SUBSONIC-TRANSONIC SUBMERGED INTAKE DESIGN FOR A CRUISE MISSILE

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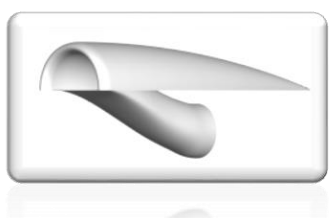
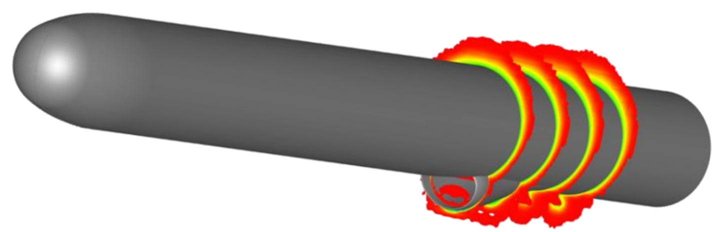
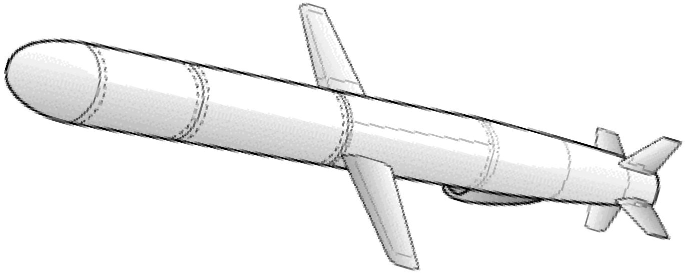




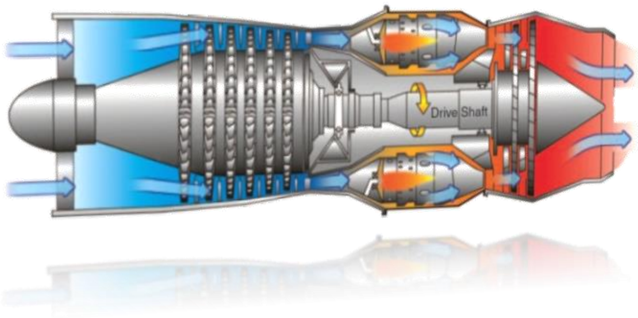
INTRODUCTION



Cruise Missiles:

Long distance in long flight time

- *Cruise missiles maintain thrust long time with low fuel cost and high efficiency.*
- *Air breathing engines (turbojet) are used for this purpose.*
- *Required air flow supplied with intakes.*



INTRODUCTION

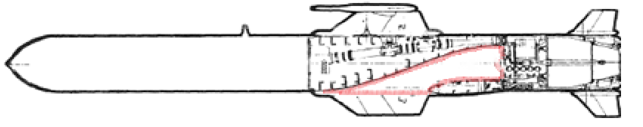
INTAKE TYPES

Pitot Type Intake

- Efficient interior aerodynamics.
- Commonly used in aircrafts and UAV’s.
- Inferior radar cross-section.
- High drag.

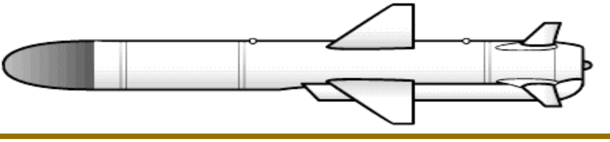
NACA Type Intake

- Low efficiency.
- Active or passive flow control required.
- Excellent radar cross-section.
- Very low drag characteristics.



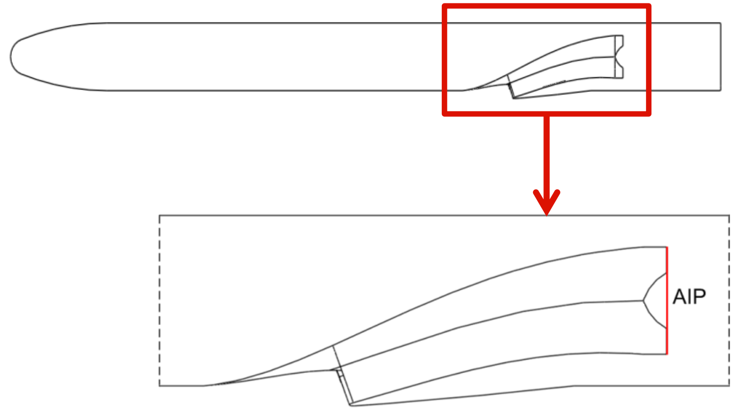
Submerged Intake

- Moderate efficiency.
- Moderate interior aerodynamics.
- Moderate radar cross-section.
- Moderate drag.



INTRODUCTION

PERFORMANCE PARAMETERS



Pressure Recovery

- *Ratio of the total pressure at the AIP to freestream.*

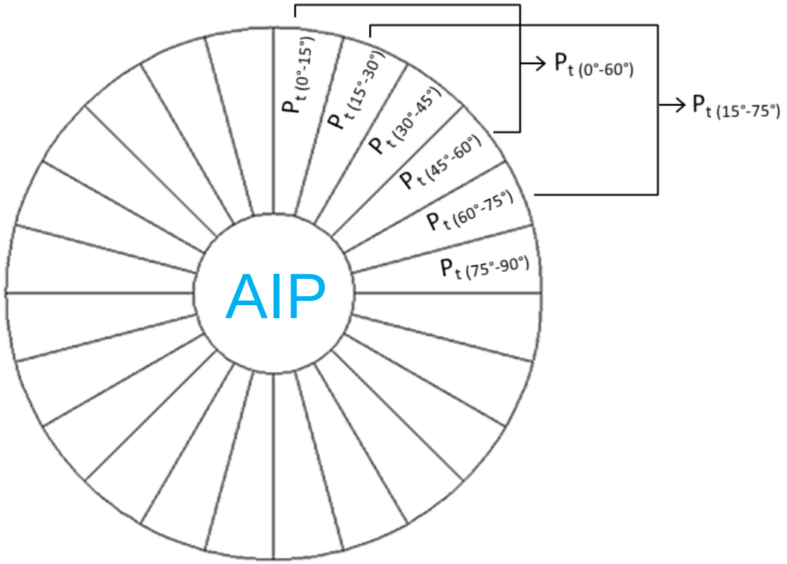
$$PR = \frac{P_{t,AIP}}{P_t}$$

Mass Flow Rate

$$\dot{m} = \rho . V . A \qquad \dot{m}_{corr} = \dot{m}\frac{\sqrt{\frac{T_t}{T_{sea\ level}}}}{\frac{P_t}{P_{sea\ level}}}$$

Distortion Coefficient

- *Total pressure distrubution on the engine face*



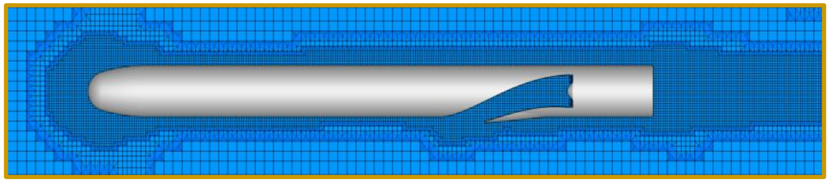
$$DC = \frac{\overline{P_{t,AIP}} - \overline{P_{t,\theta}}}{\overline{q_{AIP}}}$$

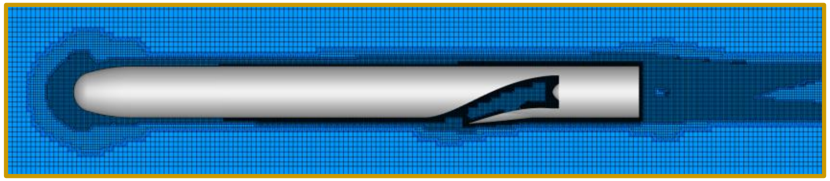
AIP: Aerodynamic Interface Plane

METHODOLOGY

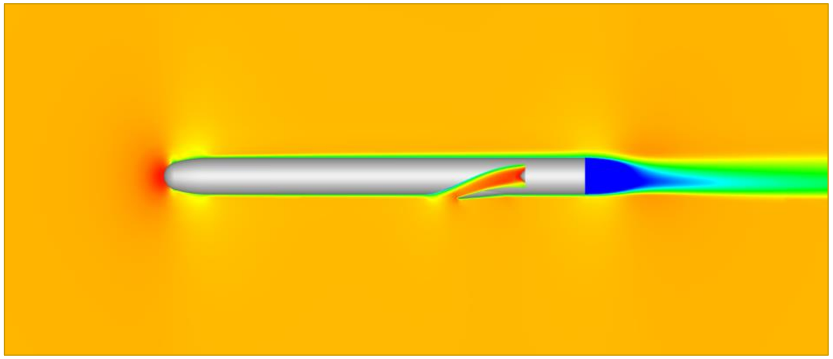
NUMERICAL METHODS AND CFD TOOL

- FloEFD CFD Analysis Tool
  - *Steady, Compressible, 3D, Navier-Stokes*
  - *Adaptive Cartesian Mesh*
  - *Modified k-ε Turbulence Model*





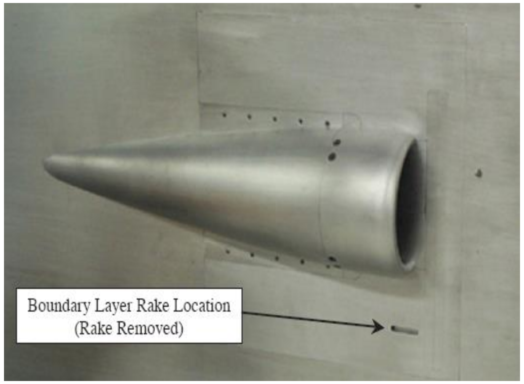
- Advantages
  - *Fast Solution Time*
  - *Accurate results.*
  - *Fast Preparation*
  - *Fast Postprocess*
  - *Same Grid can be applied.*
  - *Mesh Adaptation during analysis*
  - *Support Team (in TURKEY, in GLOBAL)*

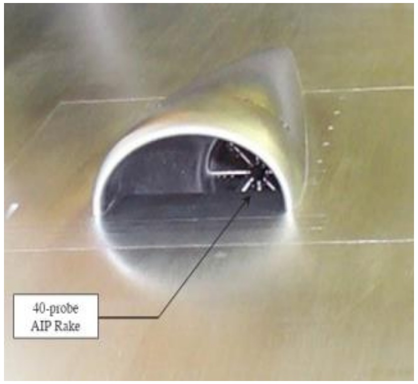


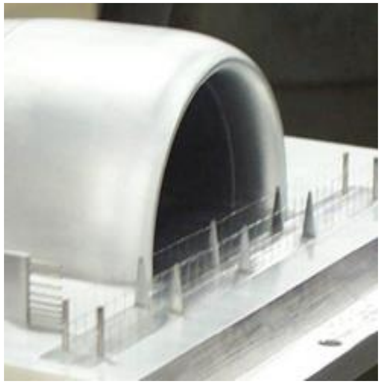
VALIDATION OF NUMERICAL METHODS

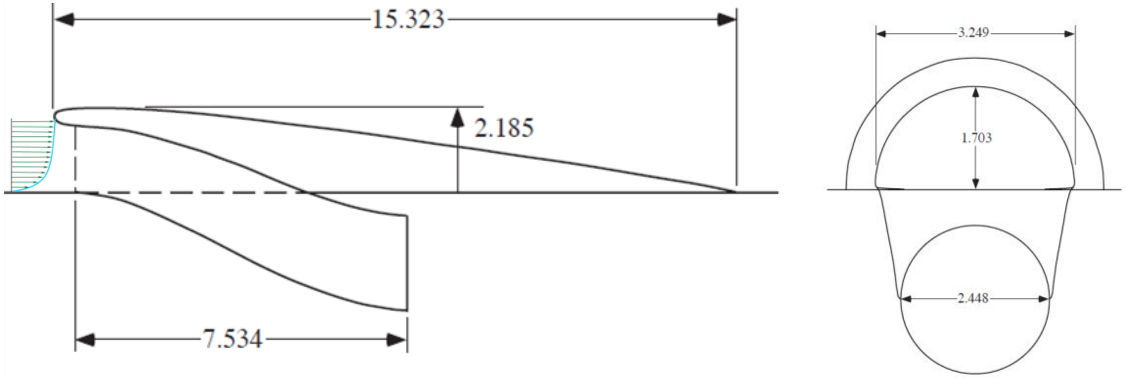
NASA FLUSH MOUNTED S-DUCT INTAKE TEST CASE

- *Test Case Model : Inlet-A*







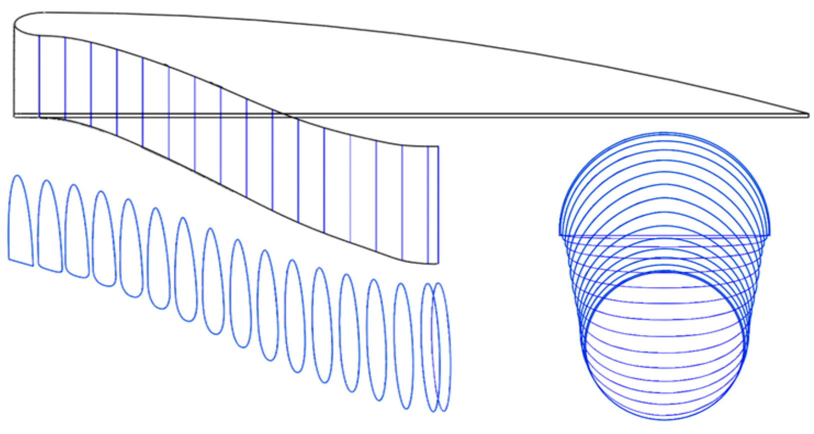


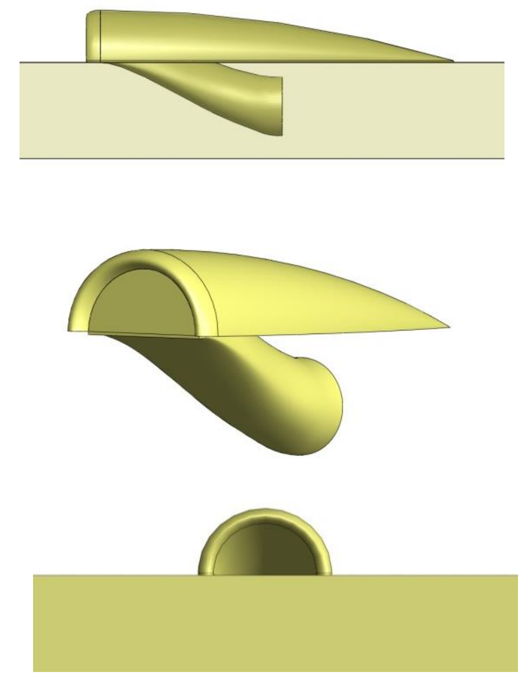
*All dimensions are inches

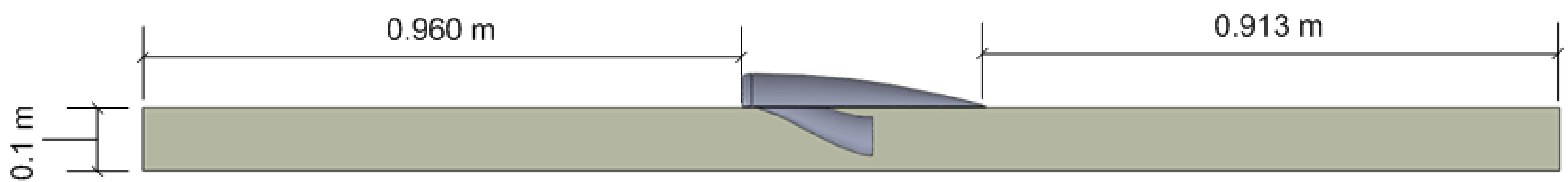
VALIDATION OF NUMERICAL METHODS

NASA FLUSH MOUNTED S-DUCT INTAKE TEST CASE

- *Solid Model of Inlet-A*



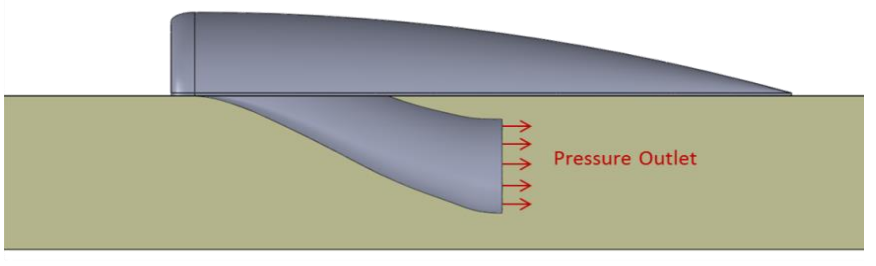




VALIDATION OF NUMERICAL METHODS

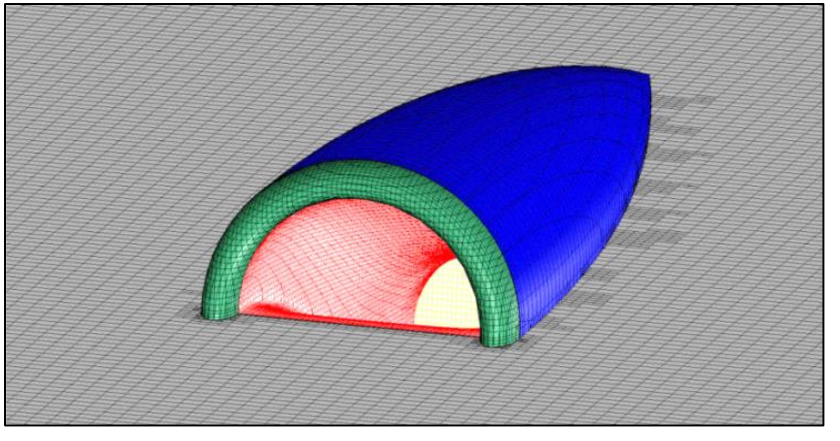
NASA FLUSH MOUNTED S-DUCT INTAKE TEST CASE

- *Analysis Conditions*



Test Conditions

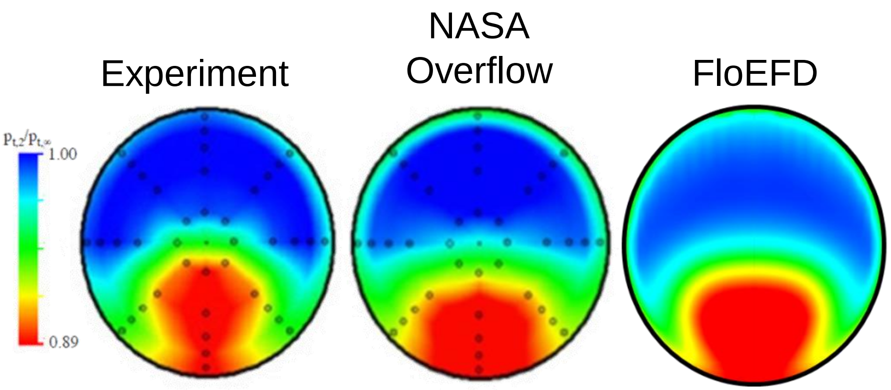
Mach Number	0.834
Reynolds Number	13.9 x 10^6
Fluid	Nitrogen
P_{static}	218528.3 Pa
T_{static}	88.2 K
ρ	8.635 kg/m^3



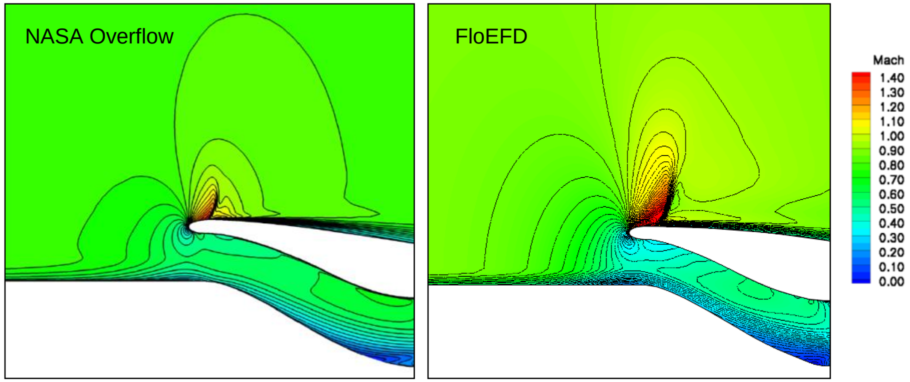
VALIDATION OF NUMERICAL METHODS

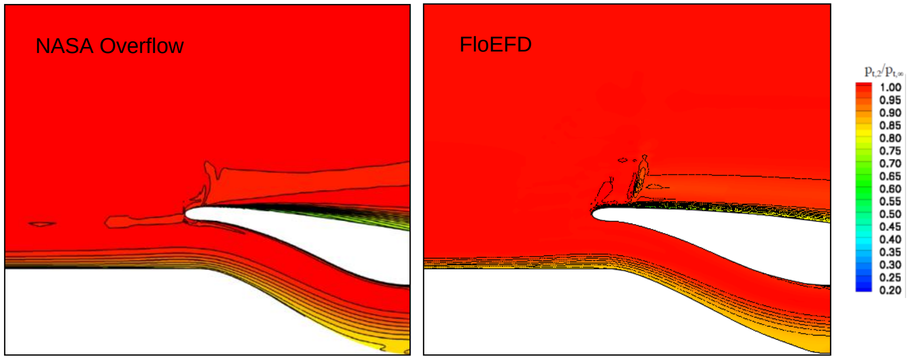
NASA FLUSH MOUNTED S-DUCT INTAKE TEST CASE

- *Results*



Parameter	Reference Experiment	Reference CFD	Present Study (FloEFD)	Present Study % Error
Mass Flow Rate (MFR)	2.570	2.610	2.502	2.64
Pressure Recovery (PR)	0.960	0.963	0.961	0.10
Distortion Coefficient (DC)	0.045	N.A.	0.046	3.24



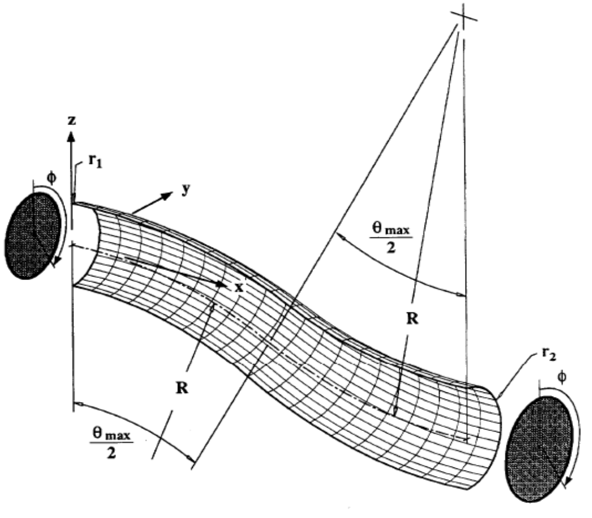


VALIDATION OF NUMERICAL METHODS

NASA S-SHAPED INTAKE DIFFUSER TEST CASE

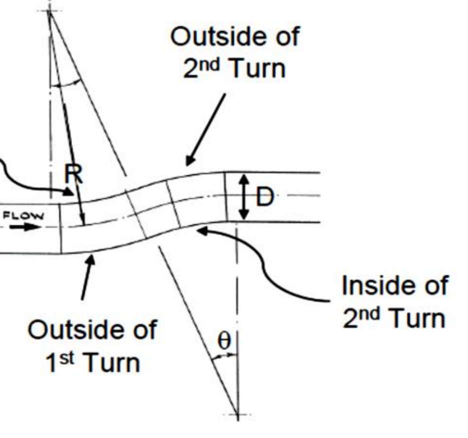
- *Test Case Model : S-Duct Intake*

Example of seperated internal flow



Wind Tunnel Test Conditions

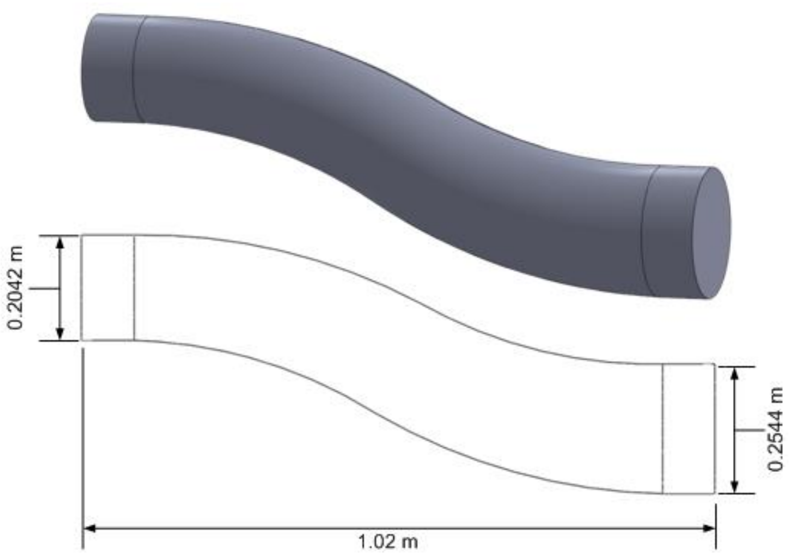
Mach Number	0.6
Mass Flow Rate	7.135 kg/s
Reynolds Number	2,600,000



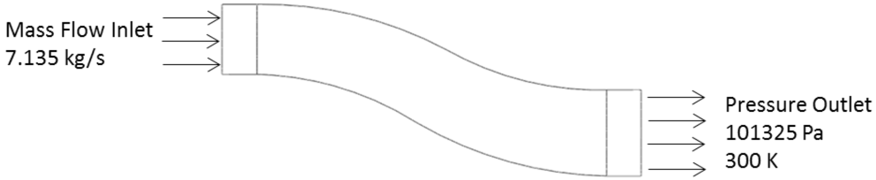
VALIDATION OF NUMERICAL METHODS

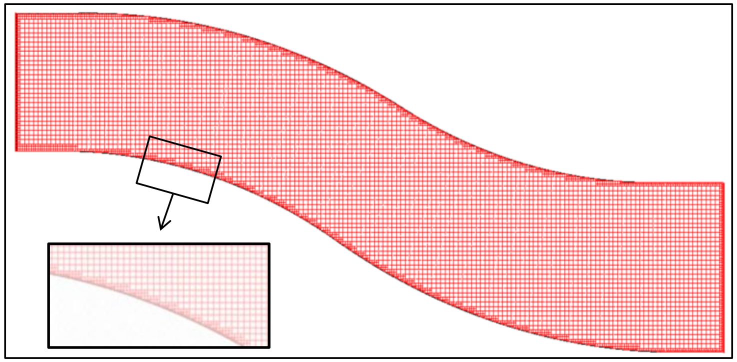
NASA S-SHAPED INTAKE DIFFUSER TEST CASE

- *Solid Model, BC's and Computational Grid*



Boundary Conditions



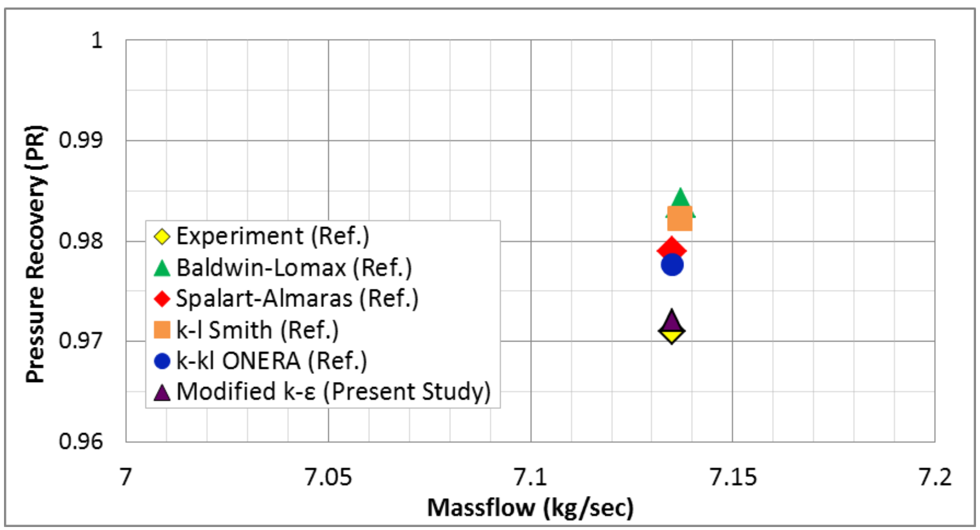


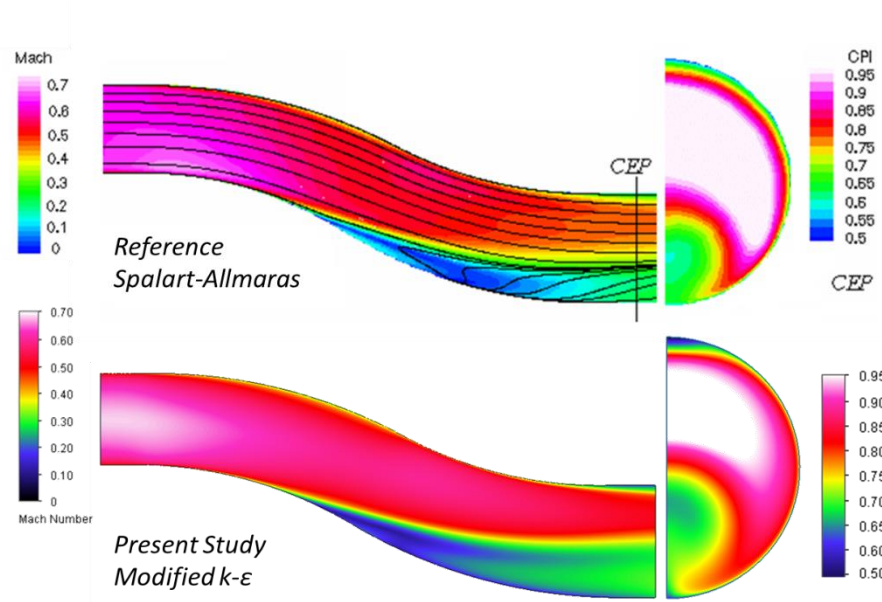
VALIDATION OF NUMERICAL METHODS

NASA S-SHAPED INTAKE DIFFUSER TEST CASE

- *Results*

	Experiment Result	FloEFD Result	%Error
PR	0.971	0.972	≈ 0.0





VALIDATION OF NUMERICAL METHODS

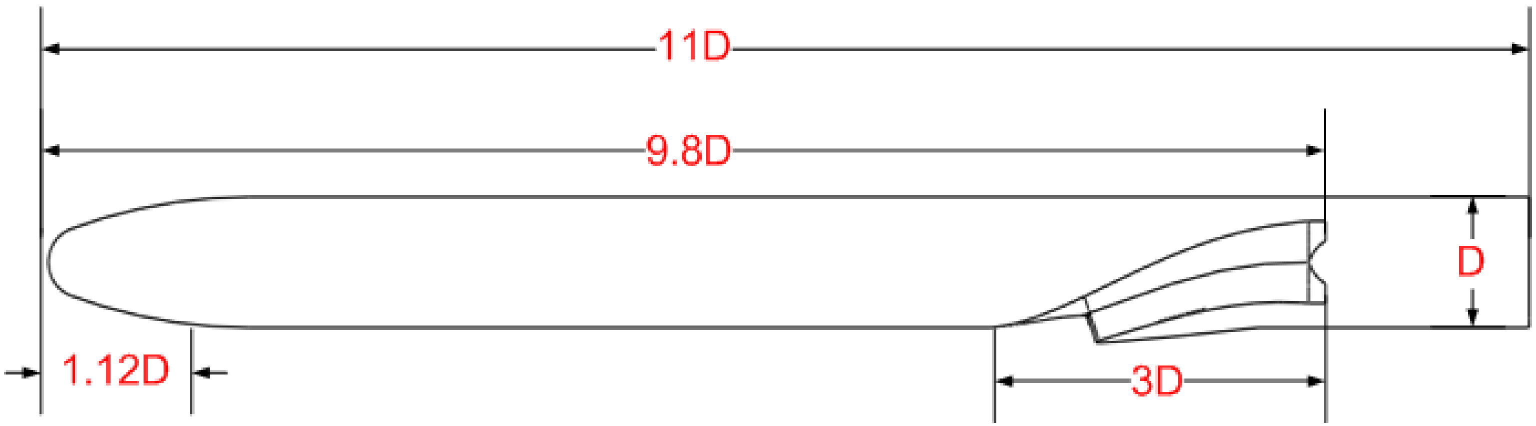
VALIDATION STUDY REVIEW

- FloEFD produced very accurate results compared to experiment.
- FloEFD's Modified k-ε turbulence model is suitable for the intake design process.
- FloEFD can be easily used for cruise missile intake design study.

DESIGN STUDY

Missile Geometry

- *Geometry of Generic Cruise Missile*



Generic Cruise Missile Dimensions

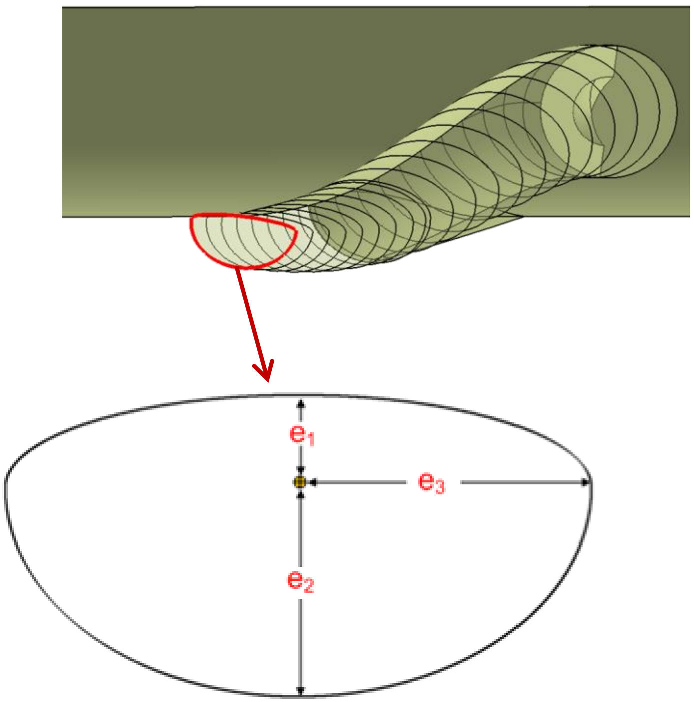
Diameter	D
Body Length	11D
Nose Length	1.12D
AIP Location	9.8D
Intake Length	3D

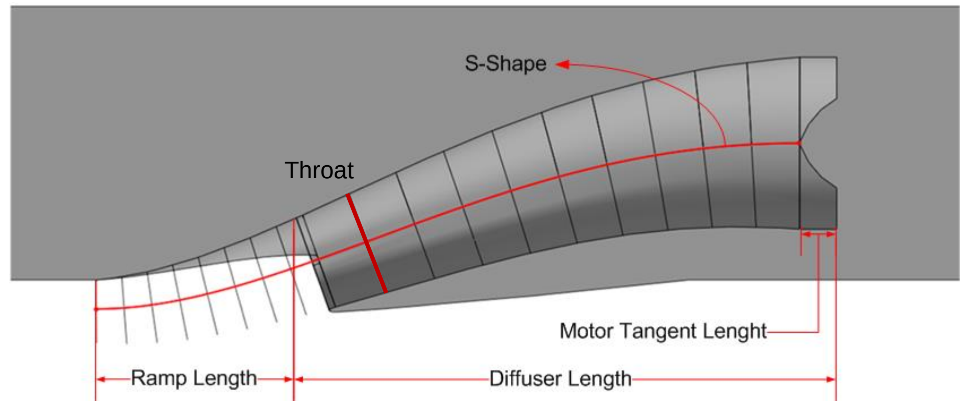
- These parameters are constant

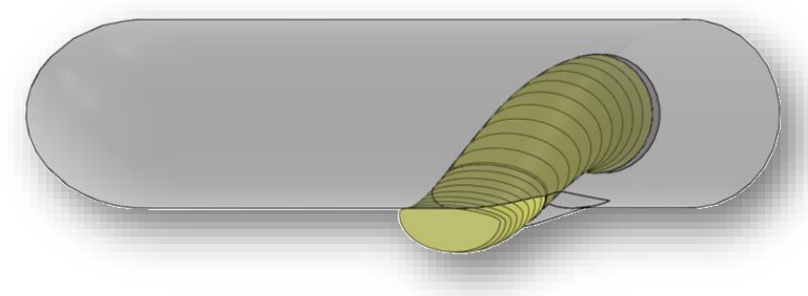
DESIGN STUDY

Geometric Optimization Parameters

- *Geometry of Generic Cruise Missile Intake*



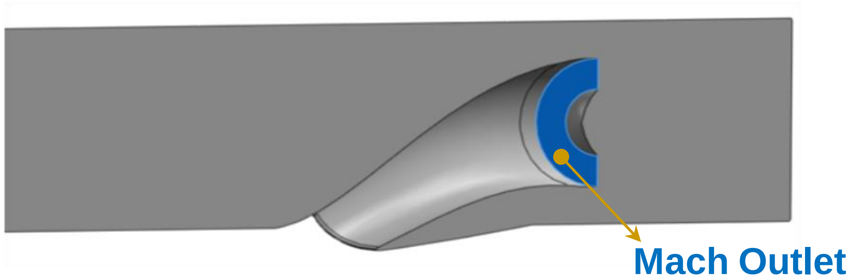




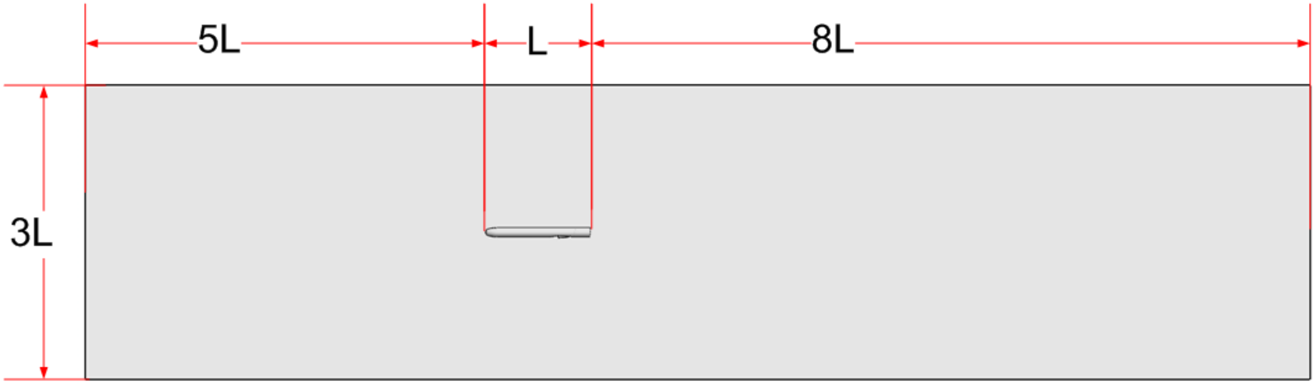
CFD MODELLING

Computational Domain and Boundary Conditions

- Optimum Computational Domain
- Mach Outlet B.C at AIP
- Sea level (101325 Pa, 300 K)
- No-slip, adiabatic wall boundary condition.



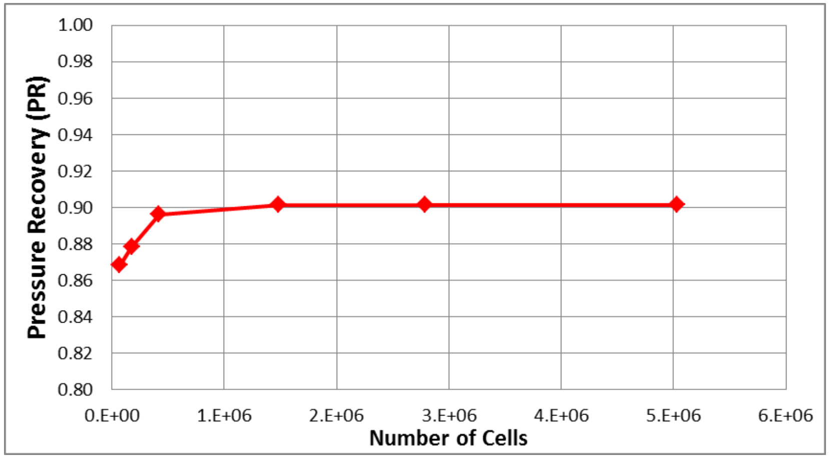
COMPUTATIONAL DOMAIN		
Height (m)	*Length (m)*	*Width (m)*
3xL	*14xL*	*3xL*

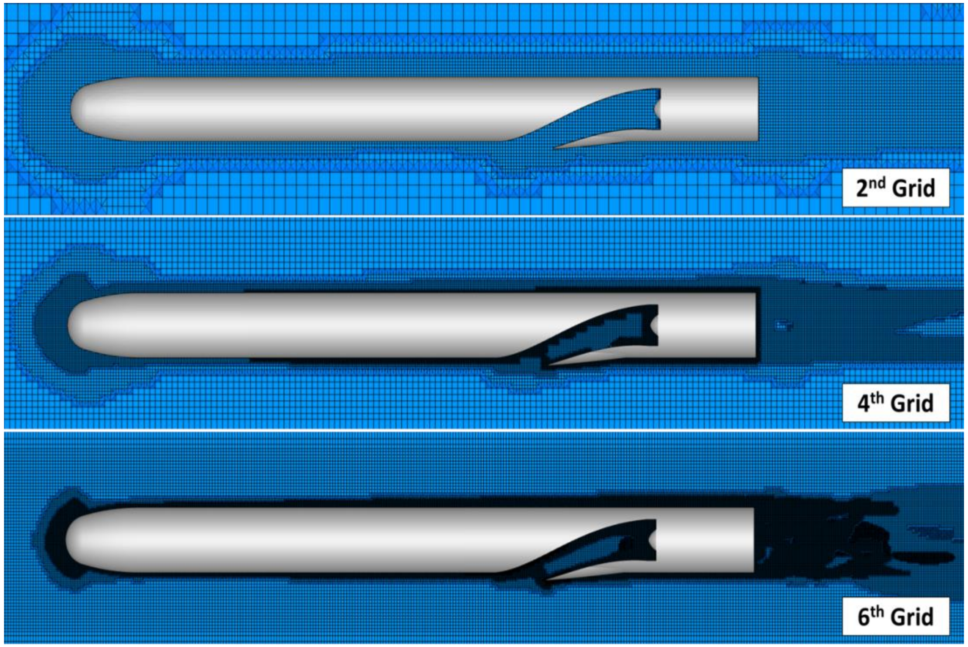


CFD MODELLING

Grid Convergence

- Solutions grid independed
- 4^{th} grid chosen
- 1,500,000 elements





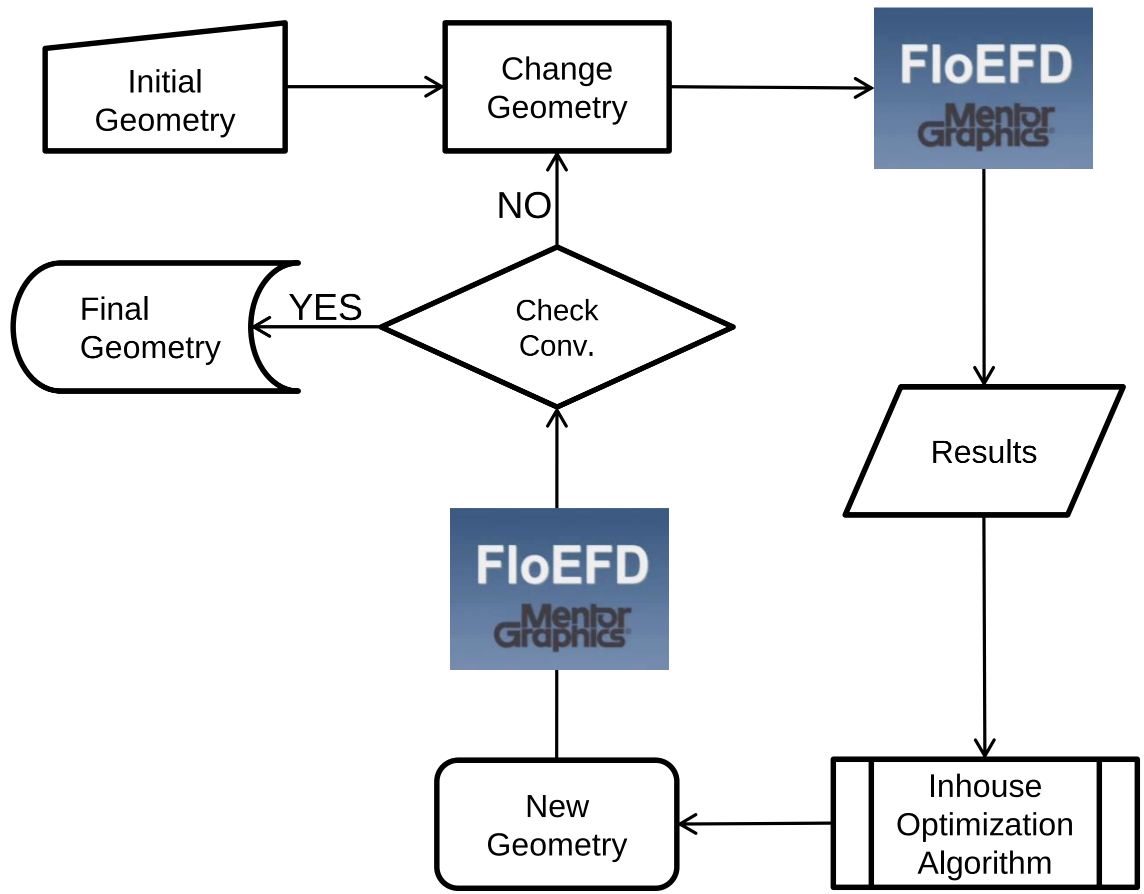
For the 4th Grid.

- 800 iterations
- 6 hours

DESIGN OPTIMIZATION

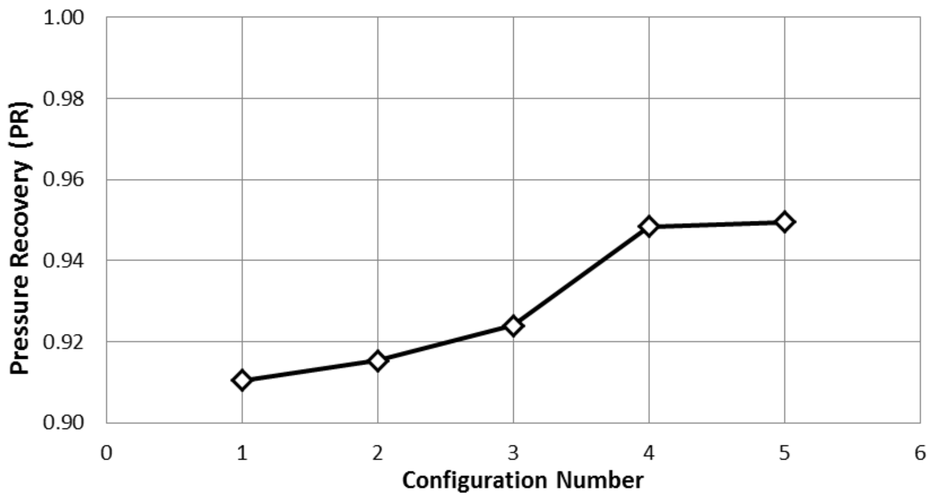
Design Optimization Algorithm

Design Parameters
S-shape «k»
Section «e_1»
Section «e_2»
Section «e_3»
Engine Tan. Length «mtl»
Diffuser Length «dfl»

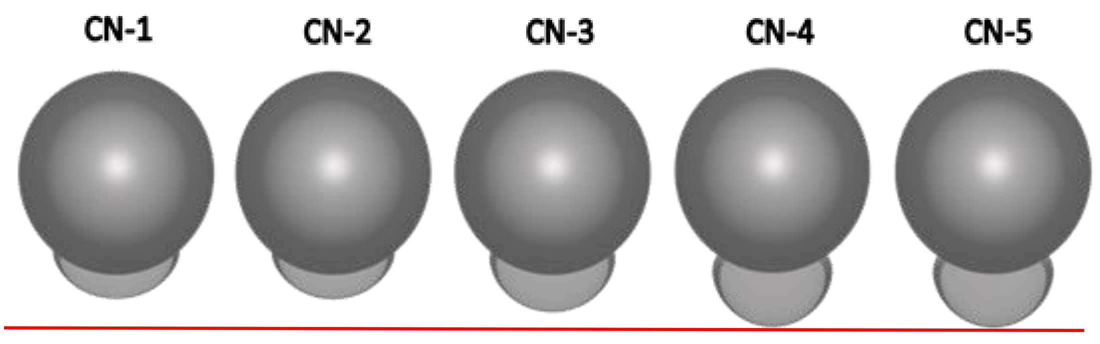


RESULTS

Unconstrained Design Study (Validation Design Method)



- No limitations.
- Objective Function determined with only PR coefficient.
- Expections: final geometry will be similar to pitot type intake
  Avoid B.Layer effects.
- Converged in 4 iterations. (Approx. 64 runs)



PR 4.3%

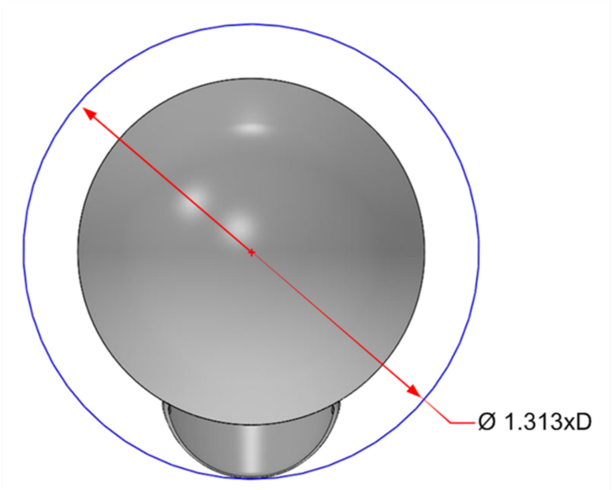
DC 40%

Improvement Achieved

RESULTS

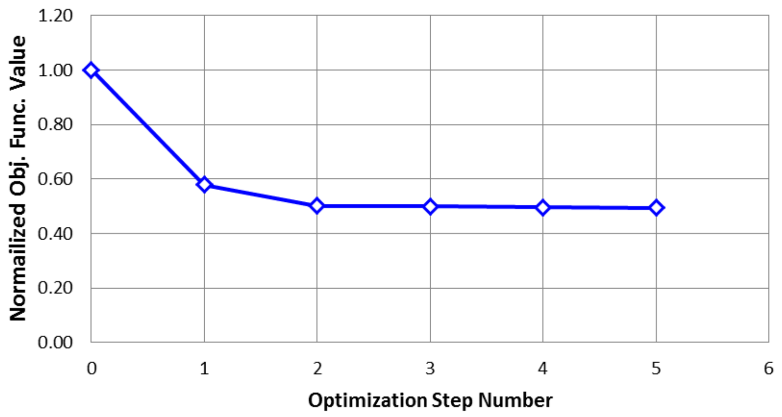
Intake Design Application

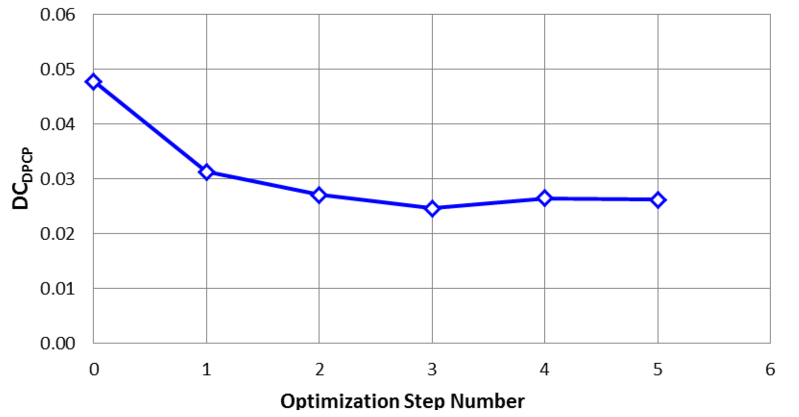
- Offset from body is limited. (Firing platform)
- A_{throat} is constant
- Keep Mass Flow Rate constant.
- Objective Function is determined PR,DC and geometric limitations.

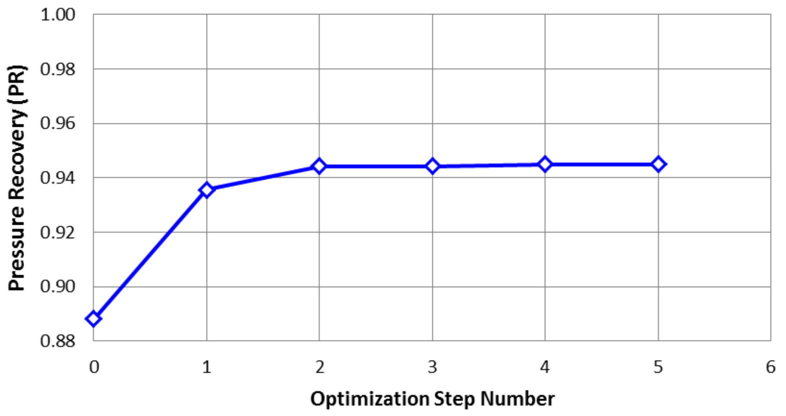


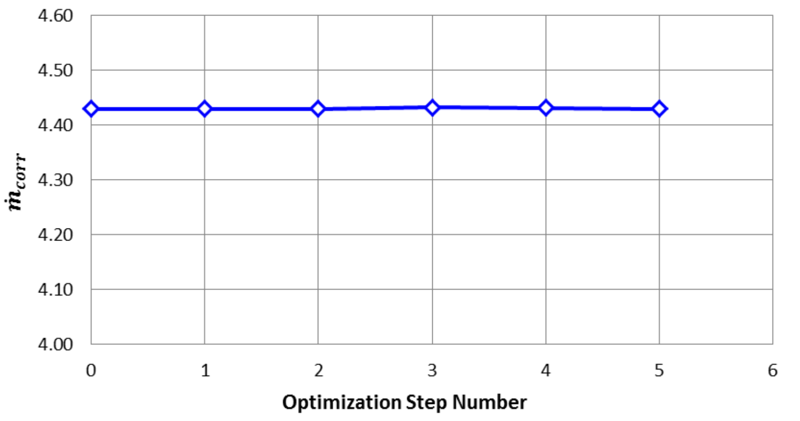
RESULTS and CONCLUSION

Results





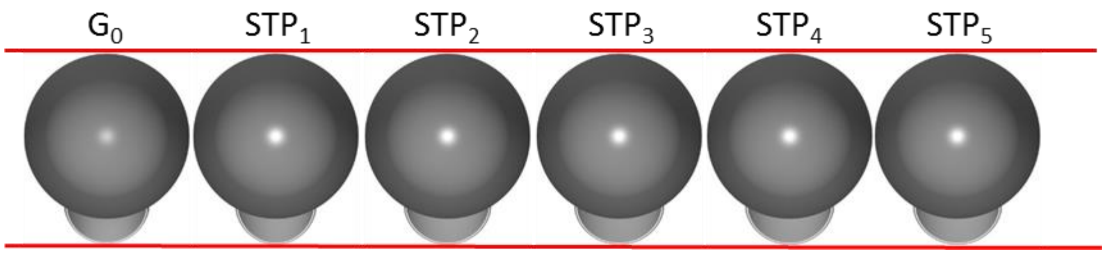


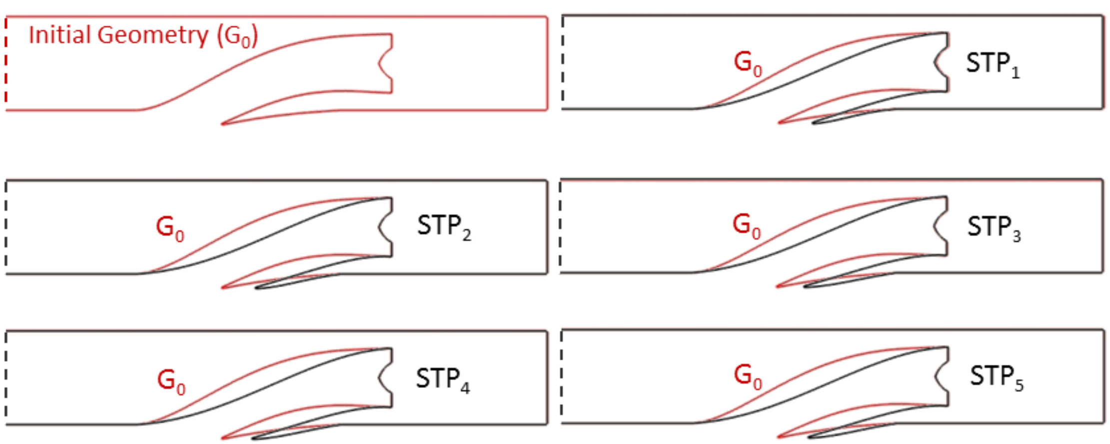


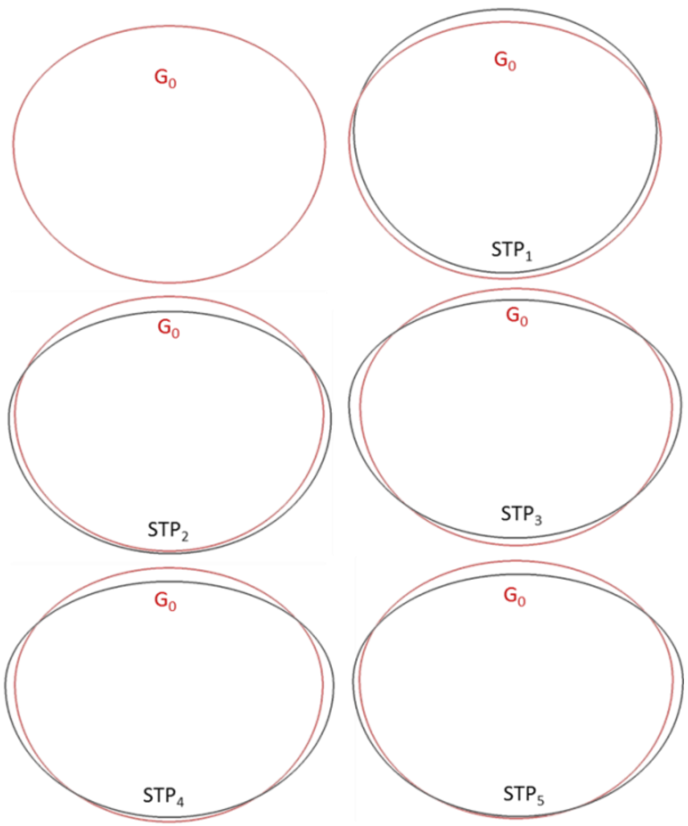
RESULTS and CONCLUSION

Results

- A_{th} keep constant
- M_{corr} keep constant
- Offset keep constant



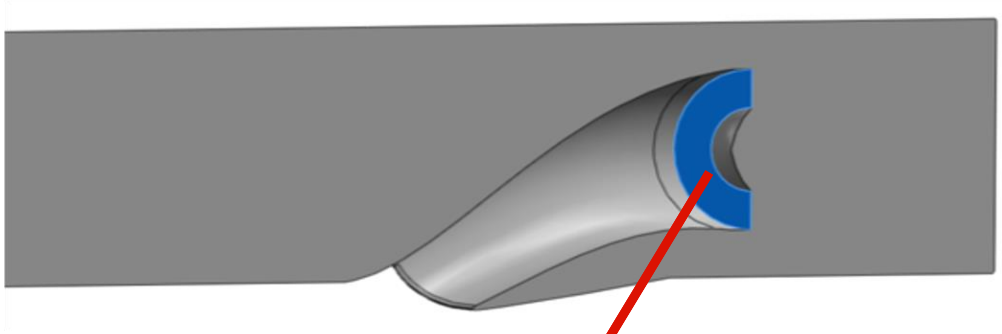


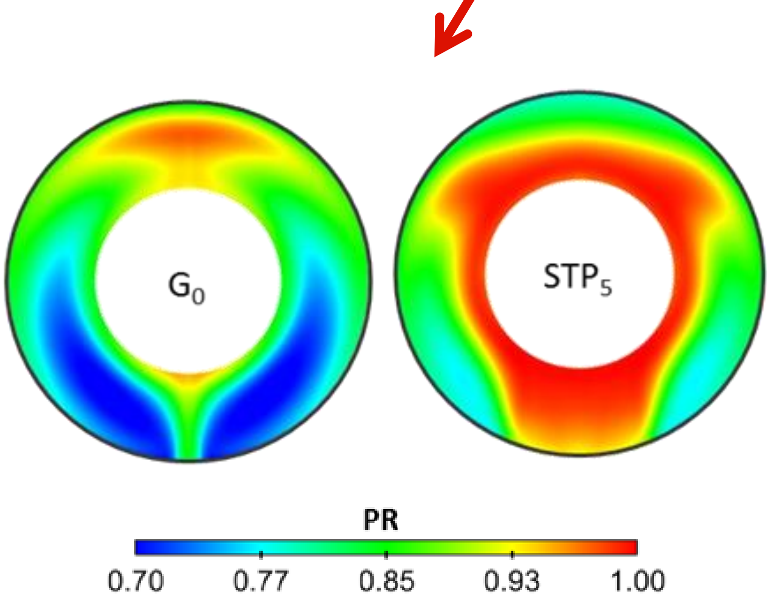


RESULTS and CONCLUSION

Results

Parameter	Initial Geometry	Final Geometry	Improvement (%)
PR	0.8882	0.9450	6.40
DC	0.0359	0.0195	45.72





CONCLUSION

- Subsonic-transonic submerged intake design is done for a cruise missile required flight conditions.
- FloEFD tool validated with two different NASA wind tunnel test-case study.
- An optimization algorithm developed for intake design
- Optimization algorithm validated with unconstrained design study.
- Remarkable PR, DC improvements obtained compared to initial geometry.

- FloEFD can be used with external inhouse optimization algorithms.
- Developed design methodology can be applied to different geometries and different design problems.
- Use of FloEFD in design optimization problems is time efficient and efford saving.

THANK YOU FOR LISTENING