Parametric Geometry, Structured Grid Generation, and Initial Design Study for REST-Class Hypersonic Inlets

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Motivation

- **Rapid high-fidelity design/analysis/optimization of hypersonic vehicles and components**
  - Lower fidelity tools don't capture all relevant physics
    - Resulting in non-optimum design
    - Not easy to redesign with higher fidelity tools
  - Currently takes too long to use high fidelity tools (CFD) in the design process
    - Geometry generation & changes
    - Grid generation
    - Not due to CFD solution execution time

Approach

- **Analysis requirements → design approach**
  - Physics-based models
  - 3D flow / viscous interactions
  - Grid resolution

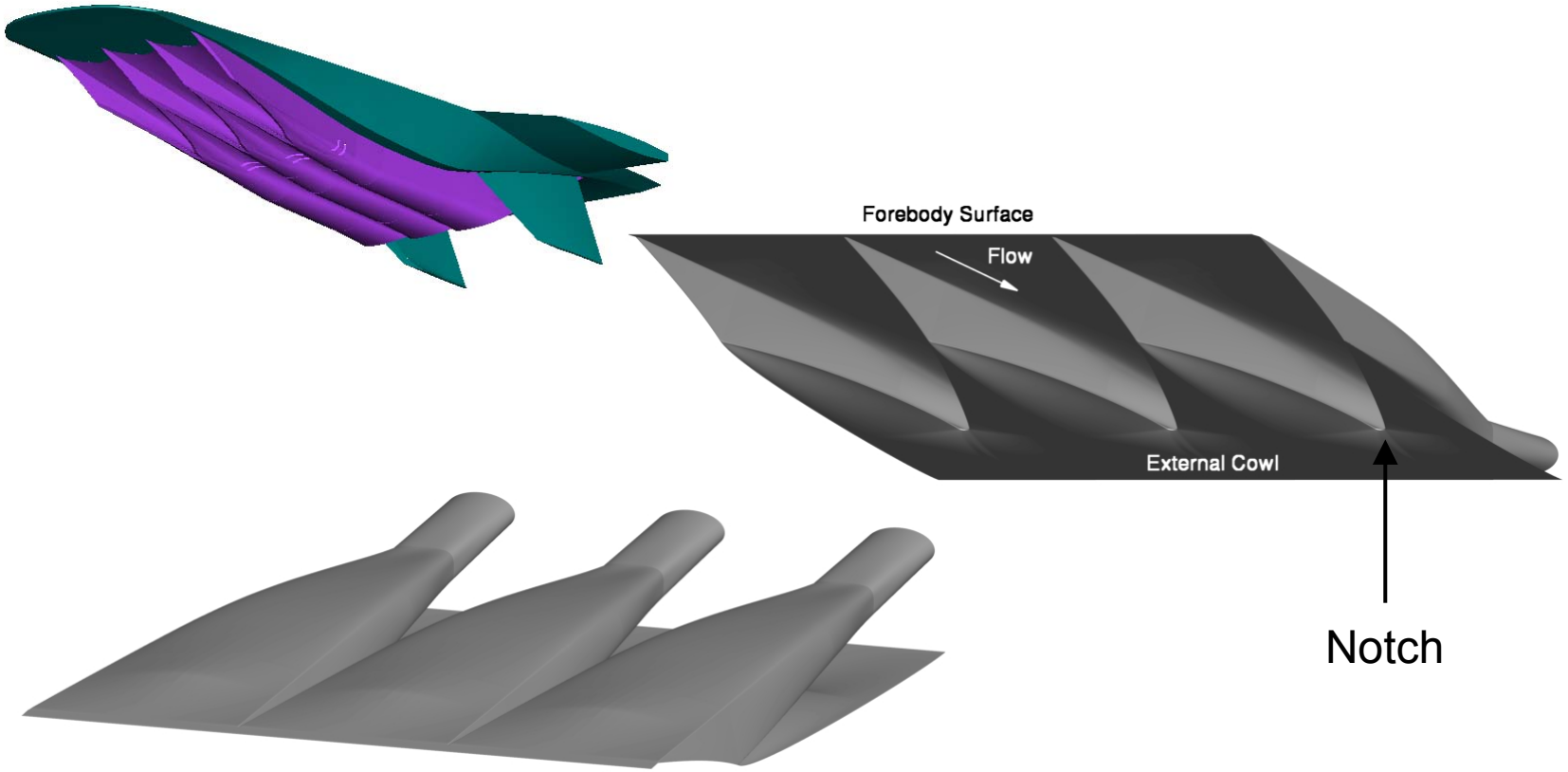
- **Developed new process for complex geometry and structured grid generation**
  - Parametric CAD geometry generation
  - Structured grid topology linked to geometry
  - Structured grid generation with GridPro

Outline

- **Application of new approach to REST-class 3D hypersonic inlet**
  - Inviscid design tool
  - Complex geometry and fluid dynamics
- **Initial design study**
  - 4 geometric variables
  - Quantify viscous effects
  - Optimization

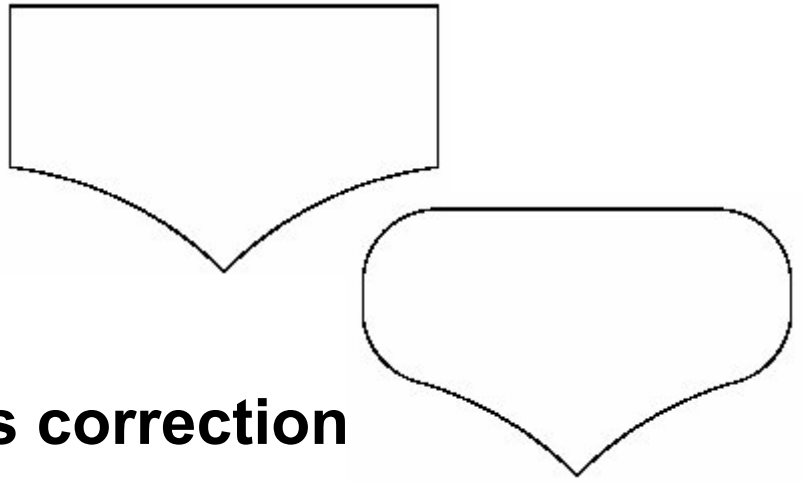
REST-class 3D Hypersonic Inlet

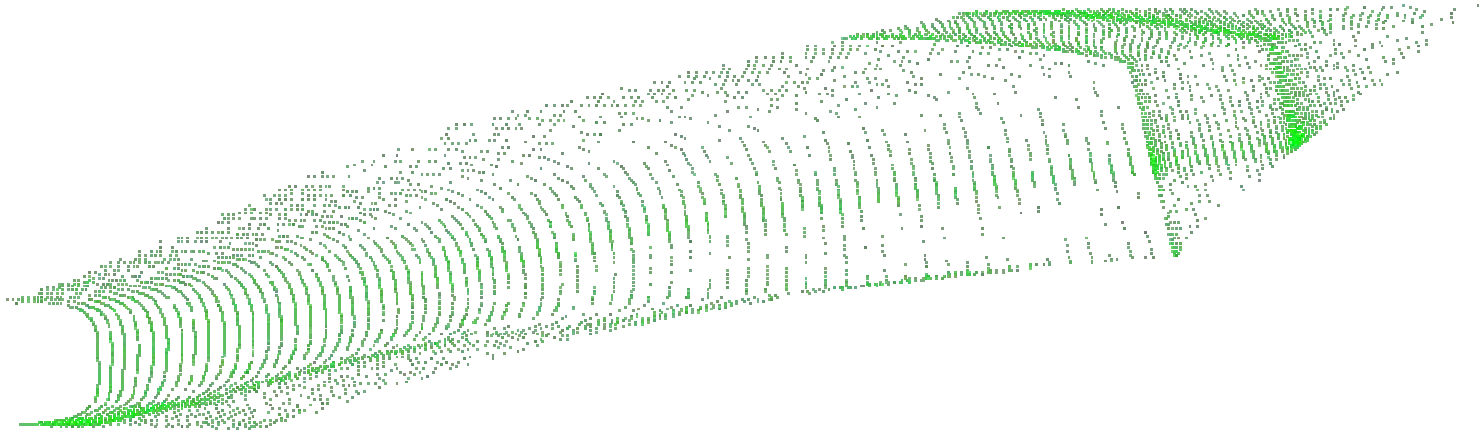
- **Rectangular-to-Elliptical Shape Transition**
  - Body-integrated, modular, elliptical throat



Inviscid Design Tool

- **Produce axisymmetric compression field**
- **Streamline trace shape 1**
- **Streamline trace shape 2**
- **Streamline trace throat shape**
- **Blend the 3 shapes together**
- **Apply an approximate viscous correction**

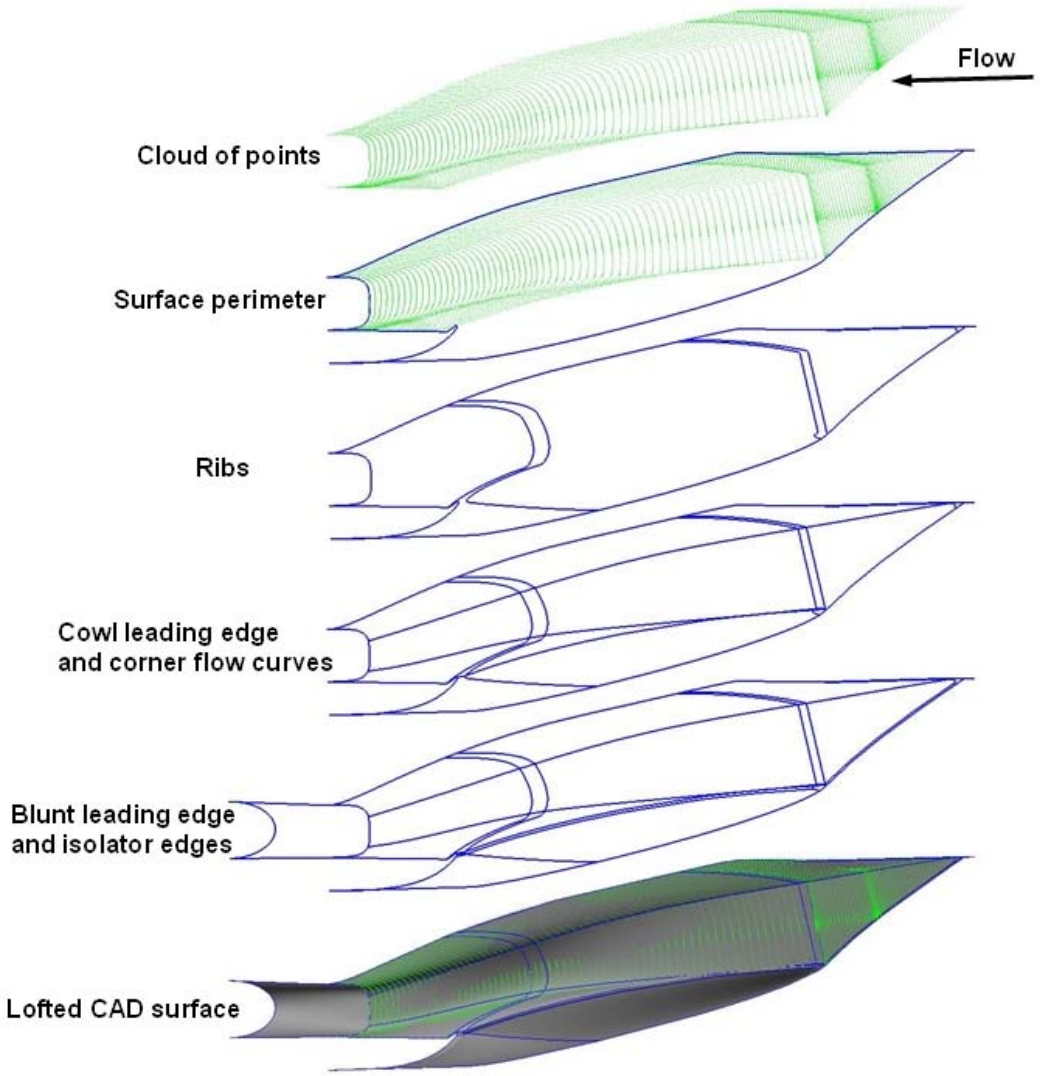




Parametric CAD Geometry

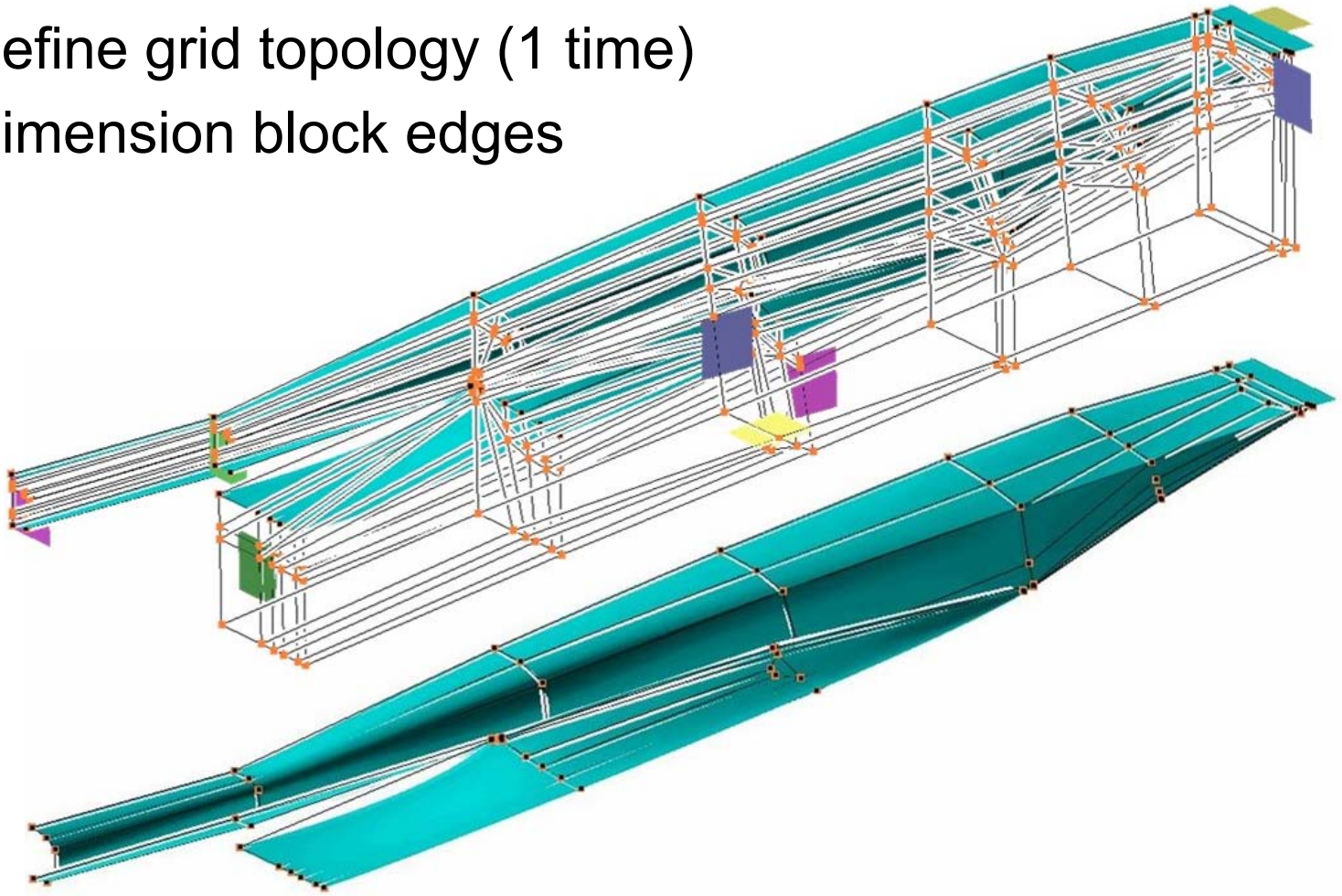
- **Adaptive Modeling Language (AML) by TechnoSoft, Inc.**
  - Used for component design and integrated systems studies in the MDAO discipline of the Hypersonics Project
- **Objective is to create a parametric continuous surface**
  - As smooth as possible
  - Accurate representation of the cloud of points
  - Requiring the least amount of information
- **Primary control of surface shape achieved with edges**
  - Perimeter, corners, cross-sections
  - Maximize dependencies and simplify user input
  - Build tangent-continuous surface patches
- **Trade-off between simplifying the topology of the geometry and the complexity of the possible optimum geometry**

Geometry Construction



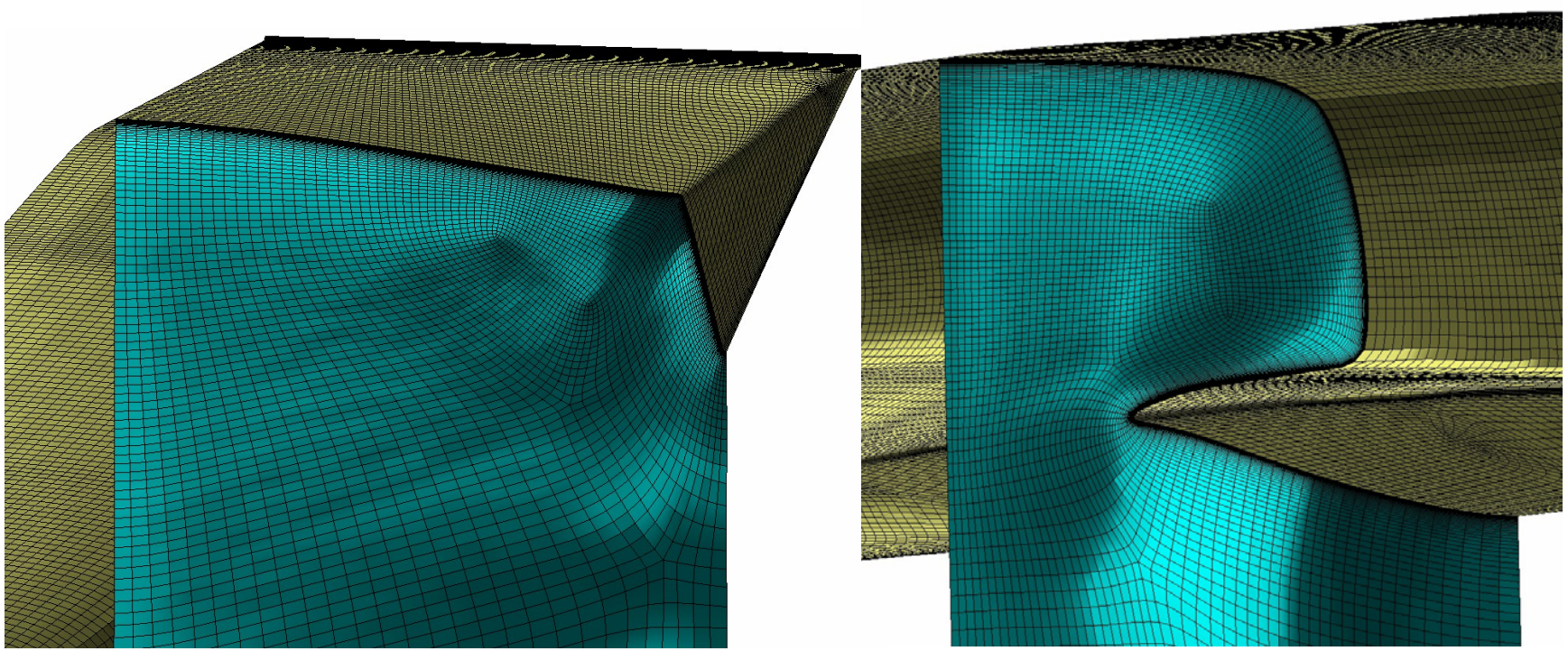
Structured Grid Topology

- **GridPro grid generation software**
  - Define grid topology (1 time)
  - Dimension block edges



Structured Grid

- **GridPro grid solver**
  - Smooth inviscid volume grid (2 minutes)
  - Clustering added afterwards

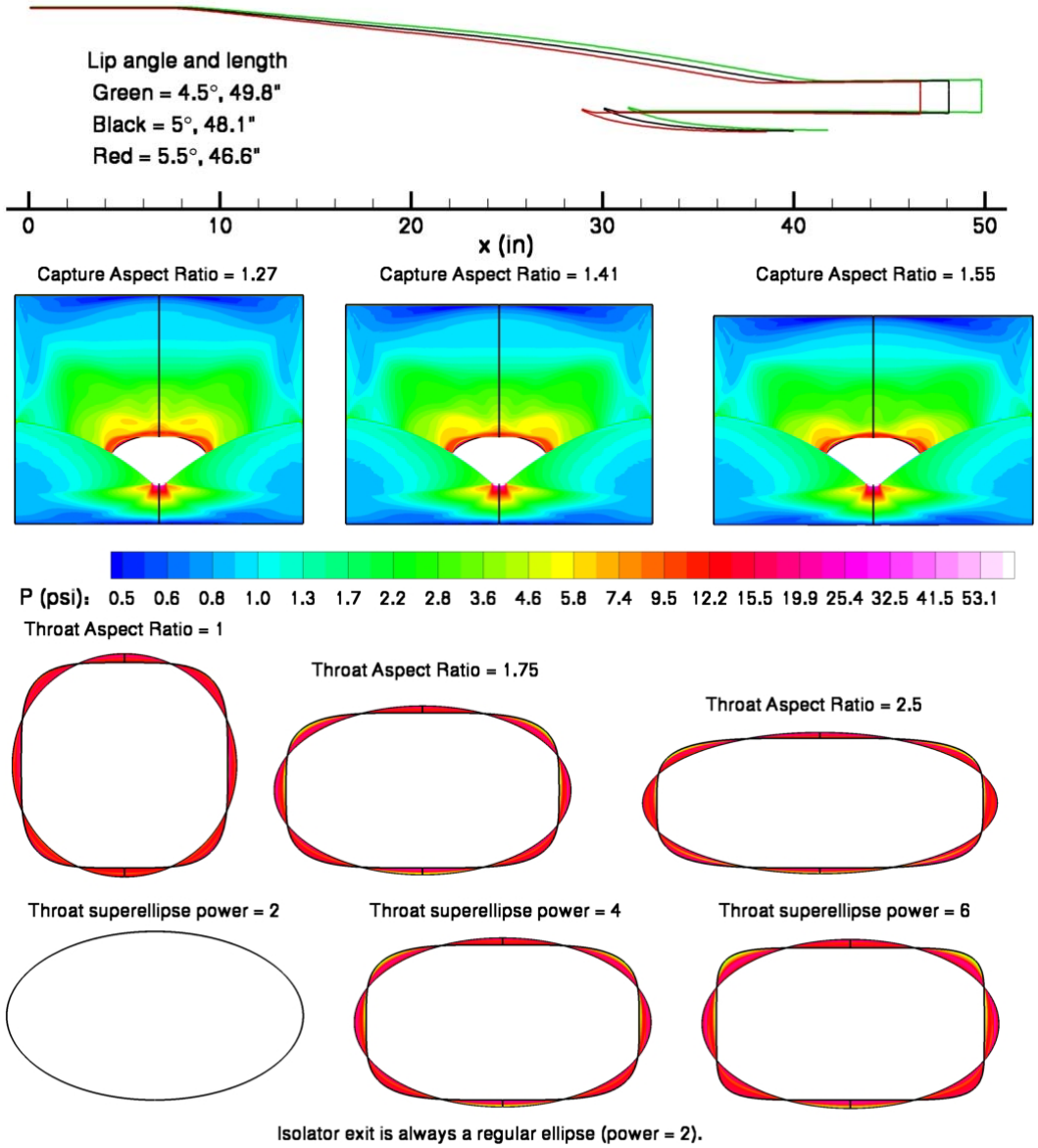


Initial Design Study

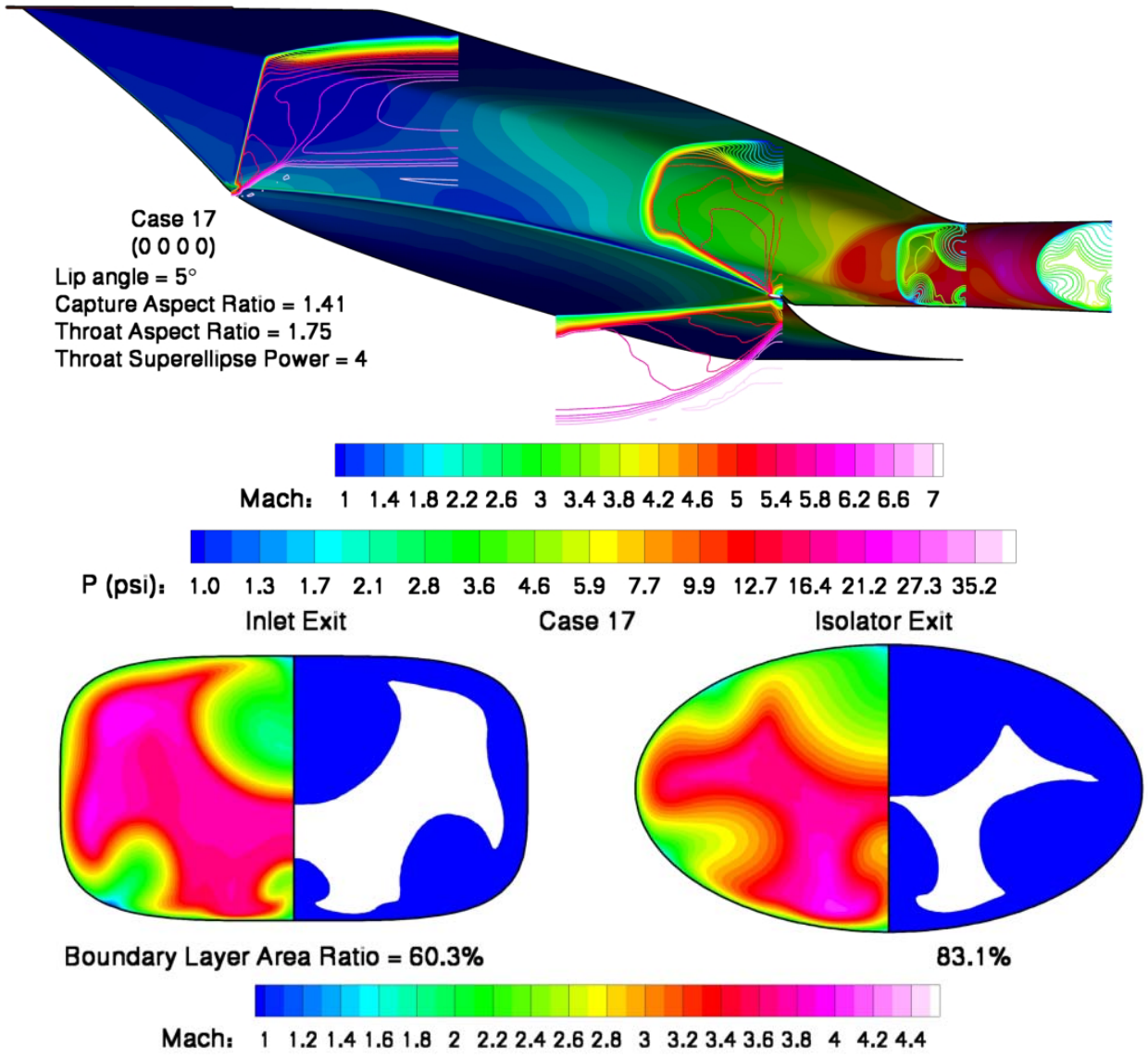
- **Drive geometry and grid generation process**
- **Explore inviscid design tool geometry variations with high-fidelity viscous 3D CFD**
  - Demonstrate a solution rate sufficient for design
  - Extract performance parameters
  - Perform a sample optimization
  - Relate viscous performance parameters to independent geometry variables
- **Used a Modern Design of Experiments approach**
  - Statistical technique to relate responses to independent design variables
  - 3 levels of 4 variables (17 cases)

Independent Variables

- **Lip angle**
- **Capture aspect ratio**
- **Throat aspect ratio**
- **Throat superellipse power**



Results at Center of Design Space



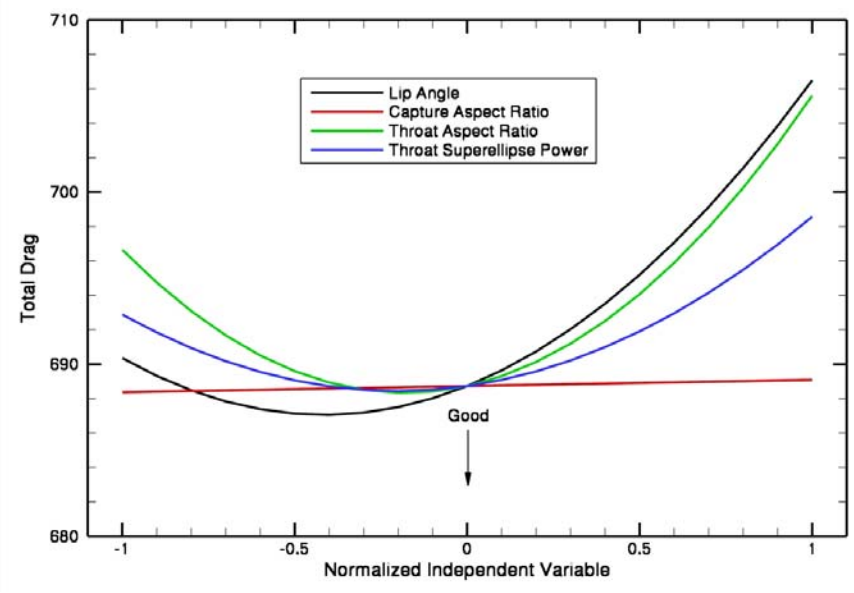
Performance Parameters

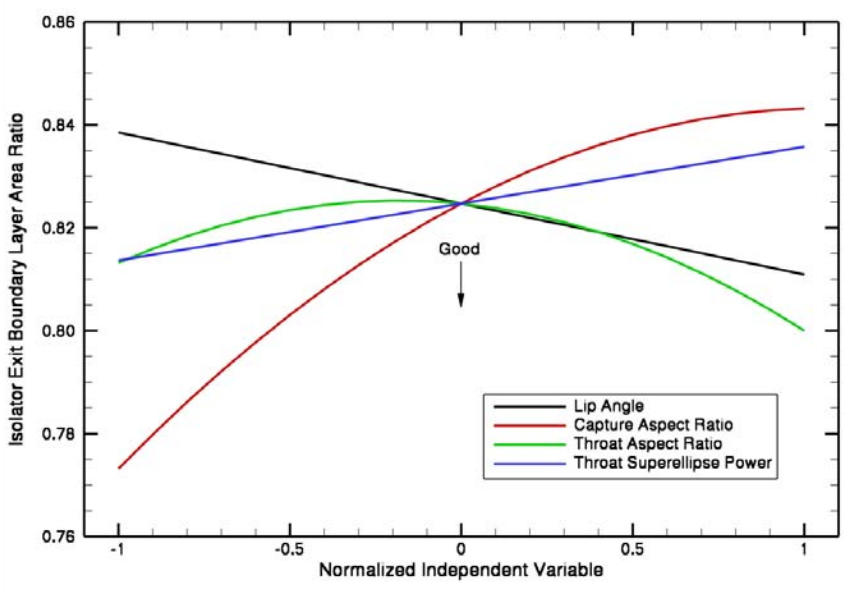
- **Apply a suite of post-processors**
  - Integrated values / loads
  - One-dimensional flow properties / efficiencies
  - One-dimensional perimeter properties
  - Boundary layer properties
  - Distortion parameters

- **Prefer integrated to local parameters for statistical analysis → 2nd order model**

Performance Parameter Trends

- **MDOE 2nd order functions**
- **Permutation plots**
- **Different performance parameters have different trends and sensitivities**





Sample Optimization Function

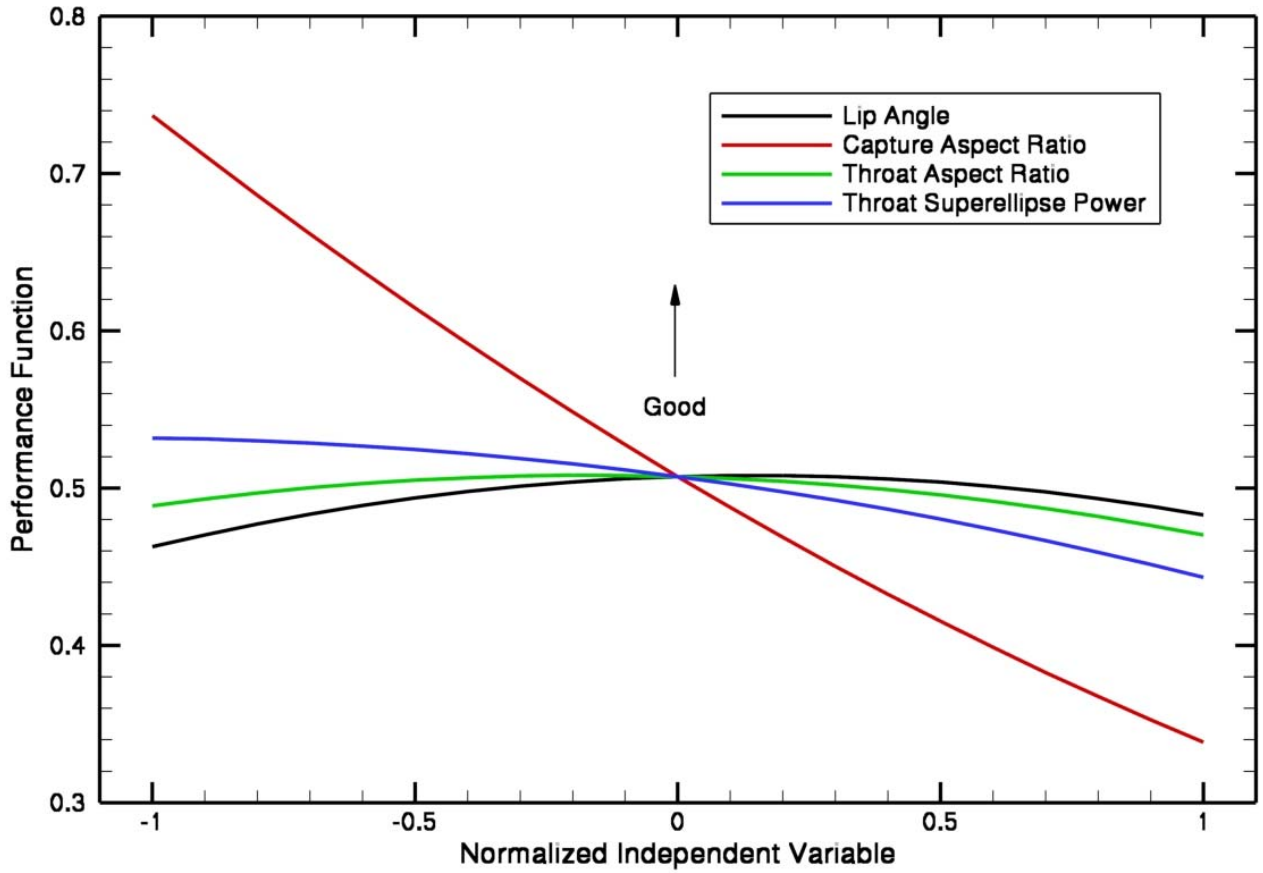
- **Vehicle integration parameter → total drag**
- **Compression efficiency → $P_{t(recov)}$**
- **Quality of inlet exit flow → BLAR**
- **Normalize:** **if min then (high-value)/(high-low)**
  if max then (value-low)/(high-low)

$$P = A\left[\frac{754 - Drag}{754 - 674}\right] + B\left[\frac{P_{t(recov)} - 0.268}{0.360 - 0.268}\right] + C\left[\frac{0.855 - BLAR}{0.855 - 0.700}\right]$$

  - **with A=B=C=**1/3

Optimization Function Trends

- **Optimum at (-0.4, -1, -0.3, -1) or**
  Lip > = 4.8°, CAR = 1.27, TAR = 1.525, TSP = 2



Initial Design Study Conclusions

- **Boundary layer roll-up at body centerline symptomatic of inviscid design tool inlet shape**

- **Must optimize a multiple-parameter function**
  - Benefit to a constant shape isolator
  - Significant benefit to a small capture aspect ratio
  - Relationship between undesirable viscous effects and independent design variables can be determined

- **Required 8 days for 17 cases**
  - Each 20 hours with 7 CPUs (119 CPUs → 1 day)
  - Previously more than 1 month for 1 grid

REST-class Inlet Summary

- **Promising type of 3D hypersonic inlet, however currently not optimized with 3D boundary layer effects**

- **Design approach must account for 3D viscous interaction (1st order effect)**
  - Complex geometry
  - Complex fluid dynamics
  - Include viscous performance parameter in the design optimization function

Geometry & Grid Generation Summary

- **Used generic capabilities in AML**
  - Parametric CAD geometry
  - Basic structured grid topology linked to geometry
  - Grid topology customization
- **Used GridPro software to generate volume grid**
- **Investigate other types of 3D inlets**
- **Apply to other components**
- **Apply to vehicle design studies**