DETechnologies

Final Presentation

March 25, 2024

- Shakib Miri
- Logan Palmer
- Patrick Cleary
- Aidan Clark

Agenda

- Preliminary Matter
- Analytical Models Results
- Final Design
- Final Computer Aided Design
- Finite Element Analysis
- Computational Finite Difference
- Manufacturing Drawings
- Preliminary Thrust Stand

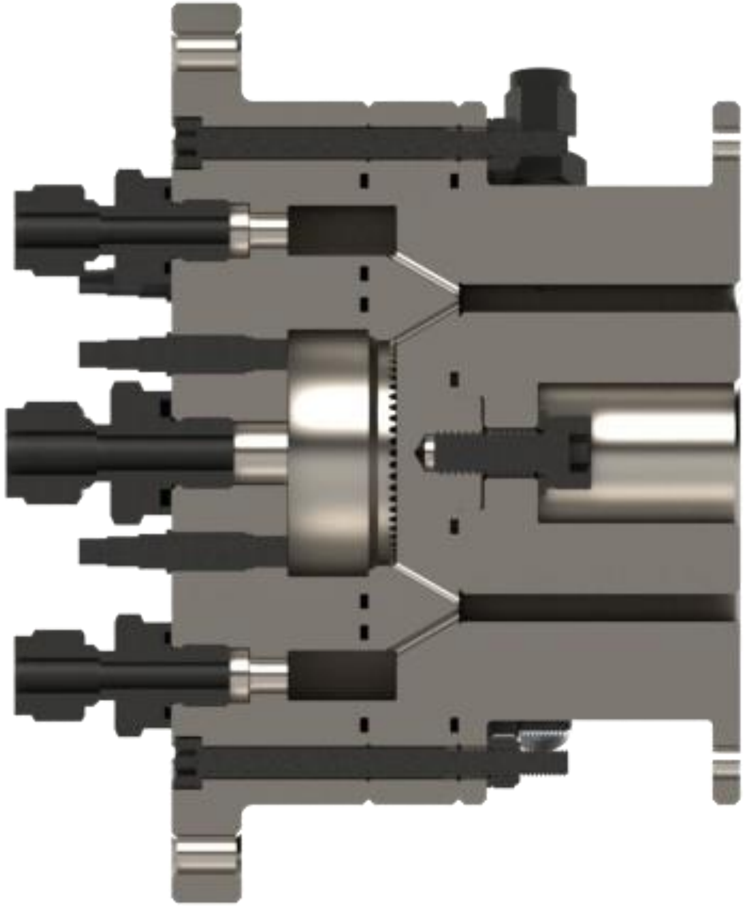


Figure: *Cross-sectional view of the final prototype CAD assembly.*

Preliminary Matter

Problem Definition: Very little literature is available that clearly outlines the design process involved in choosing engine sizing for any application.

Alternate RDE Design Approach: Trial and error engine sizing or borrow working experimental design.

Constraints:

- *Technical*
  - Lack of local technical expertise
  - Combustion temperature and pressure
- *Budgetary*
  - Propellant feed system estimated to be between $50-100k [1]
  - Sensor prices estimated > $20k
- *Safety*
  - No local combustion testing facility
  - GO_2 and GH_2 handling best practices [2][3][4].
- *Time*
  - Only 3 months from term start to finish

Budget:

Table: *Table of accrued and estimated expenditures.*

Description	Cost
ClickUp; Project Management Software	$ 300.00
Metal Pros - Stock Metal	$ 1,495.00*
Outsourced Machining Services	$ 3,450.00*
Team Clothing	$ 500.00
Total	**$ 5,745.00**

Analytical Model(s) Final Form

Combustion Parameters

- Iterate over range of input parameters; minimize chamber Pressure & Temperature.

Injector Sizing

1. Iterate A_i/A_A ratio to reach desired plenum pressure.
2. Apply DFMA constraints, update plenum pressure.

Performance Prediction

1. Calculate geometry based on iterative I/P parameters.
2. Minimum h^* predicts low thrust (322N), increase mass flow rate to reach thrust target.

Equation: Mass Flow; Choking Condition; Rearranged for plenum stagnation pressure [5]

$$P_o = \dot{m}A\sqrt{\frac{\gamma}{RT_o}}(1+\frac{\gamma-1}{2})^{-\frac{\gamma+1}{2(\gamma-1)}}$$

Equation: Mass Flow; Total Required [6]

$$\dot{M} = HW\rho_c U_{CJ}$$

Equation: Specific Thrust; Rearrange $\dot{M}$ to get T [6]

$$\left.\frac{\mathcal{T}}{\dot{M}}\right|_{P_a} = \sqrt{2C_pT_1}\left[1+\frac{q}{C_PT_1}-\left(\frac{P_a}{P_1}\right)^{(\gamma-1)/\gamma}\left(\frac{P_1}{P_2}\right)^{(\gamma-1)/\gamma}\frac{T_2}{T_1}\right]^{1/2}$$

Equation: Detonation Cell Size [10]

$$\lambda = \lambda_{\text{ref}}\frac{P_{\text{ref}}}{P}$$

Equation: Minimum Fill Height Correlation [7] [8]

$$l_{\text{f,cr}} = (12 \pm 5)\lambda$$

Analytical Model(s) Final Form

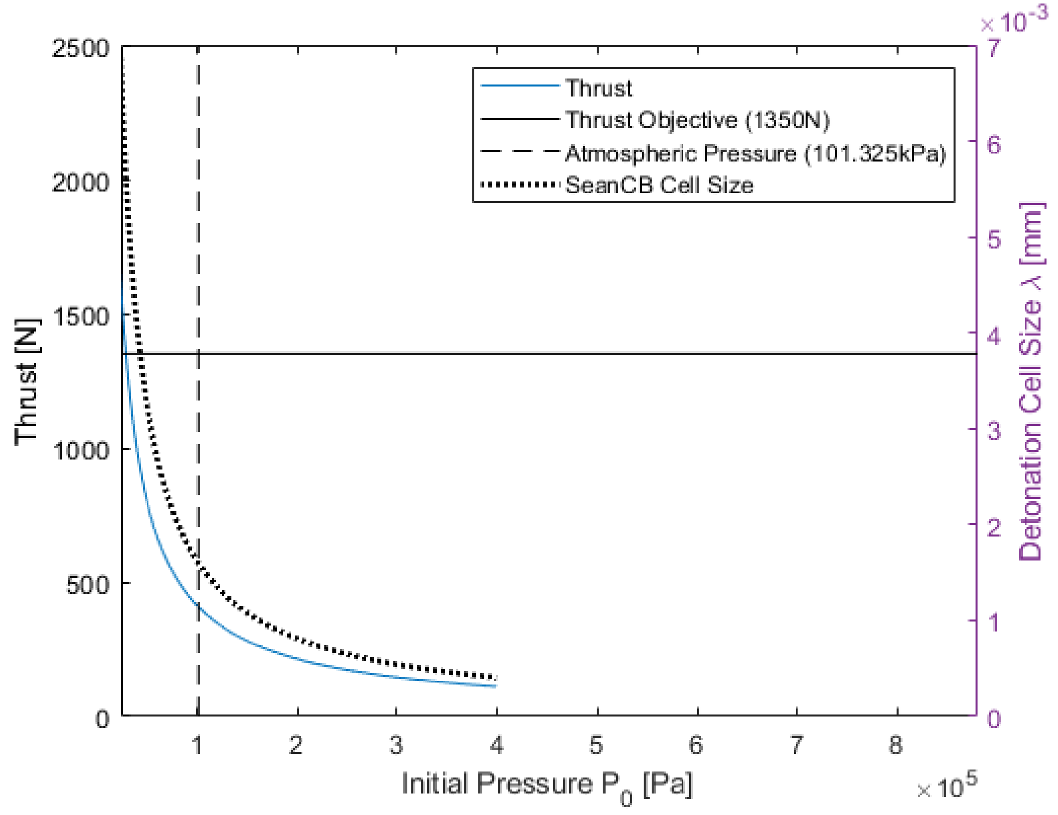


Figure: *Thrust for initial chamber pressures and detonation cell sizes; with 1 atm and target thrust indicated.*

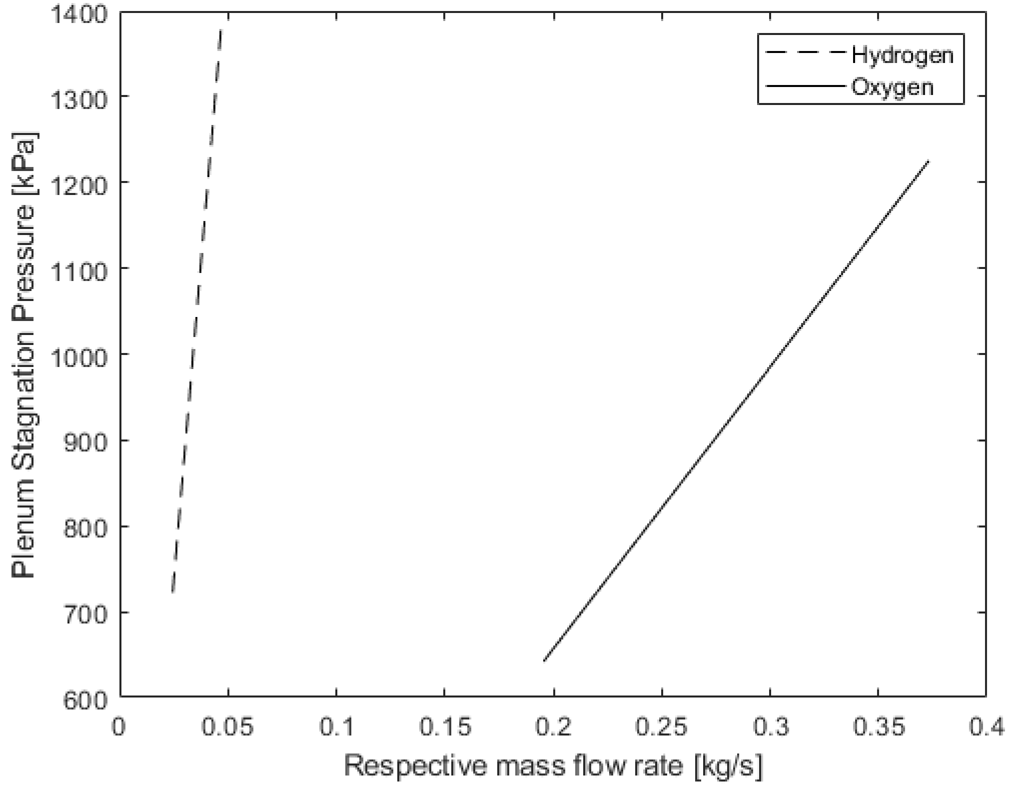
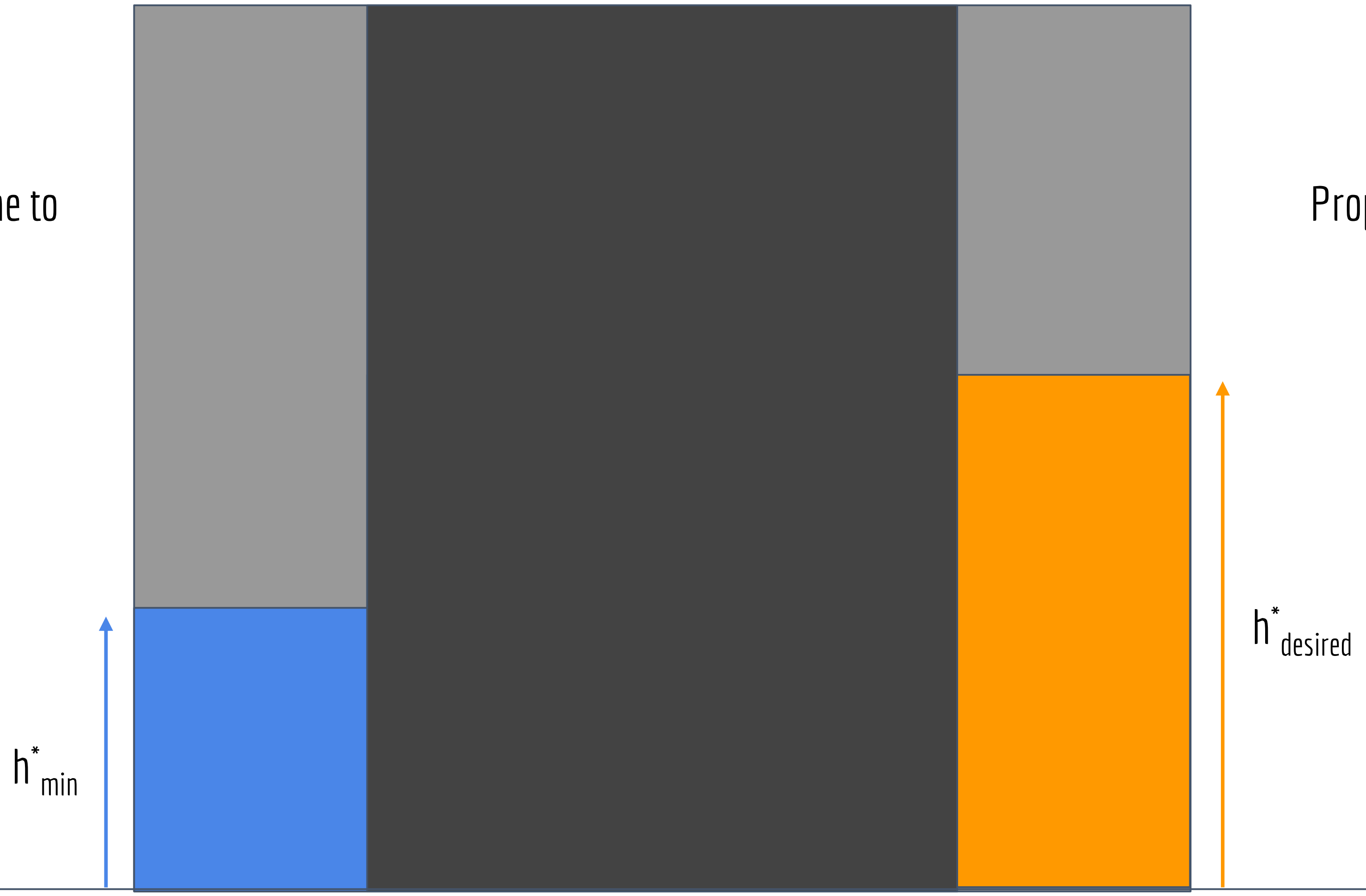


Figure: *Mass flow rate and plenum pressures for fuel and oxidizer.*

Analytical Model(s) Final Form

Minimum propellant volume to achieve detonation.

Propellant volume to reach thrust target.



Final Design Parameters

Table: Summary of Combustion Parameters

Parameter	Value
Detonation Cell Size, λ	1.214707 mm
Initial Temperature, T_0	300 K
Initial Pressure, P_0	130 kPa
Equivalence Ratio, ϕ	1.00
Mass Flow Rate, $\dot{m}$	3.20 $\frac{kg}{s}$
Specific Impulse, I_{SP}	410.6716 s
Peak Pressure, P_{VN}	4299196.4247 Pa
Peak Temperature, T_{CJ}	3720.2403 K
Combustion Speed, V_{CJ}	2848.5565 $\frac{m}{s}$

Table: Summary of Engine Geometry

Parameter	Value
Detonation Cell Size, λ	1.214707 mm
Thrust Goal	1350 N
Fill Height, h^*	$h* > 14.964923$ mm
Chamber Outer Diameter, D	60.00 mm
Chamber Inner Diameter, D	50.00 mm
Channel Width, δ	5.00 mm
Length, L	50.00 mm

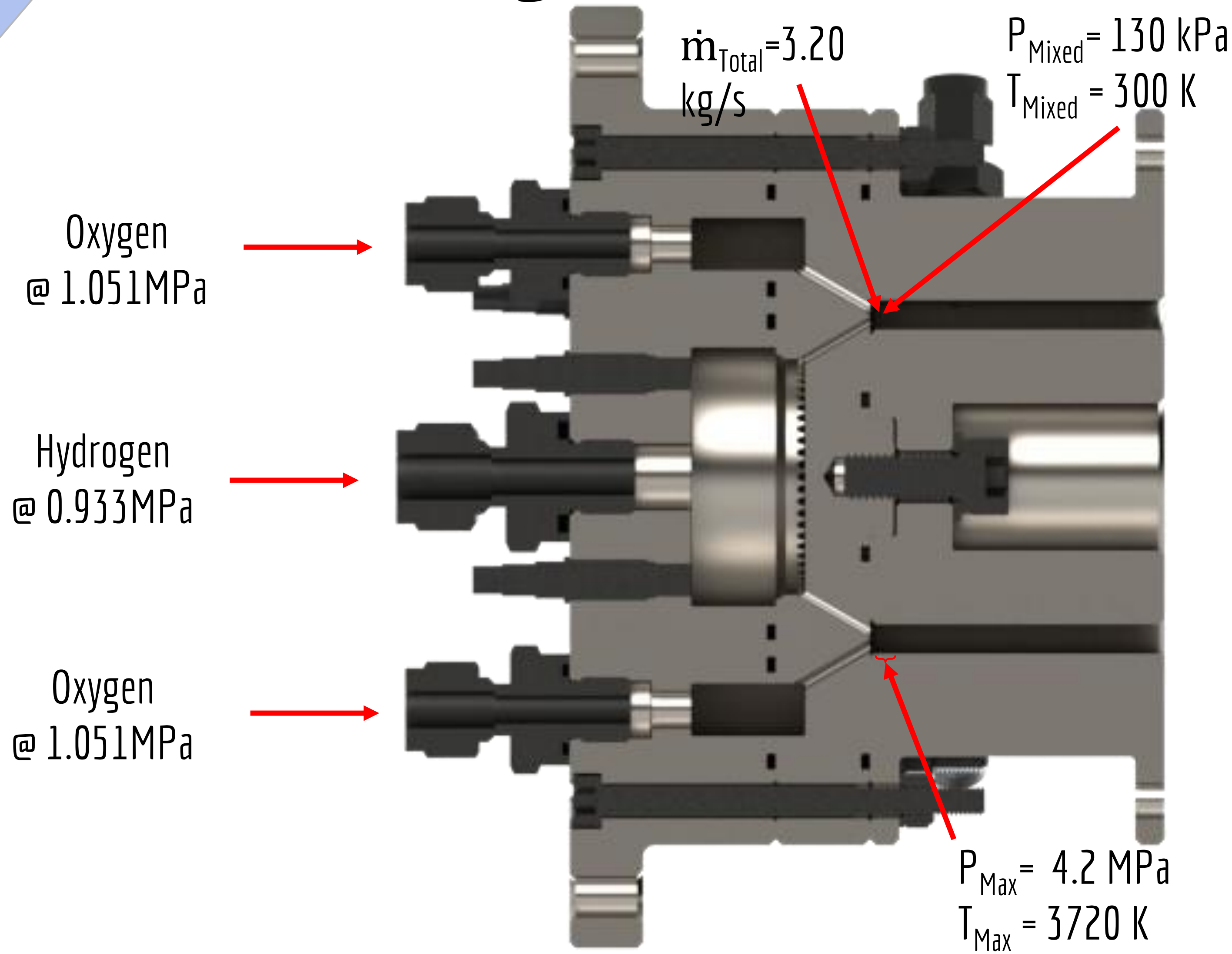
Table: Summary of Injector Plate Parameters

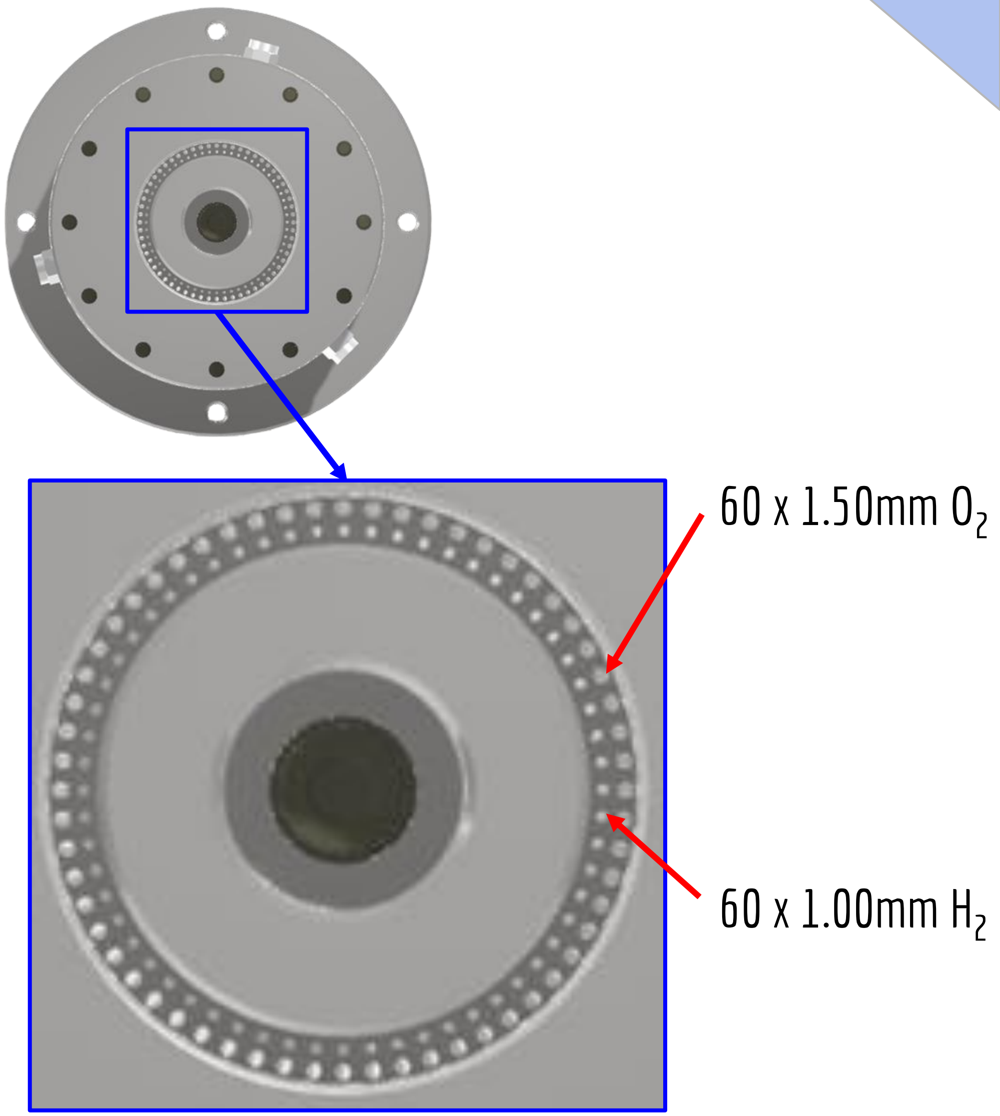
Parameter	Value
Hydrogen Plenum Pressure, P_h	1051.096564 kPa
Hydrogen Injector Area Ratio, A_h	5.4545 %
Hydrogen Injector Specifics	60 x ϕ 1 mm
Oxygen Plenum Pressure, P_O	933.436855 kPa
Oxygen Injector Area Ratio, A_O	12.2727 %
Oxygen Injector Specifics	60 x ϕ 1.5 mm

Table: Summary of Validation Paper Parameters [10]

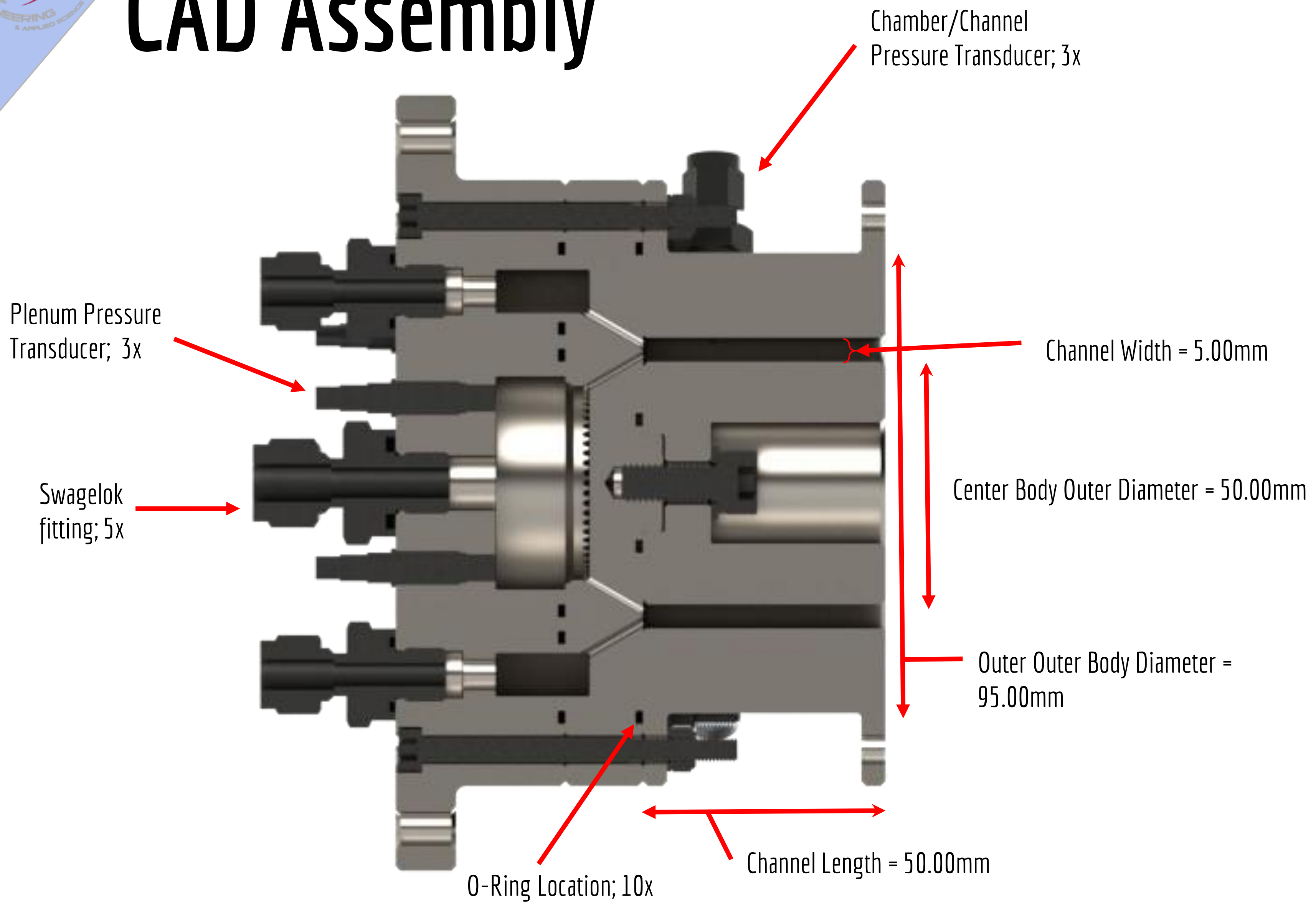
Parameter	Proposed Engine	American Engine
Thrust Target [N]	1350	1350
Designed Specific Impulse [s]	414	-
Mass Flow Rate [g/s]	320	270-375
Outer Diameter [mm]	60	76.2 (3")
Inner Diameter [mm]	50	66.2
Equivalence Ratio, ϕ	1.0	1.1-1.7
Number of Waves	2	2-3

Final Design Parameters



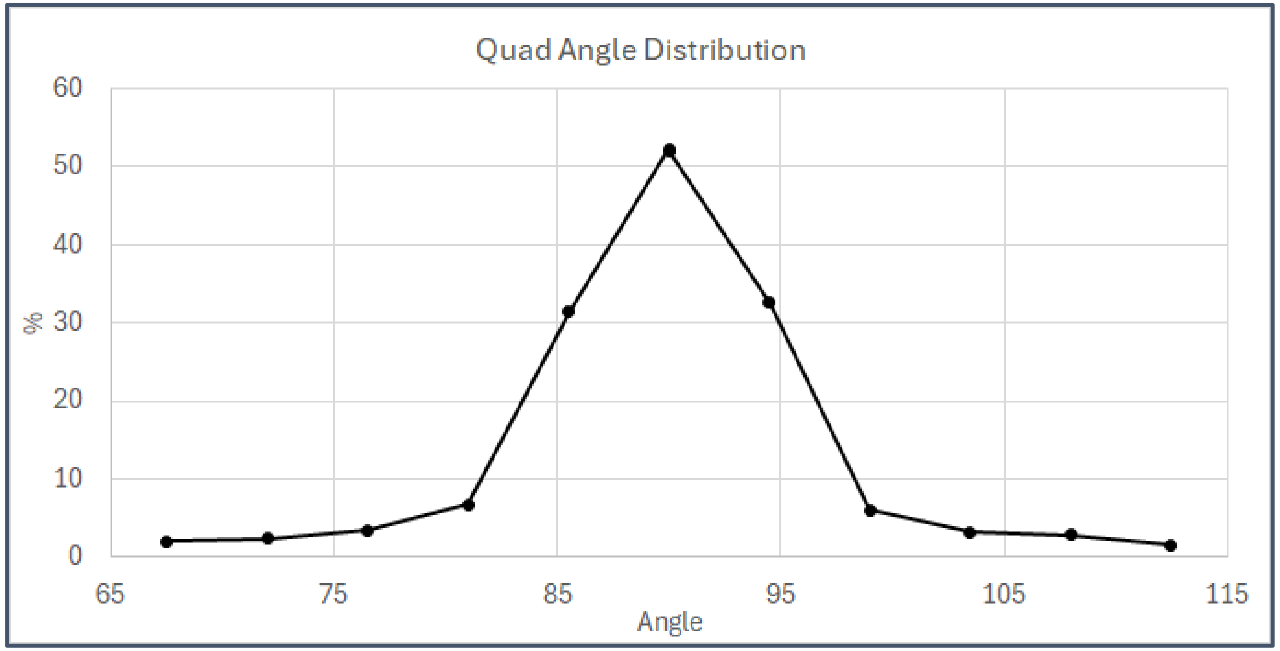


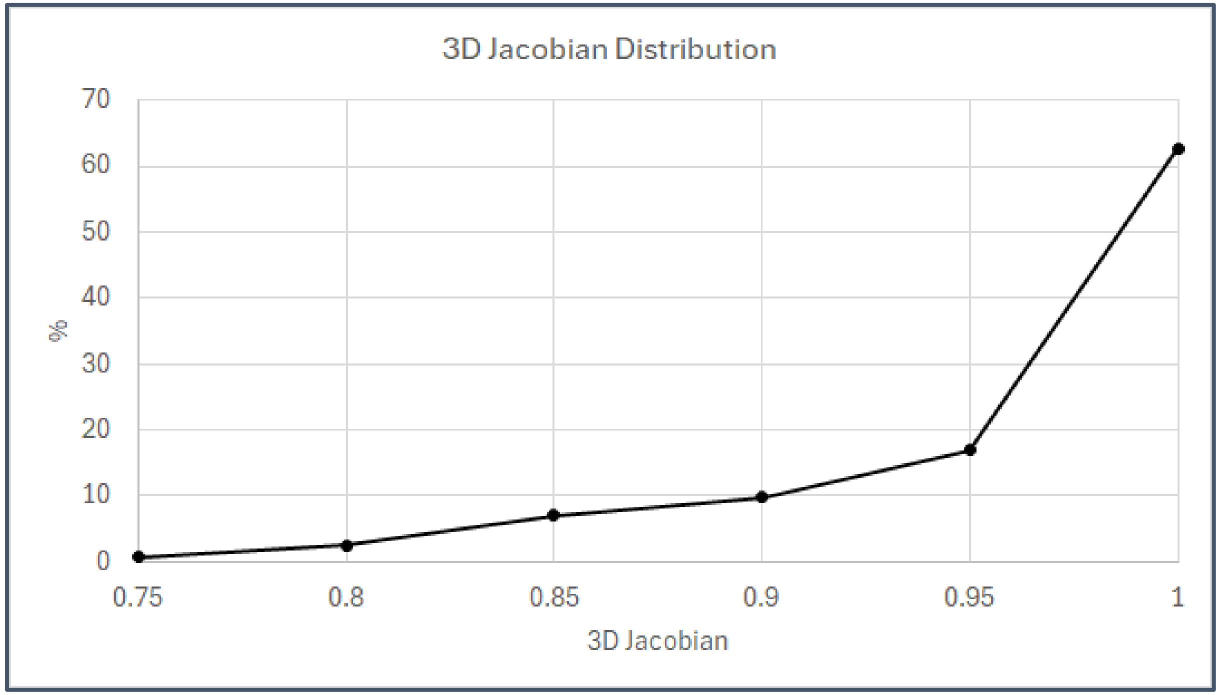
CAD Assembly



FEA: Model Setup & Mesh

Element Type	Percentage of Mesh
Hexahedral (1st Order)	97.43 %
Pentahedral (1st Order)	2.57 %



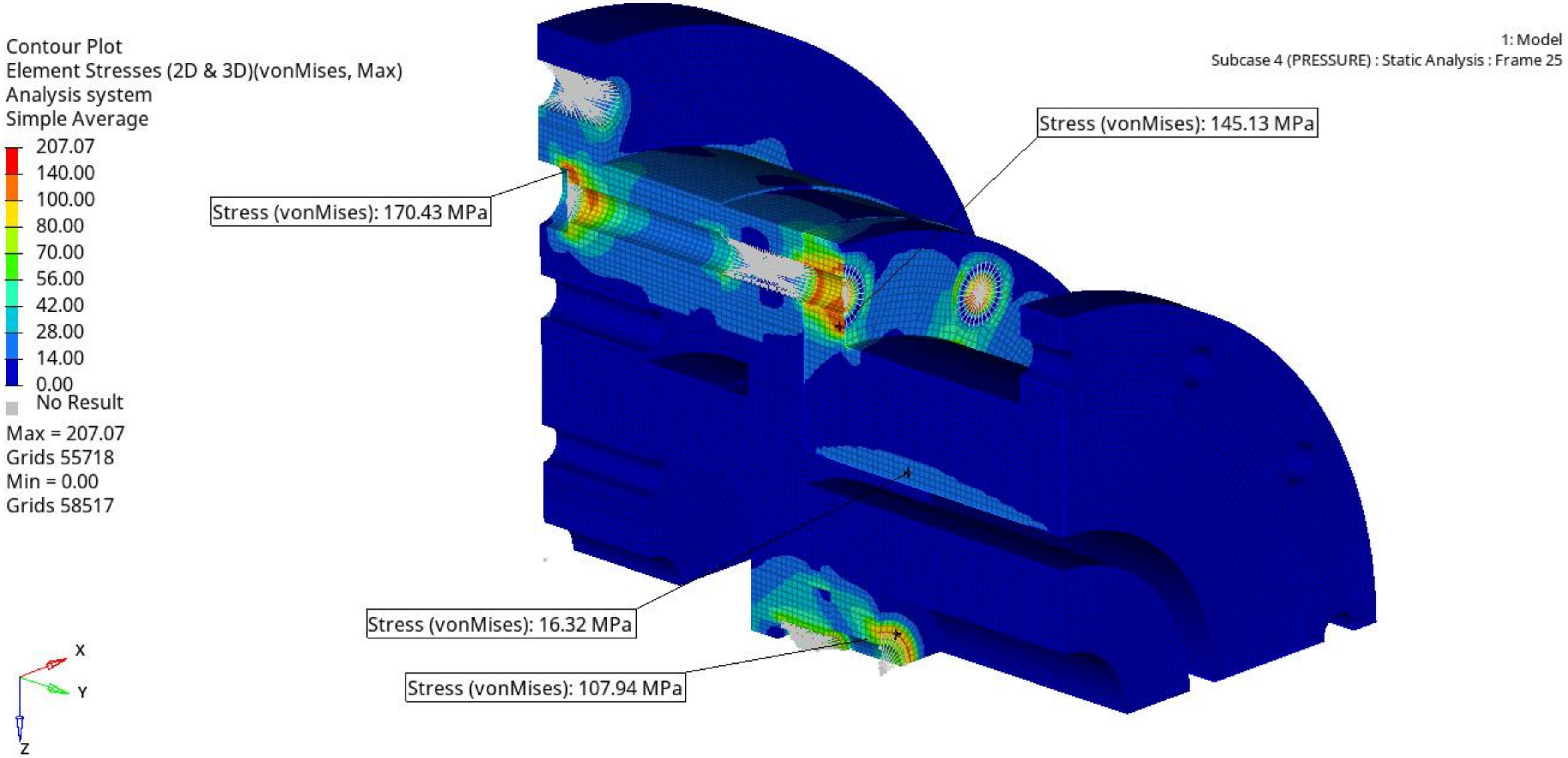


- Linear isotropic material card, using material properties for AISI 316 Stainless Steel from Washko et al., ASM [11]
- 1-D bolted joint modelling using BEAM's and RBE's

FEA: Static Loading (Pressure)

Pressure applied to inner walls of combustion chamber, center body and exposed surface of injector plate

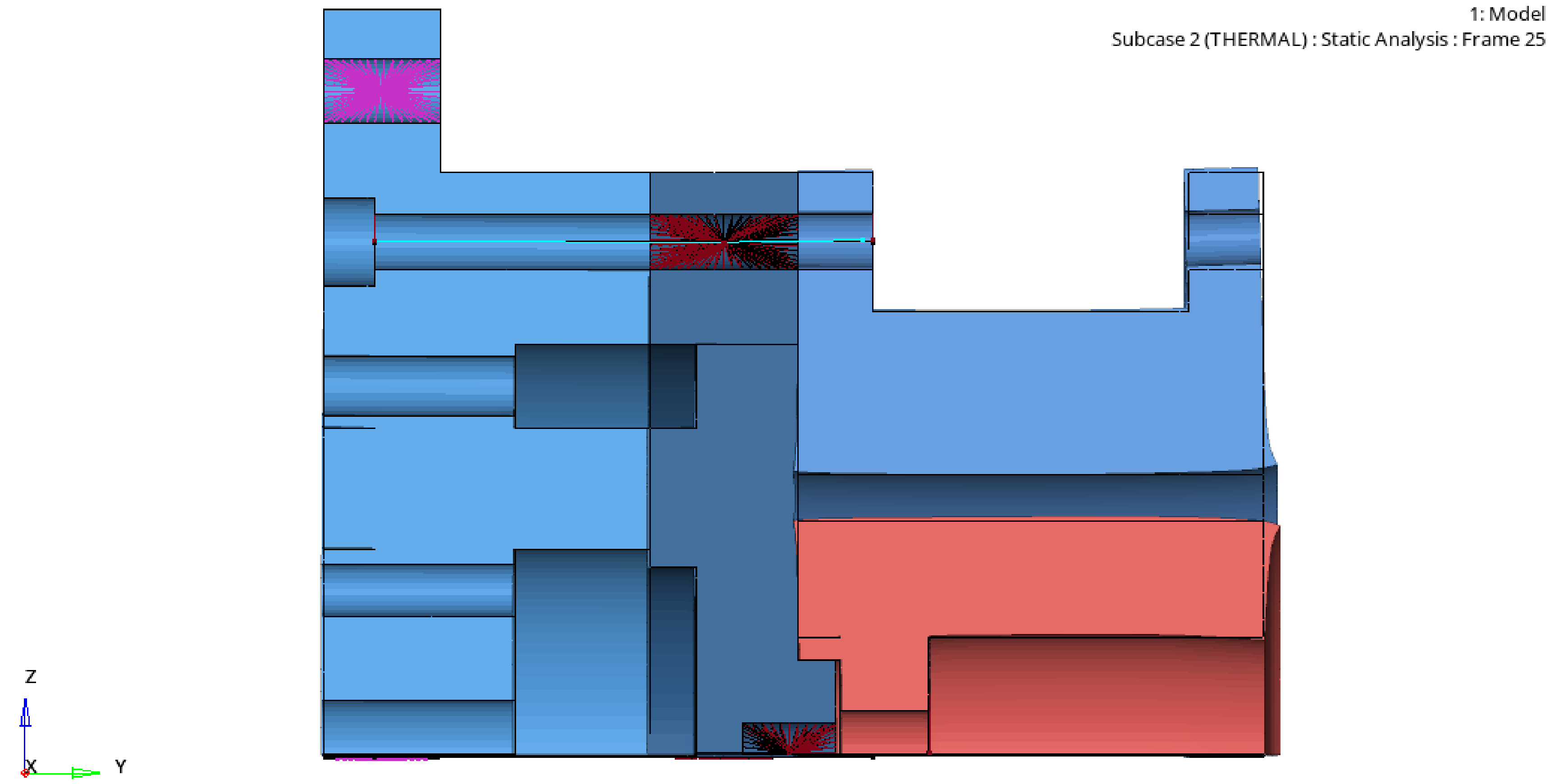
- Pressure (as per VN Spike): 4.3 MPa



FEA: Static Loading (Temperature)

Temperature applied to inner walls of combustion chamber, center body and exposed surface of injector plate

- Temperature as per analytical model: 3500 K



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Temperature applied to inner walls of combustion chamber, center body and exposed surface of injector plate

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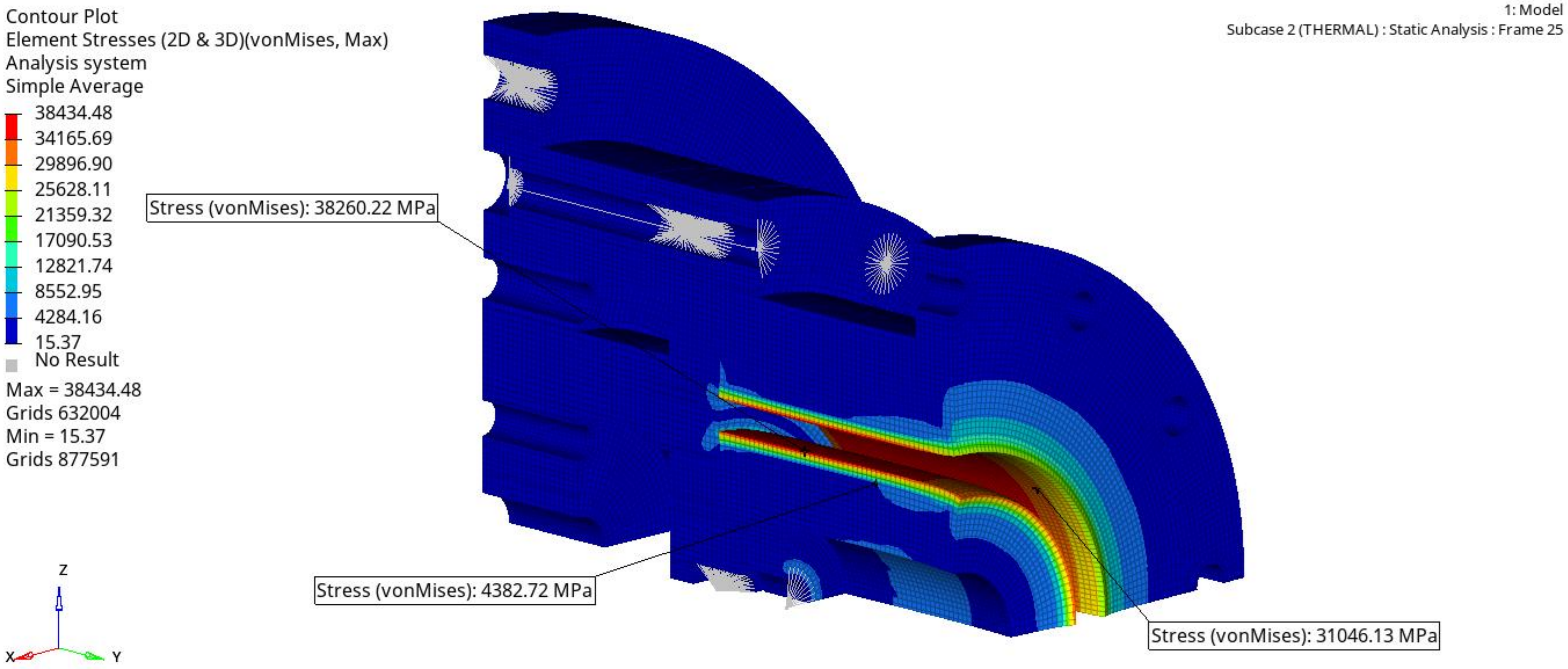
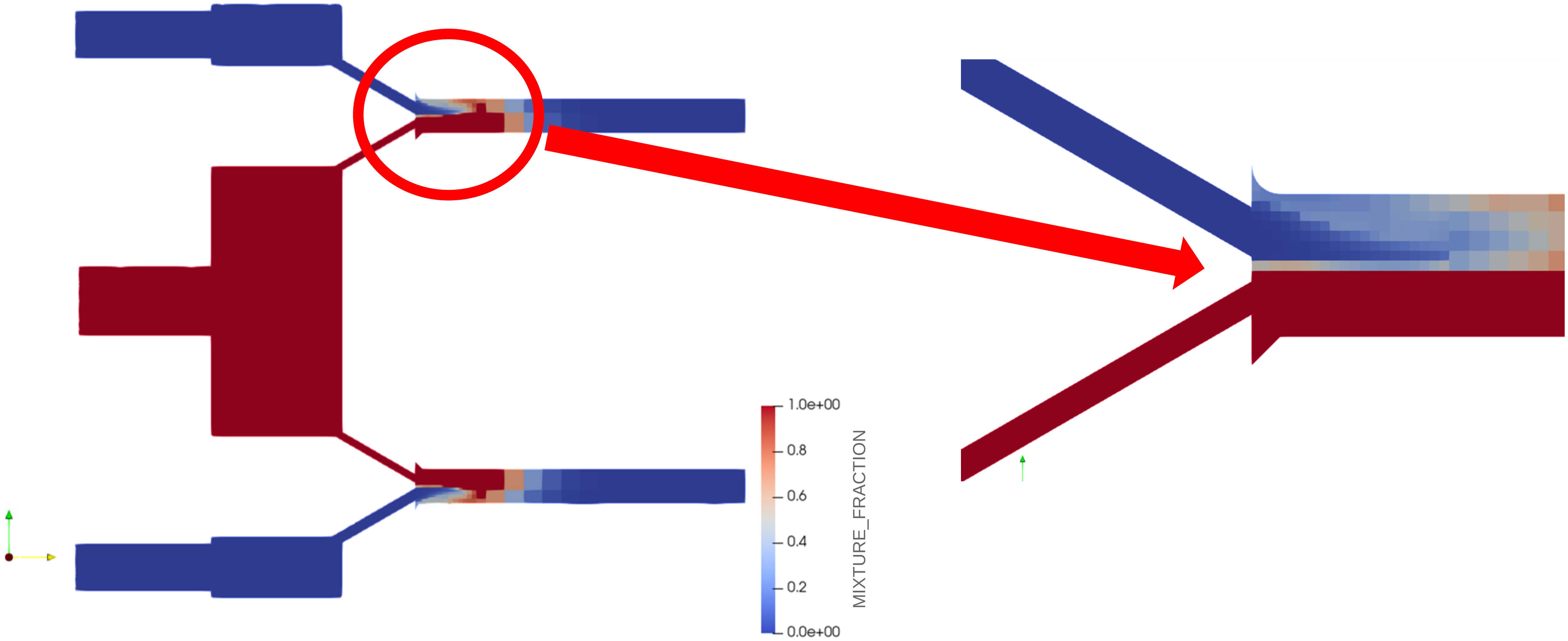


CFD: Injector Flow



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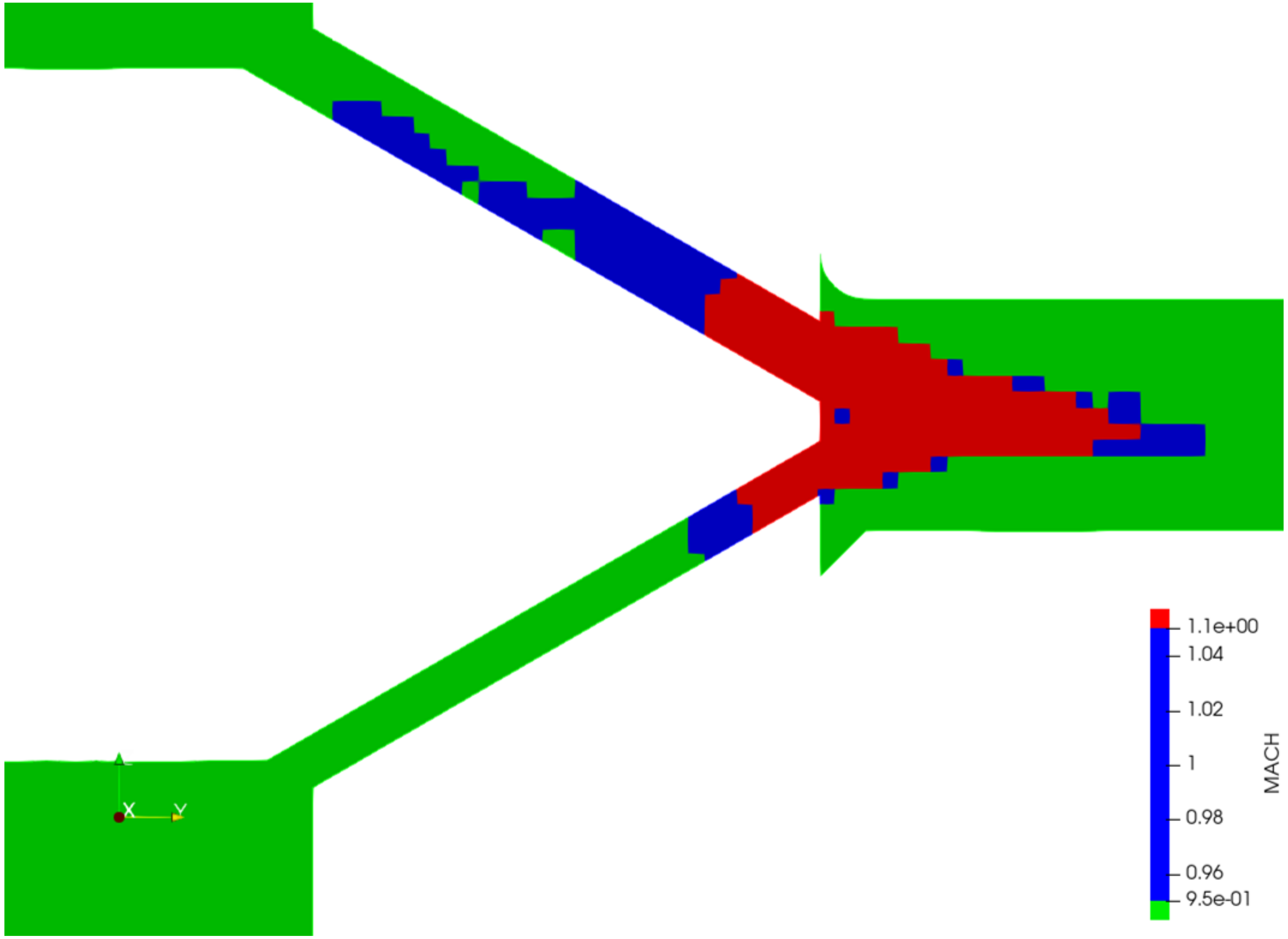
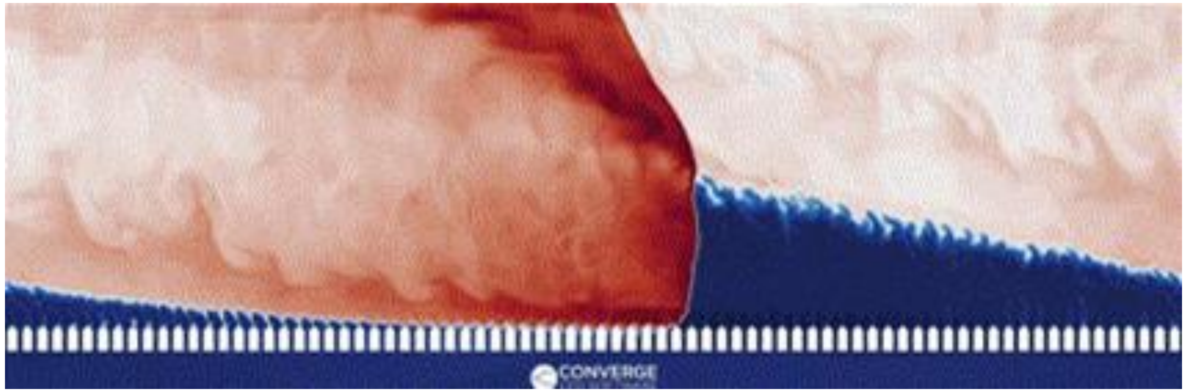
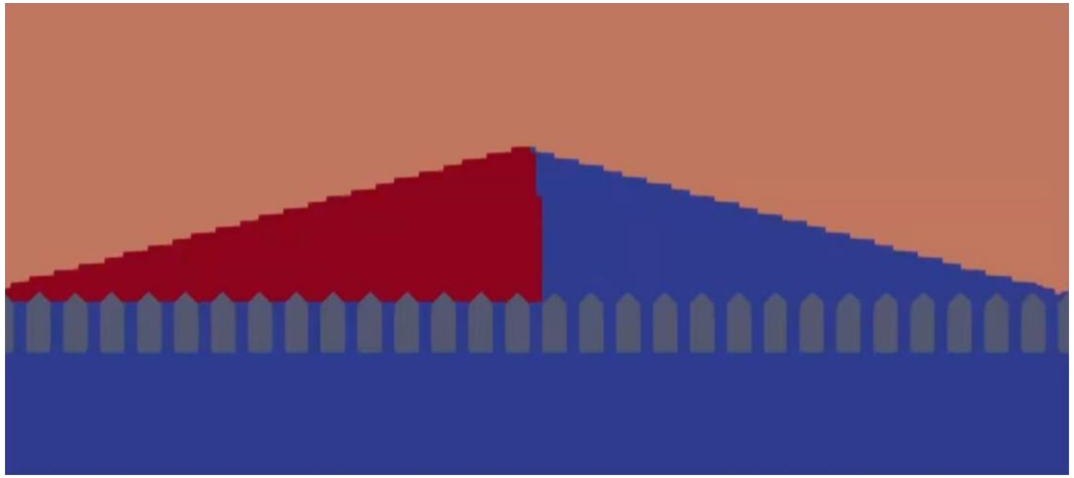


CFD: Combustion

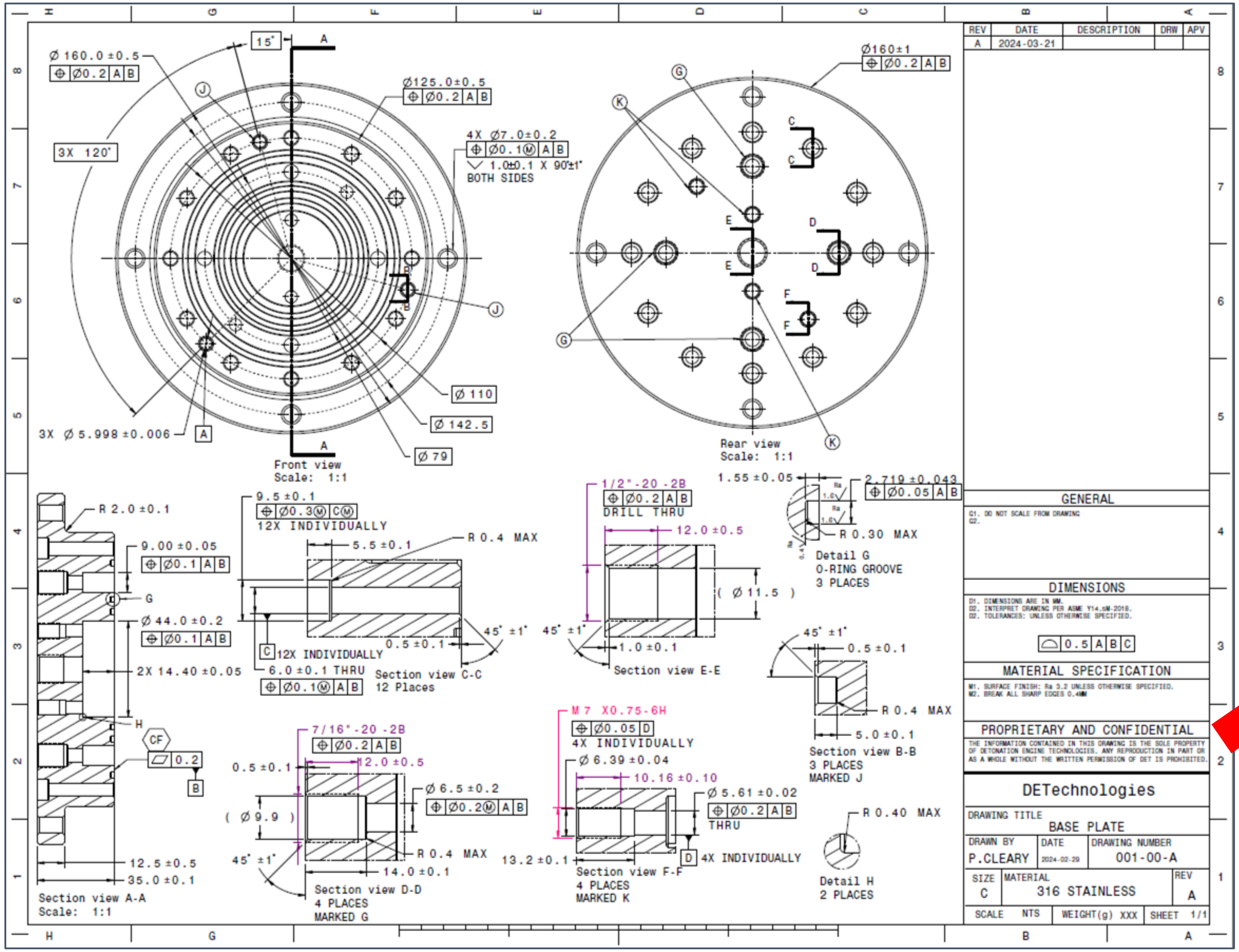


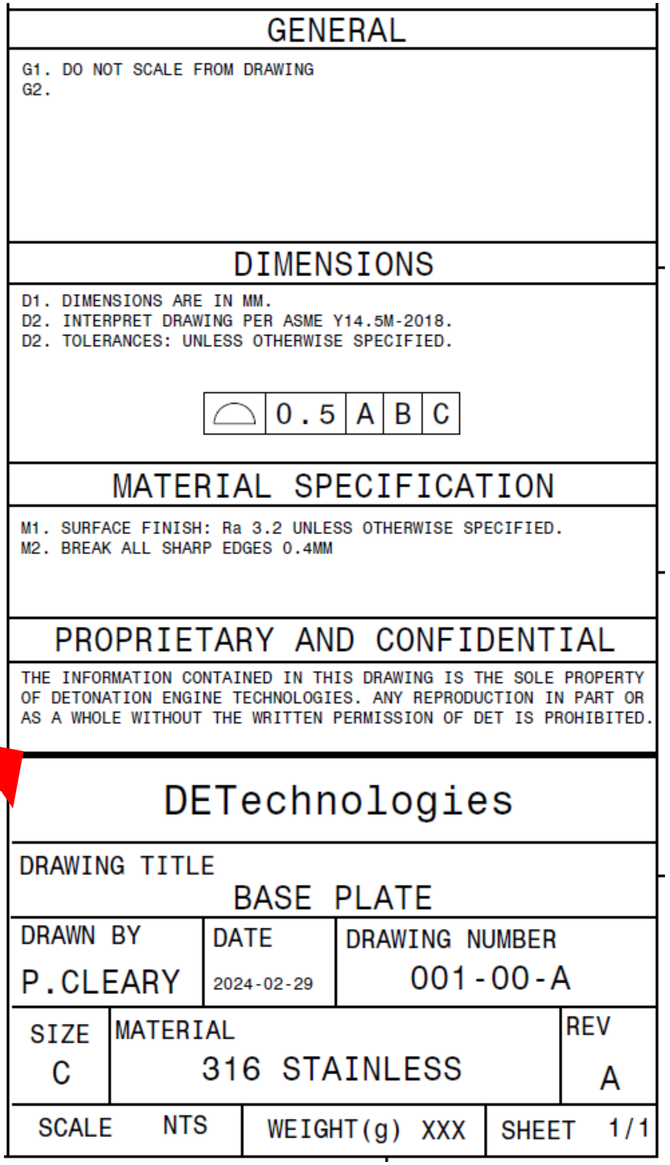
Video: 2D RDE Simulation using ConvergeCFD, by Convergent Science [12]



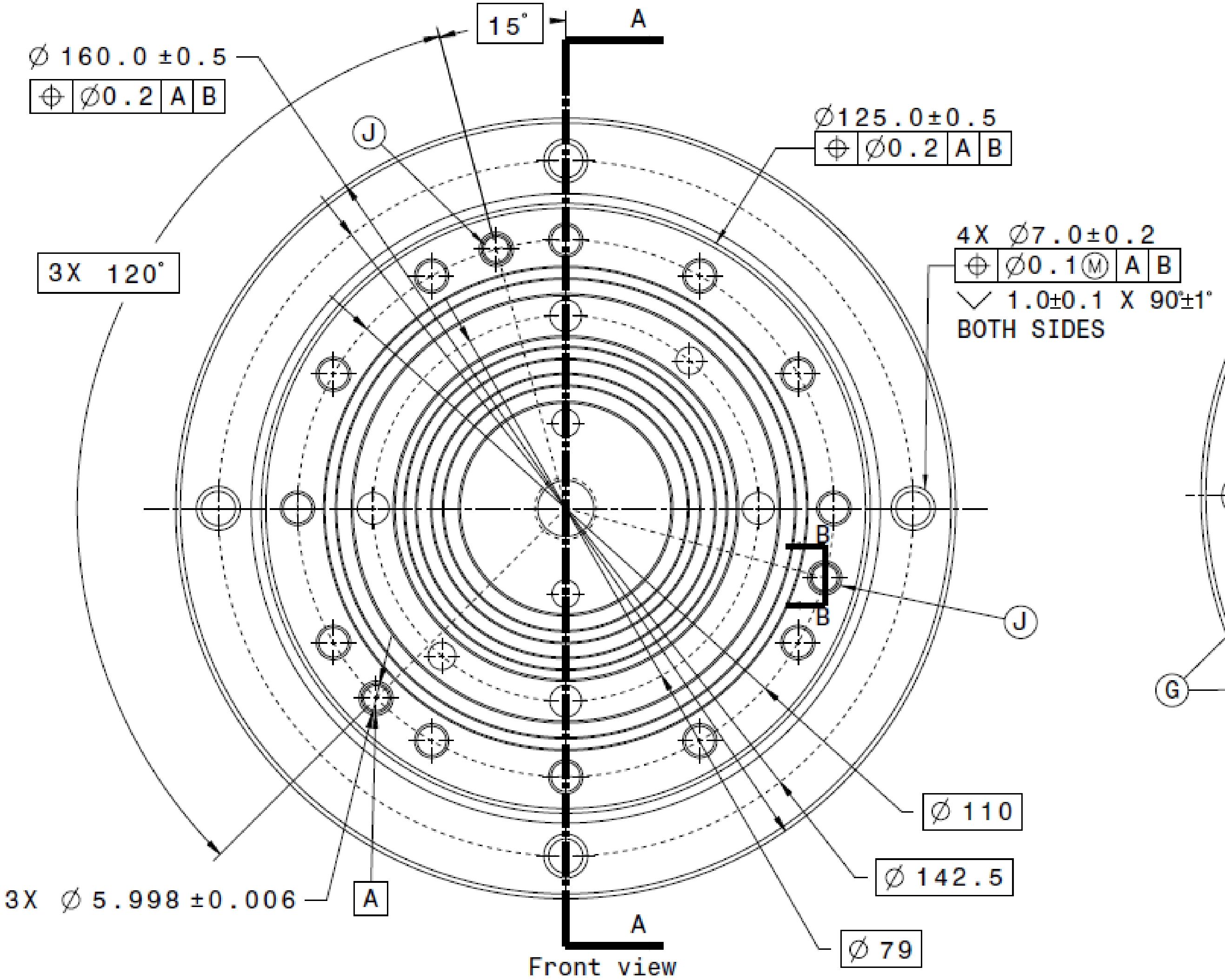
Video: Our 2D RDE - Best Progress yet

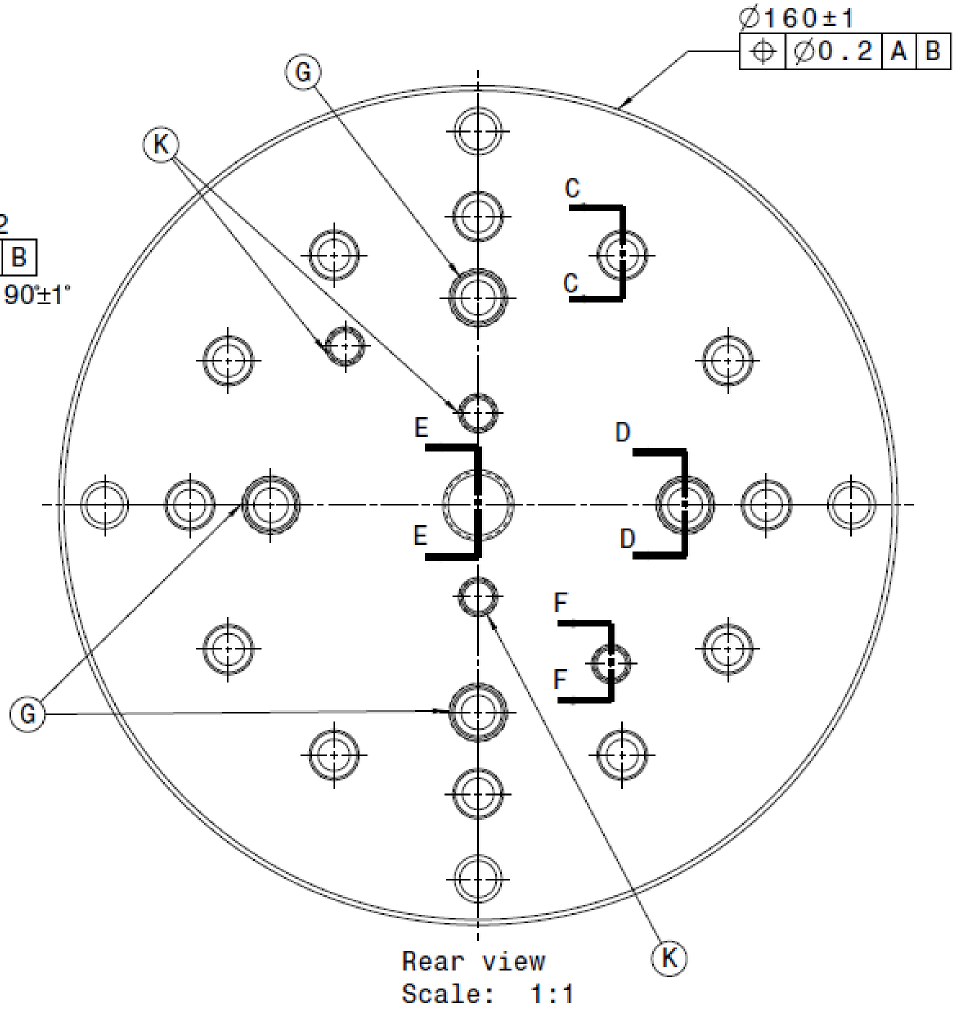
DFMA & Manufacturing Drawings





DFMA & Manufacturing Drawings





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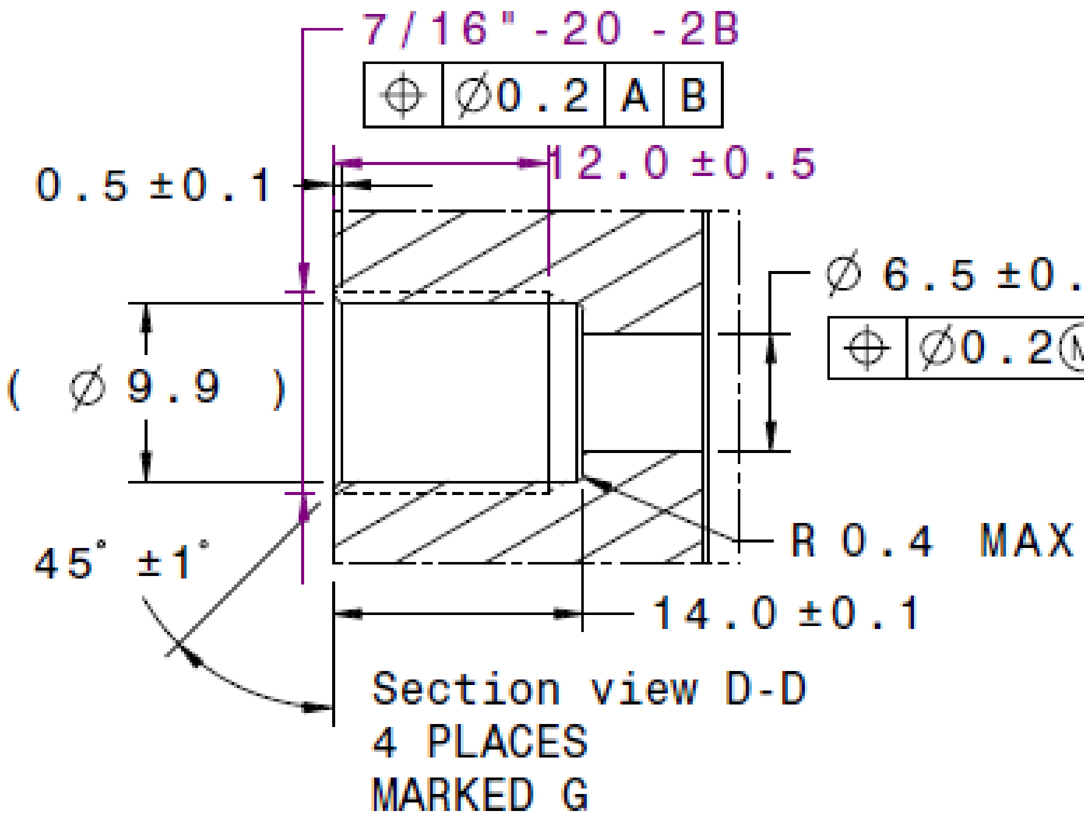
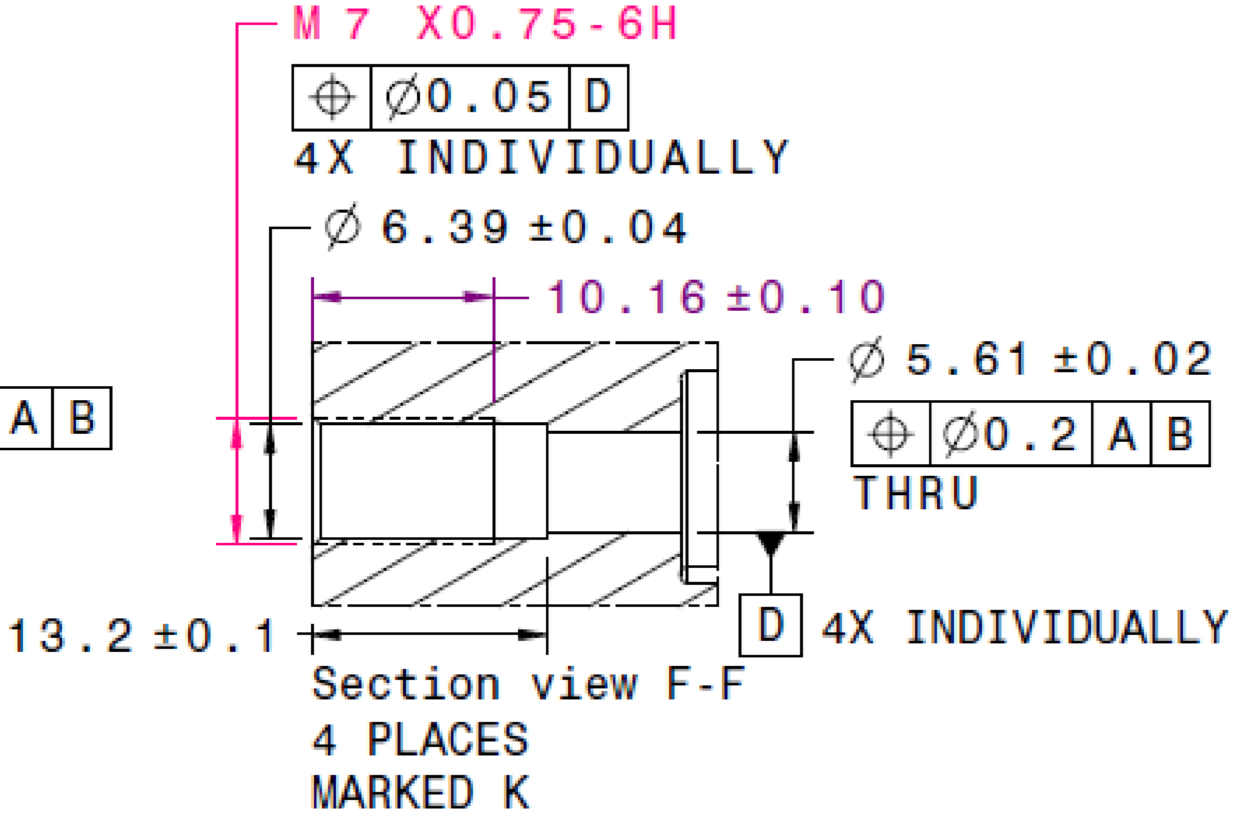
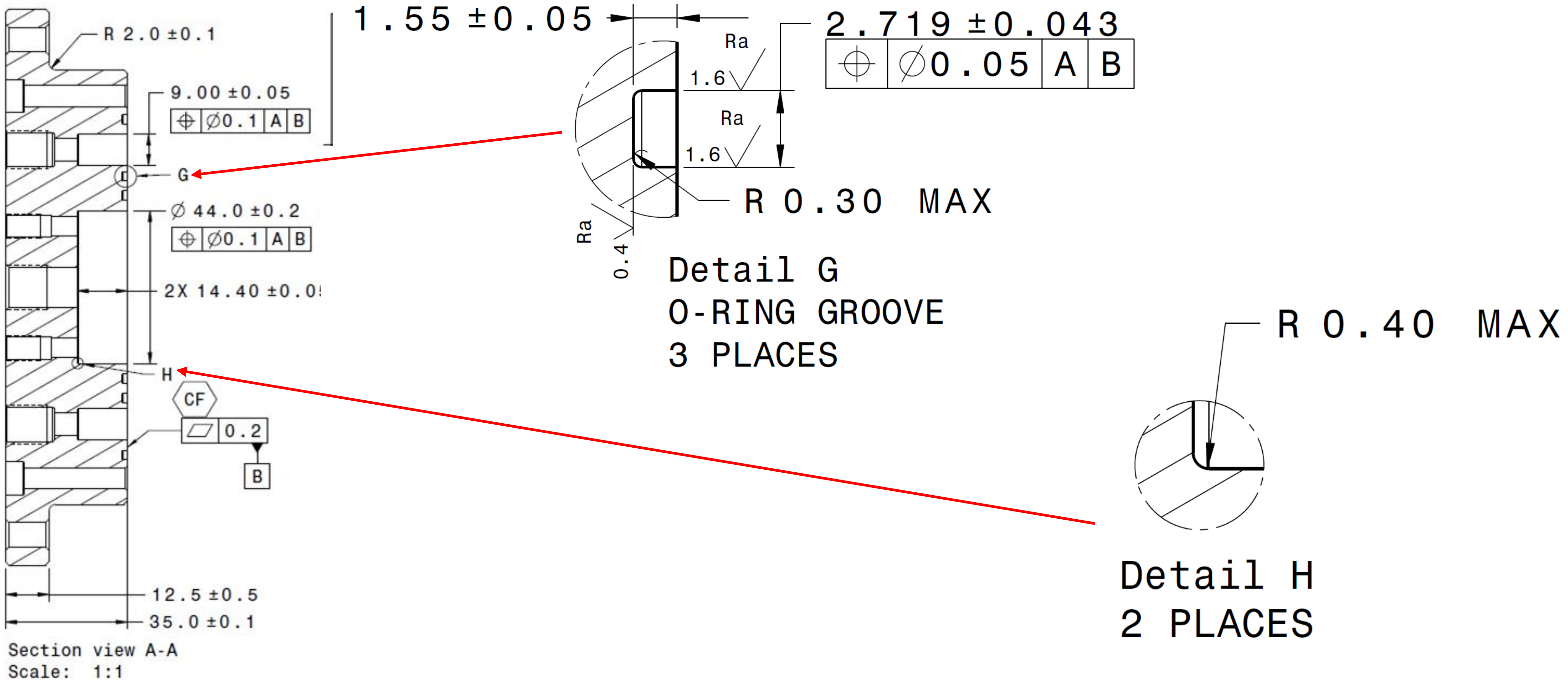




DFMA & Manufacturing Drawings



Multi-Axis Thrust Stand Design

Objective: Measure multi-axis thrust generation.

- Inherent vibrational instability / thrust vectoring effect due to rotating wave.

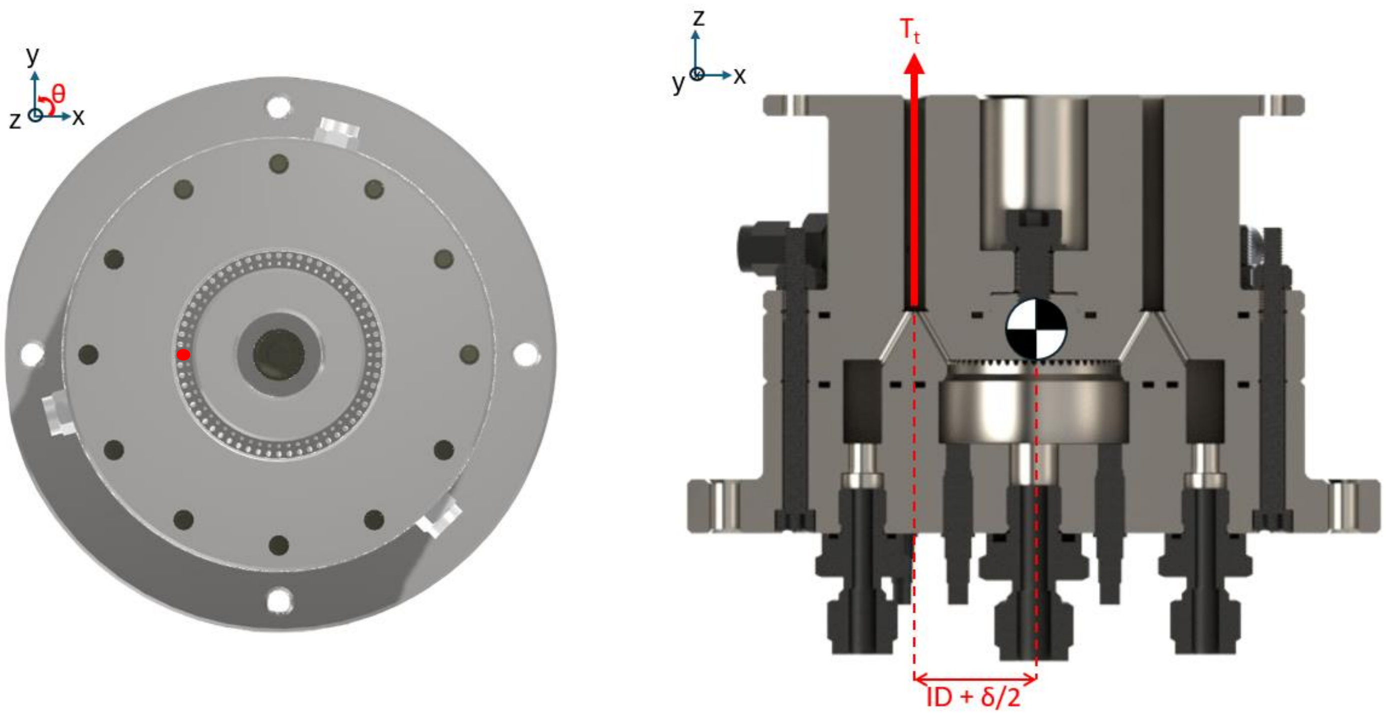


Figure: Schematics of Thrust Vectoring Moment

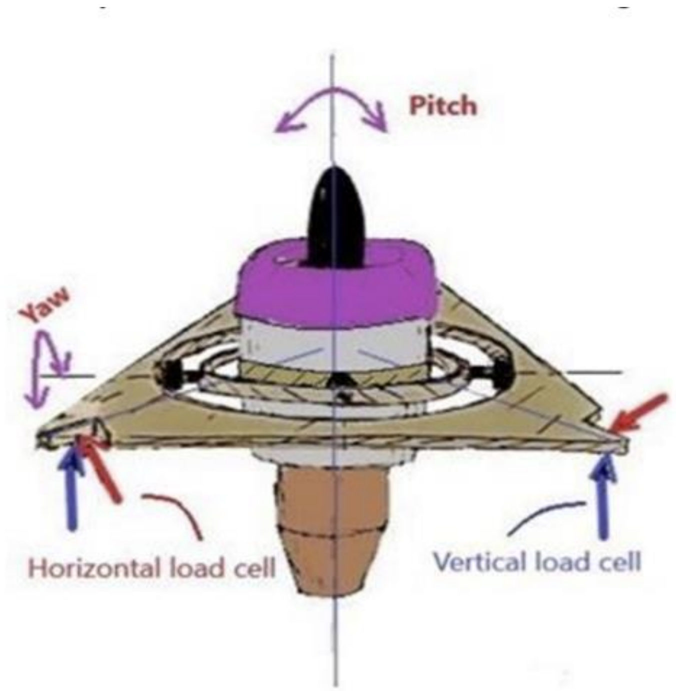


Figure: Schematic Showing Conceptual Thrust Stand DOF [13]

Multi-Axis Thrust Stand Design

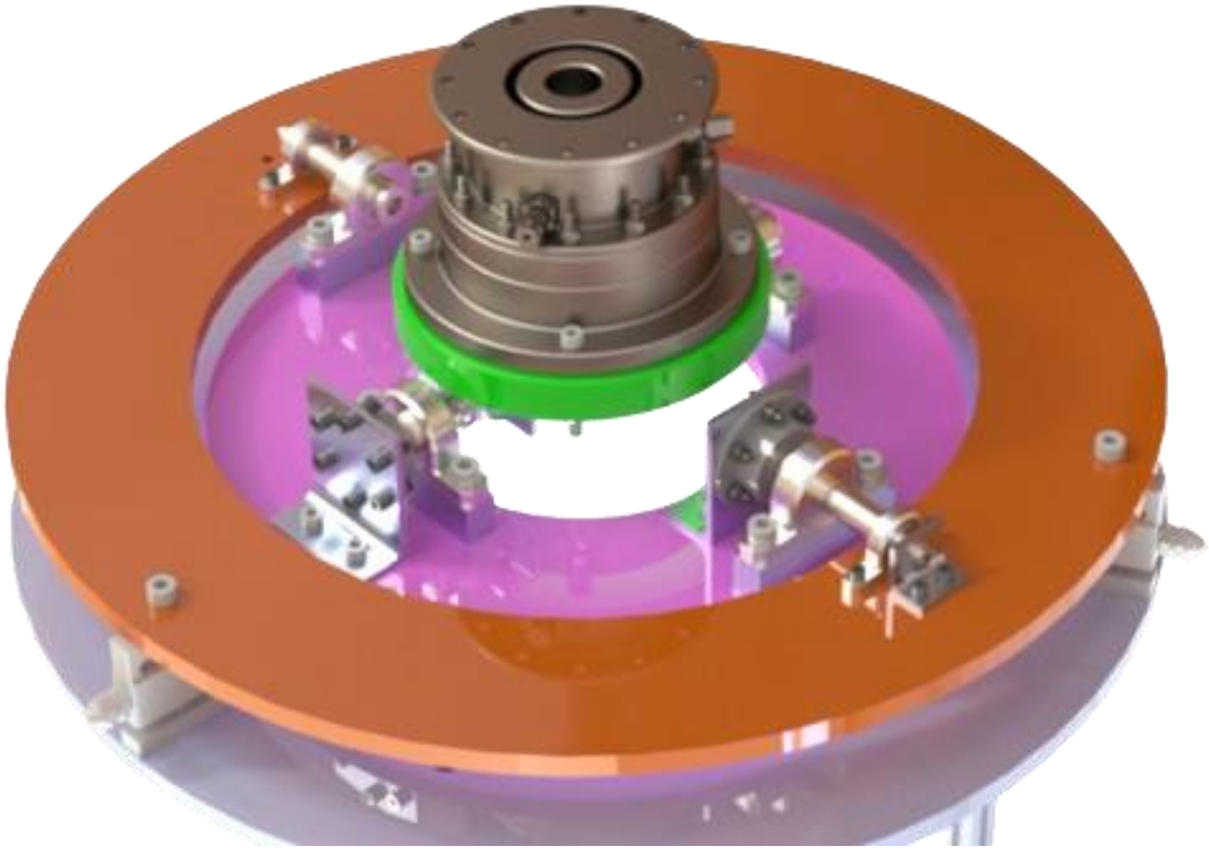


Figure: Preliminary Thrust Stand Design

Video: Showing Degrees of Freedom

References

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[9] S. F. Connolly-Boutin, Detonation Physics-Based Modelling & Design of a Rotating Detonation Engine. PhD thesis, Concordia University, 2019.

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[12] "Simulating supersonic combustion in an unwrapped rotating detonation engine," Convergent Science, https://www.youtube.com/watch?v=7Q2d9vlWdNQ (accessed Feb. 12, 2024).

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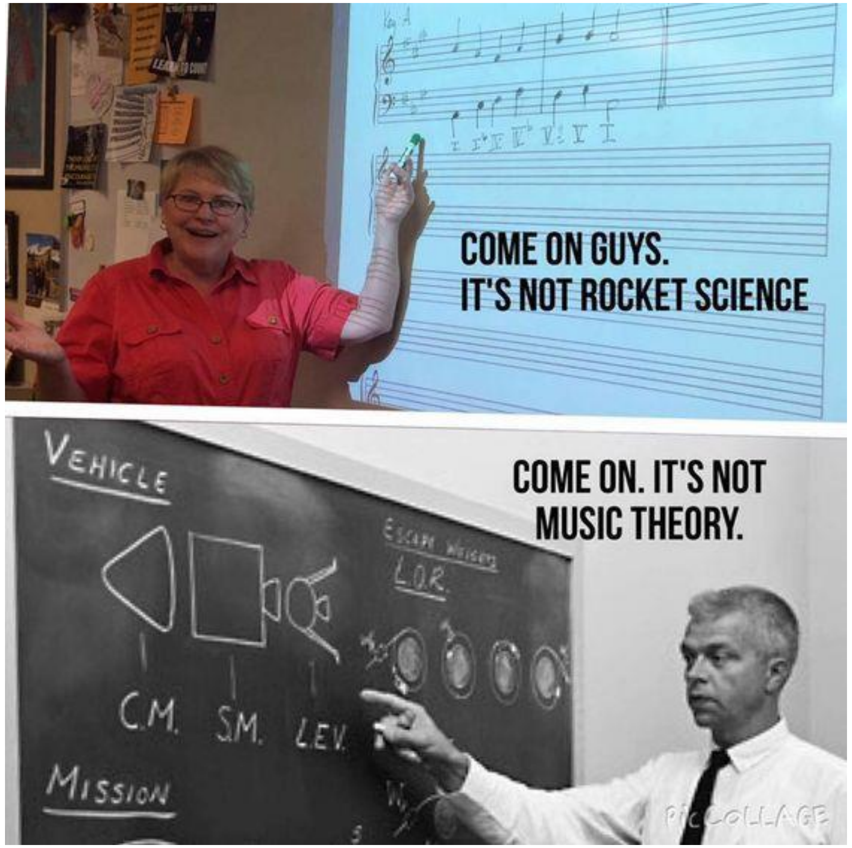

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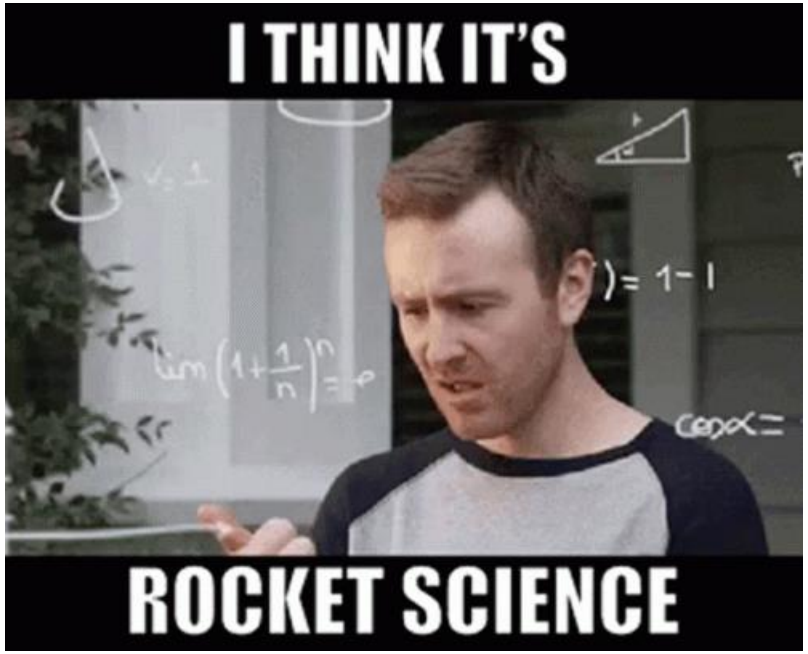

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