An Automated Analysis Process for Missile Using Open-source Software

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open source CFD consulting

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- Automated Analysis Process
- Benchmark Test
- Conclusion

Introduction

❖ Missile Aerodynamic Design

- Various shape types

- Wide range of flight conditions

Introduction

❖ Semi-empirical code

- Use text-based inputs
- Less computational time
- Low accuracy

```
CASEID Missile Geometry
DIM M
DERIV RAD
$FLTCON
  NALPHA = 4.00000,
  ALPHA =  0.00000, 1.00000, 2.00000, 3.00000,
  NMACH = 4.00000,
  MACH =  0.60000, 1.20000, 1.50000, 2.00000,
  ALT =  0.00000,
  PHI = 45.00000,
$END
```

Introduction

- ❖ Semi-empirical code
  - Use text based inputs
  - Less computational time
  - Low accuracy

```
CASEID Missile Geometry
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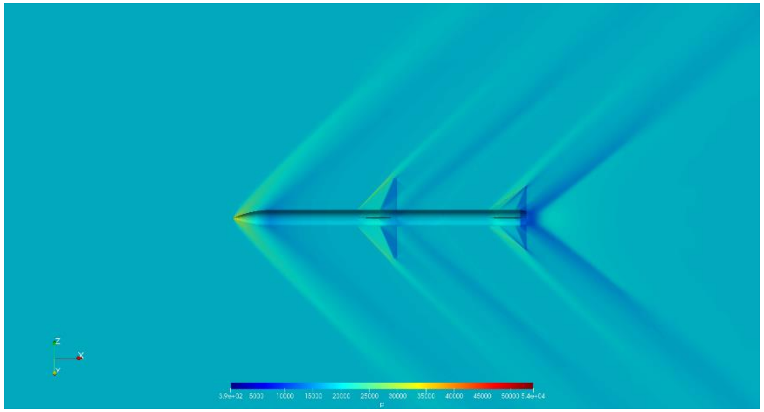
  ALT =  0.00000,
  PHI = 45.00000,
$END
```

- ❖ CFD
  - High accuracy
  - Require CAD and mesh



Introduction

❖ Challenges

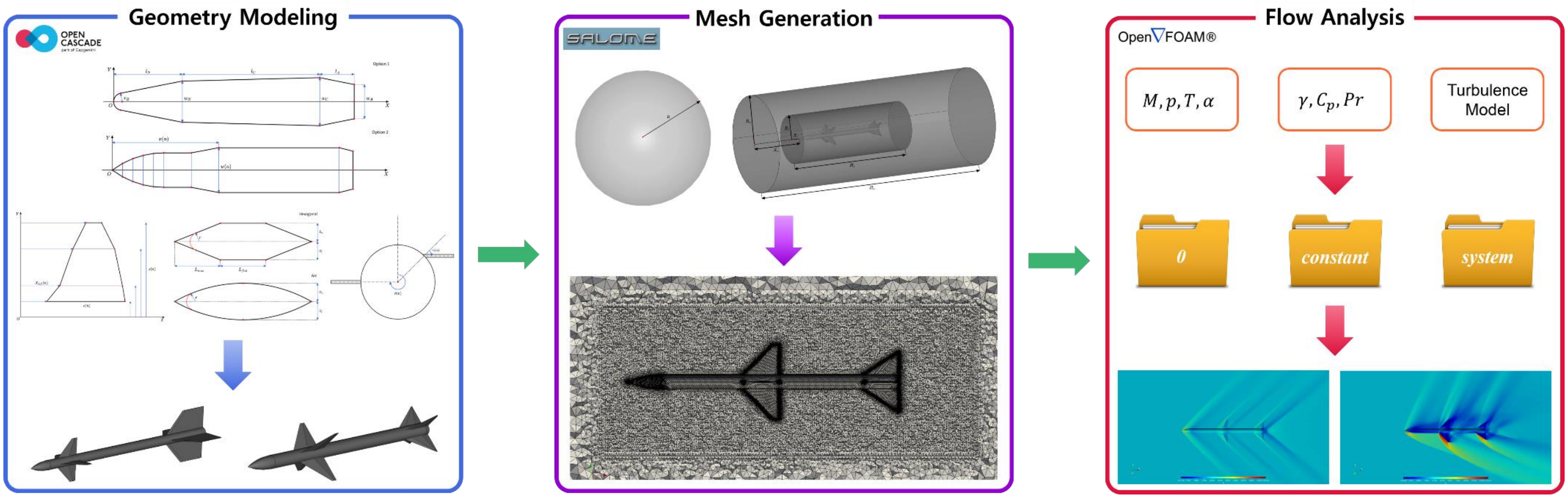
- A large number of simulation cases

- **Automation process should be required**
  - ✓ Creating CAD for various missile shapes
  - ✓ Generating volume mesh
  - ✓ Flow solver pre-processing

Introduction

❖ Objectives

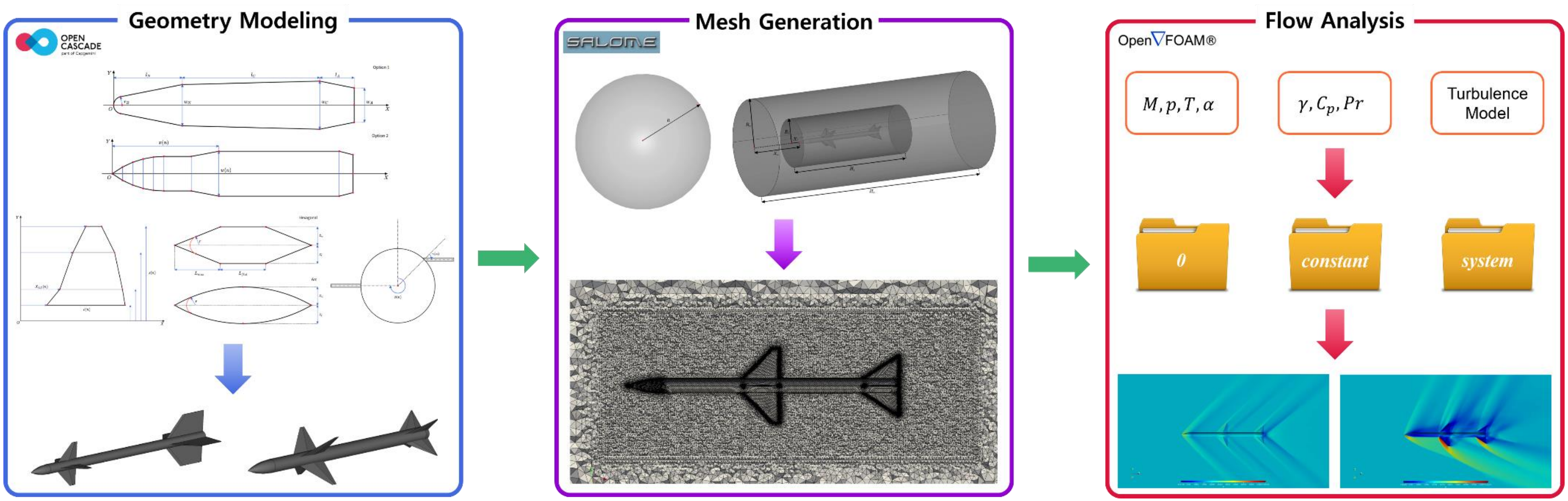
- Develop **automated aerodynamic analysis process**
  - ✓ Geometry modeling
  - ✓ Mesh generation
  - ✓ Flow Analysis



Automated Analysis Process

❖ Description

- Developed using open-source software
- XML file format is used for input parameters
- No user intervention



Automated Analysis Process

❖ Geometry Modeling

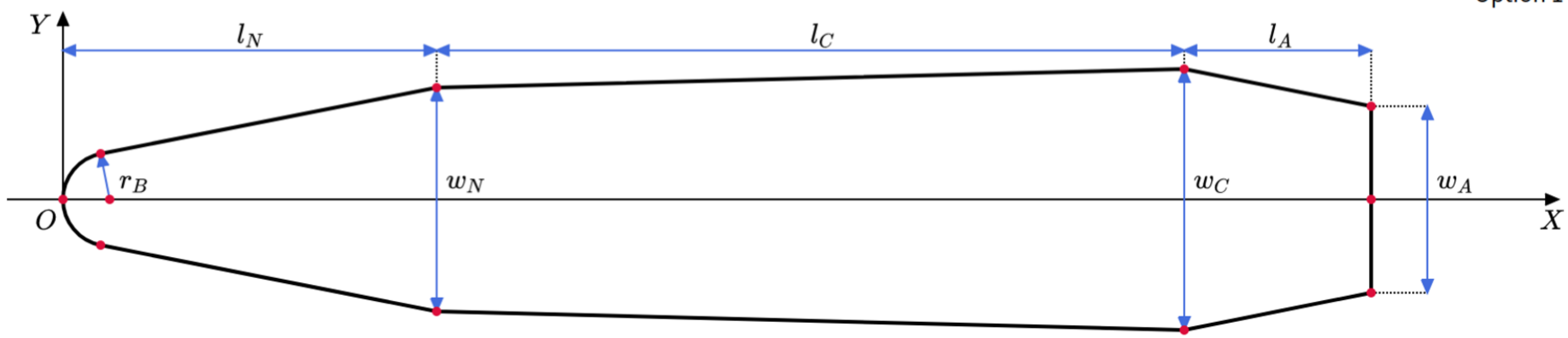
- Use pythonOCC library
  - ✓ python version of OpenCASCADE
- Based on Missile DATCOM's definition method
- All sharp edges are modified to blunted edges

Automated Analysis Process

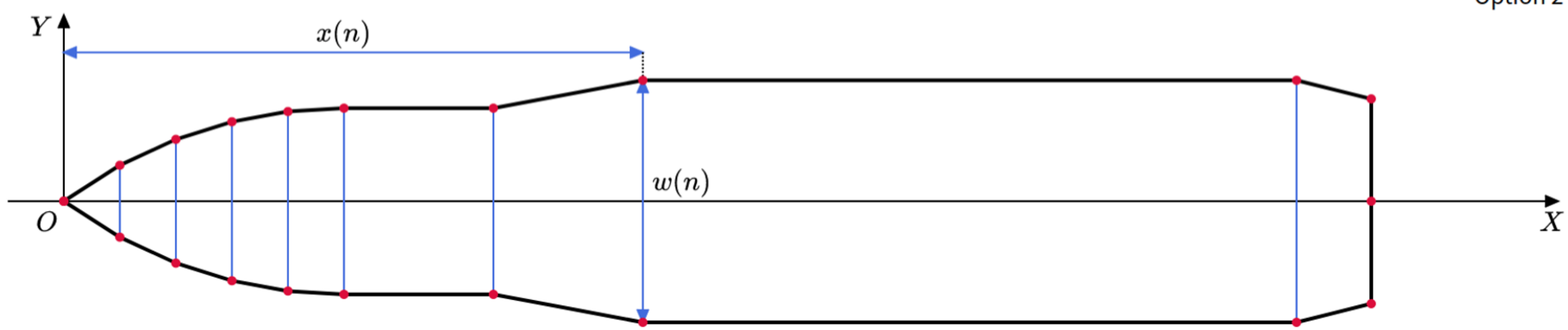
❖ Geometry Modeling

- Body
  - ✓ Option 1 : combination of nose, center body, after body
  - ✓ Option 2 : longitudinal data represented (X, R)

Option 1

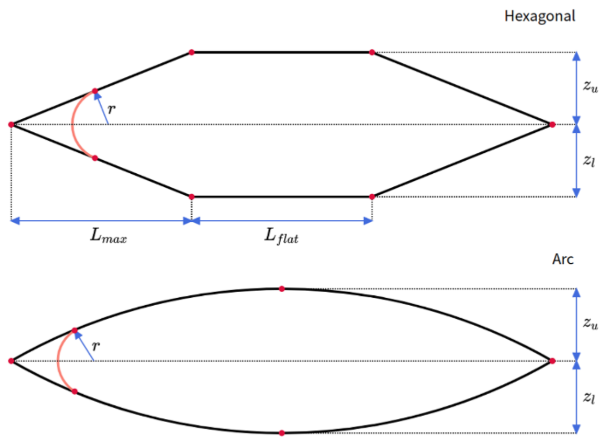


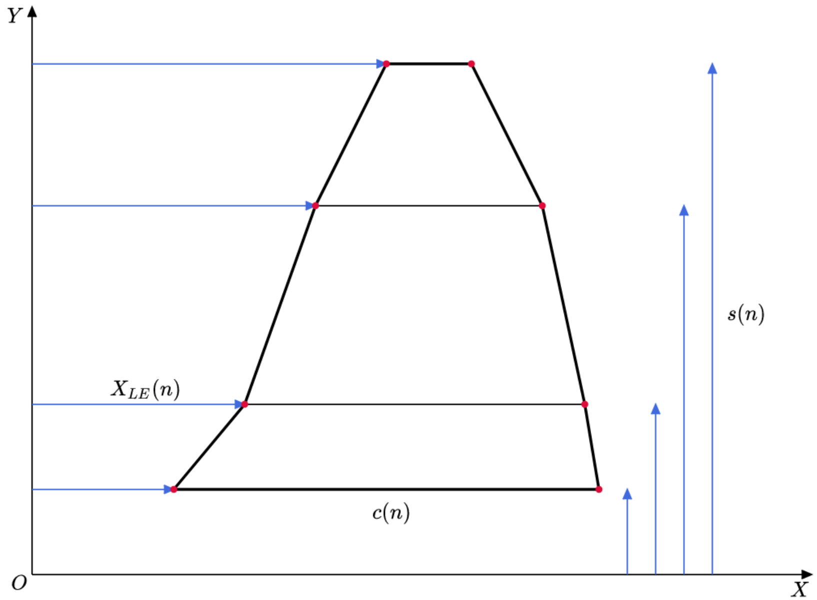
Option 2

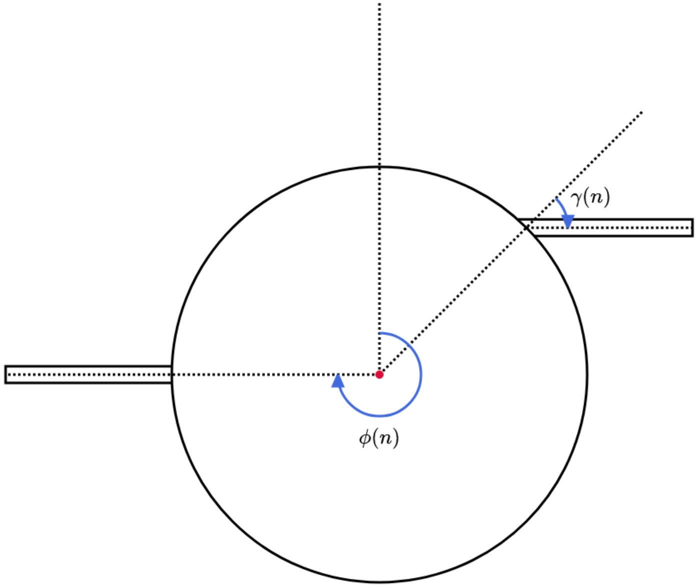


Automated Analysis Process

- Geometry Modeling
  - Finset
    - ✓ Planform
    - ✓ Airfoil
    - ✓ Attaching method







Automated Analysis Process

❖ Geometry Modeling

- Various missiles can be created with different inputs

```
<Item Name="Body" Type="Body1">
    <Item Name="Nose" Type="NOSE">
        <X0>0.000000</X0>
        <TNOSE>OGIVE</TNOSE>
        <LNOSE>0.068600</LNOSE>
        <WNOSE>0.030480</WNOSE>
        <BNOSE>0.001524</BNOSE>
        <ENOSE>1.000000</ENOSE>
        <TRUNC>.FALSE.</TRUNC>
    </Item>
    <Item Name="Centr" Type="CENTR"...>
    <Item Name="Aft" Type="AFT"...>
</Item>
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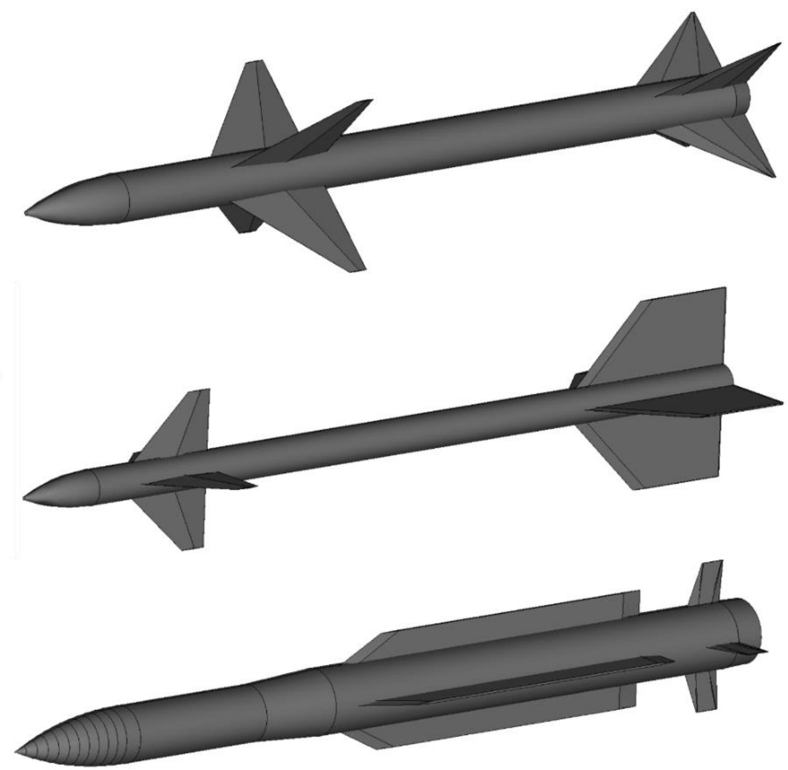


Automated Analysis Process

❖ Mesh Generation

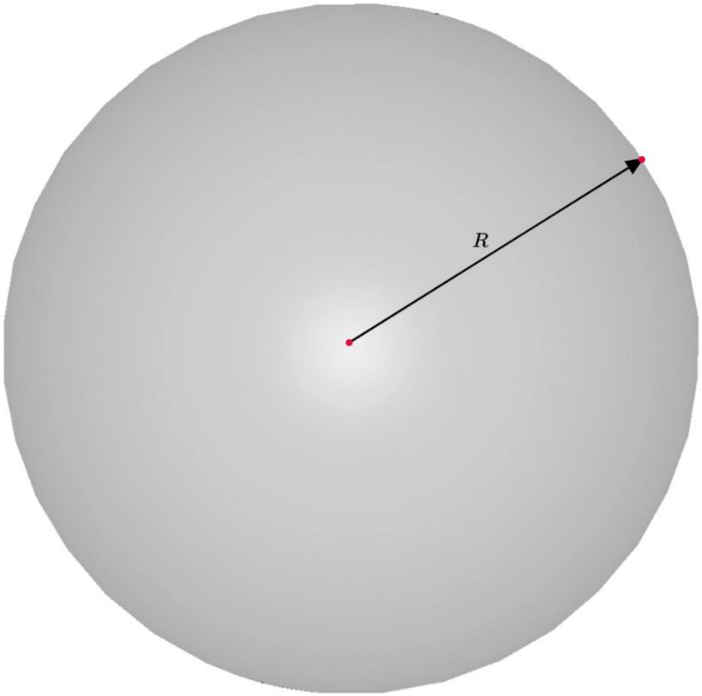
- Volume mesh is generated using SALOME
  - ✓ Open-source platform for numerical simulation
  - ✓ Limitation : Mesh parallelization is not supported

- Unstructured tetrahedral mesh with prism layers

Automated Analysis Process

❖ Mesh Generation

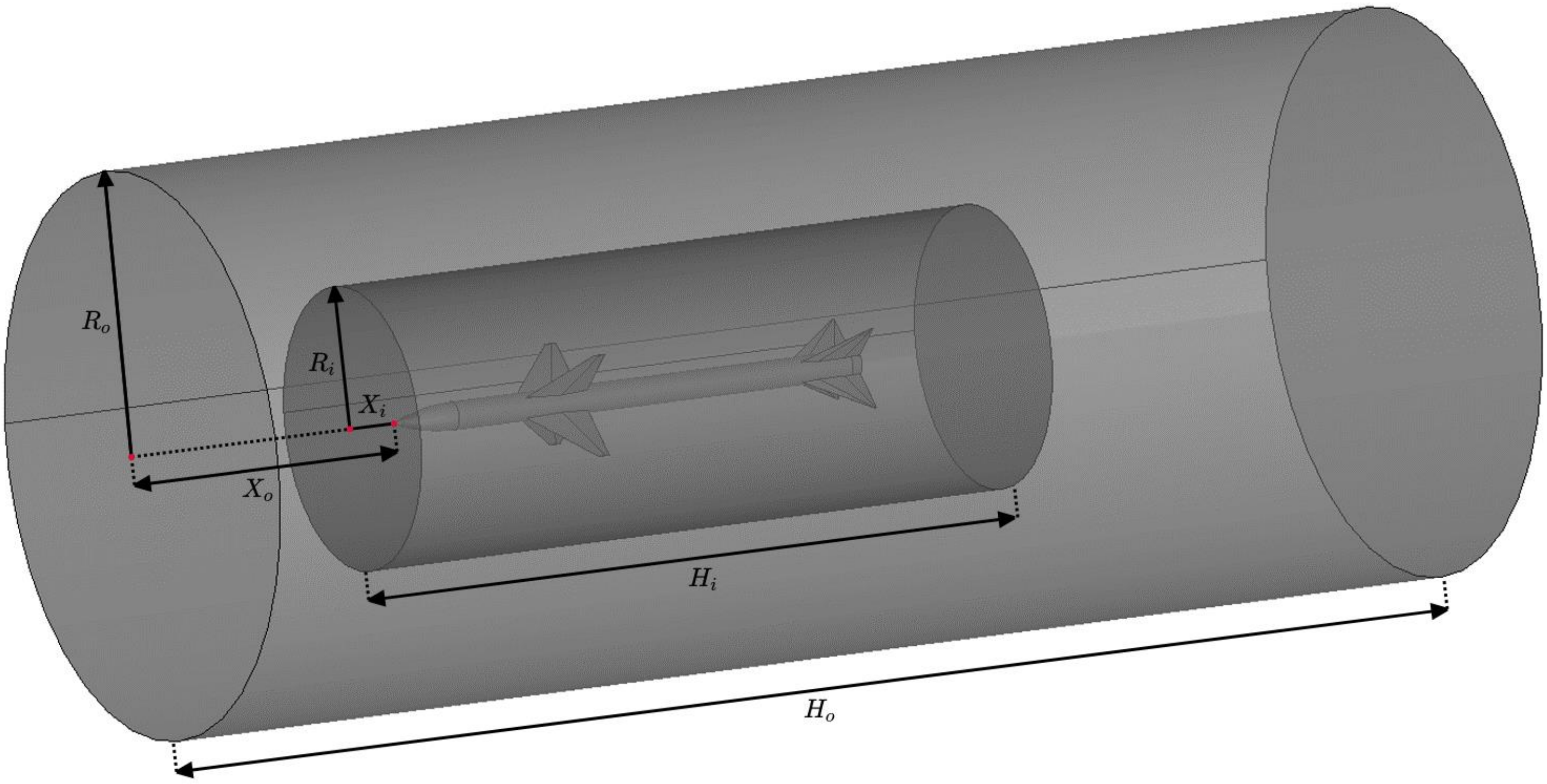
- Domain
  - ✓ Sphere



Automated Analysis Process

❖ Mesh Generation

- Refinement regions
  - ✓ To accurately capture shock wave and wake flow



Automated Analysis Process

- ❖ Mesh Generation
  - Mesh size parameters are applied at each regions
    - ✓ Min, max, growth rate
  - Mesh size at specific surface is automatically set
    - ✓ Body – Nose / Base surface
    - ✓ Finset – Tip surface

Automated Analysis Process

❖ Flow Analysis

- RANS analysis is conducted using OpenFOAM
  - ✓ Simulation case is consist of *0, constant,* and *system* directory
- TSLAeroFoam is used for numerical solver
  - ✓ Density-based compressible coupled solver
- $k-\omega\ SST$ model is set for turbulence model

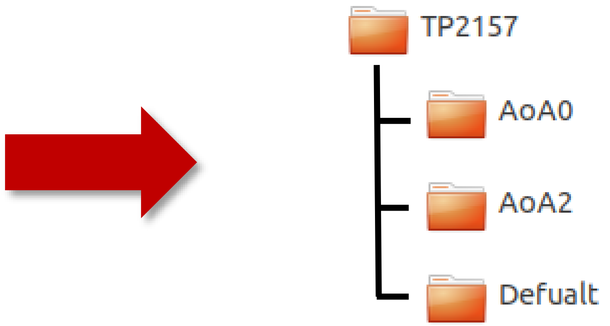
Automated Analysis Process

❖ Flow Analysis

- Flow conditions and gas constants are considered as input parameters
  - ✓ Flow conditions : M, P, T, AoA
  - ✓ Gas constants : γ, C_p, Pr

- Case directories are automatically generated

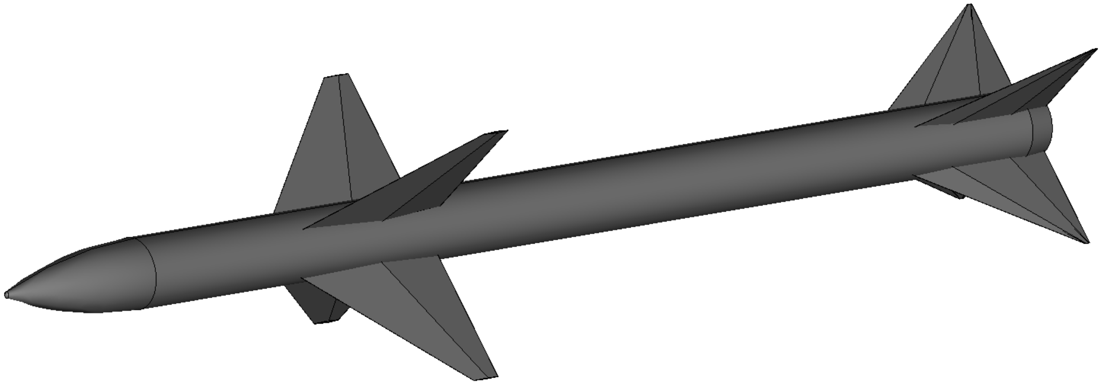
```xml
<Item Name="FLTCON" Type="FLTCON">
    <MACH>3.500000</MACH>
    <PFREE>1696.550000</PFREE>
    <TFREE>94.202900</TFREE>
    <ALPHA>
        <param>0.000000</param>
        <param>2.000000</param>
    </ALPHA>
</Item>
```



Benchmark Test

❖ Case 1 (NASA Sparrow)

- Geometry : X Configuration



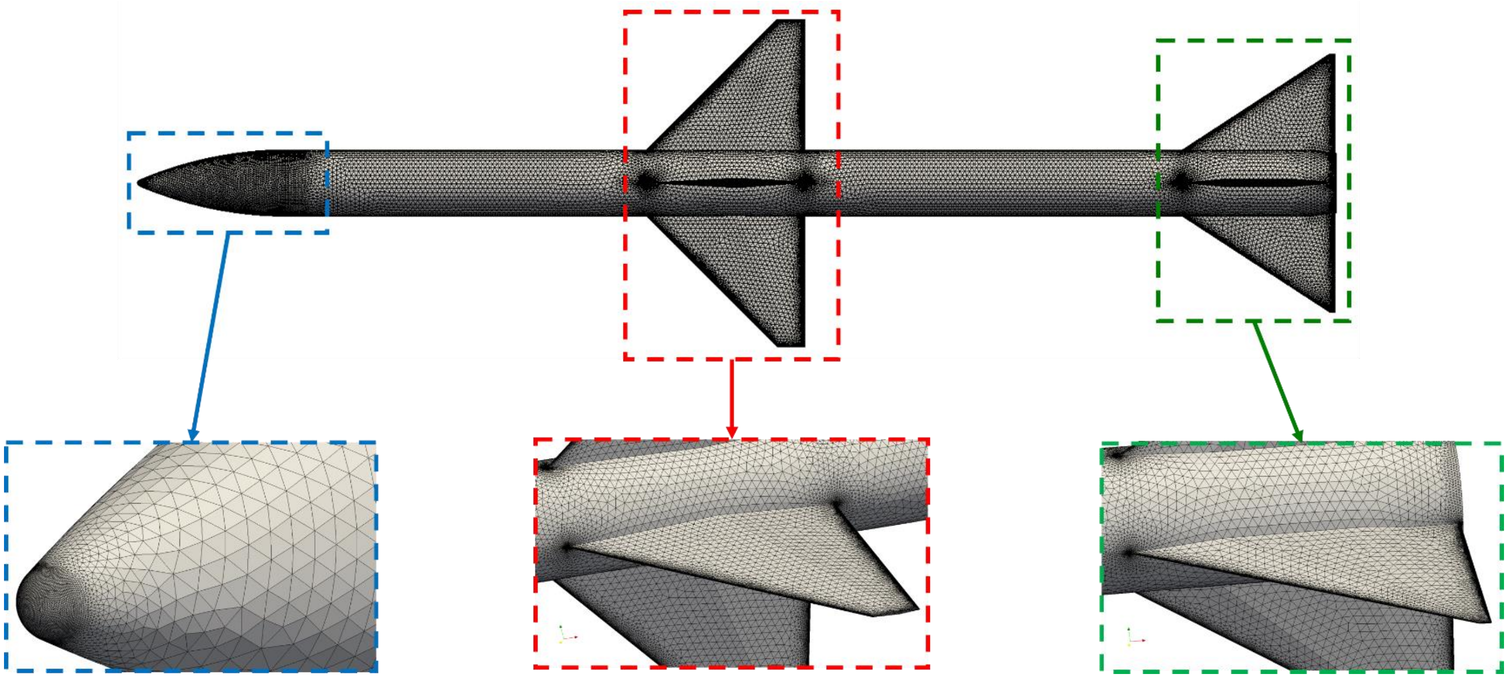
- Flow Condition

	Value
M	1.5
$P(Pa)$	18114.8
$T(K)$	233.793

Benchmark Test

❖ Case 1 (NASA Sparrow)

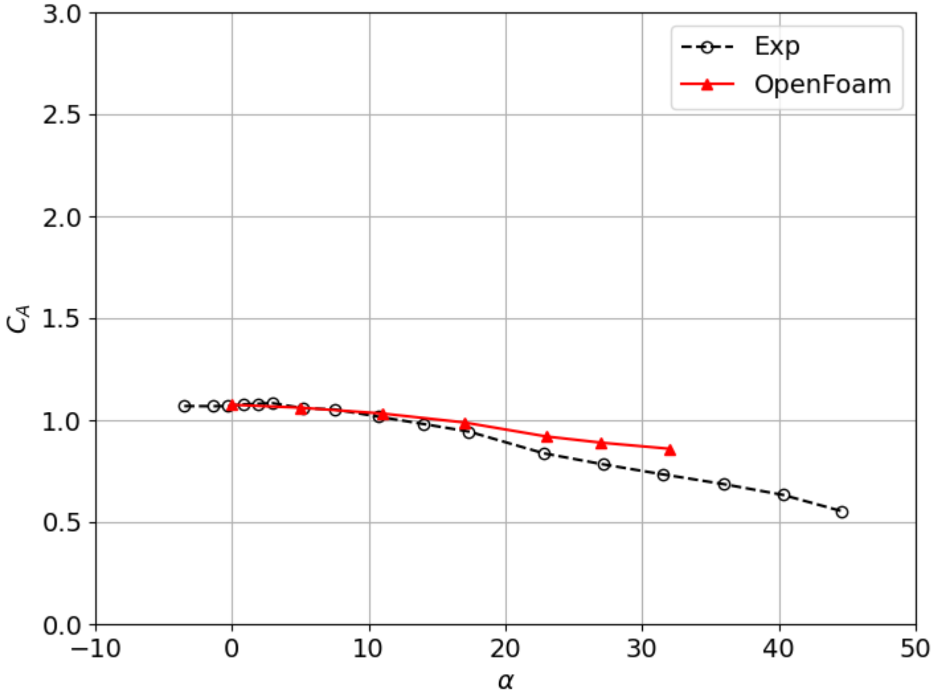
- Mesh
  - ✓ 20 prism layers with $y^+ = 1$
  - ✓ Total 23.3 million volume mesh



Benchmark Test

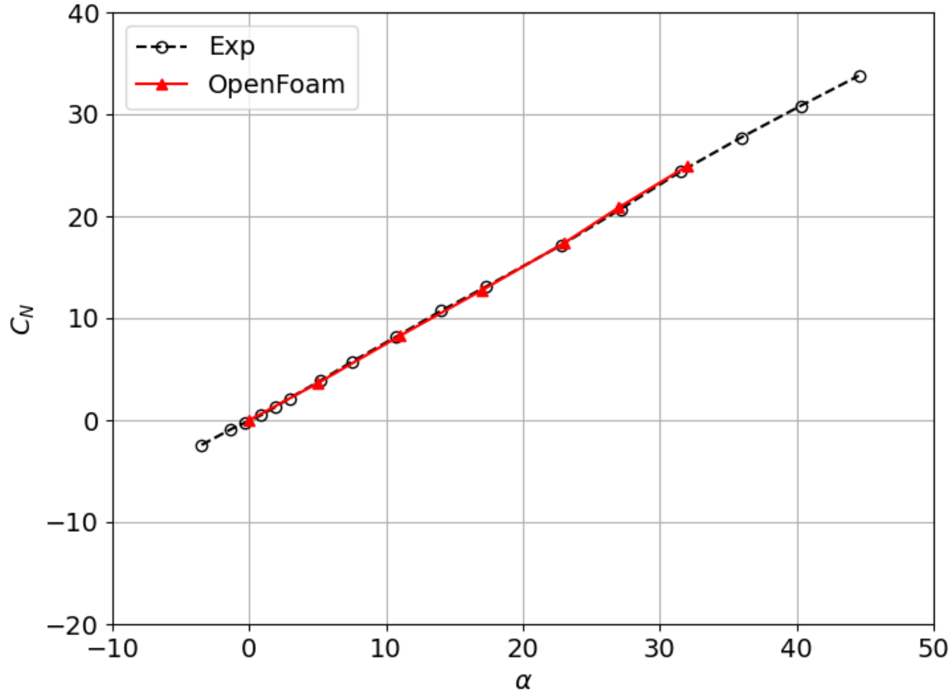
❖ Case 1 (NASA Sparrow)

- Result
  - ✓ C_A is overpredicted at high α



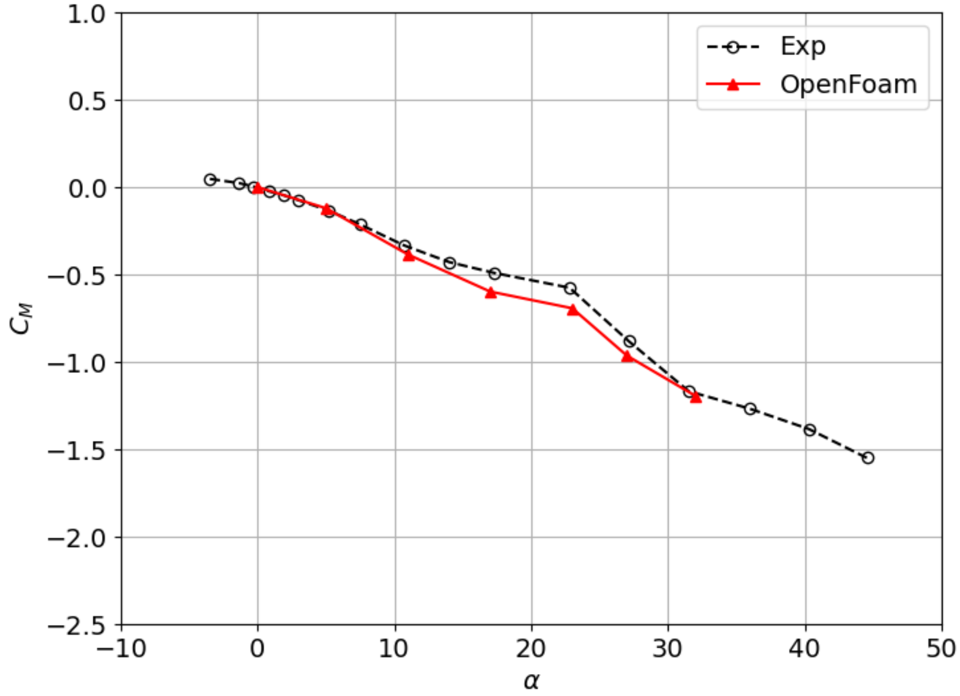
Benchmark Test

- ❖ Case 1 (NASA Sparrow)
  - Result
    - ✓ C_N is in very good agreement at all α



Benchmark Test

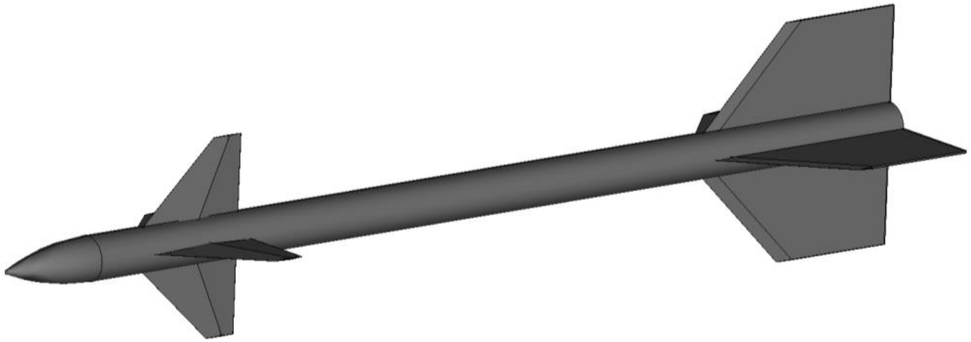
- Case 1 (NASA Sparrow)
  - Result
    - ✓ C_M matches overall trendline



Benchmark Test

❖ Case 2 (NASA TCM)

- Geometry : + Configuration



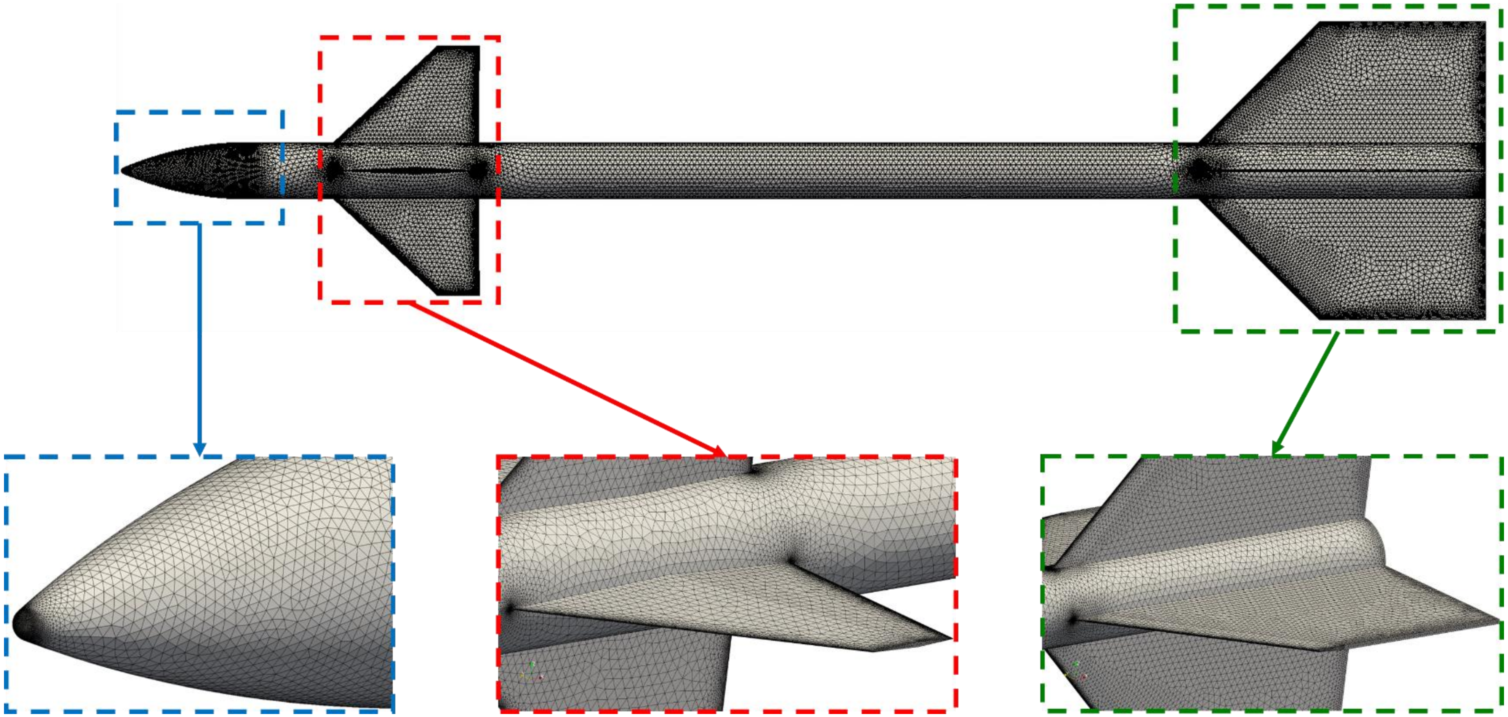
- Flow Condition

	Value
M	3.5
$P(Pa)$	1696.55
$T(K)$	94.2029

Benchmark Test

❖ Case 2 (NASA TCM)

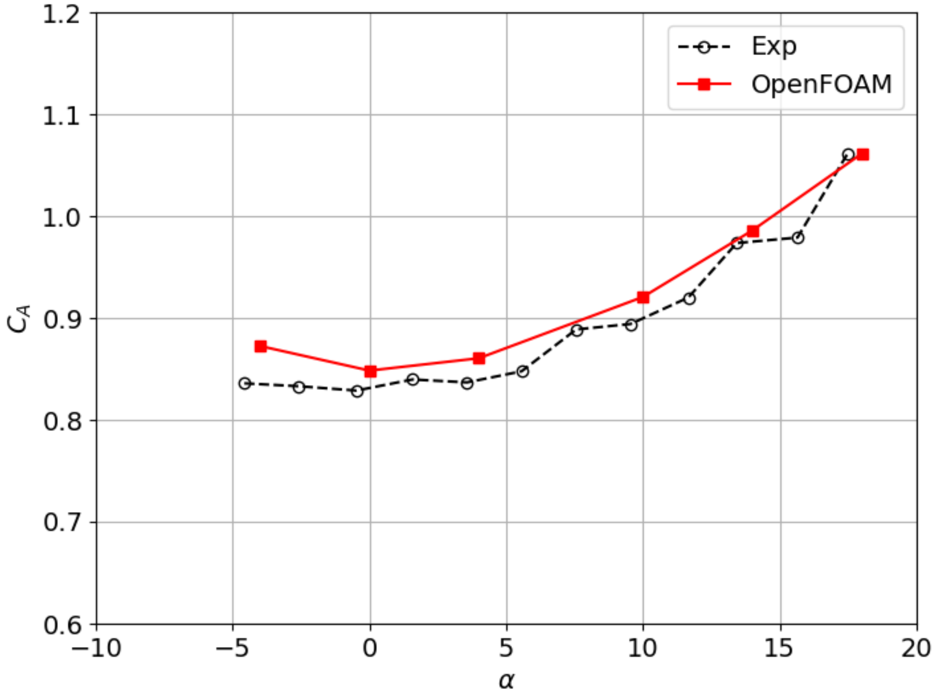
- Mesh
  - ✓ 20 prism layers with $y^+ = 1$
  - ✓ Total 25.5 million volume mesh



Benchmark Test

❖ Case 2 (NASA TCM)

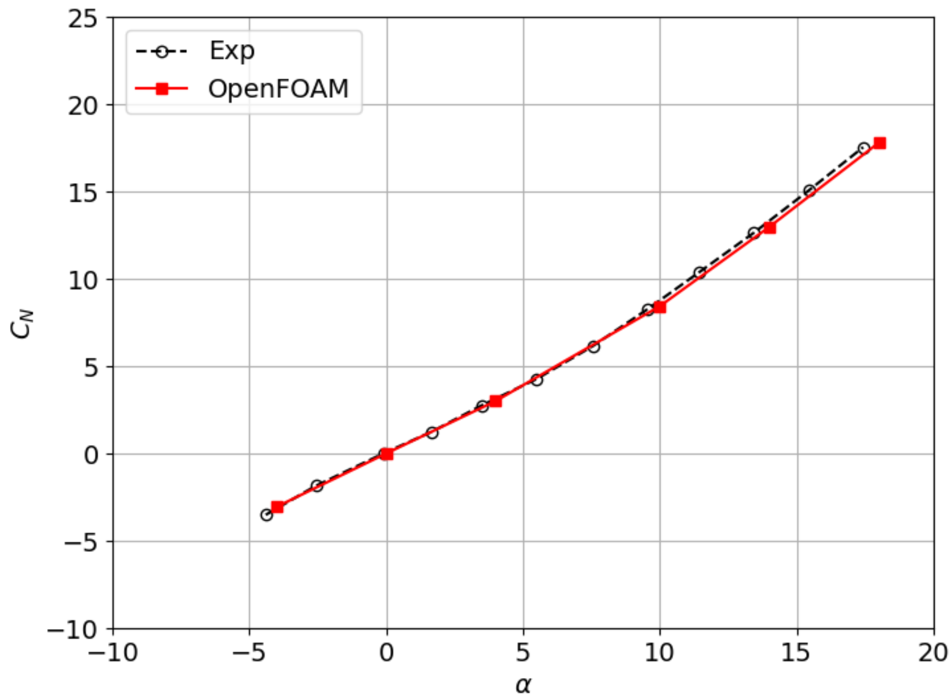
- Result
  - ✓ Experiment data have some oscillation
  - ✓ C_A is overpredicted but matches overall trendline



Benchmark Test

❖ Case 2 (NASA TCM)

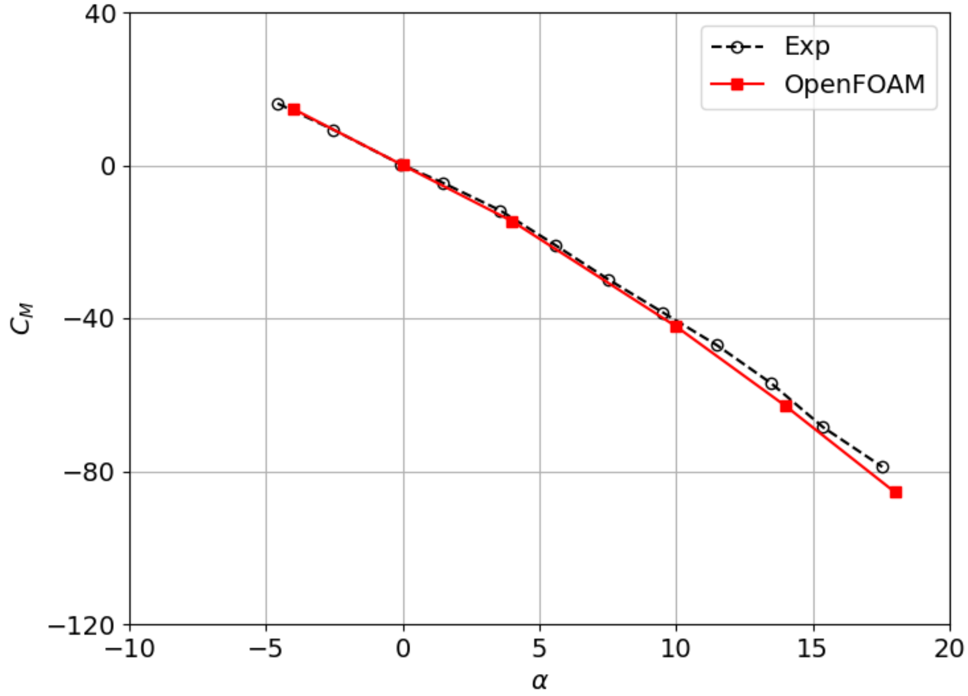
- Result
  - ✓ C_N , C_M are in very good agreement at all α



Benchmark Test

❖ Case 2 (NASA TCM)

- Result
  - ✓ C_N , C_M are in very good agreement at all α



Conclusion

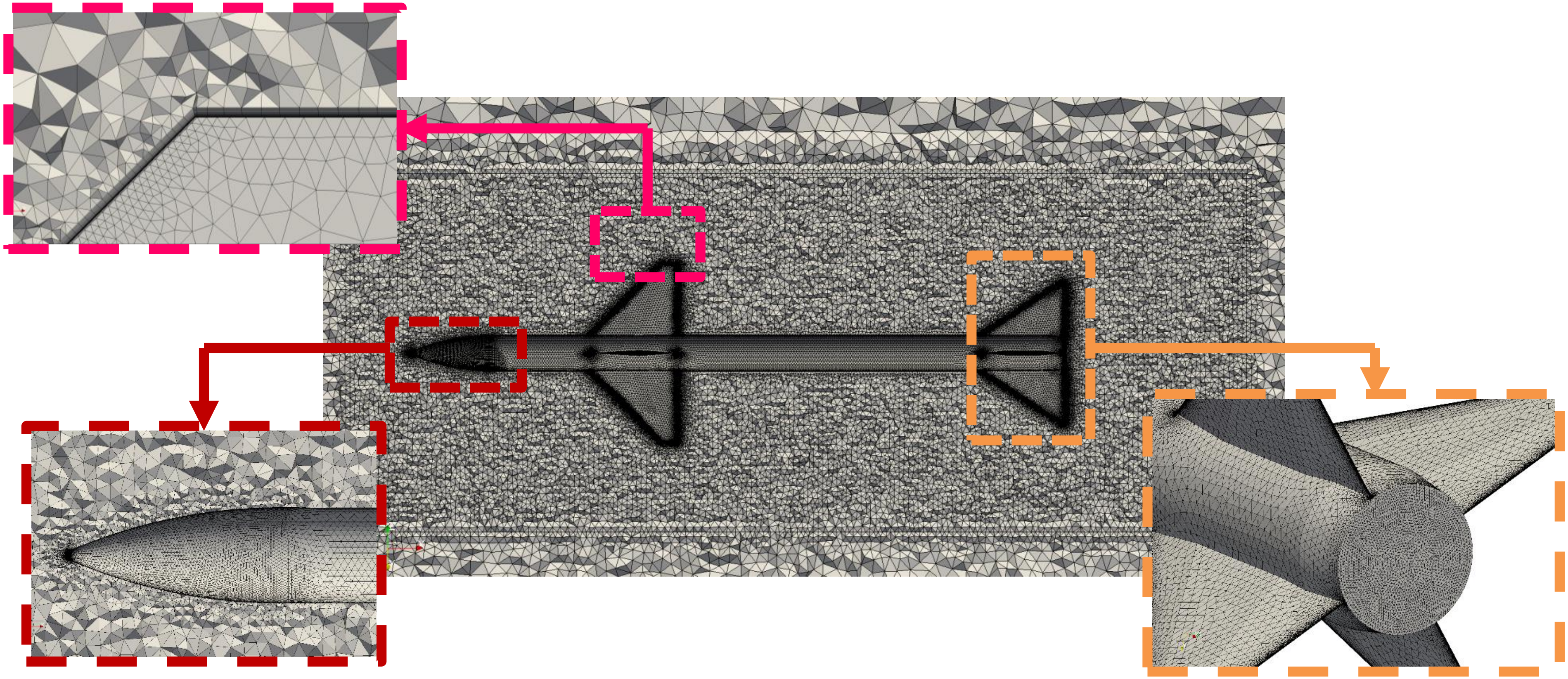
- Fully automated aerodynamic analysis process is developed based on open-source software
  - Geometry Modeling
  - Mesh Generation
  - Flow Analysis
- Automated process is verified with two missiles
  - Prediction accuracy is in good agreement

Thank You.

Automated Analysis Process

❖ Mesh Generation

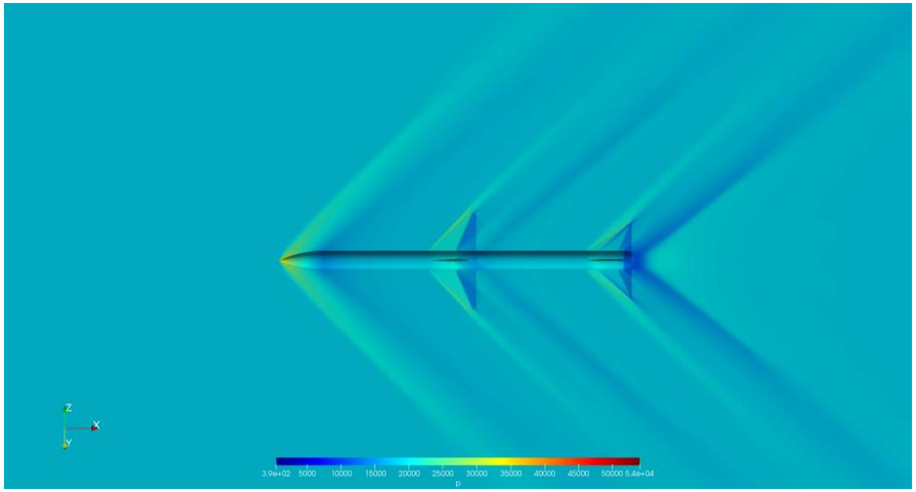
- Example



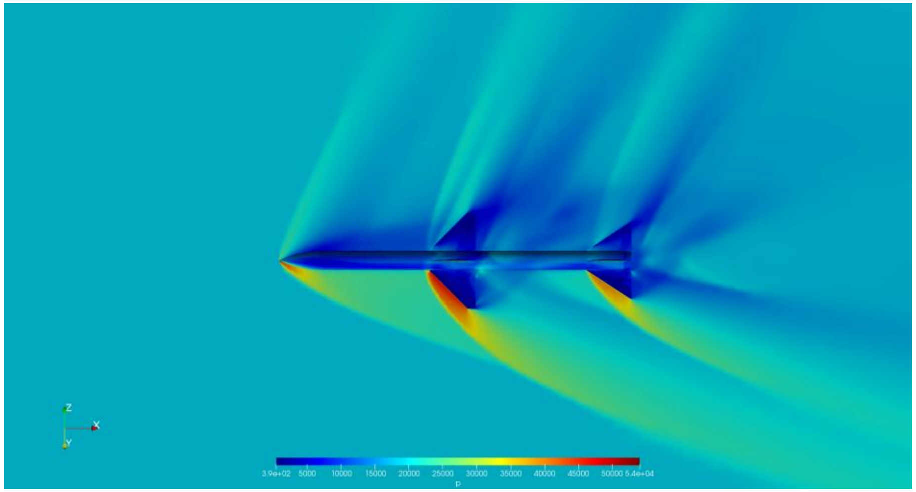
Benchmark Test

❖ Case 1 (NASA Sparrow)

- Pressure Contour
  - ✓ Shock wave is accurately captured



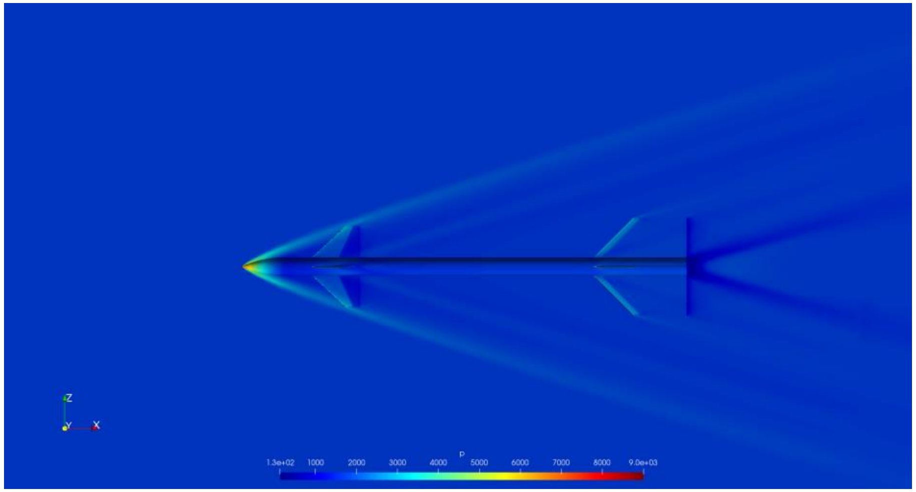
$\alpha = 0°$



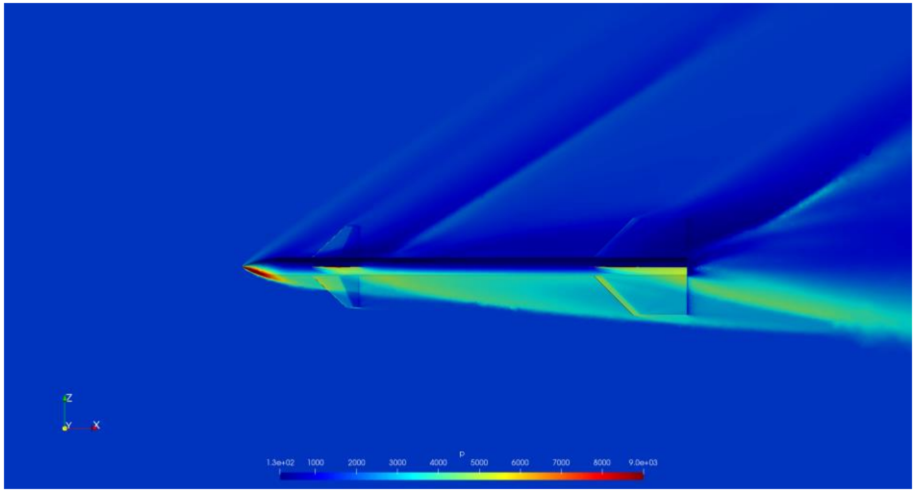
$\alpha = 32°$

Benchmark Test

- **Case 2 (NASA TCM)**
  - Pressure Contour
    - ✓ Shock wave is accurately captured



$\alpha = 0°$



$\alpha = 18°$