Summer 2025 NASA Internship

By **Cosimo Casotto**

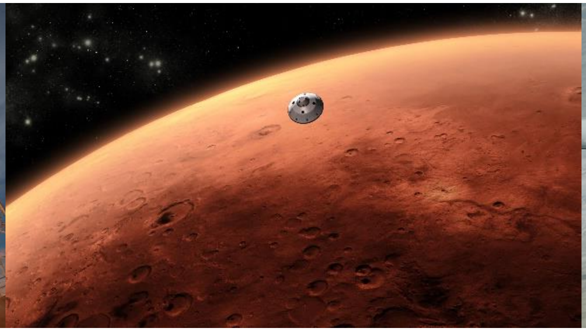
Mentors: Manan Vyas, John Slater, Will Banks

With lots of ***Tecplot help*** *from* ***Marco Gomez Fierro***

About Myself

- Last semester of Master’s at Georgia Tech
- Researching Turbulent structures in Supercritical mixing layers (reacting/non-reacting)
- I like Soccer, Formula 1 and Rockets






Outline

1. SUPIN-Vulcan-CFD Sketch-2-Solution (S2S) workflow
2. Inlet Analysis
   - Axisymmetric Pitot Inlet (K1)
   - Axisymmetric Spike Inlet (K3)
   - Streamline traced Inlet (K5)
3. Burrows and Kurkov Reacting Flow Case
4. Summary

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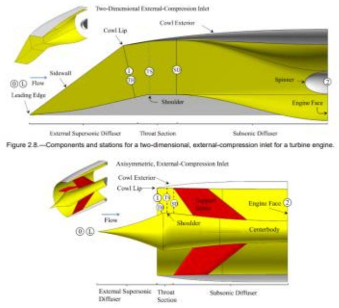
Workflow I developed over the summer

1. SUPIN → 2. ESP → 3. S2S → 4. Vulcan → 5. Solution

"Supersonic Inlet Design and Analysis Tool"

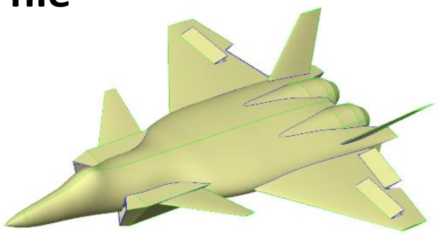
Application developed by John Slater to perform geometric modeling and aerodynamic design and analysis of inlets



"Engineering Sketch Pad"

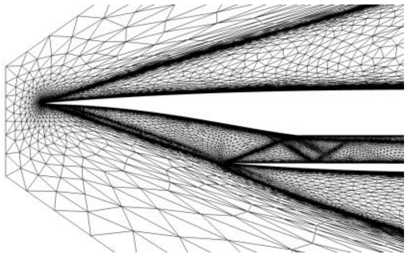
Geometry creation system to support design of aerospace vehicles.

Useful because it allows us to create a **CAD file from a text file**



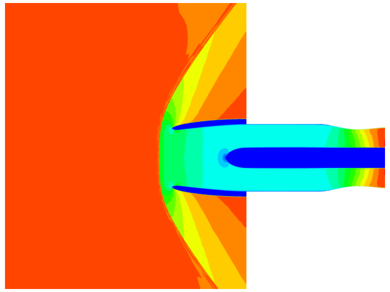
"Sketch-2-Solution"

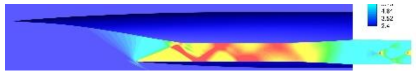
NASA's **adaptive grid** generation Methodology

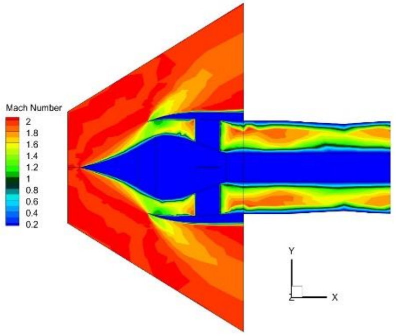


NASA's Hypersonic CFD solver

Solutions as Validation of the workflow







Step 1: SUPIN

1. SUPIN → 2. ESP → 3. S2S → 4. Vulcan → 5. Solution

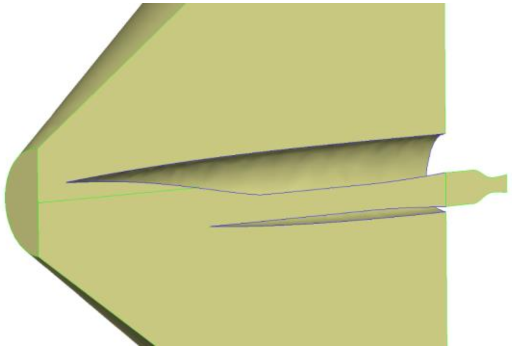
Freestream
External supersonic diffuser
Cowl
Throat Section
Subsonic Diffuser
Struts and more

→ SUPIN →

Results
Surfaces grids
Coordinates

- Pitot Inlets (K1) ☆
- Two-dimensional Inlets (K2)
- Mixed compression Inlets (K3) ☆
- Streamline traced Inlets (K5) ☆





Step 2: Engineering Sketch Pad

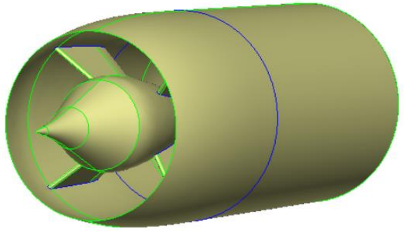
1. SUPIN → **2. ESP** → 3. S2S → 4. Vulcan → 5. Solution

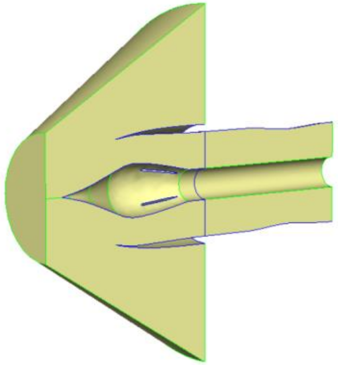
.csm files:

Lists of instructions for construction of geometry

CAD

- **Inlet Geometry**
- **Simulation Domain**





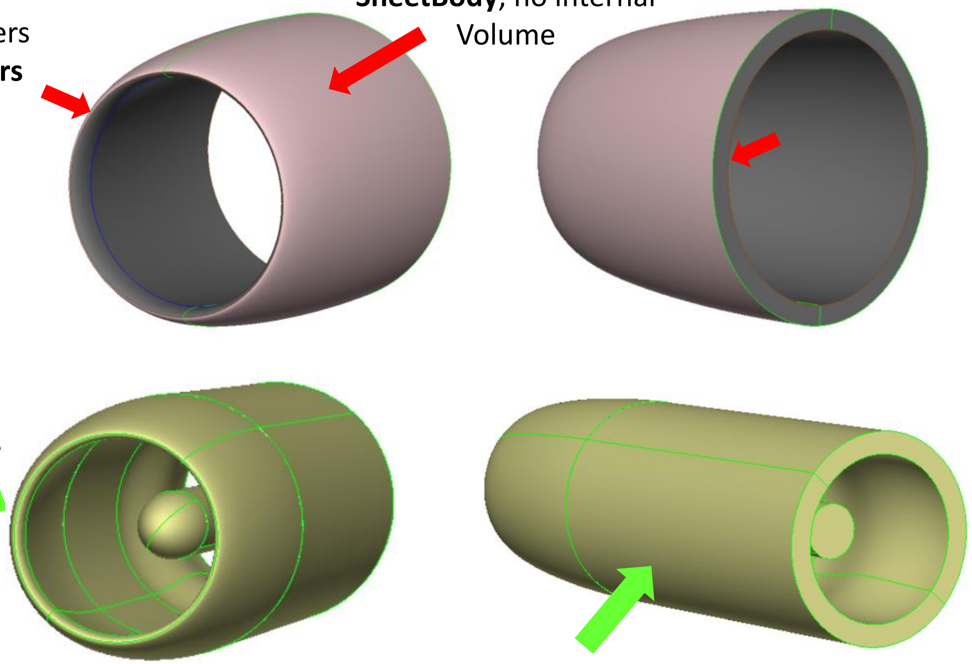
- The inlet Geometry is created so that the user may **visualize** the inlet Geometry
- The Simulation creates a **fluid body**. It takes advantage of the axis of symmetry to lower the computational cost of the simulation. A thin slice of this domain would be cheaper to simulate but 180^{o} necessary to investigate non-zero angles of attack

Step 2: Engineering Sketch Pad

1. SUPIN → **2. ESP** → 3. S2S → 4. Vulcan → 5. Solution

Pink Surface indicates a **SheetBody**, no internal Volume

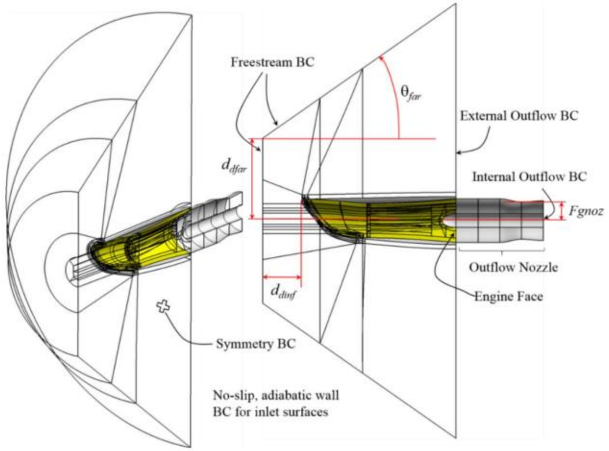
Orange borders indicate **errors**



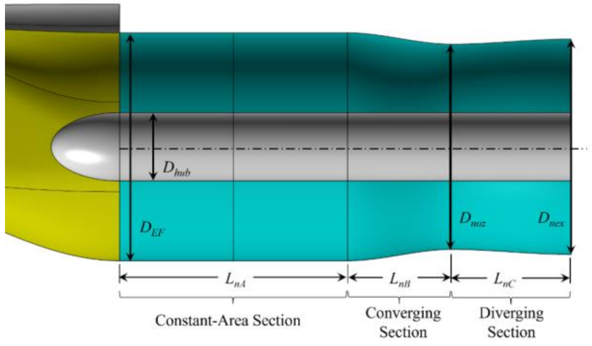
Green lines indicate **no errors**

Yellow Surfaces indicate SolidBodies

Simulation Domain CONE

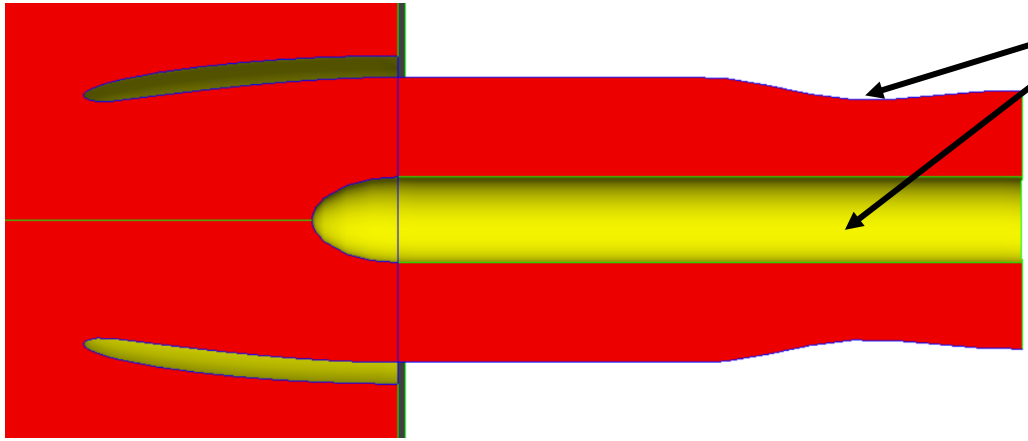


Nozzle Extension



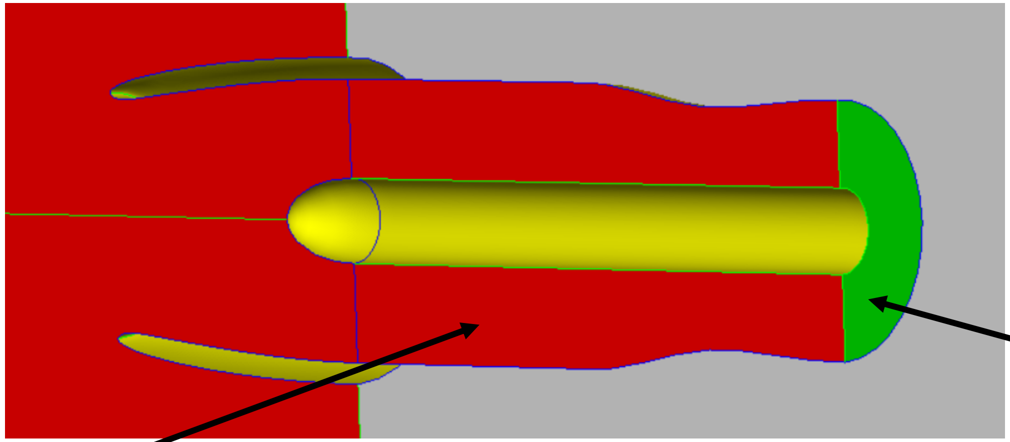
Dimensions specified in SUPIN **input file**

ESP geometries: Axisymmetric Pitot Inlet (K1)



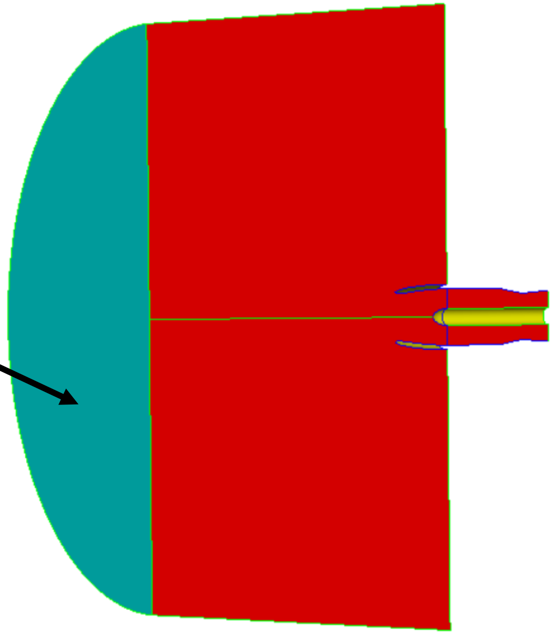
No-Slip wall (Wall Function)

Freestream Reference conditions



Extrapolation / $\dot{m}_{\text{out}}$

Symmetry

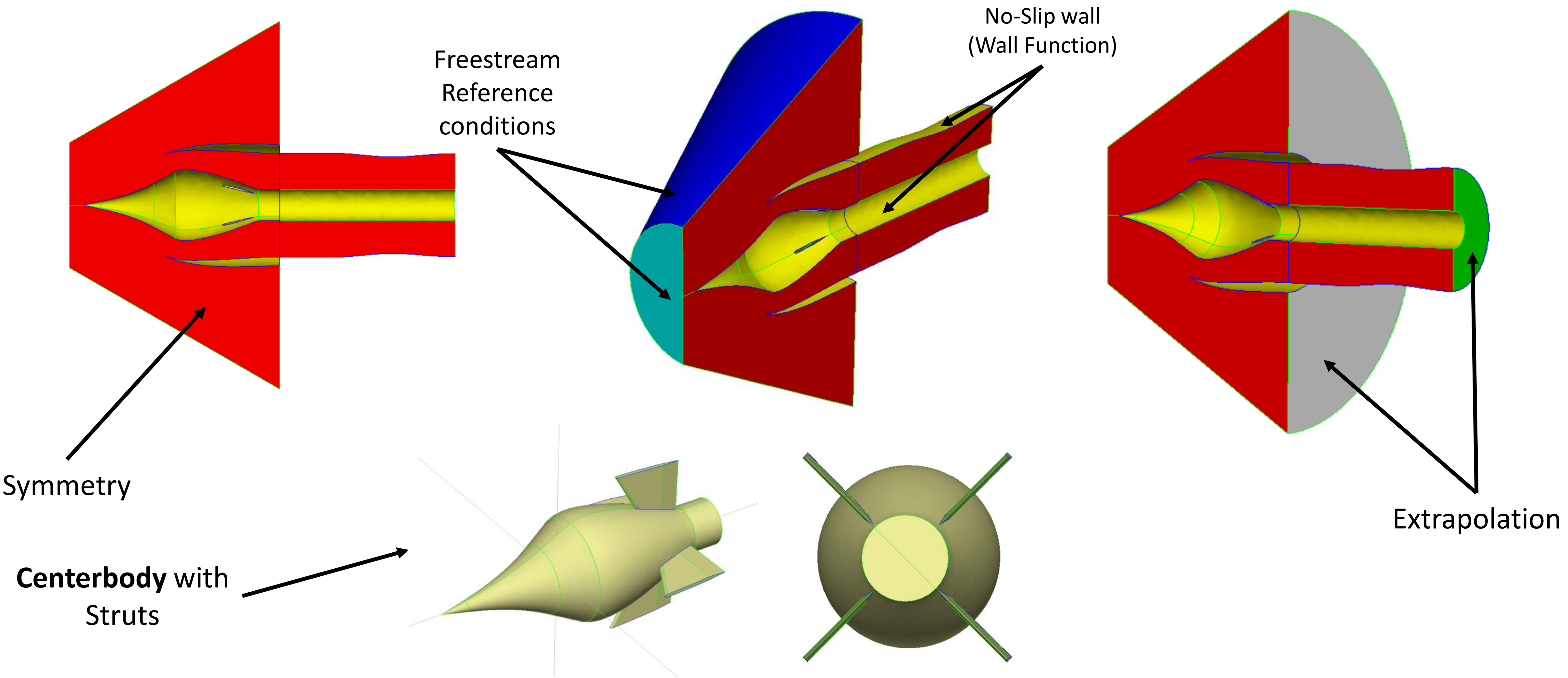


Revolution of a

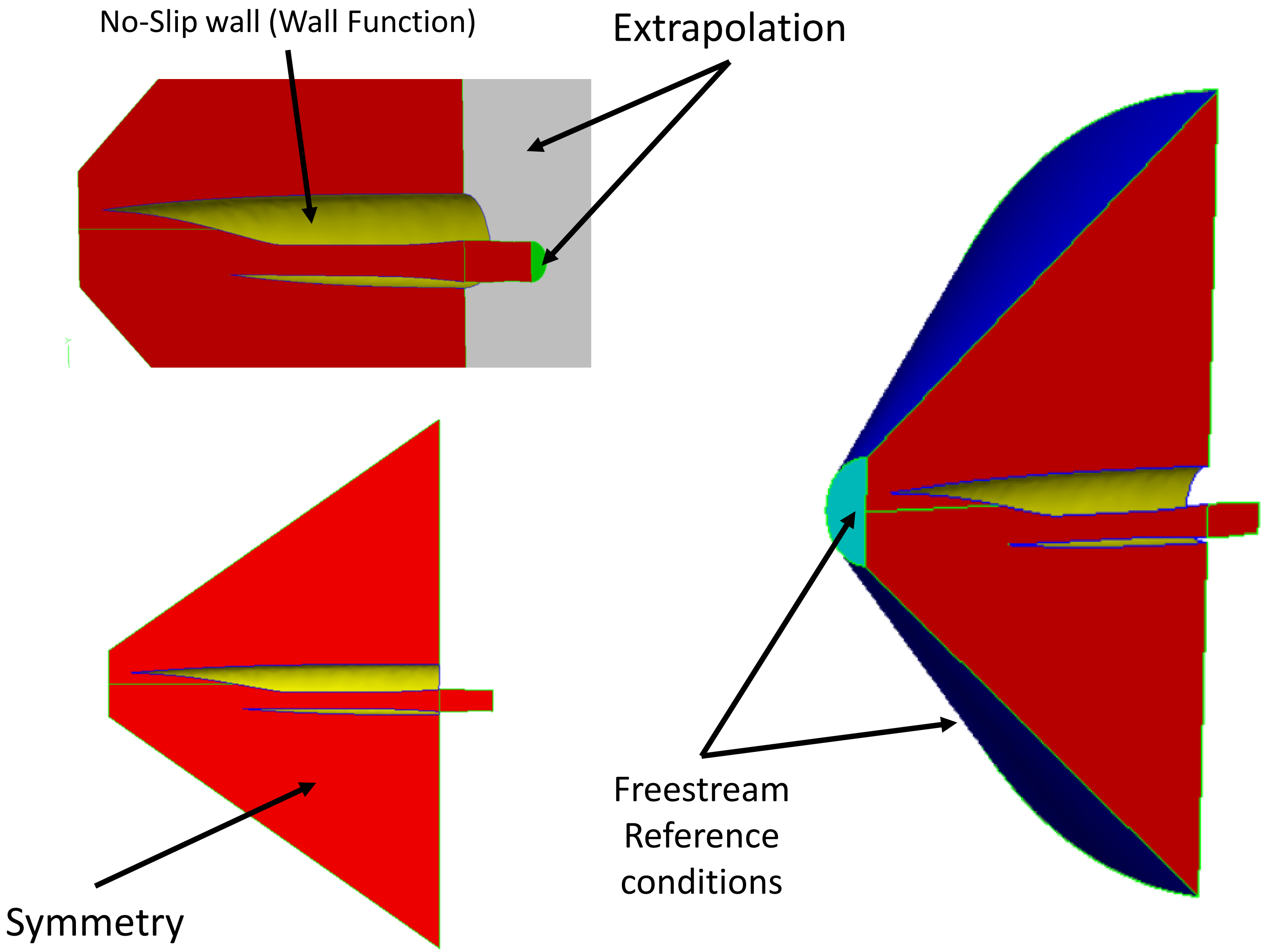
List of Spline points strategy

```
SKEND
REVOLVE 0 0 0 1 0 0 180
ROTATEX 180 0 0

UNION
store CFDdomain

    PATBEG i 2
      SKBEG    0.000647    1.781266   0.0
      # COWL lip exterior profile
        SPLINE      0.000624     1.781256     0.0
        SPLINE      0.000538     1.781218     0.0
        SPLINE      0.000460     1.781178     0.0
        SPLINE      0.000389     1.781137     0.0
        SPLINE      0.000323     1.781094     0.0
        SPLINE      0.000263     1.781050     0.0
        SPLINE      0.000208     1.781005     0.0
        SPLINE      0.000159     1.780959     0.0
        SPLINE      0.000115     1.780912     0.0
        SPLINE      0.000076     1.780862     0.0
        SPLINE      0.000044     1.780812     0.0
        SPLINE      0.000018     1.780760     0.0
        SPLINE      -0.000001     1.780707     0.0
        SPLINE      -0.000010     1.780653     0.0
        SPLINE      -0.000010     1.780601     0.0
        SPLINE      0.000000     1.780552     0.0

     # COWL Lip interior Profile
        SPLINE      0.000000     1.780552     0.0
        SPLINE      0.000019     1.780506     0.0
        SPLINE      0.000049     1.780463     0.0
        SPLINE      0.000087     1.780424     0.0
        SPLINE      0.000132     1.780390     0.0
        SPLINE      0.000183     1.780361     0.0
        SPLINE      0.000239     1.780337     0.0
        SPLINE      0.000299     1.780318     0.0
```

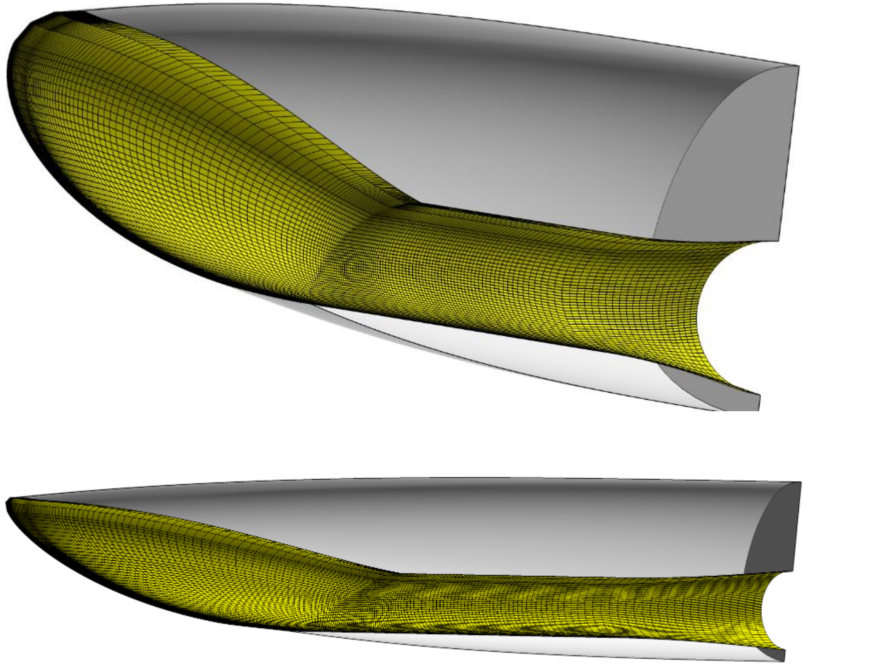
ESP Geometries: Axisymmetric Spike Inlet (K3)



ESP Geometries: Streamline Traced Inlet (K5)



Importing SUPIN point cloud files strategy

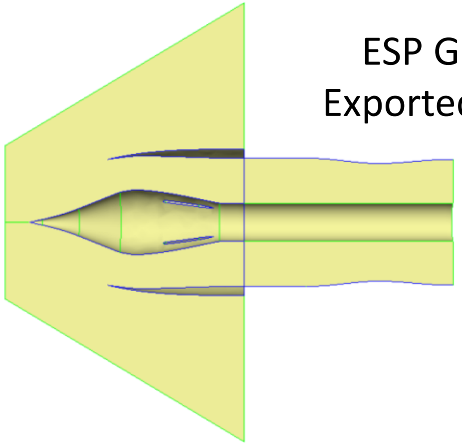


Step 3: Sketch-2-Solution

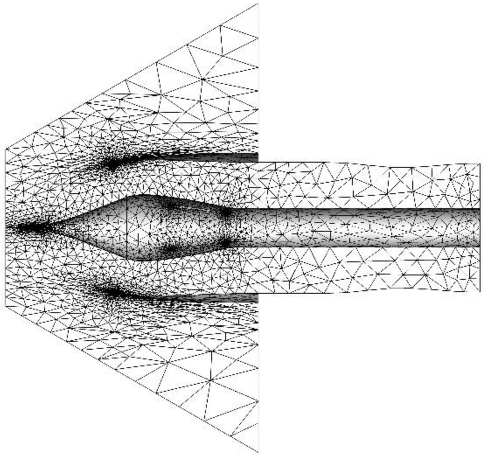
1. SUPIN → 2. ESP → 3. S2S → 4. Vulcan → 5. Solution

initial_complexity = 2e4
max_grid_iterations = 15-30
complexity_multiplier = 2

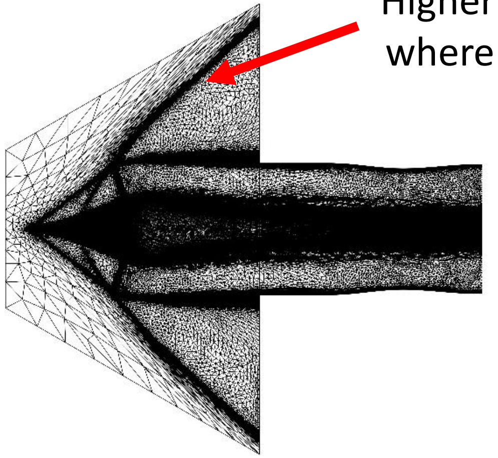
adapt.input



ESP Geometry
Exported as .egads



1st Grid

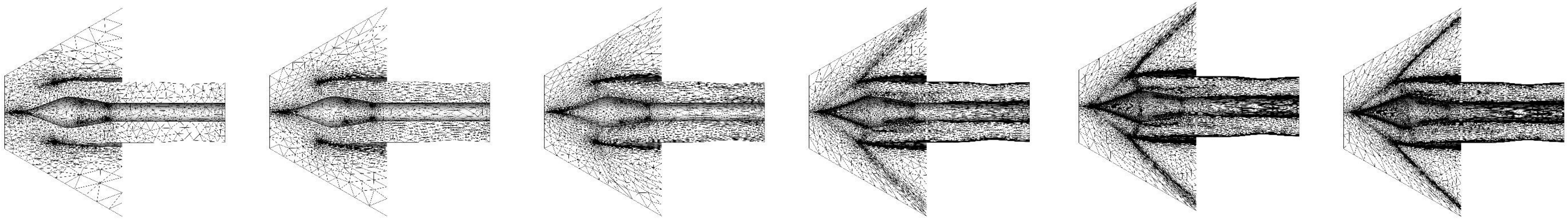


Higher resolution
where necessary

21st Grid

S2S: Grid Refinement Process

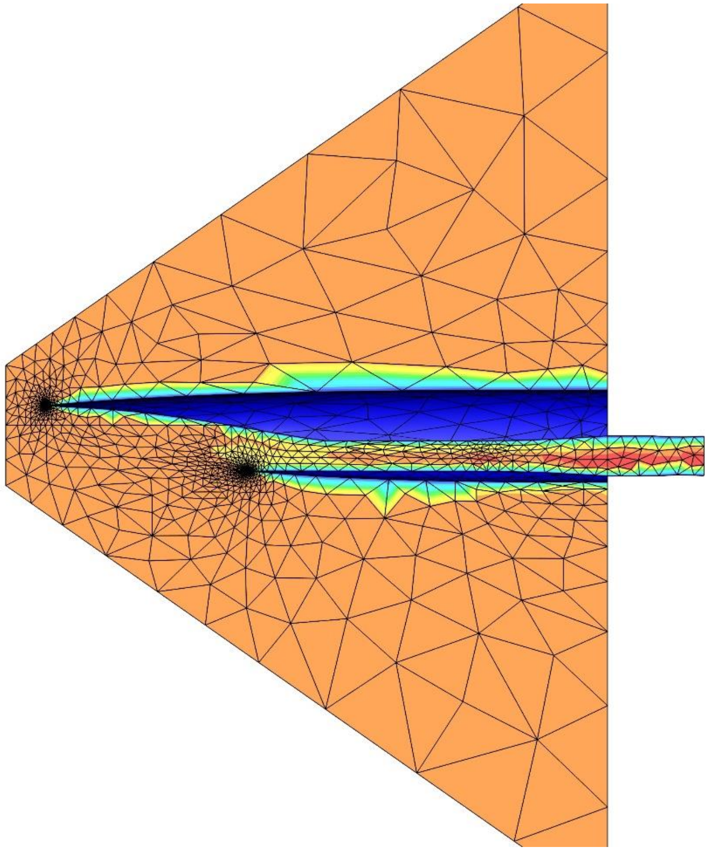
1. SUPIN → 2. ESP → 3. S2S → 4. Vulcan → 5. Solution



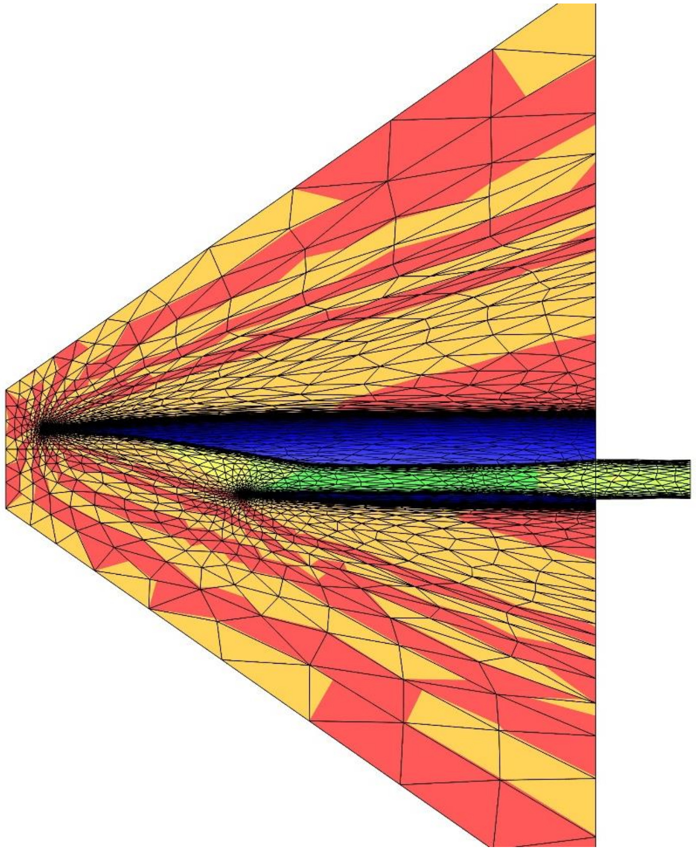
1st	2nd	3rd	6th	7th	9th
Complexity	Complexity	Complexity	Complexity	Complexity	Complexity
↓	↓	↓	↓	↓	↓
2,051,262	733,716	739,318	1,030,710	1,486,337	1,564,325

Grid Adapting to Flowfield

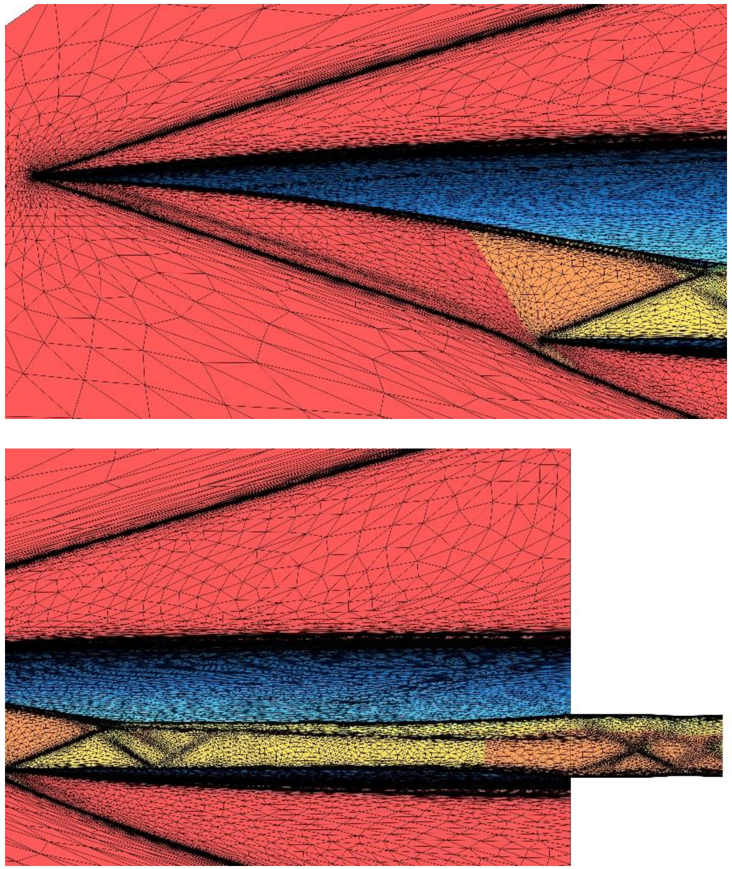
1st



15st



30th



Solution not well defined at end of grid iterations 1 and 15. At iteration 30, the grid has become more refined in the locations of shocks, capturing all flow features

Step 4: Vulcan Solver

1. SUPIN → 2. ESP → 3. S2S → 4. Vulcan → 5. Solution

- **Vulcan Input File:**
  - Selecting appropriate BCs
  - Selecting appropriate CFL Schedule
- **Difficulties encountered:**
  - CFL number ramp: Had to use **very low CFL (≈0.5)** to avoid simulation crash
  - Some simulations not fully converged as of the making of this presentation.

Workflow I developed over the summer

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1. SUPIN-Vulcan-CFD Sketch-to-solution (S2S) workflow

2. Inlet Analysis

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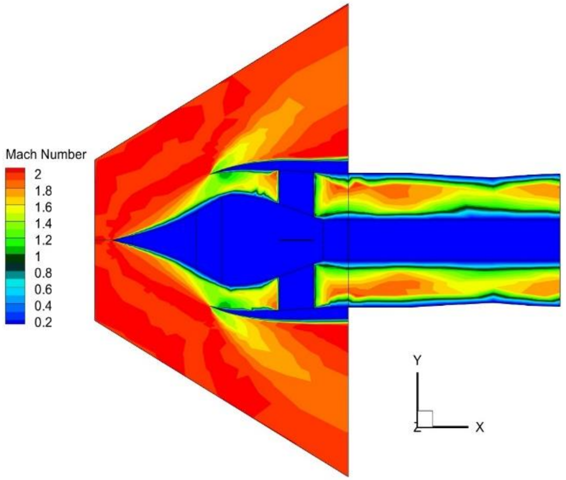
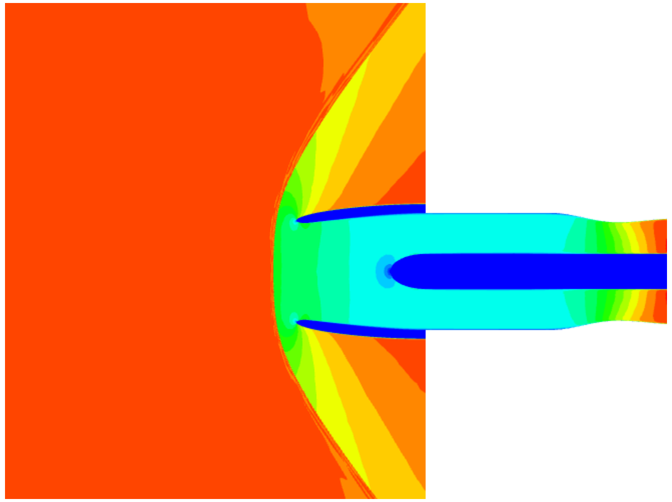
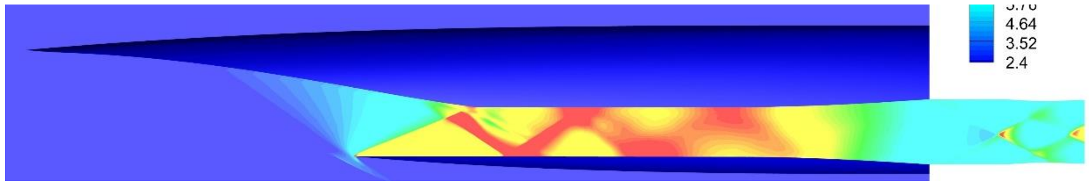
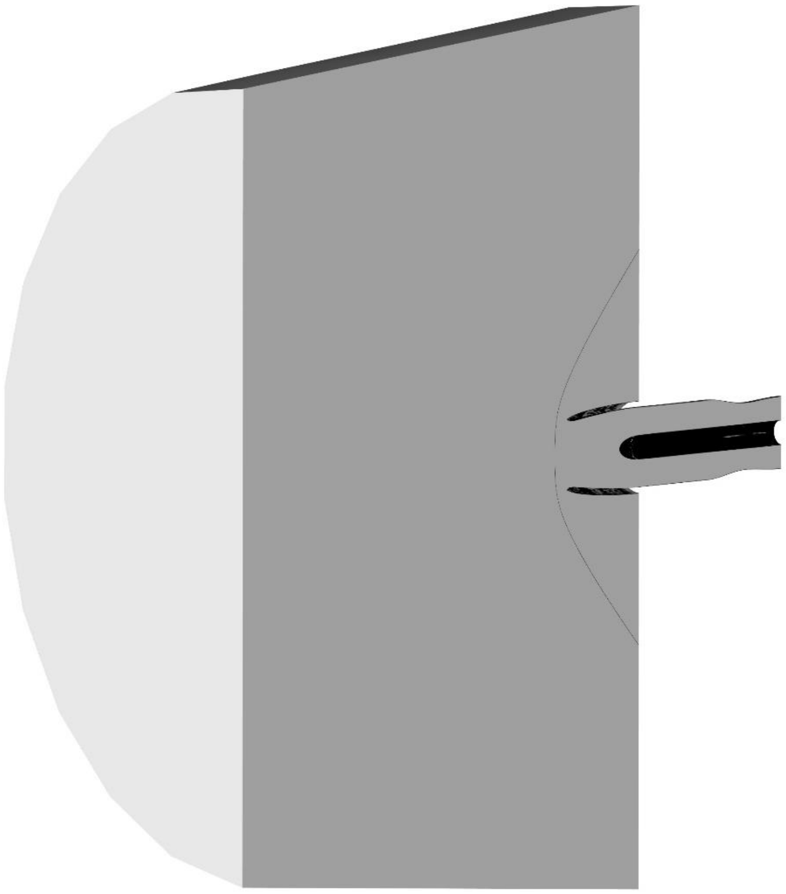




3. Burrows and Kurkov Reacting Flow Case

4. Summary





Axisymmetric Pitot Inlet

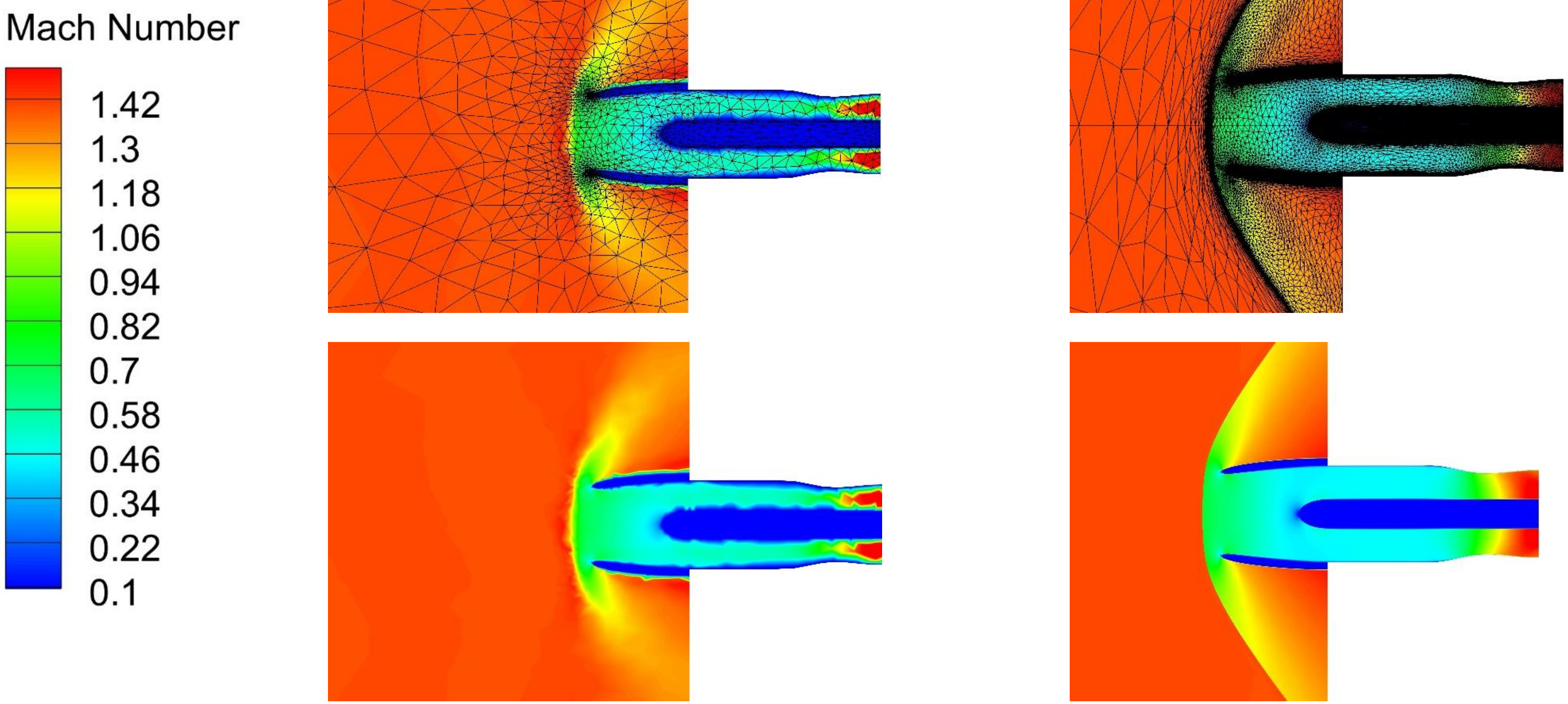
- **Mach = 1.4**
- **Altitude = 50,000 ft**

Equations for Schlieren images by Marco Gomez Fierro

Grid Adapting to Flowfield

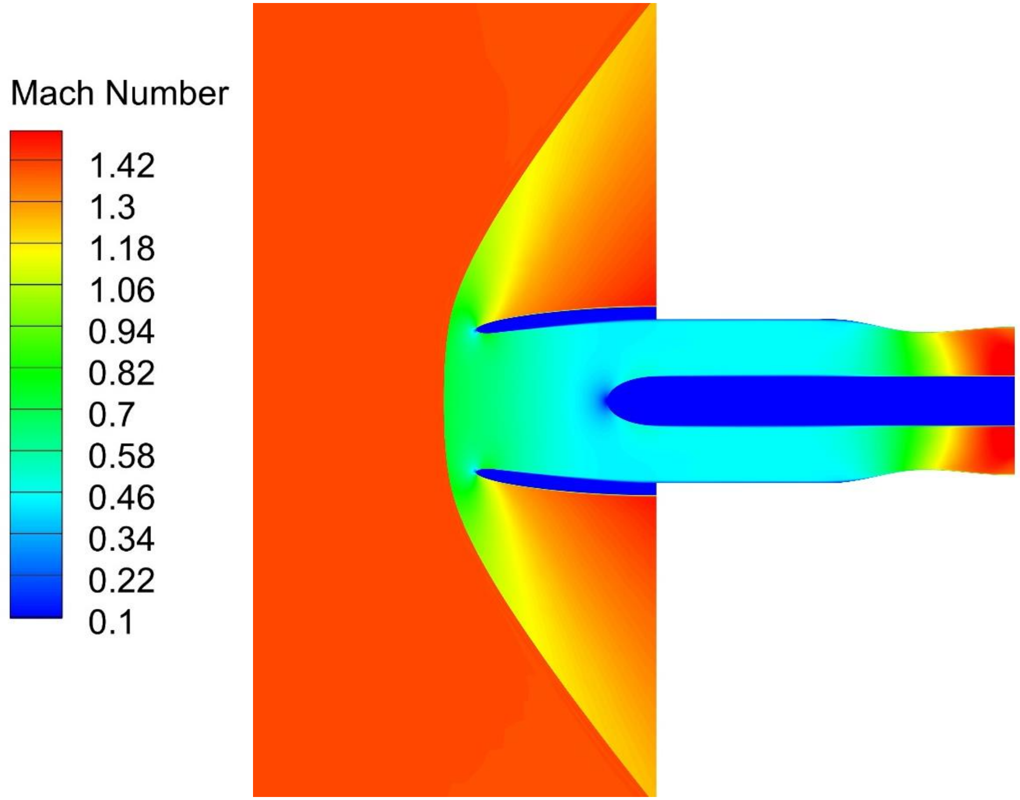
1ST GRID ITERATION

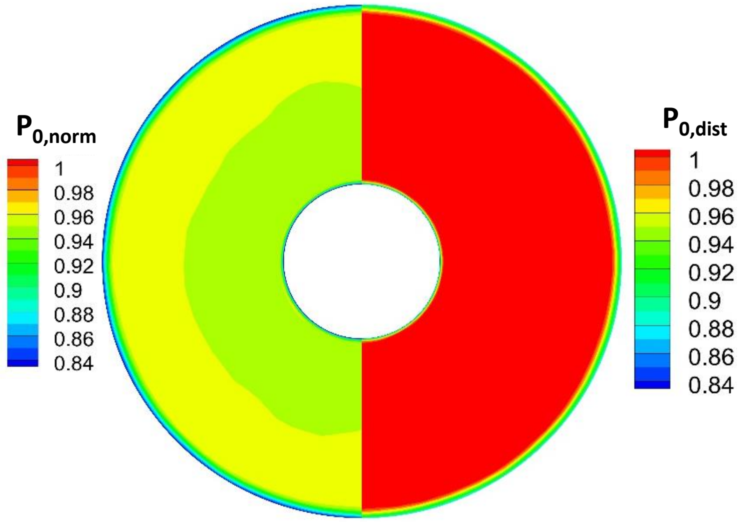
30TH GRID ITERATION



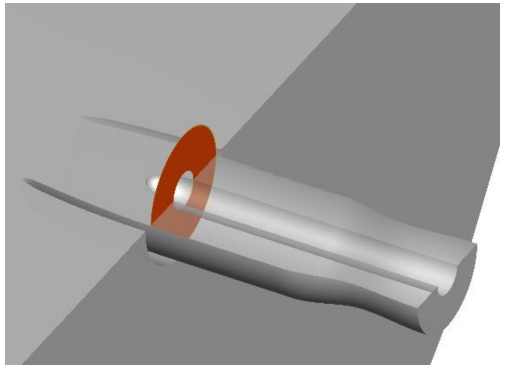
Grid adaptation of 30th grid iteration id **aligned** with the **bow shock** leading edge, allowing **flow features** to be resolved more **accurately**

Axisymmetric Pitot Inlet at D_{th}/D_{AIP} = 0.95



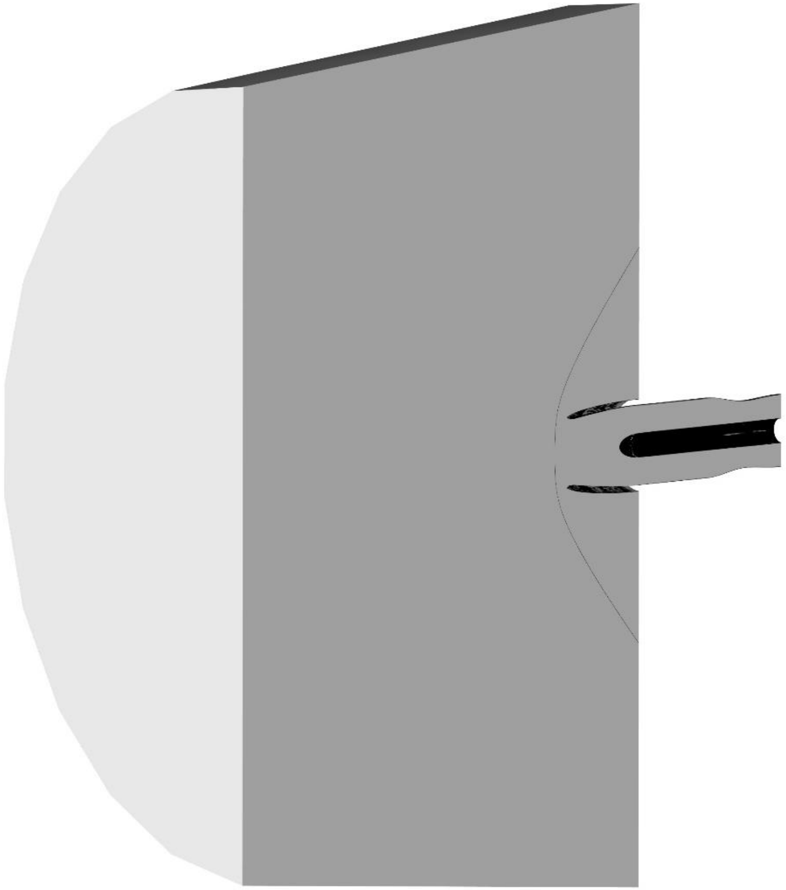


AIP plane Location



- $P_{0,norm} = \frac{P0_{AIP}}{P0_{\infty}}$
- $P_{0,dist} = \frac{P0_{AIP}}{\overline{P0_{AIP}}}$

Throat area is too small and causes the inlet to be in subcritical state. *Total* pressure is uniform at AIP plane and Pressure recovery is around 95%.

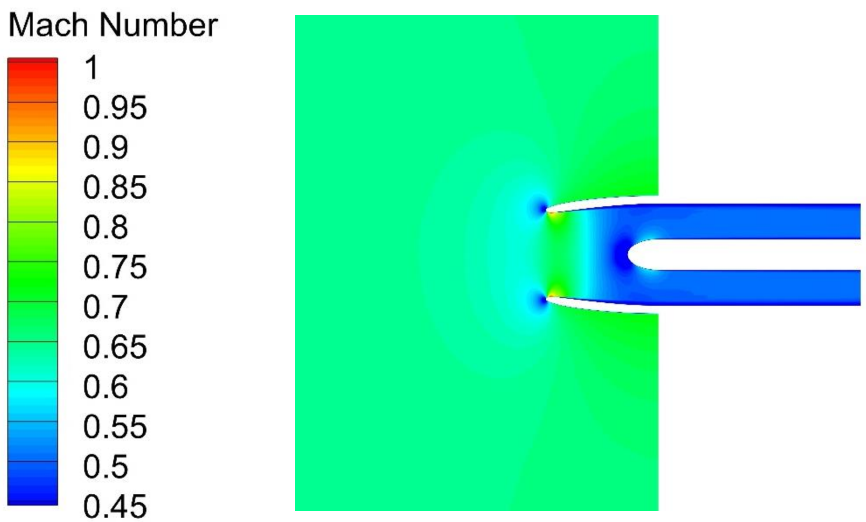


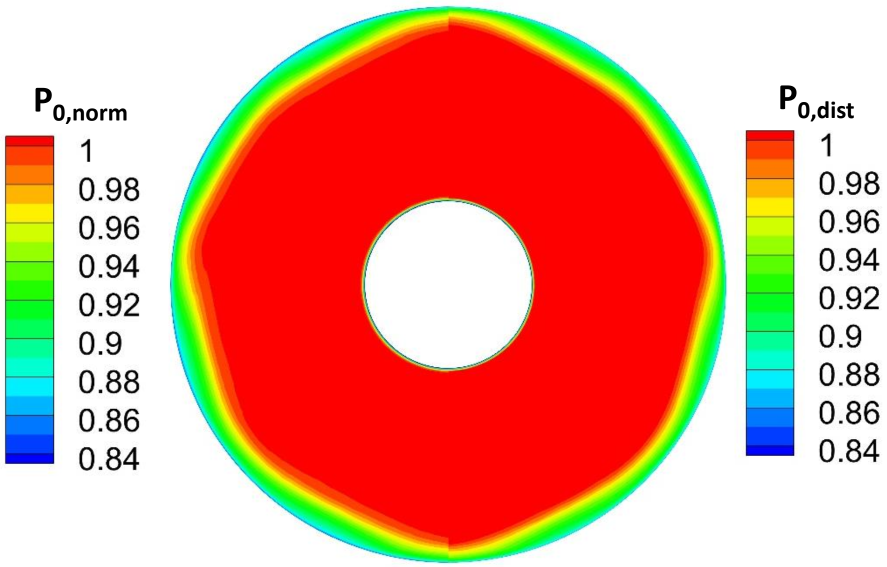
Axisymmetric Pitot Inlet

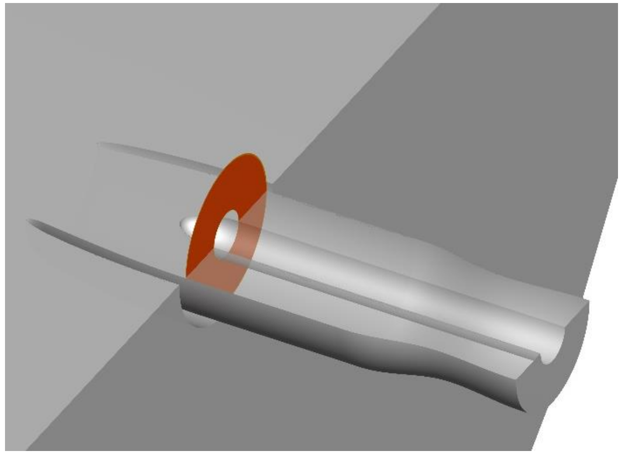
- **Mach = 0.65**
- **Altitude = 50,000 ft**

Equations for Schlieren images by Marco Gomez Fierro

Pitot Inlet Subsonic Flow (Throat Absent)



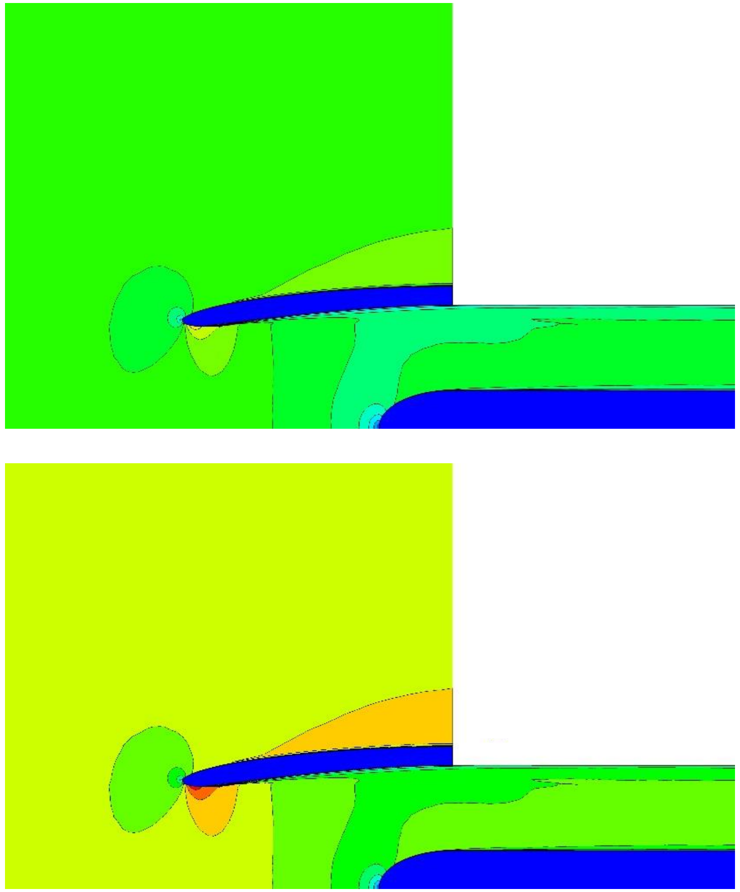




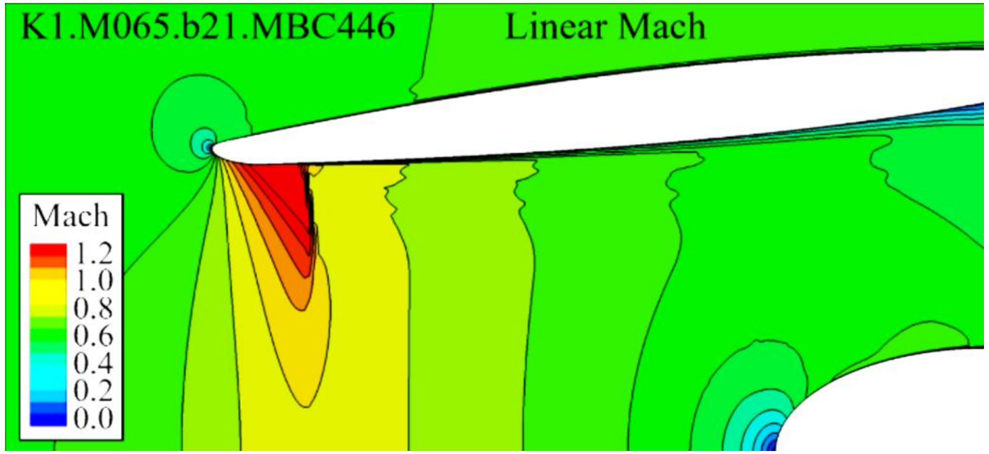
- $P_{0,norm} = \frac{P0_{AIP}}{P0_{\infty}}$
- $P_{0,dist} = \frac{P0_{AIP}}{\overline{P0_{AIP}}}$

The outflow boundary condition of mass flow out is set to obtain an outflow Mach Number of 0.5, which was correctly implemented. The nozzle throat is absent. Total pressure at the is uniform and about the same as the freestream pressure

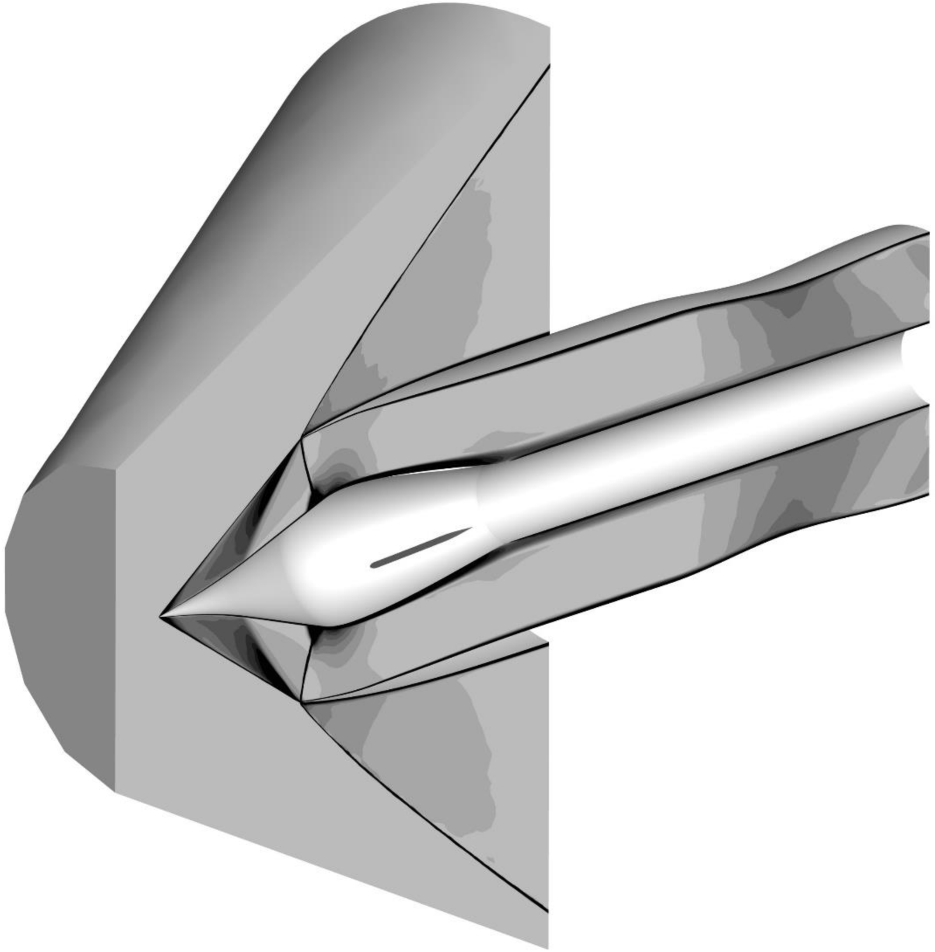
Vulcan



Wind-US



The resulting contour plots are **similar** to the ones obtained form **Wind-US**. A possible cause of discrepancy could be the **different geometry** of the **cowl profile**

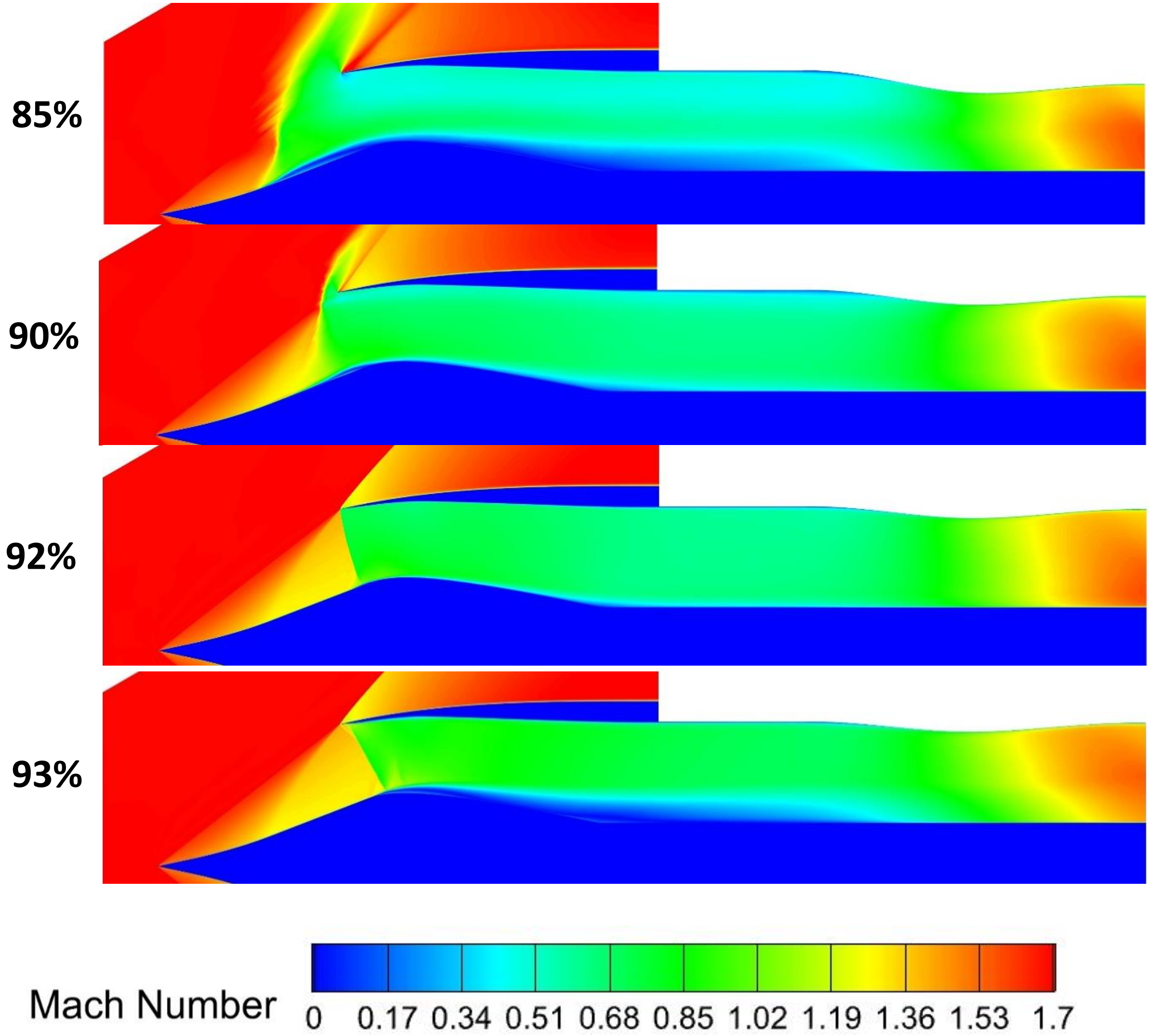


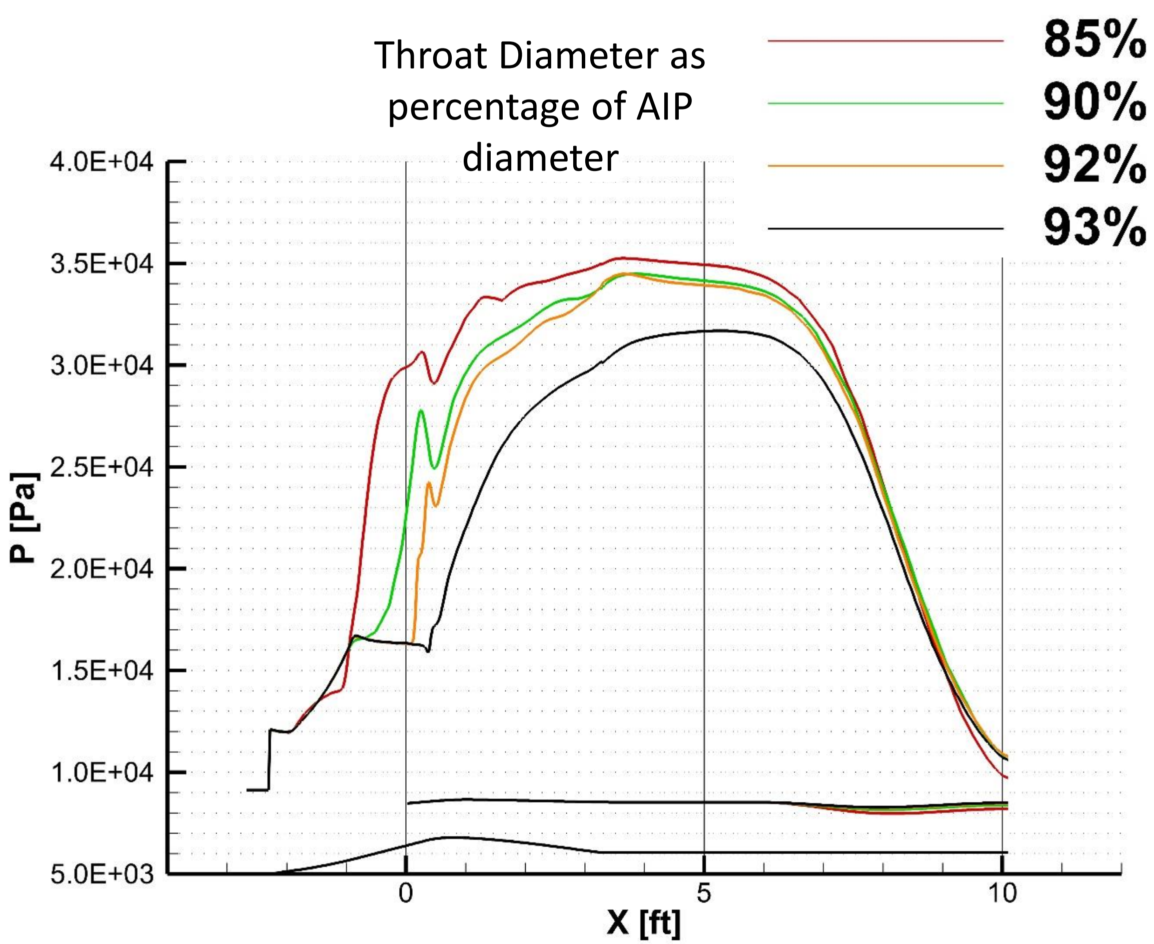
Axisymmetric Spike Inlet

- Mach = 1.7
- Altitude = 55,000 ft

Equations for Schlieren images by Marco Gomez Fierro

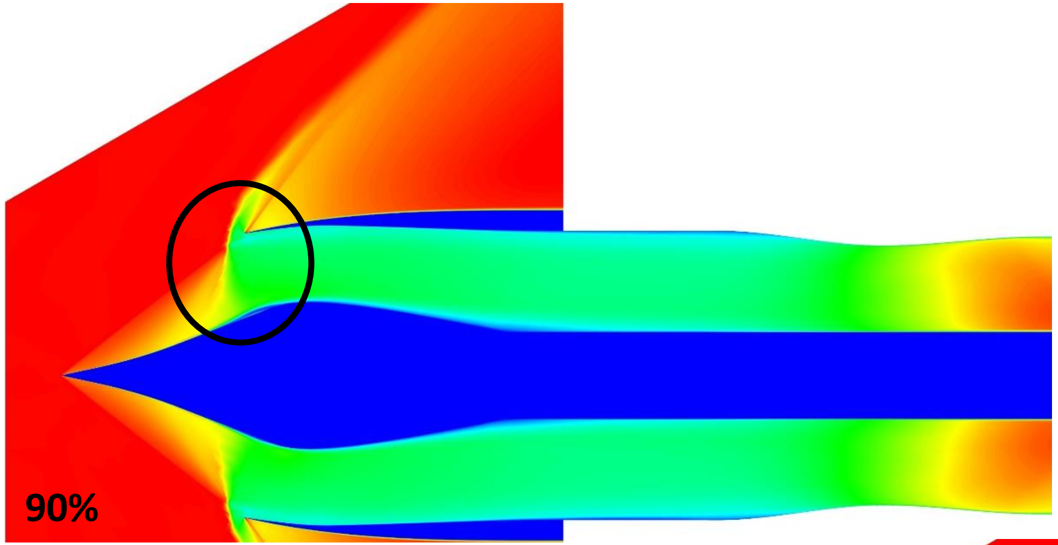
Mach Number and Centerbody Wall Pressure



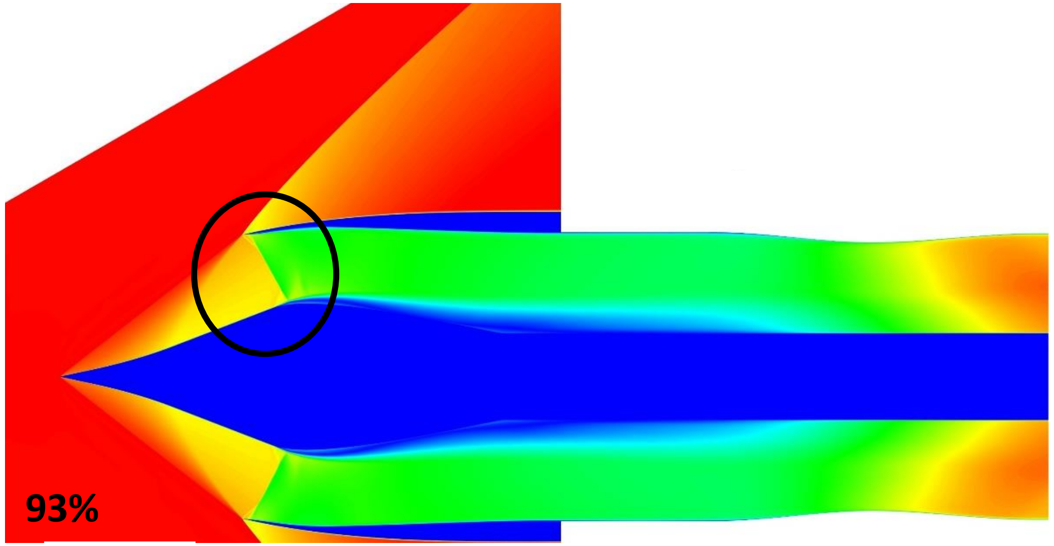


Below **92% D_{th}/D_{AIP} ratio** inlet is in subcritical state

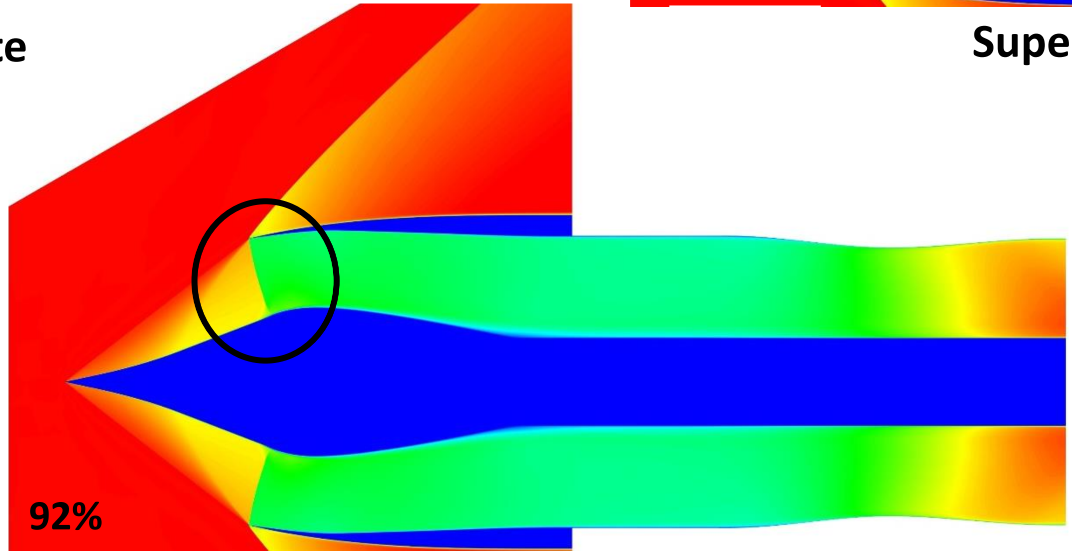
Backpressuring to change location of normal shock



Subcritical State



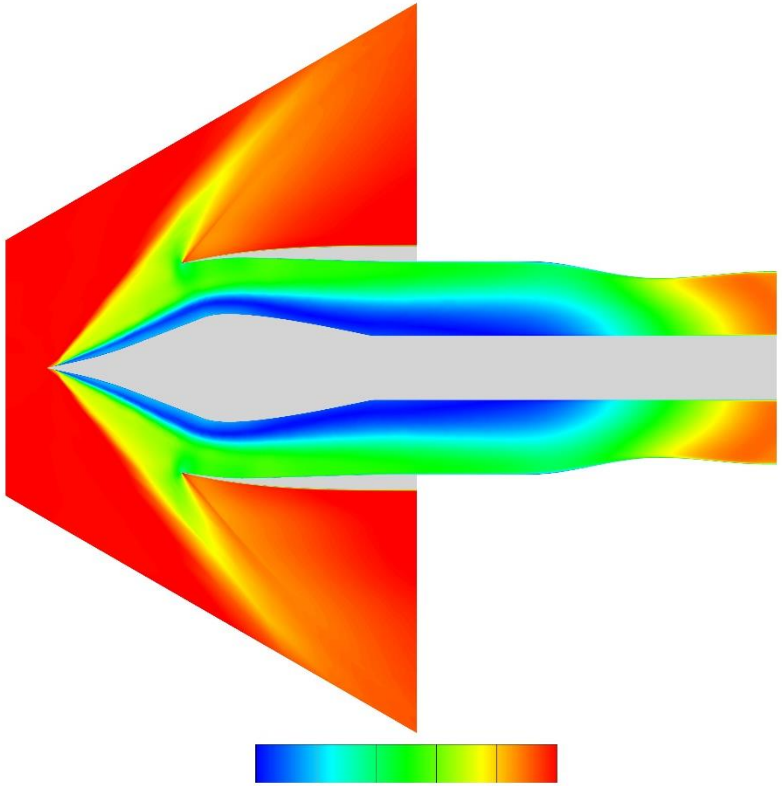
Supercritical State

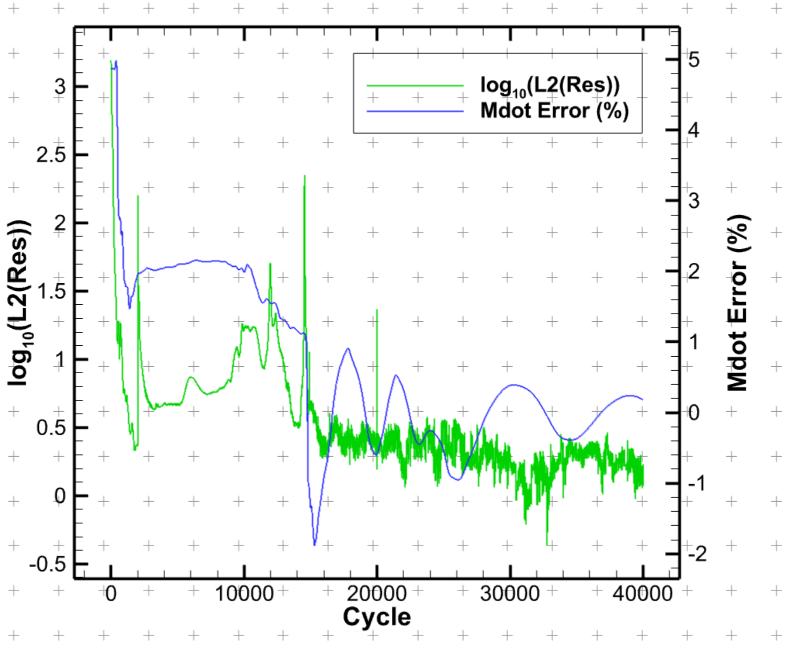


Shock at Design Point

This demonstrates how modifying the nozzle throat diameter can change the location of the normal shock. A **D_{th}/D_{AIP} ratio of 0.92 places the shock at the design point.**

Updated K385 case

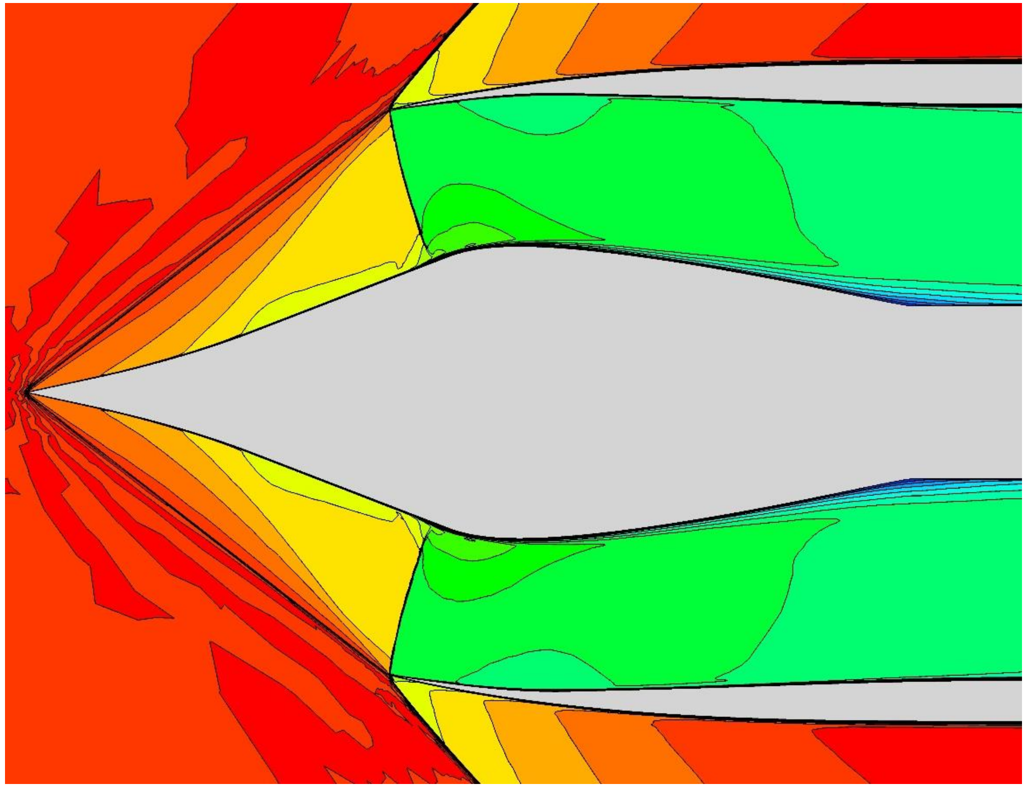




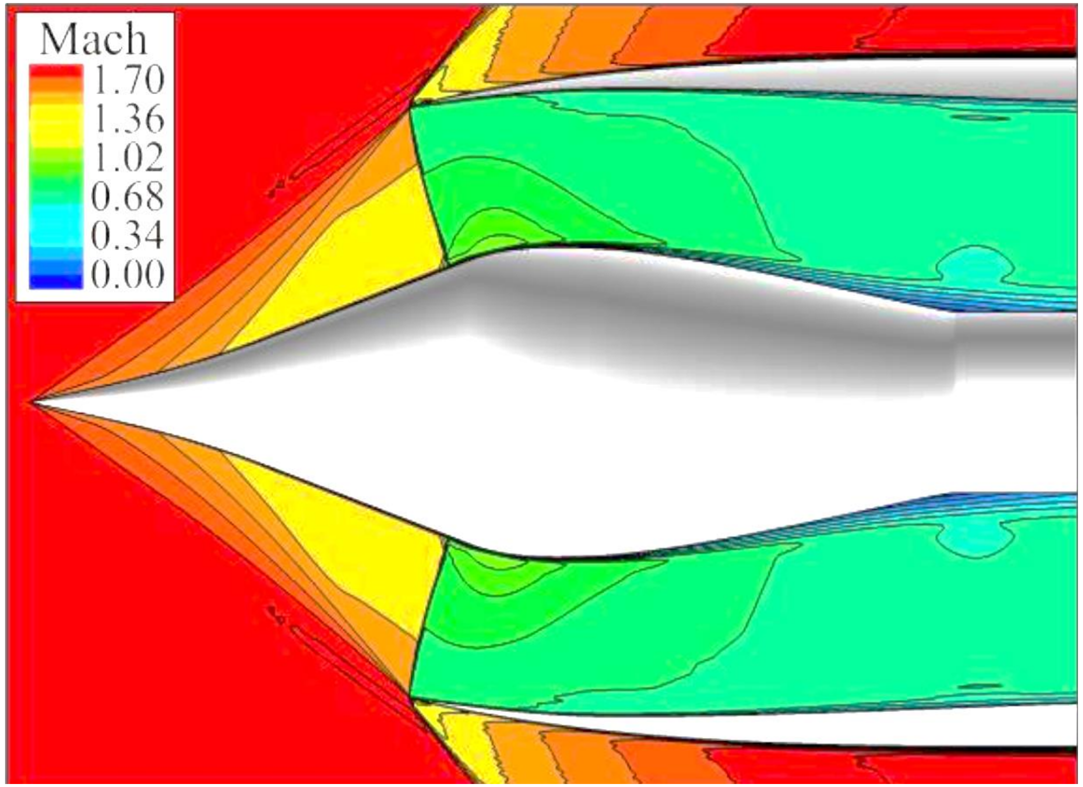
The day after this presentation was given, the K385 case was run up to 40,000 iterations. The convergence plots showed oscillations. The inlet fully unstarted.

Comparing Wind-US to Vulcan

Vulcan

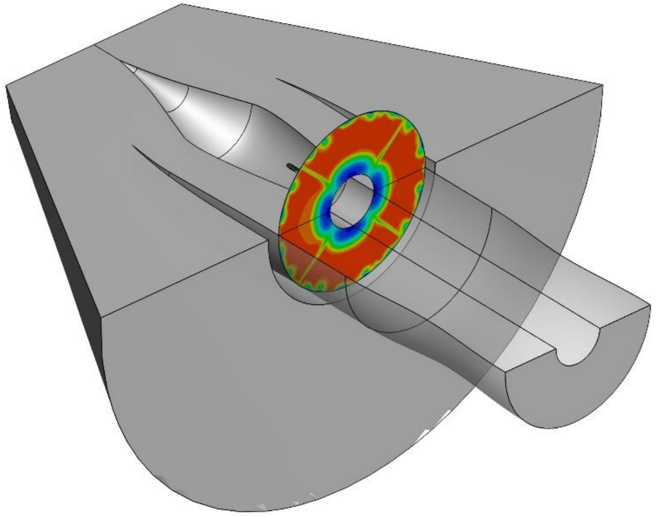


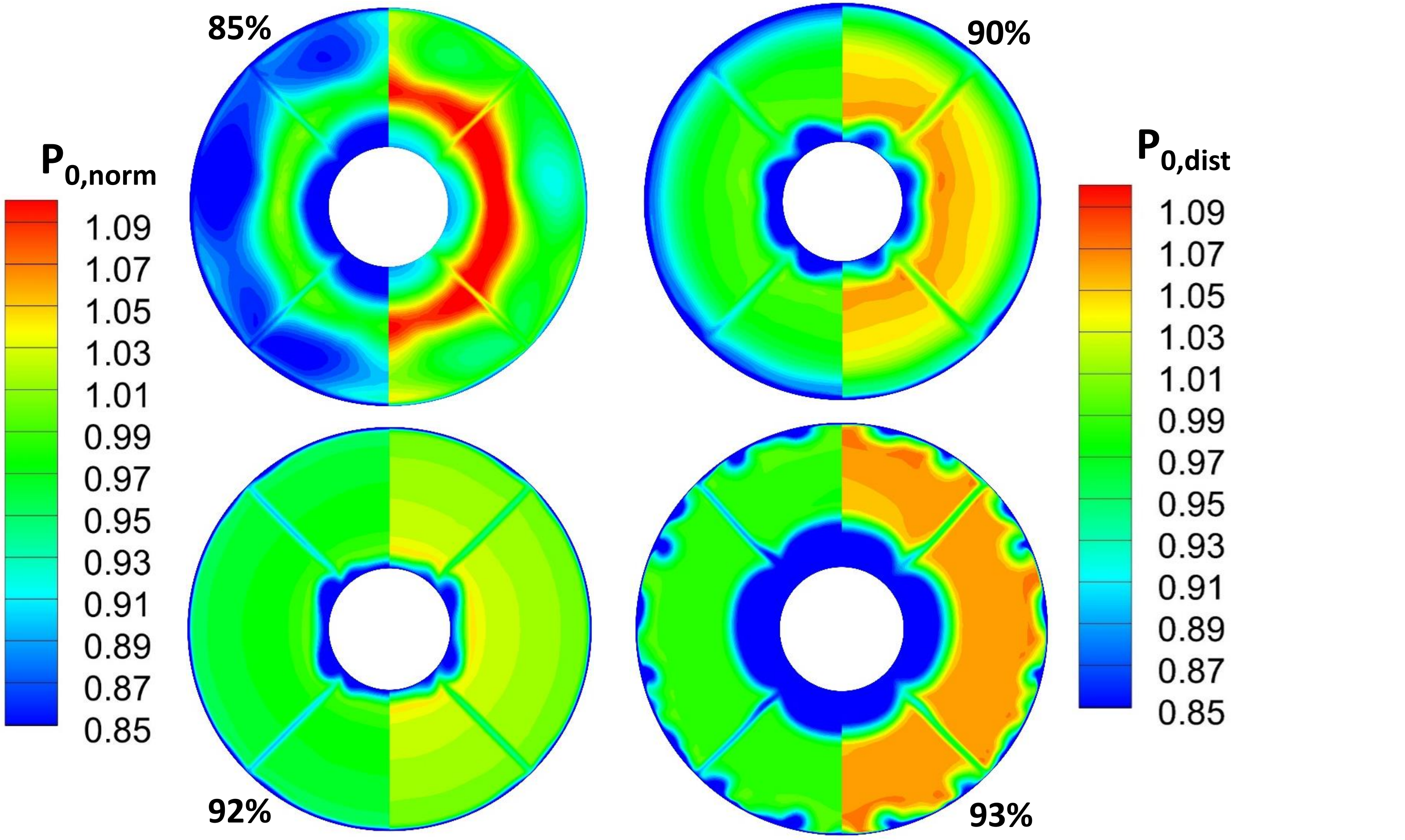
Wind-US



The flow field of the **Vulcan** Solution **accurately replicates** the one obtained with **Wind-US**, further **validating** the complete **workflow** from SUPIN to Vulcan

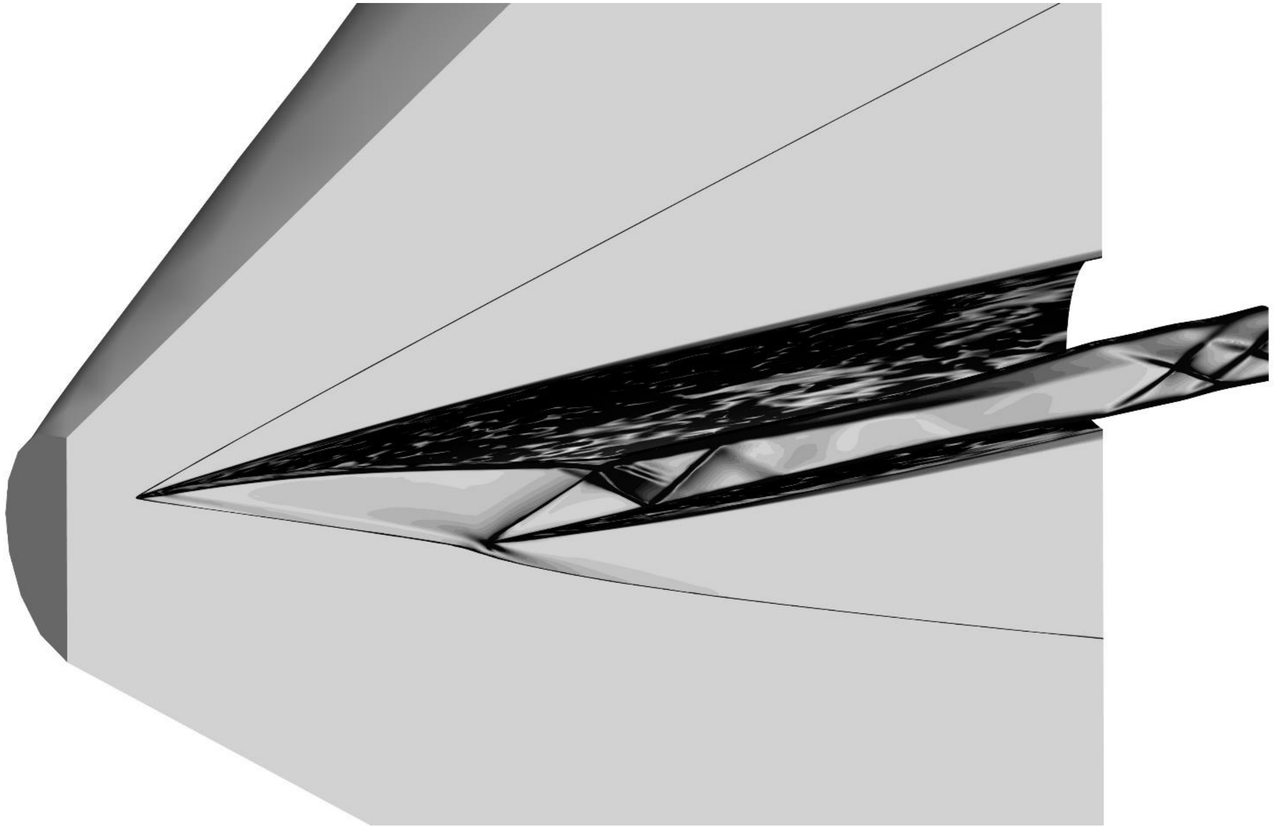
Pressure Recovery and Distortion Pattern Indicator at the AIP





- $P_{0,norm} = \frac{P0_{AIP}}{P0_{\infty}}$
- $P_{0,dist} = \frac{P0_{AIP}}{\overline{P0_{AIP}}}$

The effect of the struts is still present at the AIP plane and is reflected in the flow features in the BL. The Total pressure is most uniform at a **D_{th}/D_{AIP} ratio of 0.92**

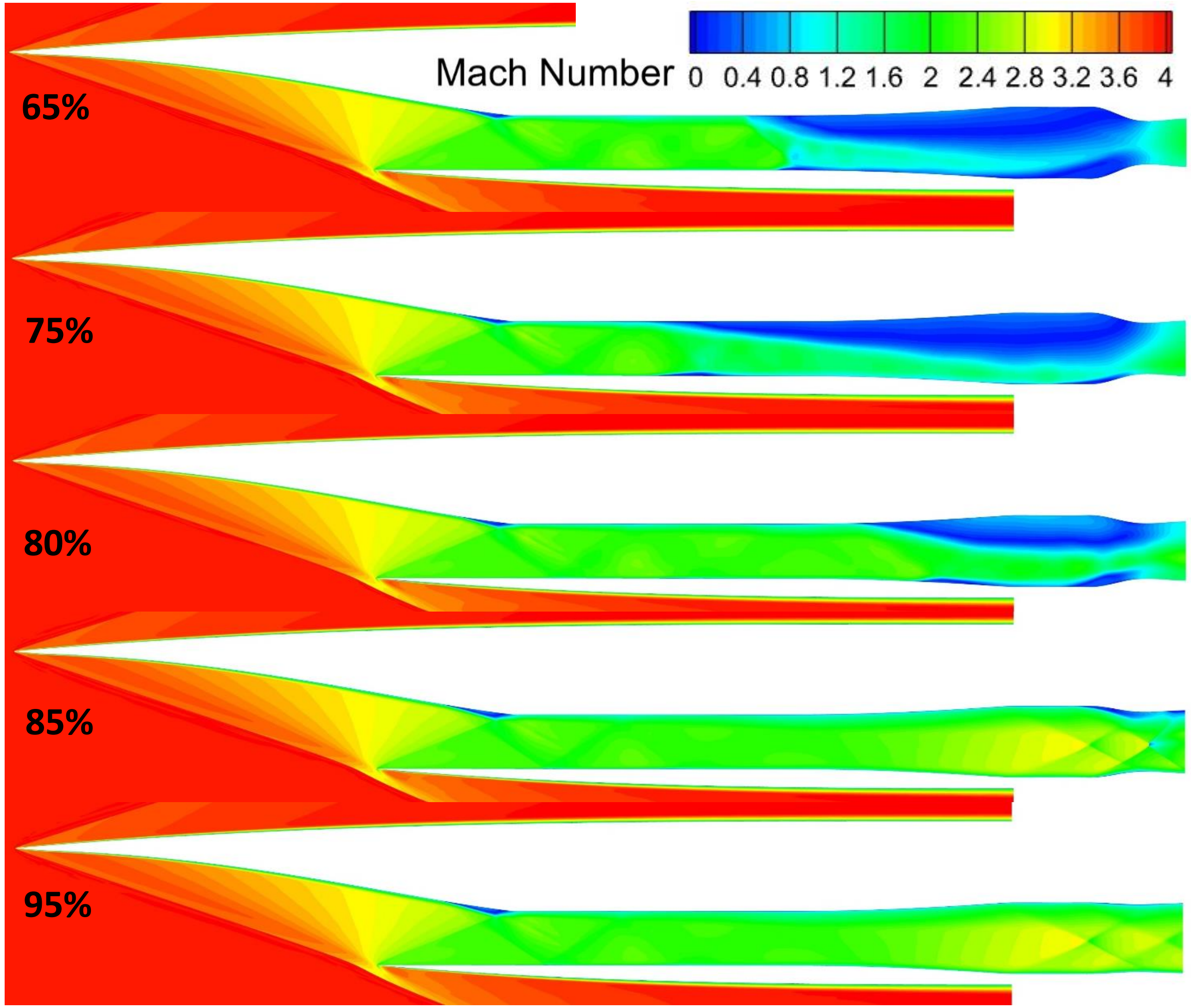


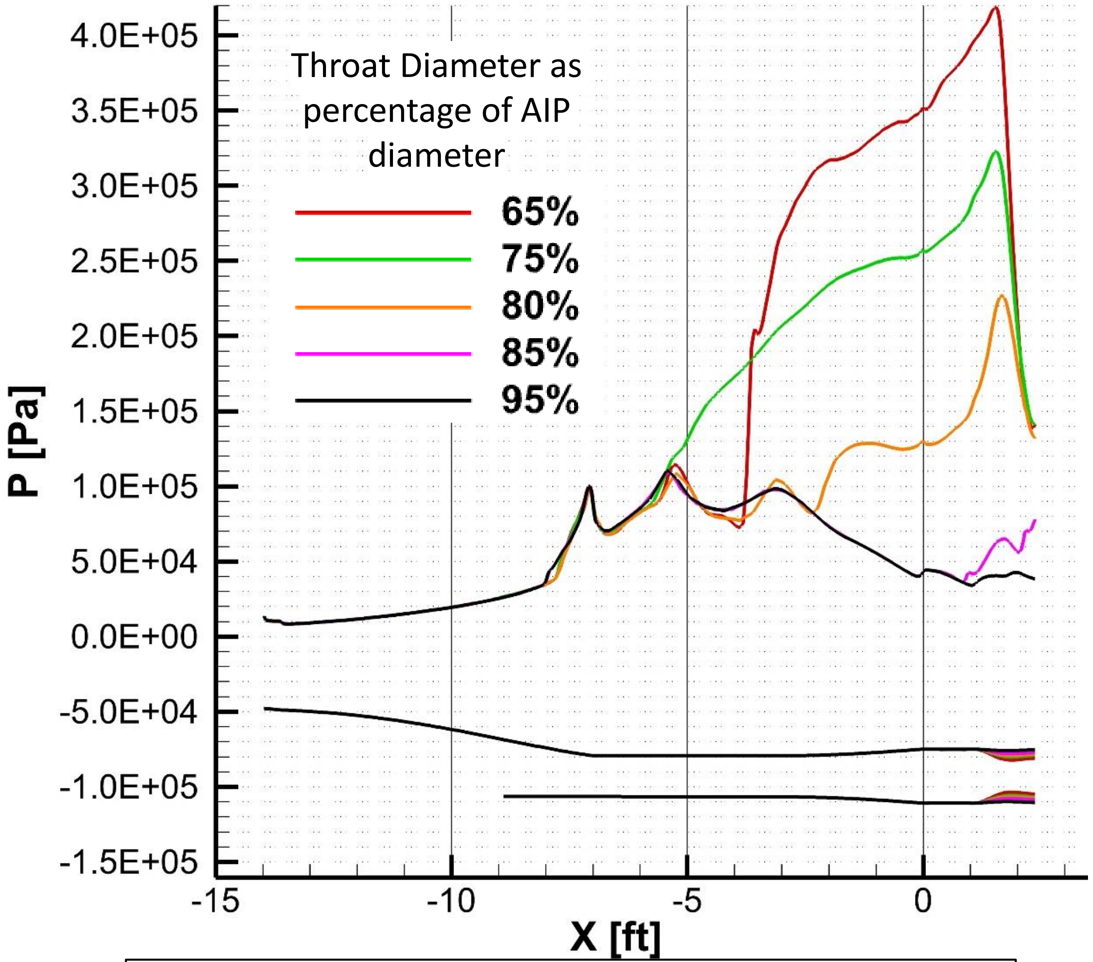
Streamline traced Inlet

- **Mach = 4**
- **Dynamic pressure = 1500 psf**

Equations for Schlieren images by Marco Gomez Fierro

Mach Number and Ramp Wall Pressure

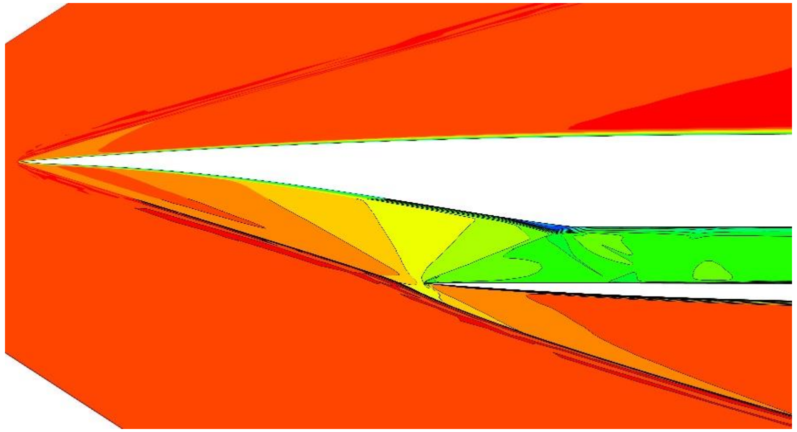


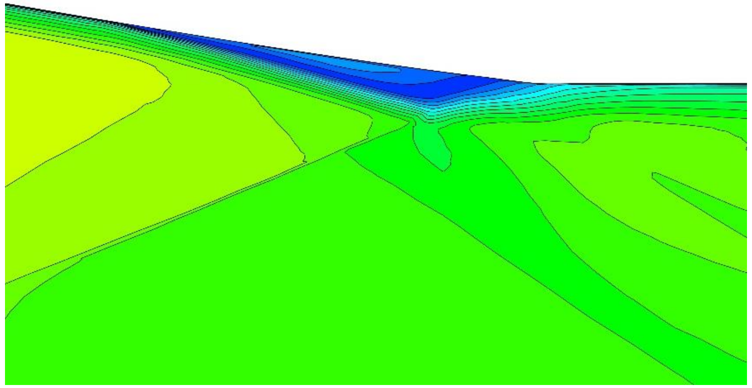


As expected, backpressuring the inlet causes the pressure rise to increase and move upstream

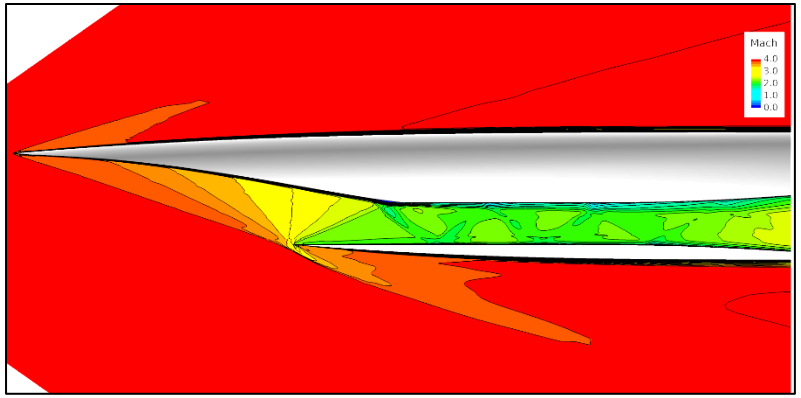
Comparing Wind-US to Vulcan

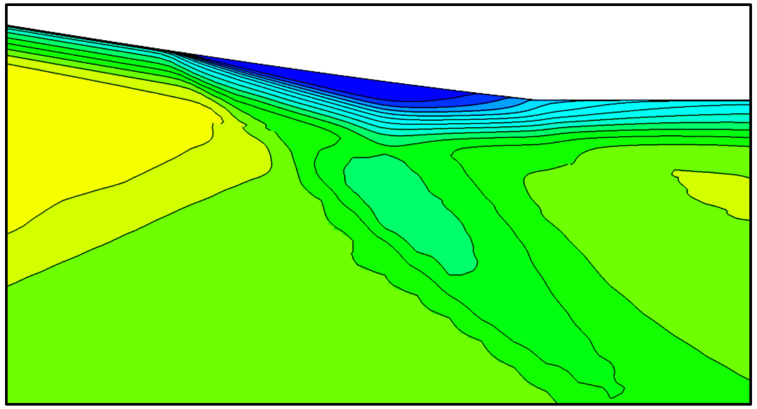
Vulcan





Wind-US

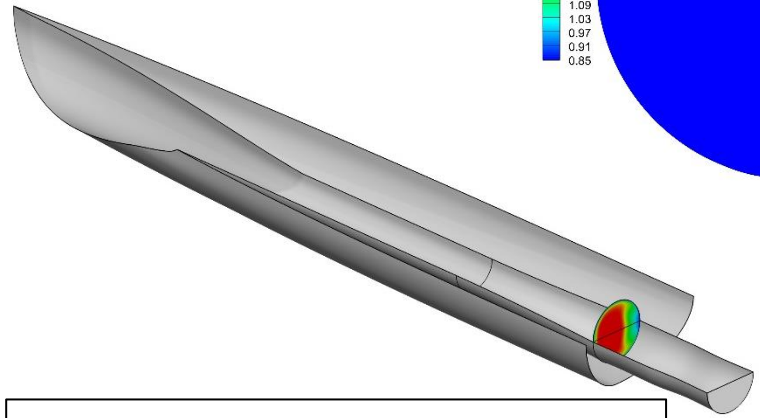


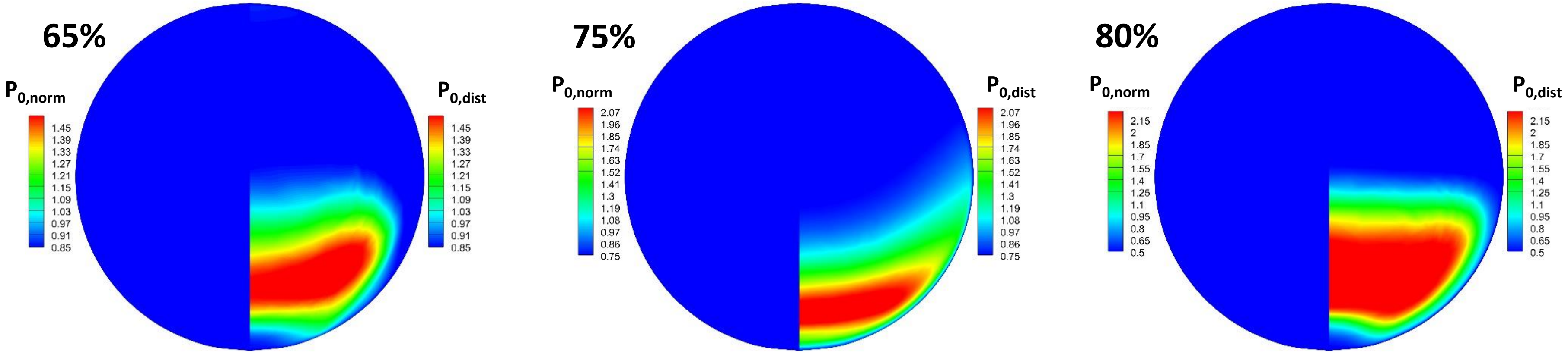


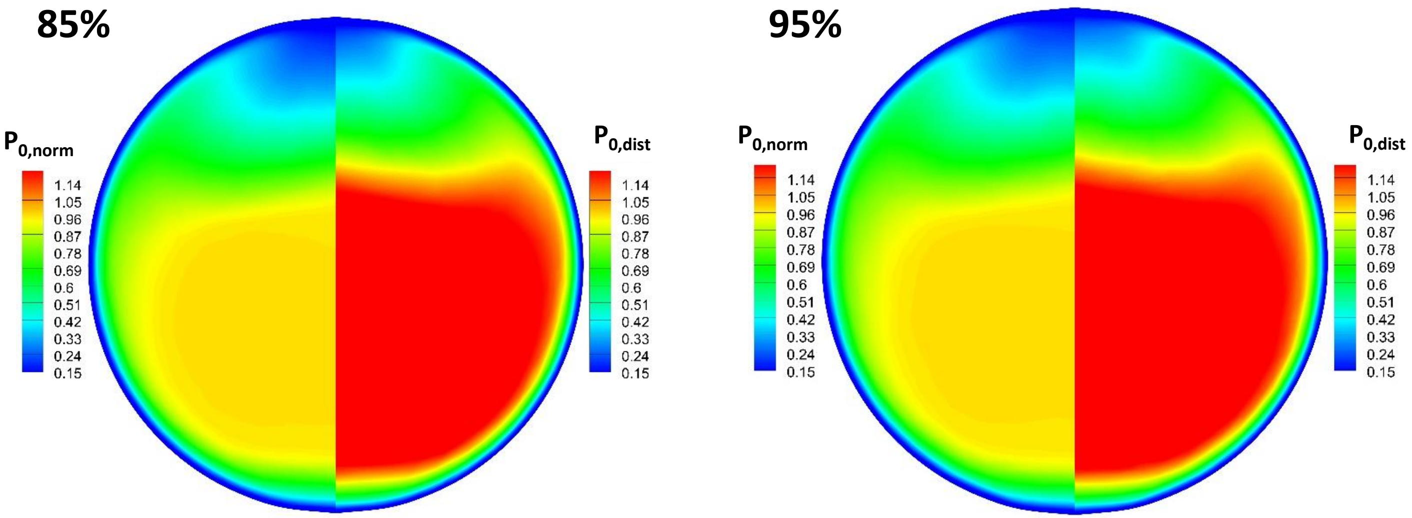
The flow field of the **Vulcan** Solution **accurately replicates** the one obtained with **Wind-US**, further **validating** the complete **workflow** from SUPIN to Vulcan

Pressure recovery and Distortion Pattern Indicator at the AIP

- $P_{0,norm} = \dfrac{P0_{AIP}}{P0_{\infty}}$
- $P_{0,dist} = \dfrac{P0_{AIP}}{\overline{P0_{AIP}}}$







- Evidence of the low momentum region is clearly seen in cases when backpressuring is higher.
- Placing bleed on ramp surface would mitigate pressure distortion.

Outline

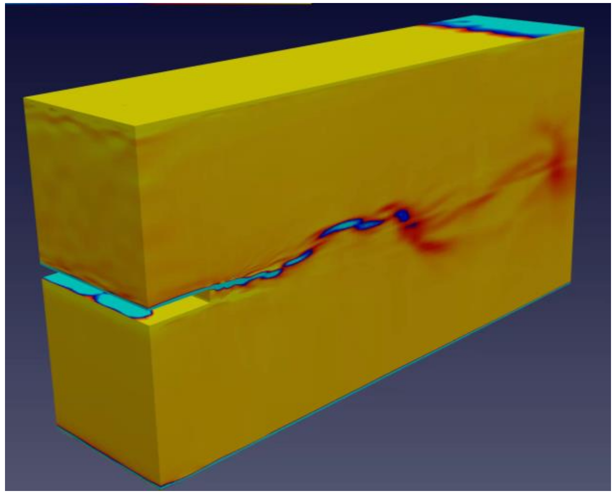
1. SUPIN-Vulcan-CFD Sketch-to-solution (S2S) workflow
2. Inlet Analysis
   - Axisymmetric Pitot Inlet (K1)
   - Axisymmetric Spike Inlet (K3)
   - Streamline traced Inlet (K5)

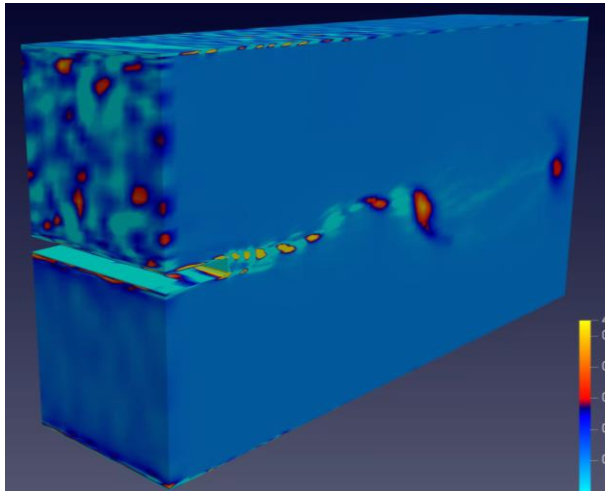
3. **Burrows and Kurkov Reacting Flow Case**

Burrows and Kurkov Supersonic Combustion Study

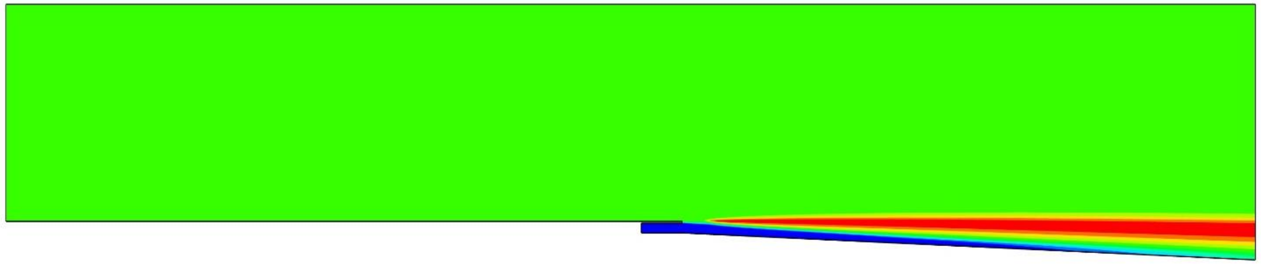
- Relevant to research conducted at **Georgia Tech**
  - Low speed (O2/CH4) supercritical mixing layer
  - Comparisons between:
    - Ignition delay
    - Species Distribution
- Personal interest in reacting flows
- Useful validation tool to compare Vulcan To Wind-US
- Create a workflow to test on future Vulcan Releases

Georgia Tech Research



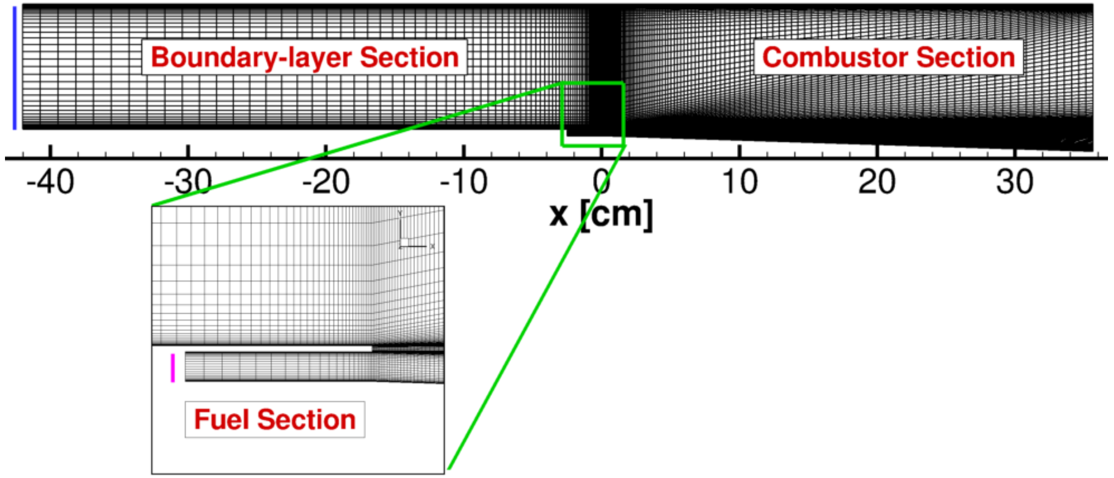


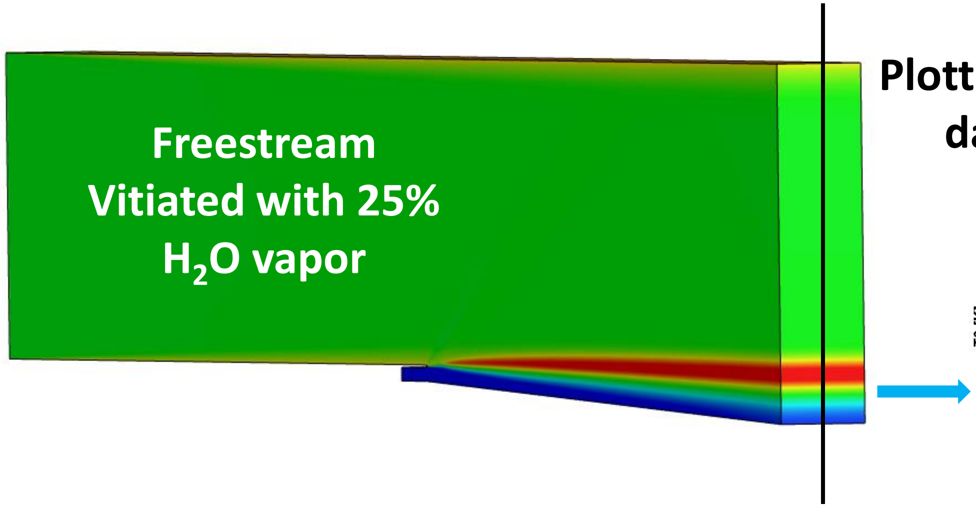
Burrows and Kurkov Case



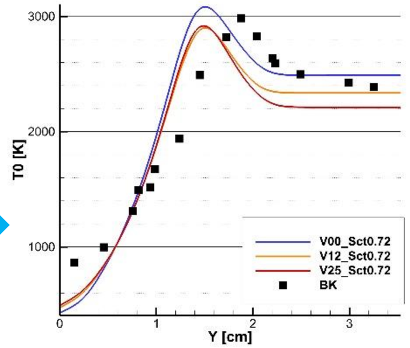
Burrows and Kurkov Supersonic Combustion Study

Case Geometry





Plotting Extracted data Points



	Freestream	Hydrogen
Mach	2.44	1
Pressure (psi)	14.7	14.7
Temperature (R)	2286	457.2

Chemistry Model Used on Wind-US:

- Simplified **Peters and Rogg** (13x27) -> **(9x18)**

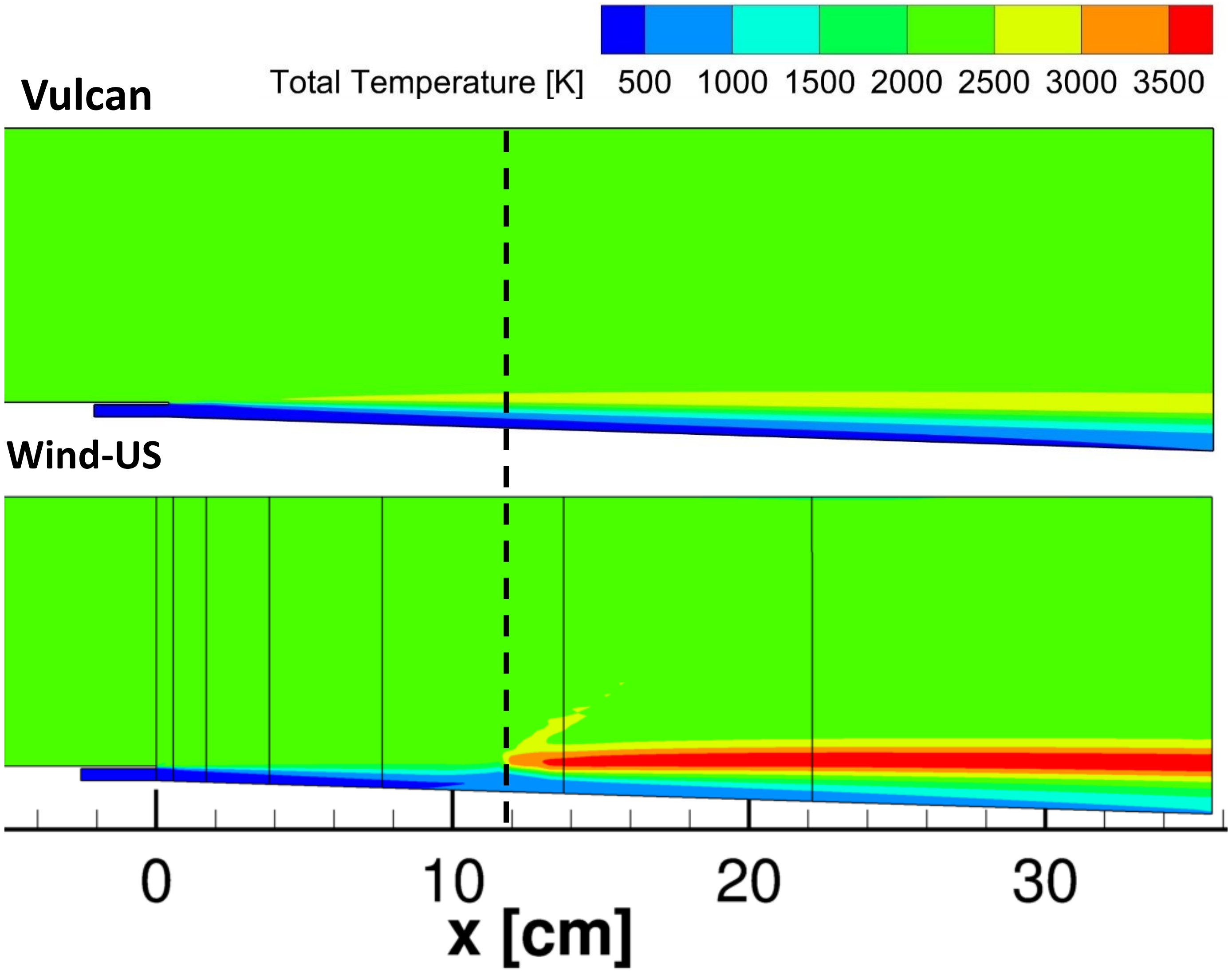
Chemistry models tested on Vulcan:

- **Larc (9x18)** ☆
- Westbrook (9x21)
- Dryer (9x21)

Vulcan Simulation was run by **matching both turbulent and laminar Schmidt and Prandtl Numbers** to what was used in the Wind-US case

- **Prt = 0.72**
- **Sct = 0.72**

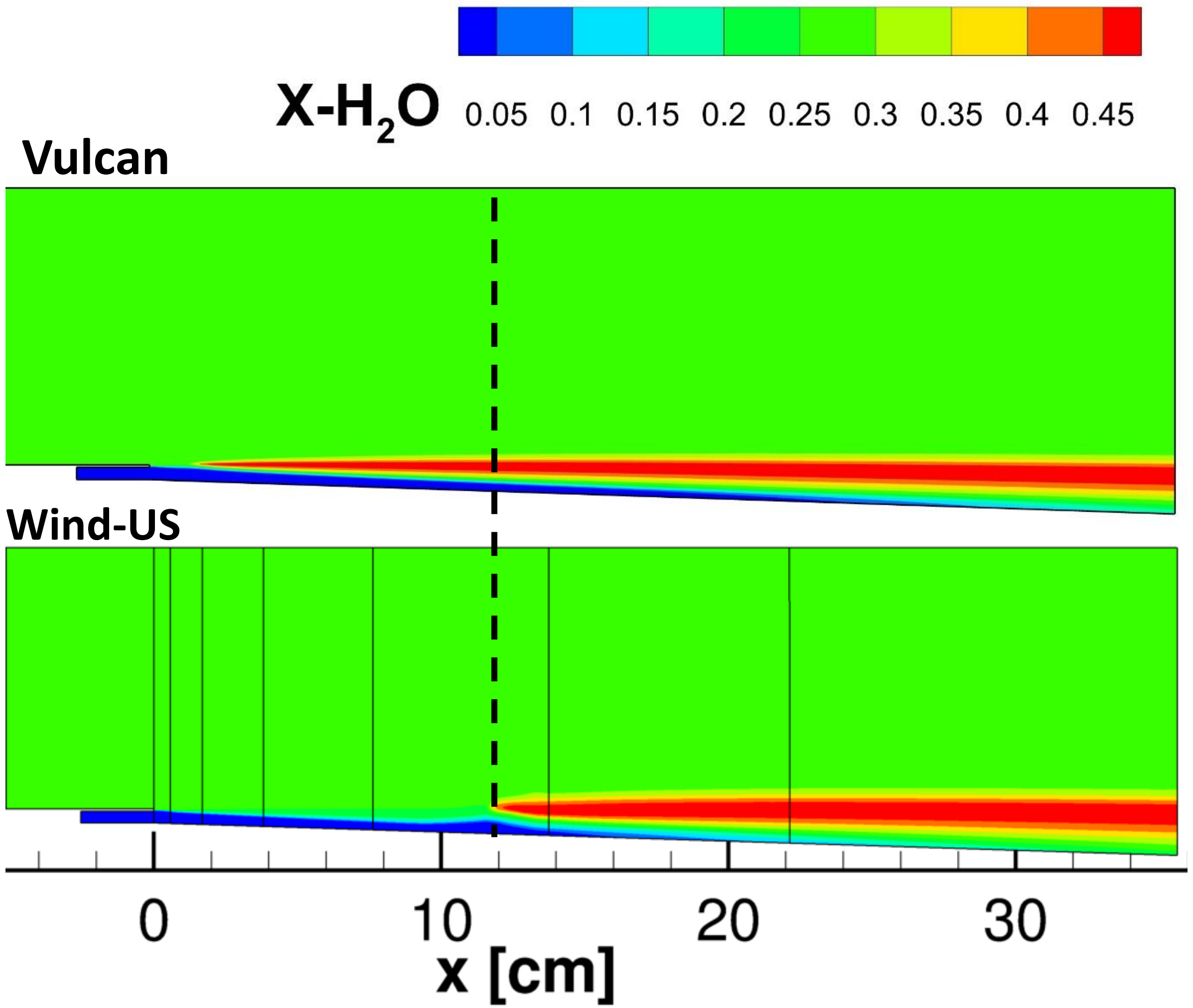
Total Temperature Contour Plot (Larc_9x18)



Vulcan captures the combustion process, but the flame structure, temperature, and ignition delay are different.

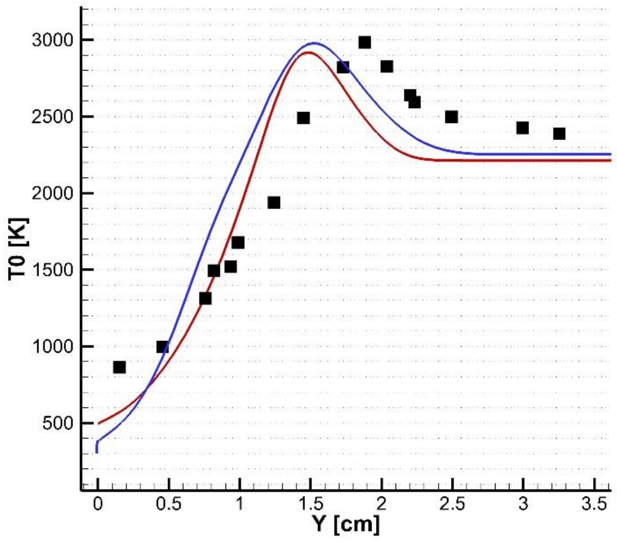
- Ignition in **Vulcan** simulation occurs at about **5 cm.**
- Ignition in **Wind-US** simulation occurs at about **12 cm.**

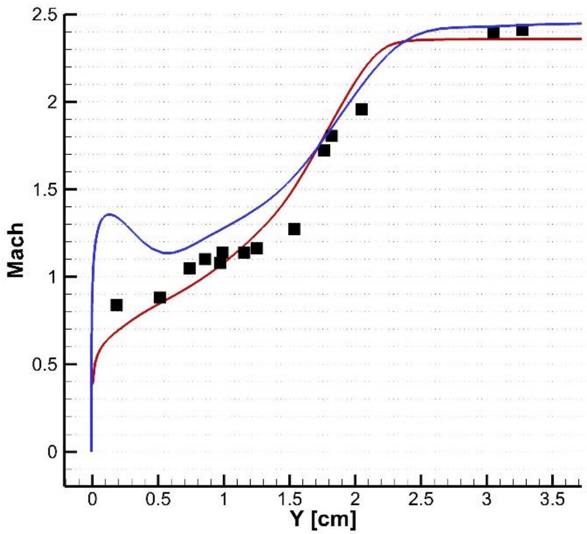
X-H2O Contour Larc_9x18

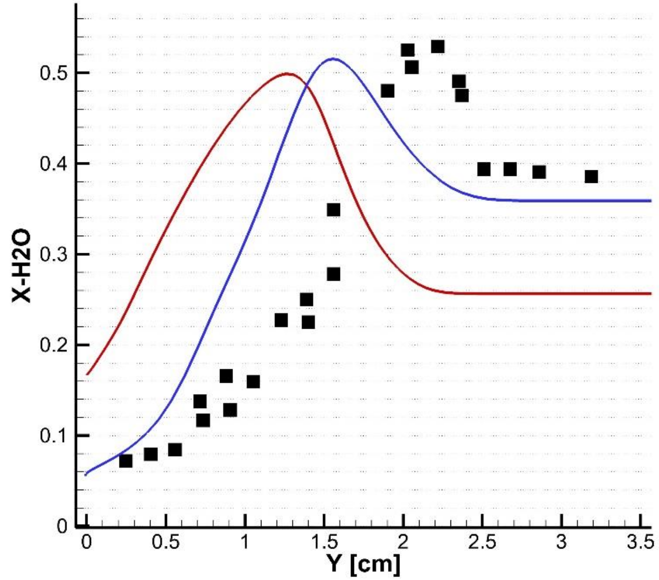


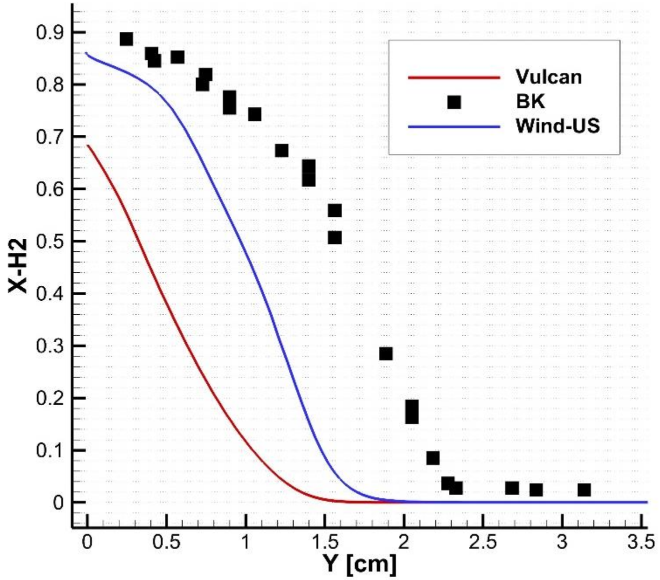
The **H_2O mass fraction** is numerically similar to the solution obtained with Wind-Us, with a maximum Mass Fraction of **X-H_2O ≈ 0.5**.

V25_Sct0.72 vs Wind-US









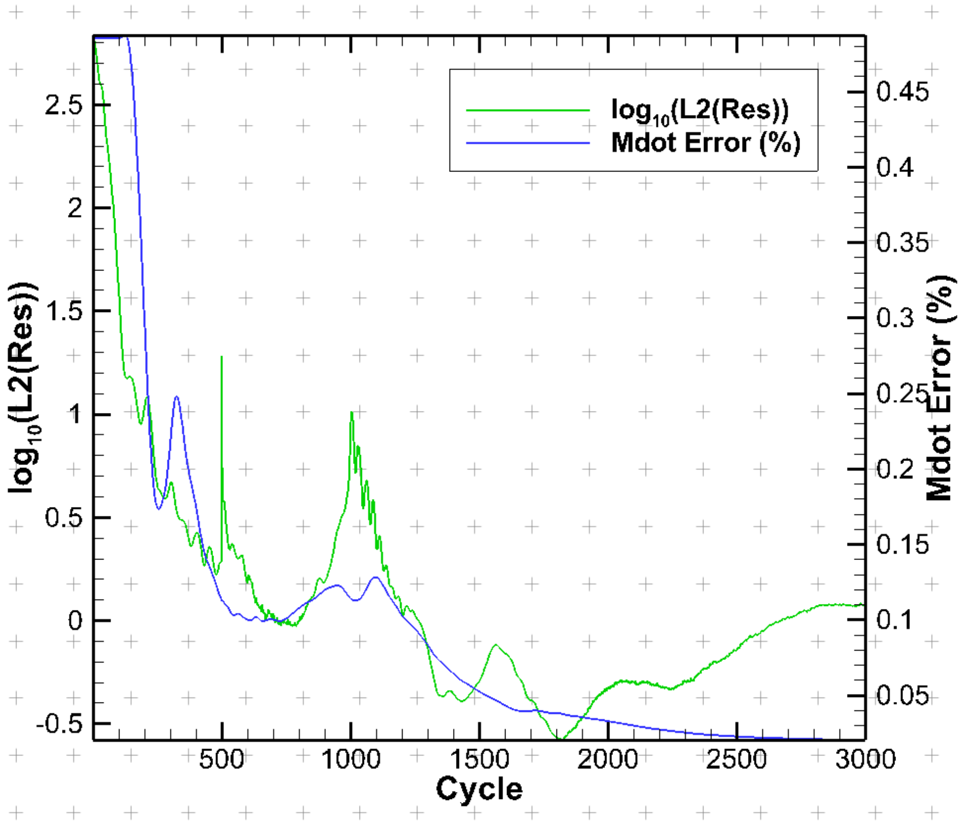
- Comparison **shows Total Temperature and Mach Number** data is close to **Wind-Us** simulation and **experimental** data.
- **Mass fraction** plots show significant **discrepancies**: further investigation necessary.

Summary

- **Inlet analysis**
  - **Demonstrated SUPIN to Vulcan workflow using Sketch-2-Solution**
    - Found appropriate way to construct csm files to avoid errors in geometry
    - Implemented this approach for Axisymmetric Pitot, axisymmetric spike, streamline traced inlets
  - **Investigated multiple backpressure conditions**
  - Future work:
    - Adapt workflow to analysis of 2D inlets
    - Find optimal CFL schedule and determine what is needed for simulations to converge
- Burrows and Kurkov Reacting flow case
  - Replicated Burrows and Kurkov case study in Vulcan.
  - Future work:
    - Further investigation necessary to understand differences between effects of chemistry models

Thank you!

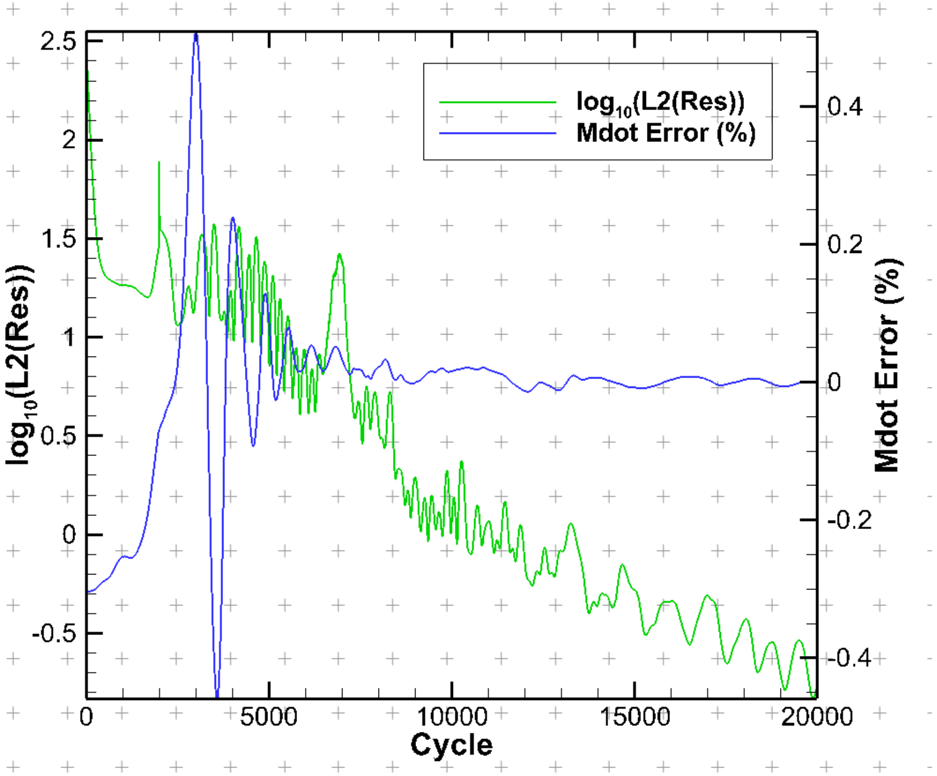
- Thanks to everyone in the branch for making me feel welcome!
- A special thanks to **Manan** for this **life changing opportunity** and the trust he put in me!



- K195 case

Axisymmetric Pitot Inlet

- **Mach = 1.4**
- **Altitude = 50,000 ft**

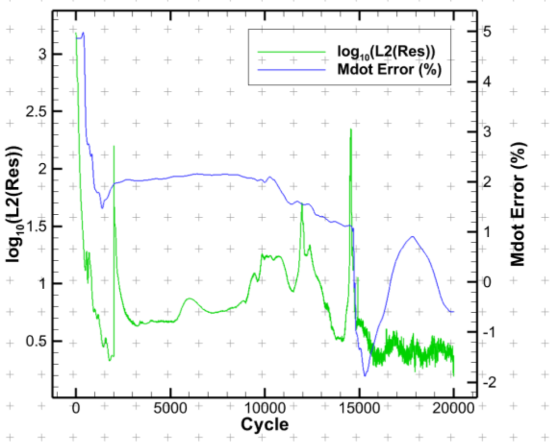


- K195 case

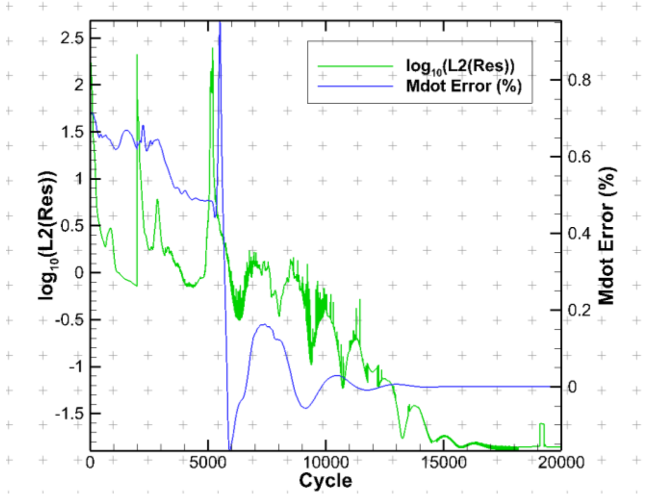
Axisymmetric Pitot Inlet

- **Mach = 0.65**
- **Altitude = 50,000 ft**

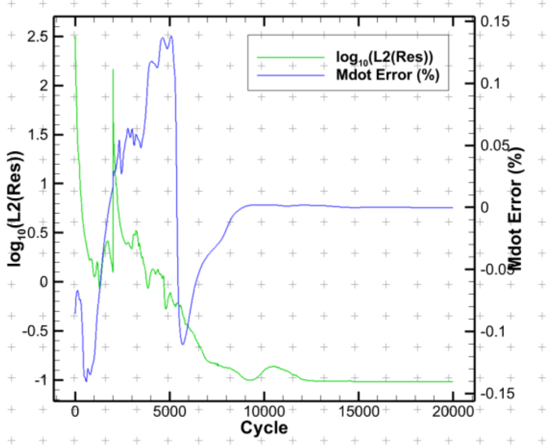
- K385



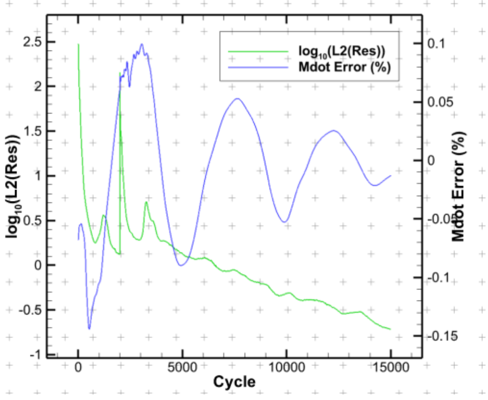
- K390



- K392



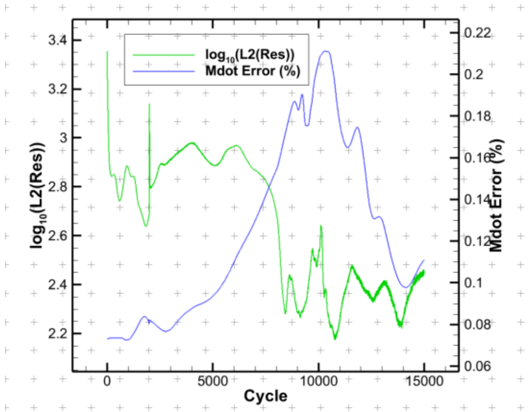
- K393



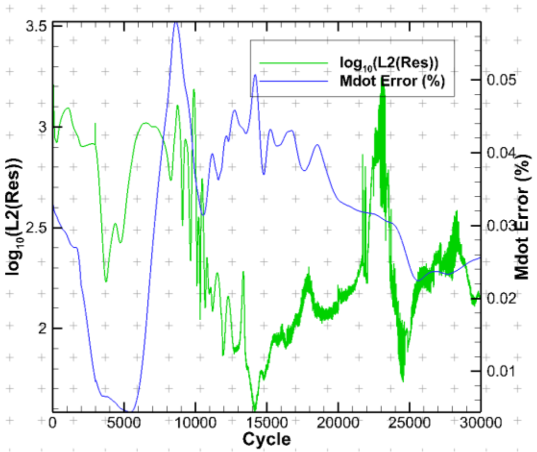
Axisymmetric Spike Inlet

- **Mach = 1.7**
- **Altitude = 55,000 ft**

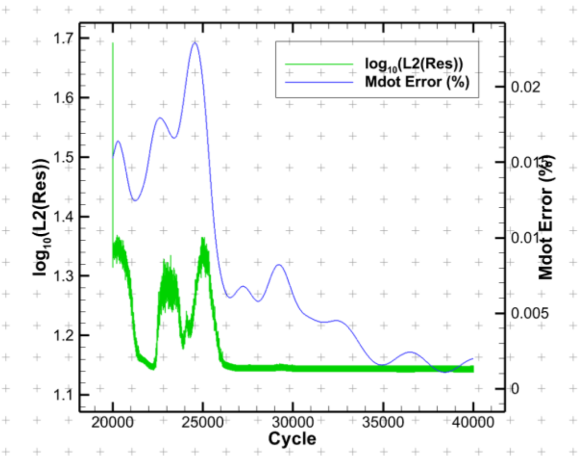
- K565



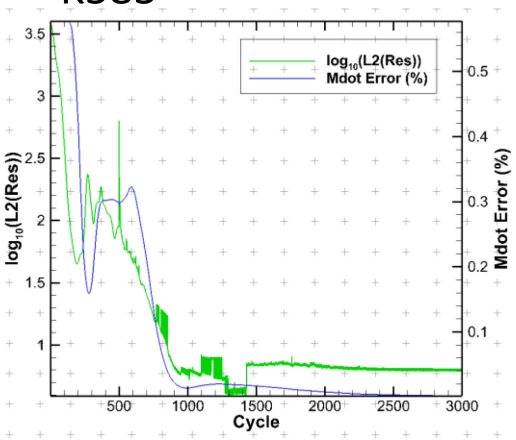
- K575



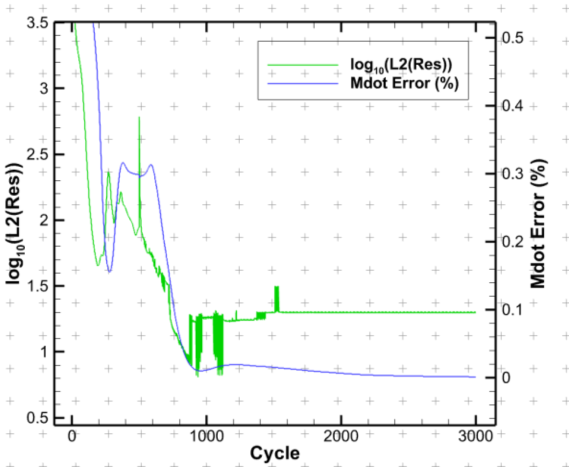
- K580



- K585

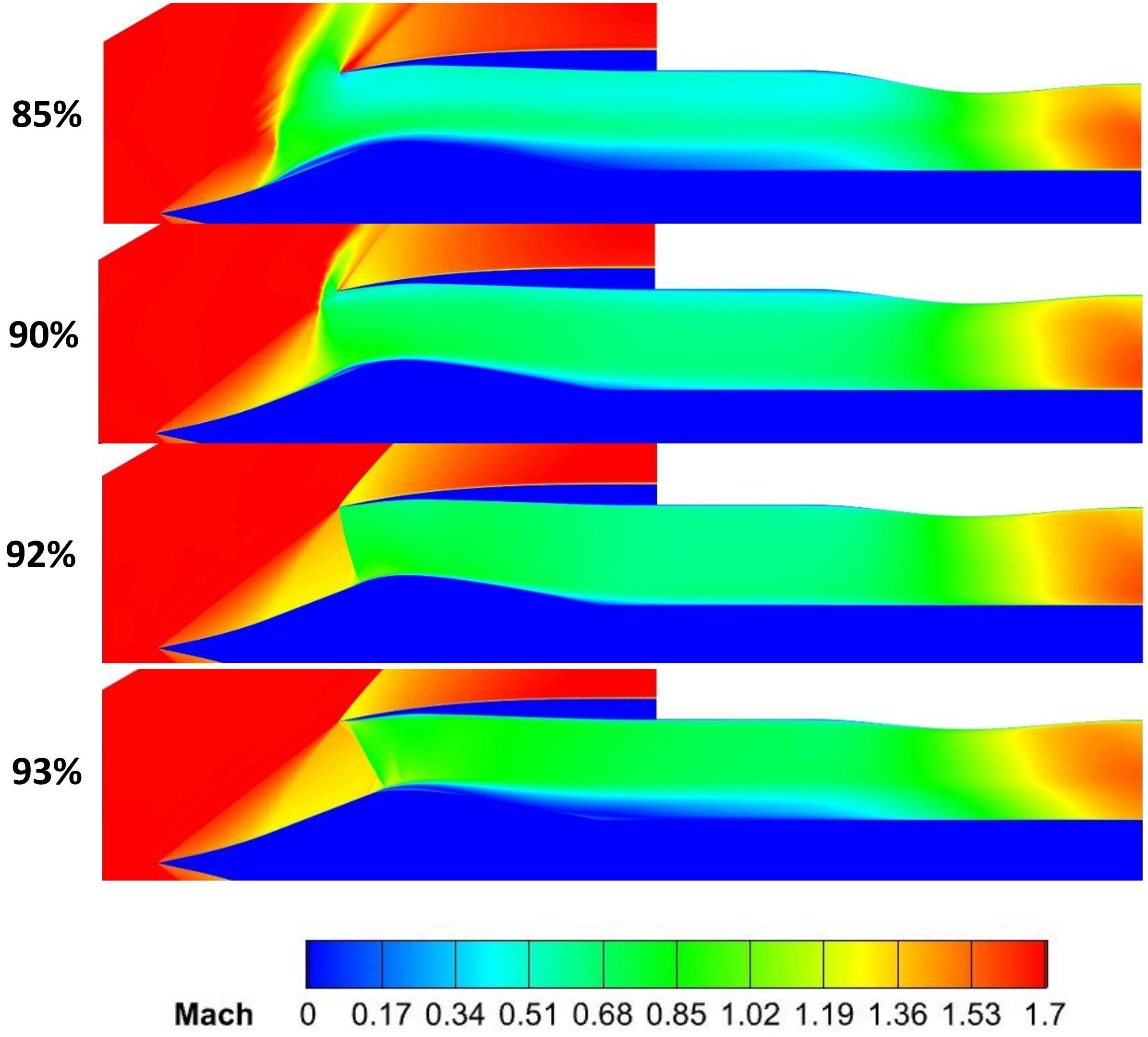


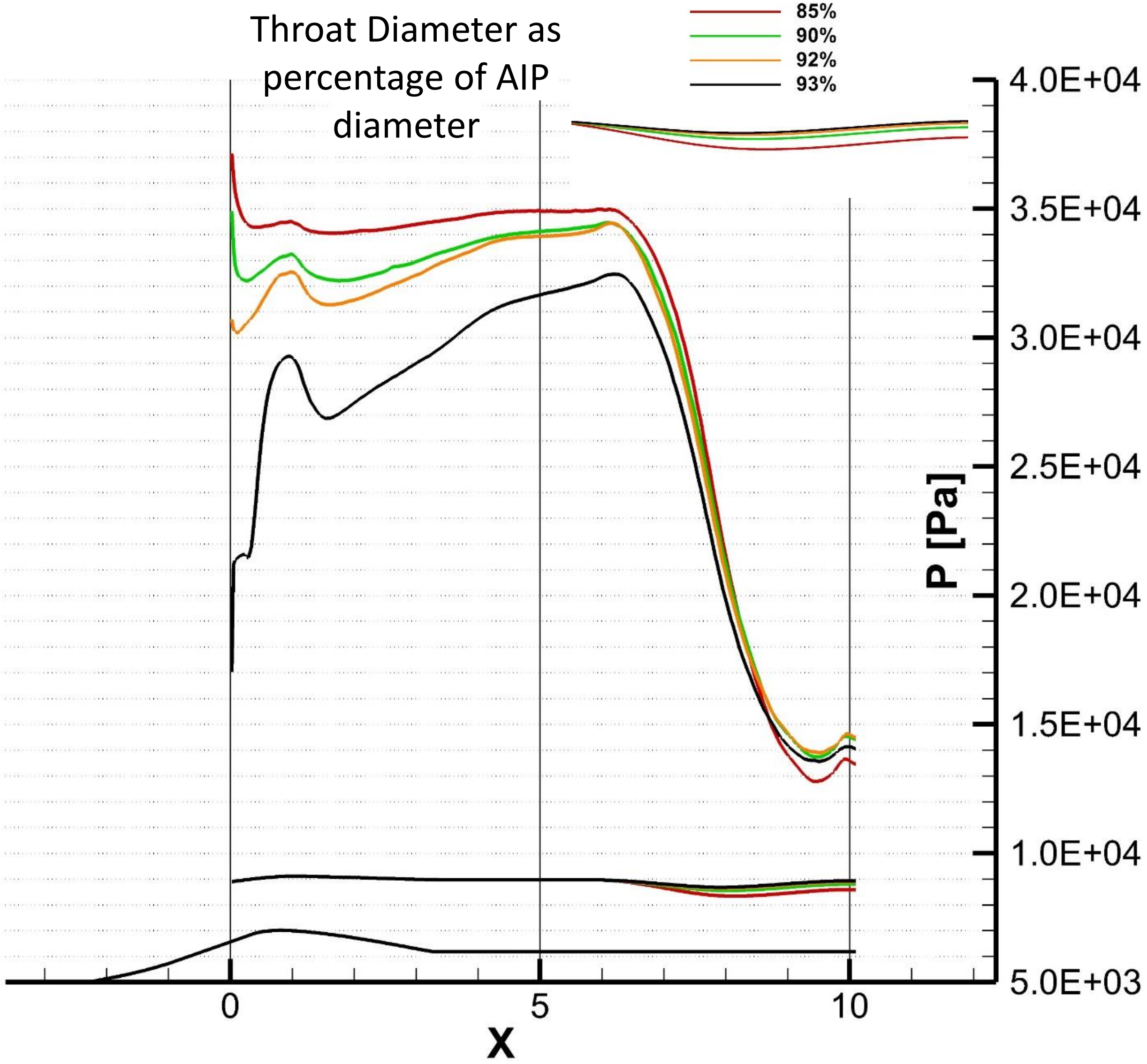
- K595



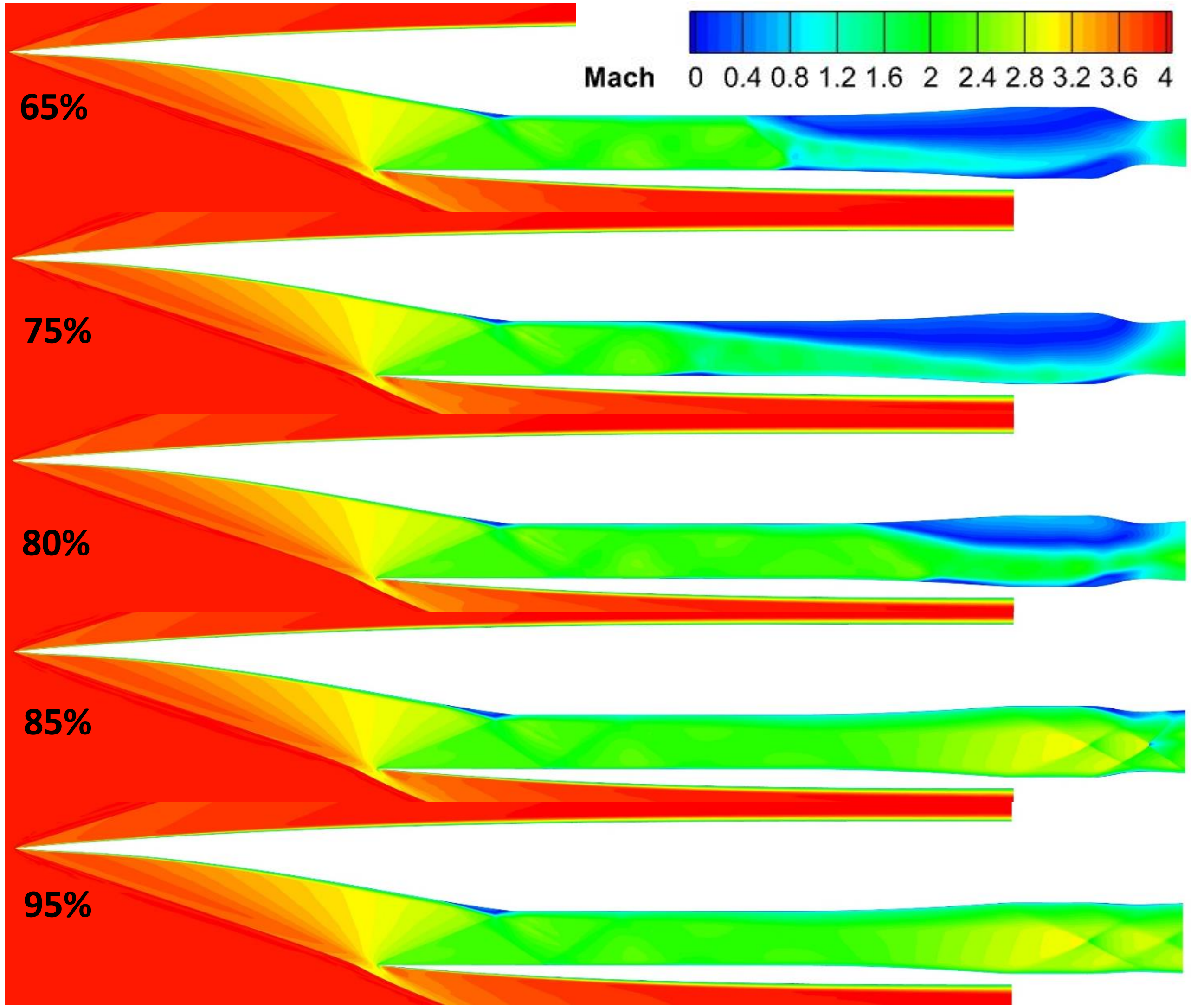
Streamline traced Inlet

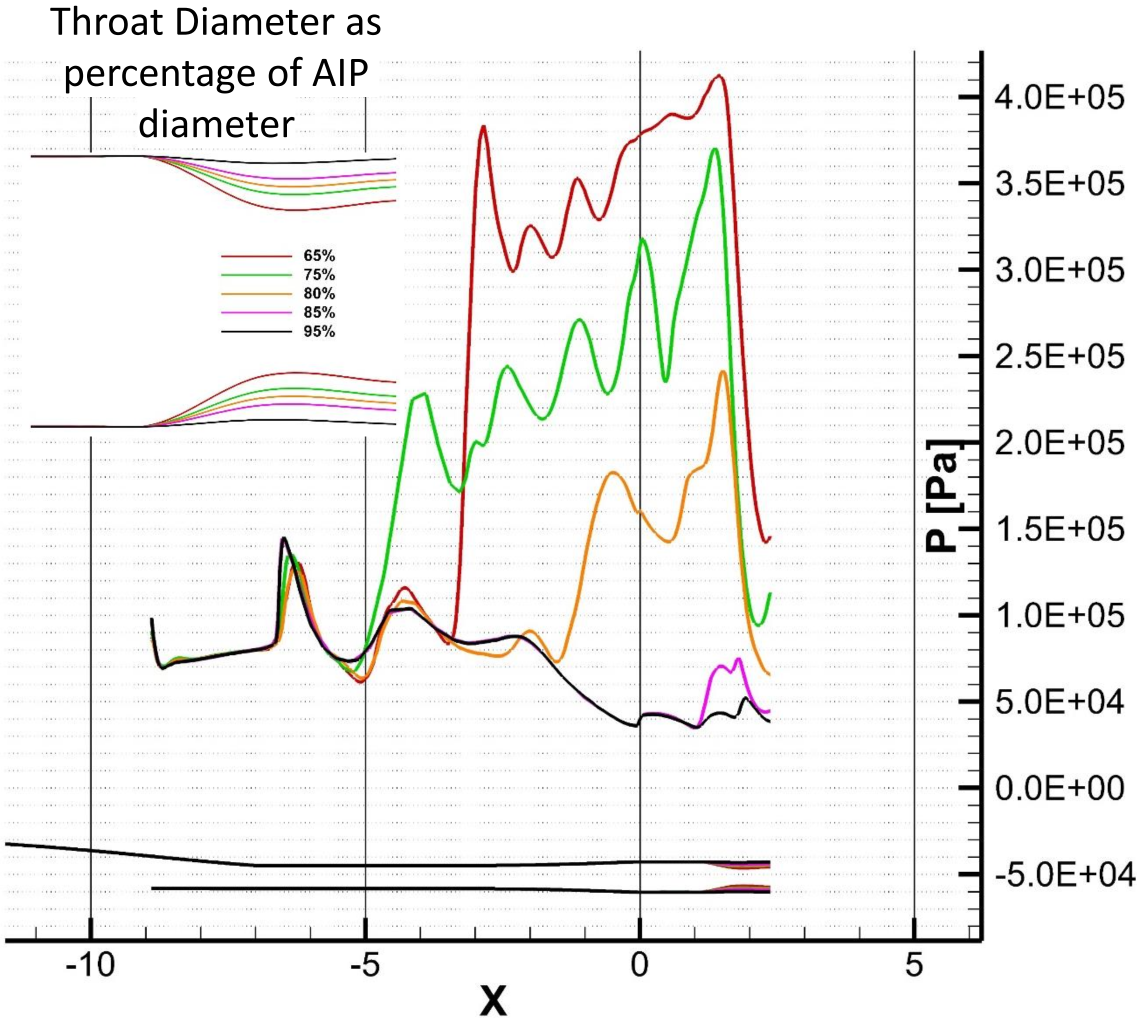
- **Mach = 4**
- **Dynamic pressure = 1500 psf**


85%
90%
92%
93%
Mach 0 0.17 0.34 0.51 0.68 0.85 1.02 1.19 1.36 1.53 1.7


Throat Diameter as percentage of AIP diameter
85%
90%
92%
93%
P [Pa]
4.0E+04
3.5E+04
3.0E+04
2.5E+04
2.0E+04
1.5E+04
1.0E+04
5.0E+03
0
5
10
X

Extra slides





Extra slides