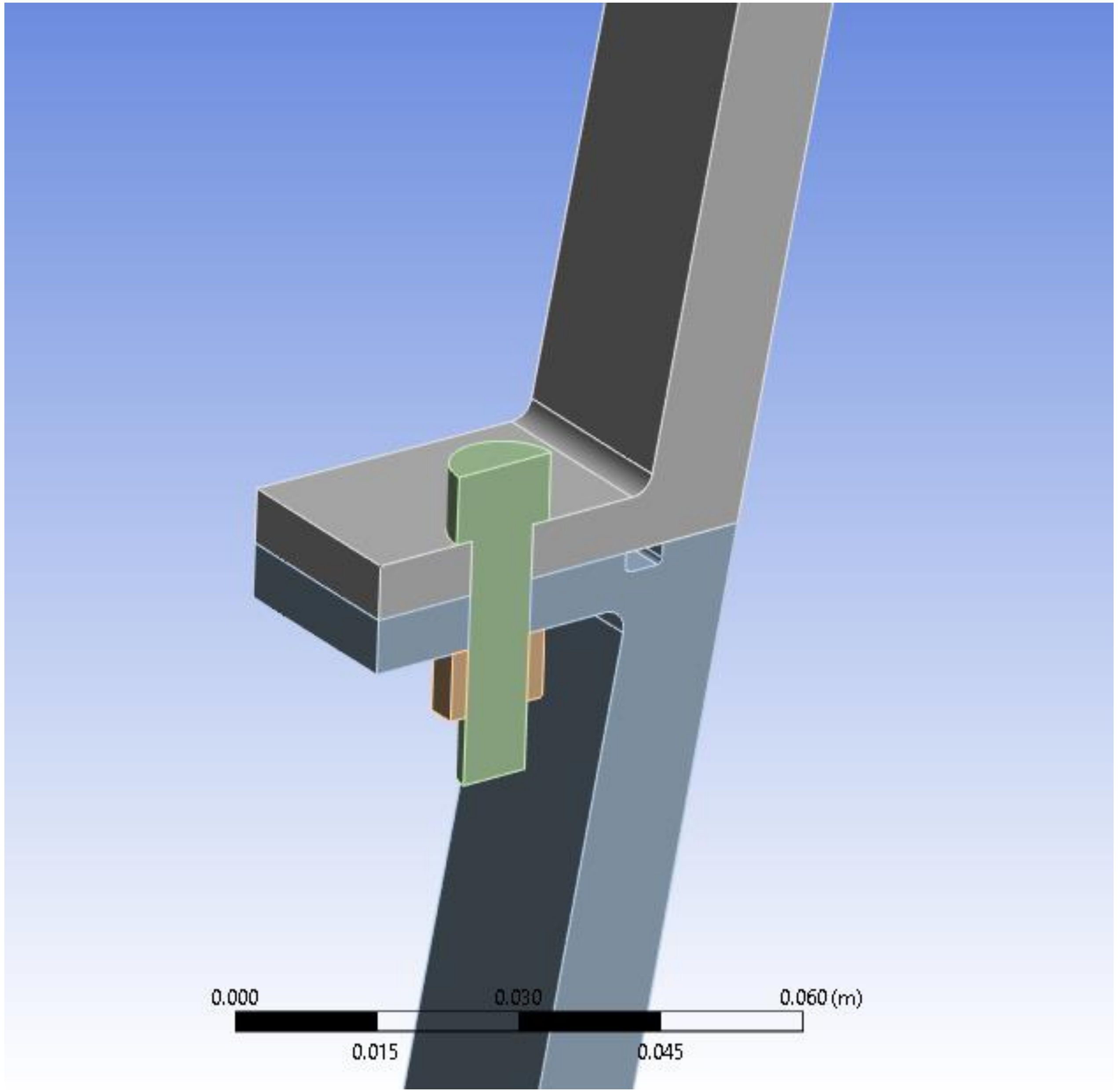
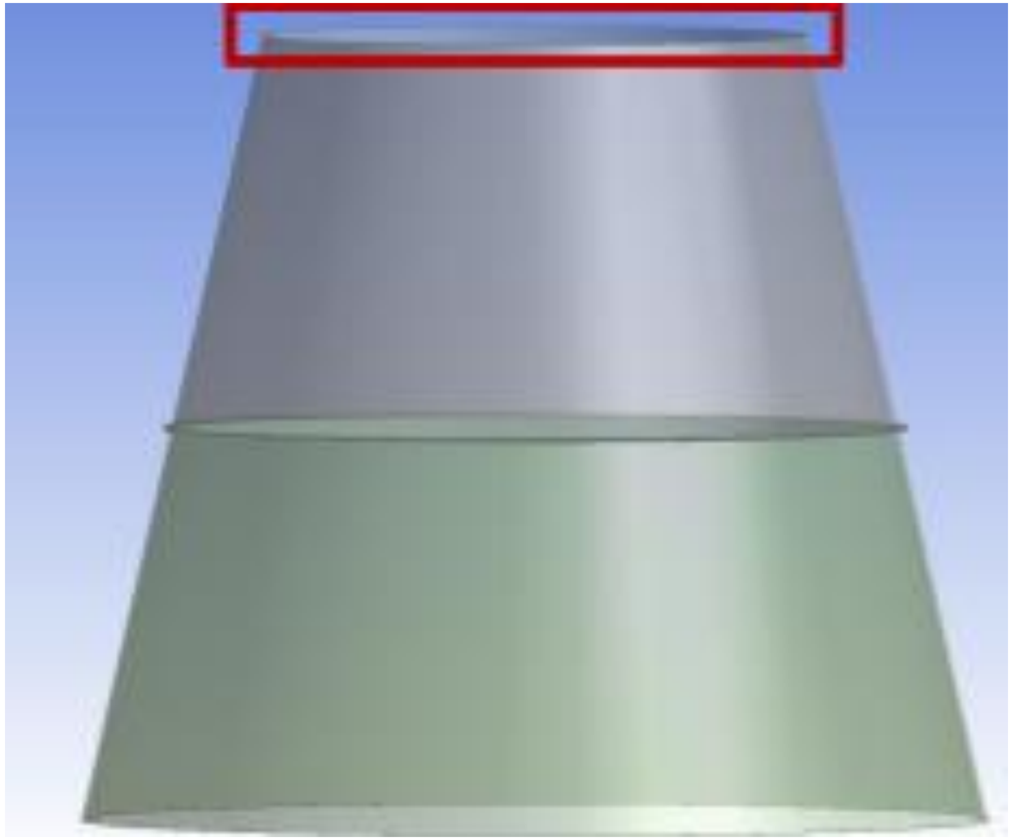
Geometry

- The model considers only half of a bolt and nut.
- Axial symmetry can be used to find the results for the whole domain
  - Assume that all thermal and structural loads, and material properties are axially symmetric
- Parts:
  - Mid Nozzle
  - Lower Nozzle
  - Bolt
  - Nut



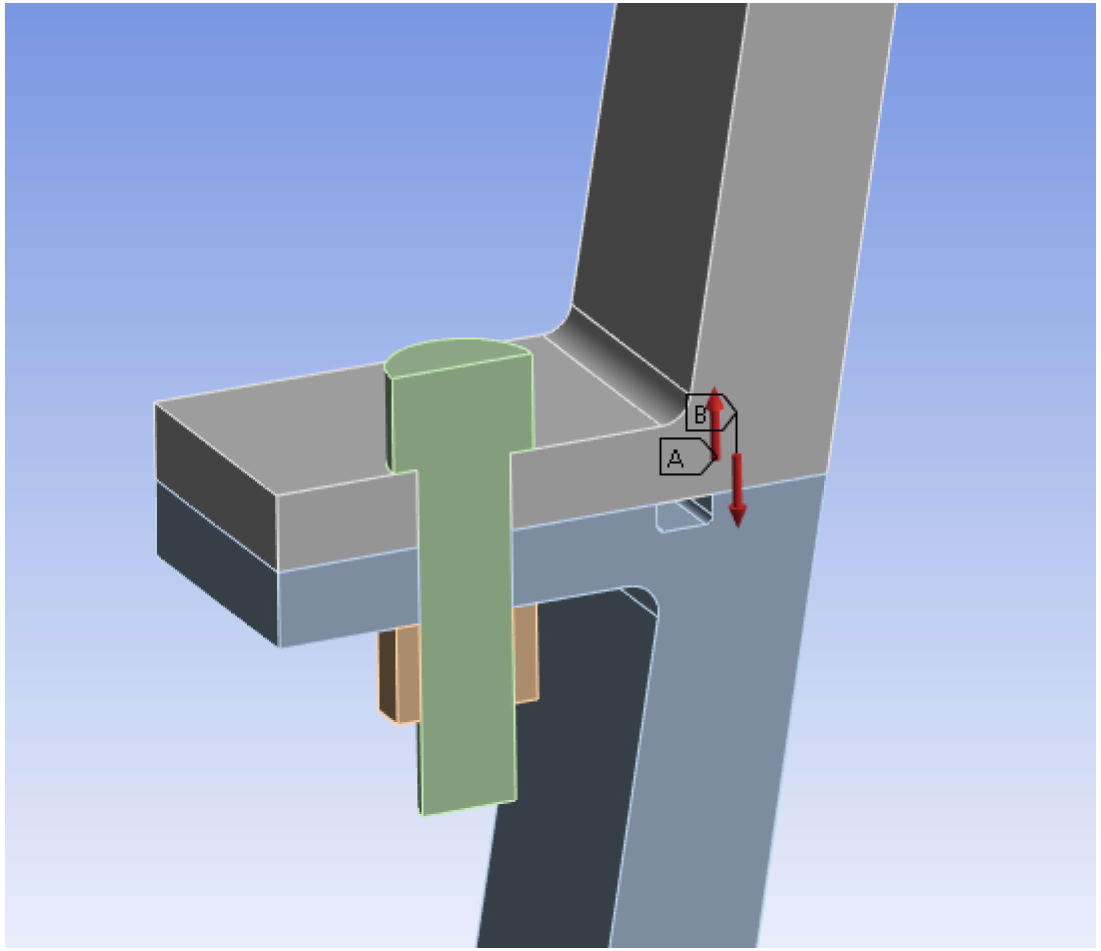
Boundary conditions (1/2)

- Frictionless support on the top of the mid nozzle
  - This implies that there is not displacement and tangential traction, which approximates the connection to the upper nozzle, which is not considered in the model



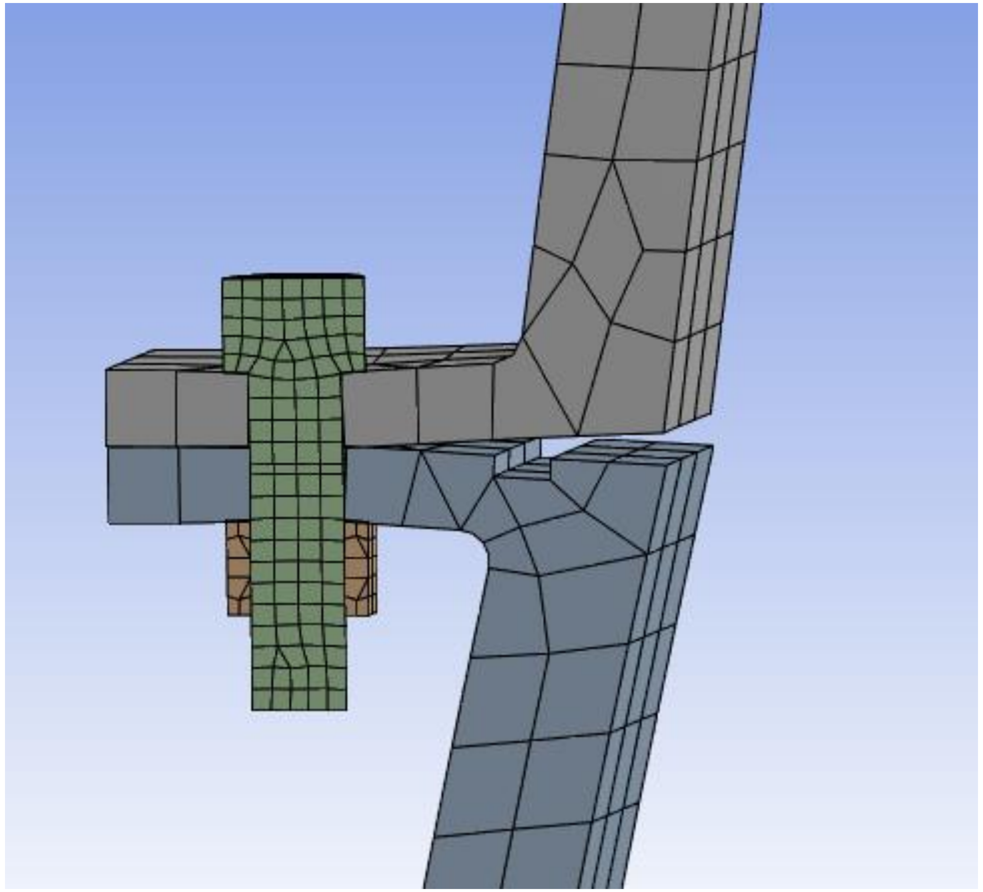
Boundary conditions (2/3): Cooling channel pressure

- Calculated using 1D thermal analysis
- F = 1000 lbf
- The coolant applies the force on both lower and upper nozzle



Boundary condition (3/3): Pressure from the hot gas

- It acts on both the internal surface of the nozzle, but also on the surface that will be exposed after deformation due to the cooling cannel pressure
- Need to set traction=0 to allow these surfaces to move during the simulation



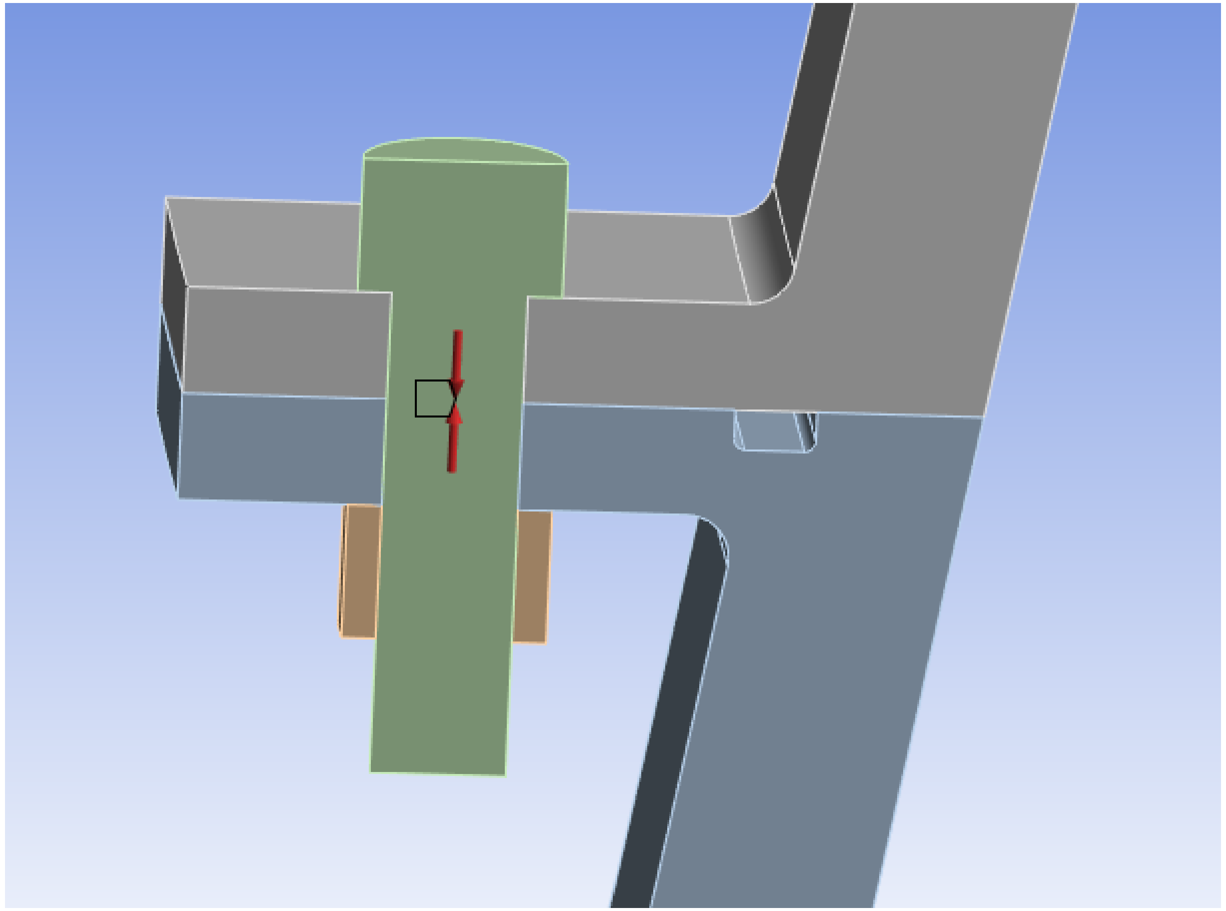
The deformation shown in this image is 2 times bigger for better visibility

Boundary condition (4/4): Thermal load

- Body subject to hot gas temperature
- T = 700 F
  - This is the temperature at the wall on the gas side
  - It was found starting from the hot gas recovery temperature and the heat transfer coefficient (found with the Bartz correlation)

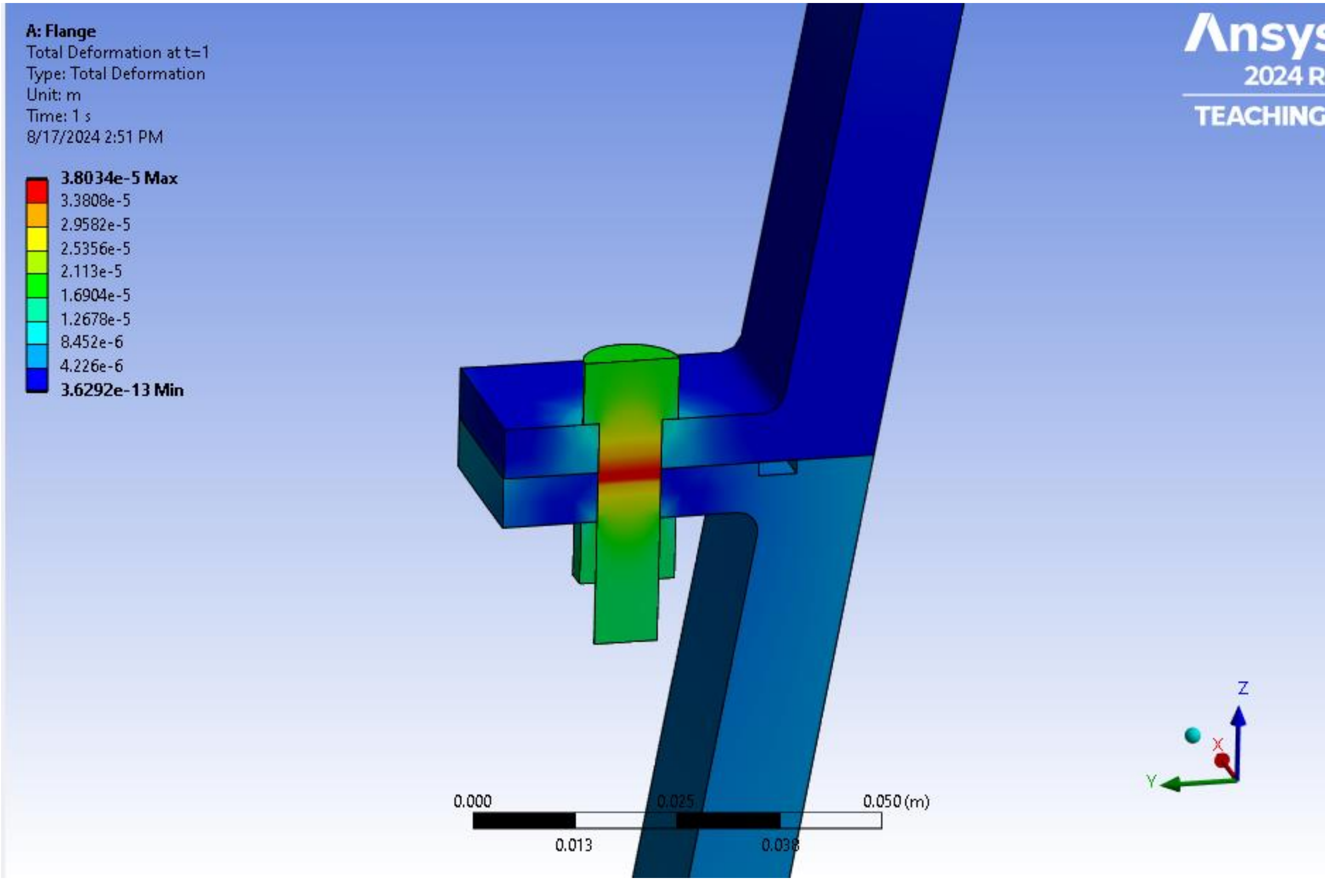
Bolt preload

- 2320 lbf



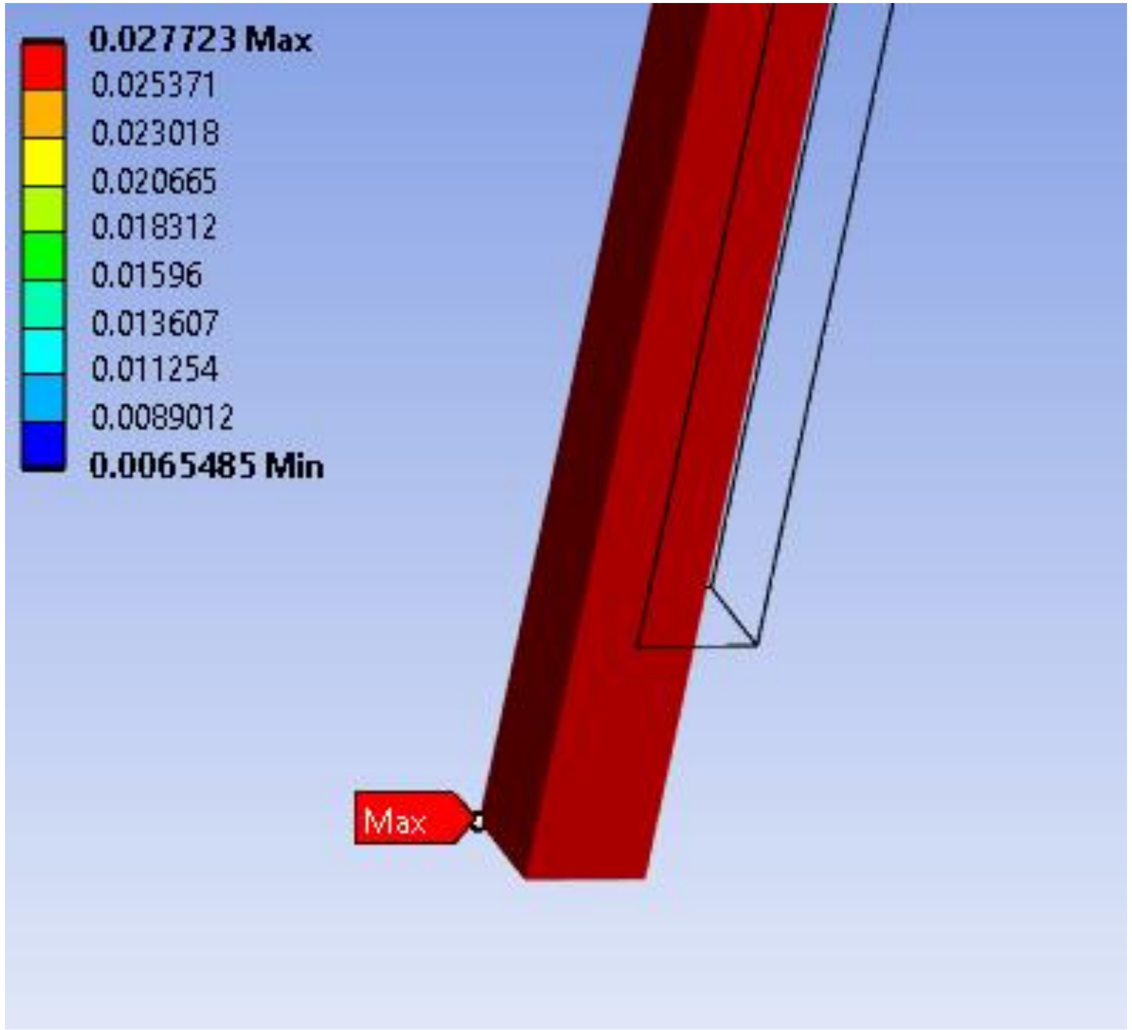
Deformation at t=1 (only bolt preload)

- Loads at t=1:
  - Bolt preload
- Nozzle doesn't have high deformation, which was expected
- The bolt pretension is visible



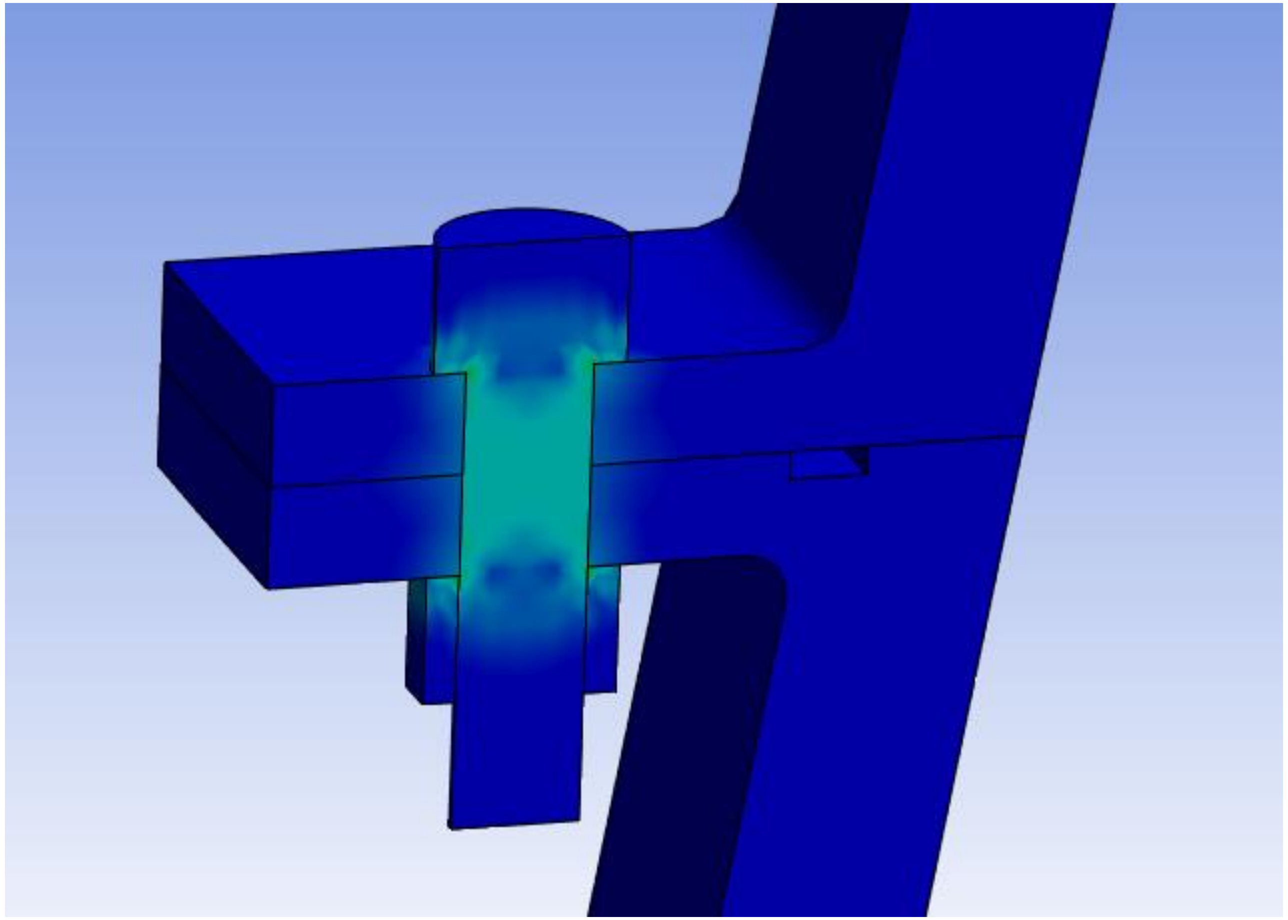
Deformation at t =3

- Additional Loads:
  - Thermal expansion due to hot gas
  - Coolant pressure
- The nozzle grows radially, and axially
- Total deformation is 0.0277 m (1.09 inches)
- The hoop stress at the nozzle exit (calculated using the normal stress) is 1672 psi < 30,000 psi, which is the yield strength of 300 stainless steel



Equivalent stress at t=1 (Bolt pretension)

- Maximum stress in the bolt is: 1.26e5 psi
- This is lower than the bolt capability which is 1.60e5 psi (A-286 steel)



Model validation

- Nozzle thermal expansion

DL = alpha * DT * L = 1e-5[1/F] * (700 F – 30 F) * 160 in = 1.008 in

ANSYS predicted thermal expansion = 1.09 in

- Hoop stress

Sigma = P*r/t

P = 12.17 psi

r = 69.5 in

t = 0.5 in

Sigma = 1692 psi

ANSYS predicted hoop stress : 1672 psi