Framework for Multidisciplinary Design Optimization

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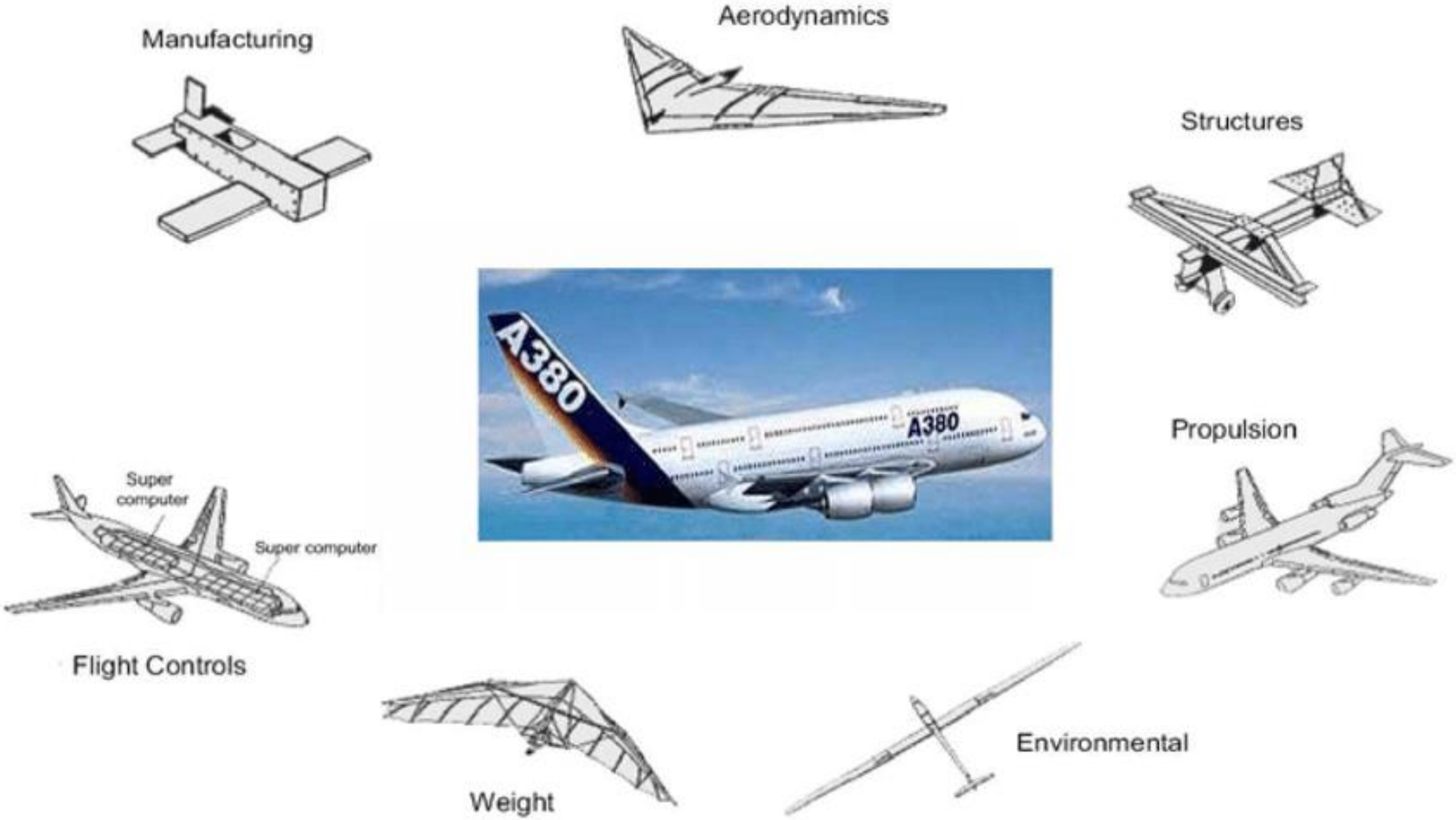
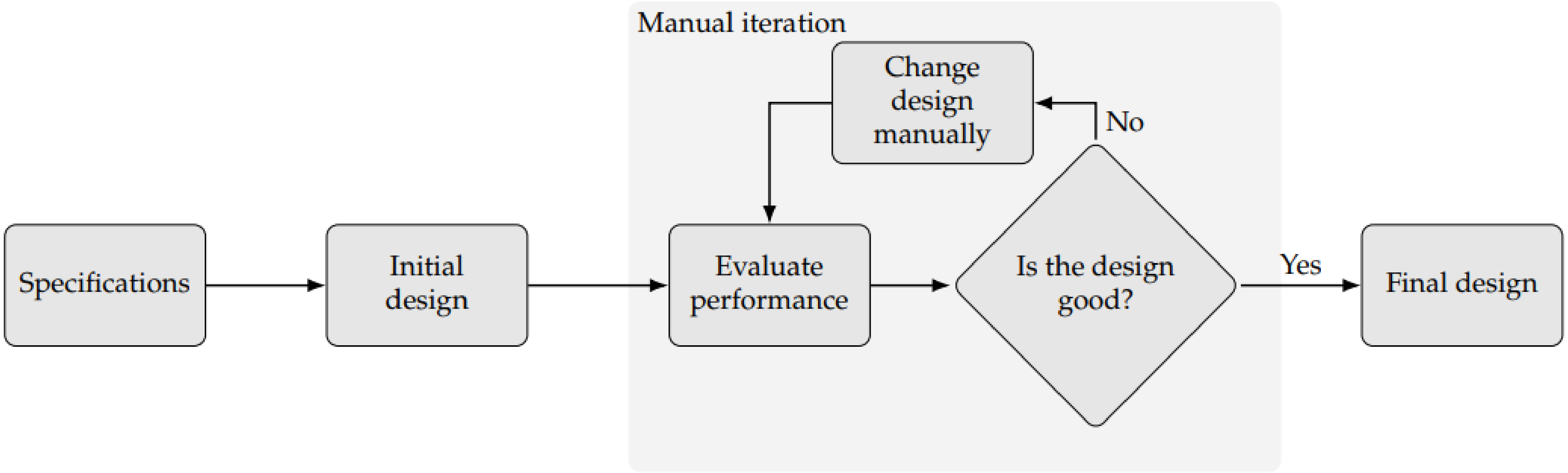
Why Optimization?



Traditional Approach



But why automation? Why is a framework necessary?

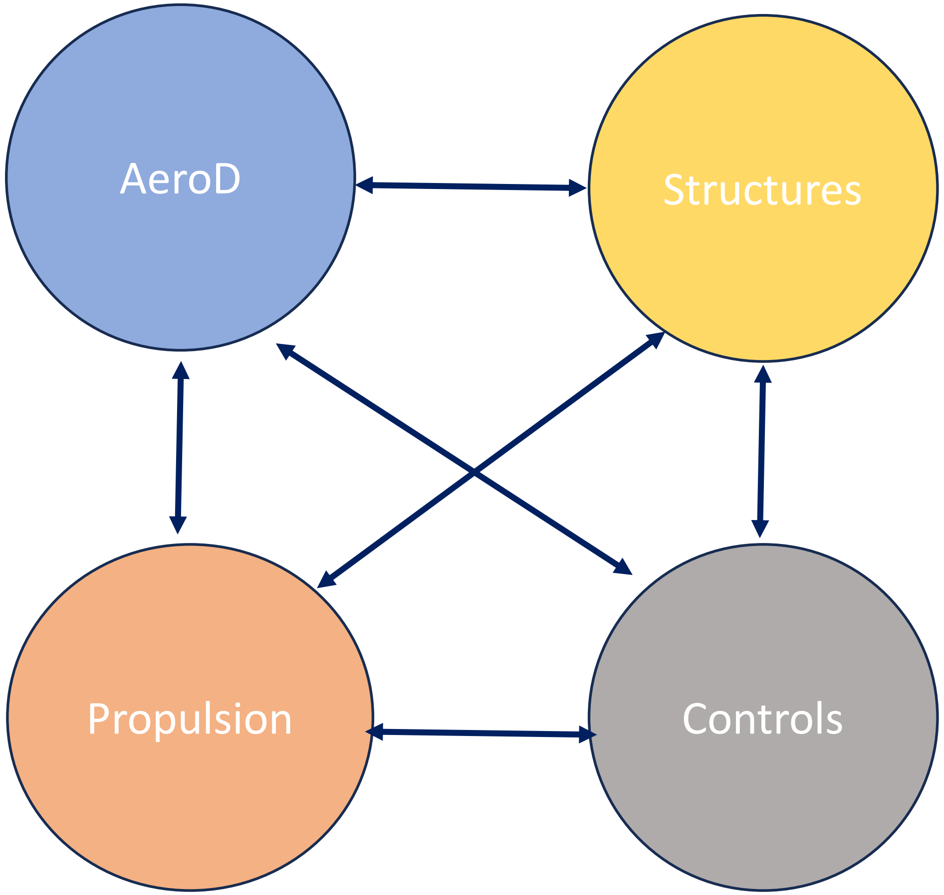
Source: Martins and Ning, Engineering Design Optimization

New Requirements – New Approach

"The Department of Defense (DoD) is seeking a concept of design (CoD) of an advanced aircraft configuration that provides at least 30% more aerodynamic efficiency than the Boeing 777 and Airbus A330 families of commercial and military aircraft, enabling operational advantages such as increased range, loiter time, and offload capabilities. When integrated with projected 2030 engine technology, this advanced aircraft configuration is expected to provide at least 60 percent mission fuel burn reduction compared to current day technology"

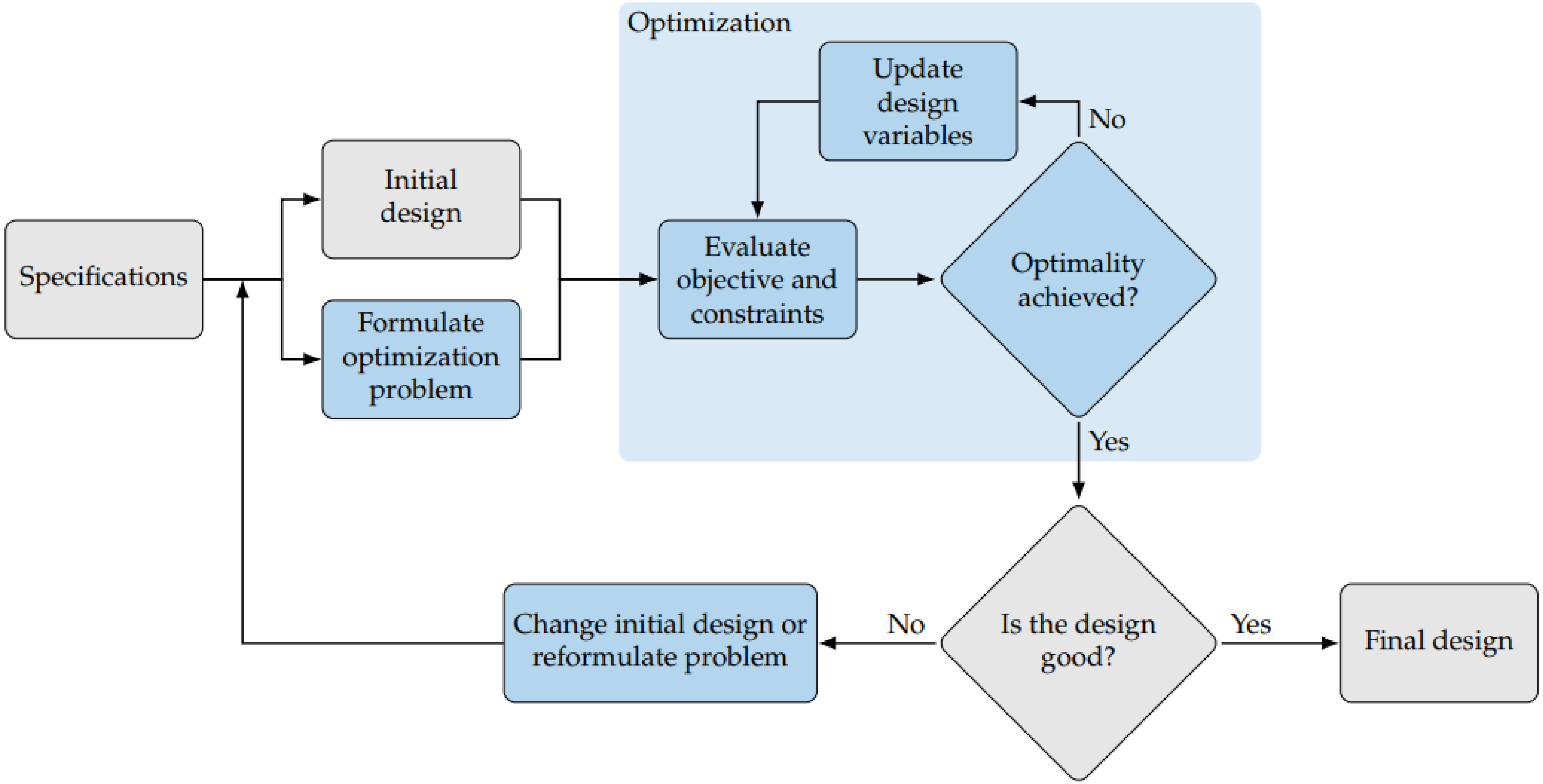
Source: WarZone Website

Tightly Coupled Integrated Systems



DarkStar – Top Gun 2

Relevance of a Framework



Source: Martins and Ning, Engineering Design Optimization

Features of the Framework

- **Solver Agnostic**
  - Simple plug and run with any solver
  - Treat analysis tools as black boxes
- **Modularity**
  - Integrate additional disciplines without modification
  - Building on top of each other
- **Simplicity**
  - User need not work with more than 2 files at most
- **Scalability & Flexibility**
  - Scaling to thousands of design variables should be feasible
- **Efficient Gradient Evaluation**
  - Offer different methods to compute gradients efficiently

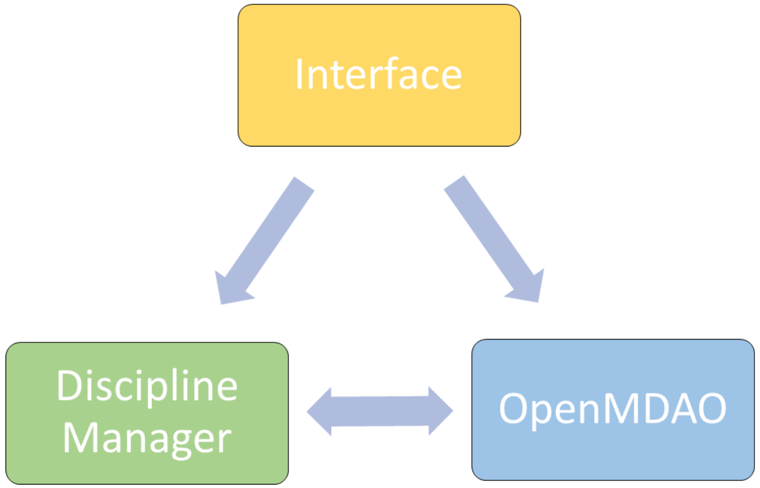
Goals of this Project

Leverage OpenMDAO* *[1]*

* *https://github.com/OpenMDAO/OpenMDAO*

Design of the Framework

Three Key Modules of the Framework

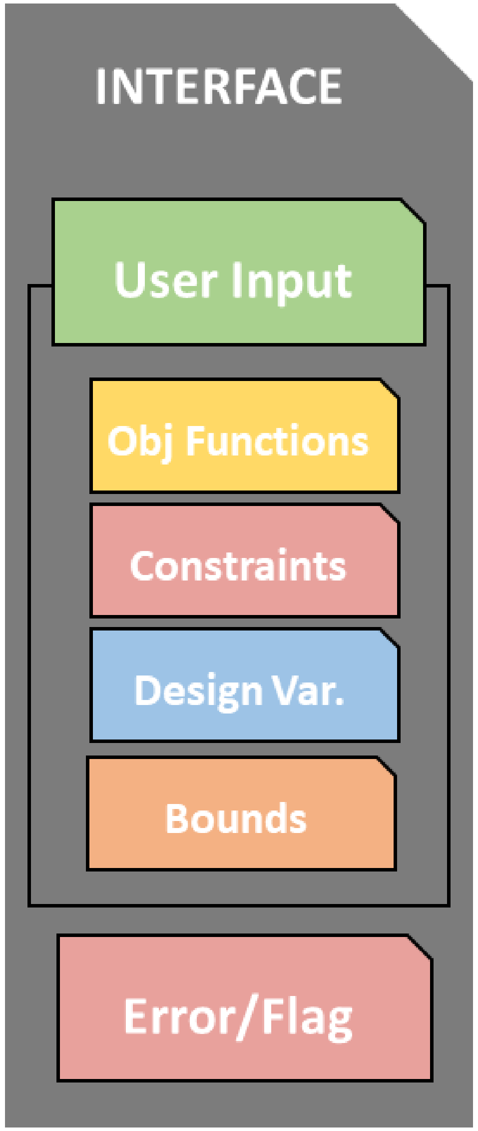


Note:

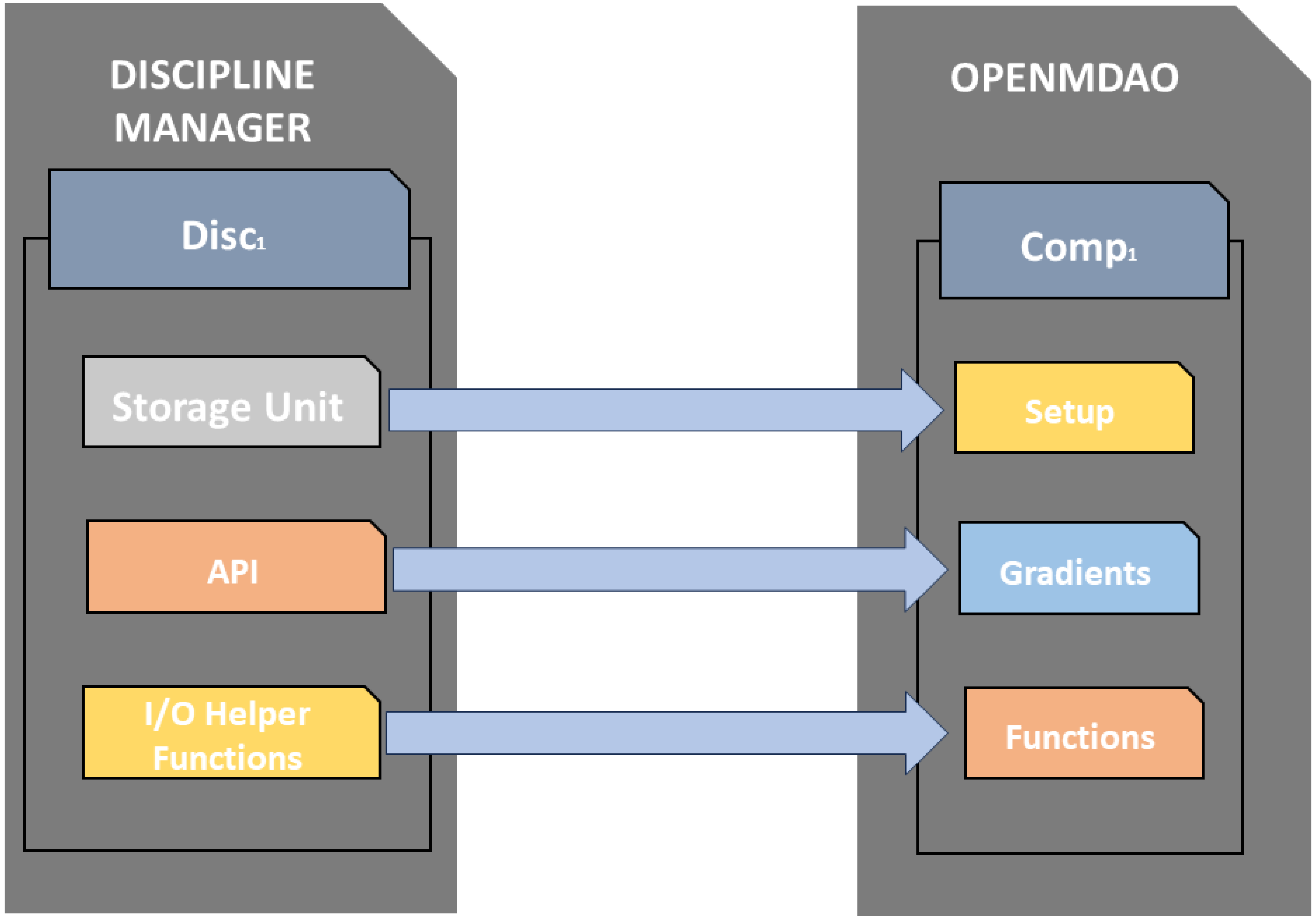
- Arrows do not indicate flow of information or order of processes carried out

Interface

- User inputs to define the setup
- Only 1 or 2 files at max. to tweak
- Structure is similar to Optimization packages in Python/MATLAB
- Check for consistency and errors



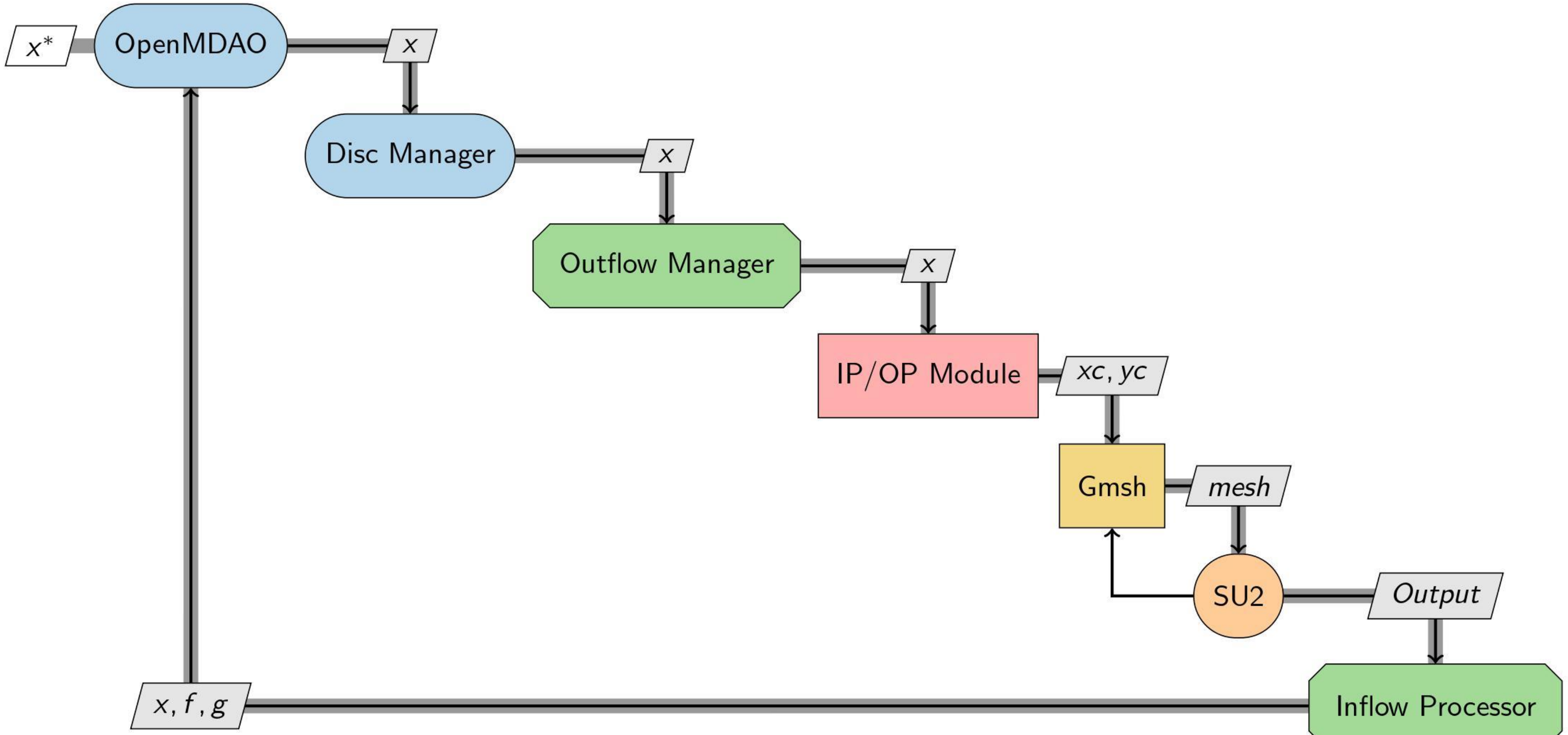
OpenMDAO + Discipline Manager



Framework Building - I

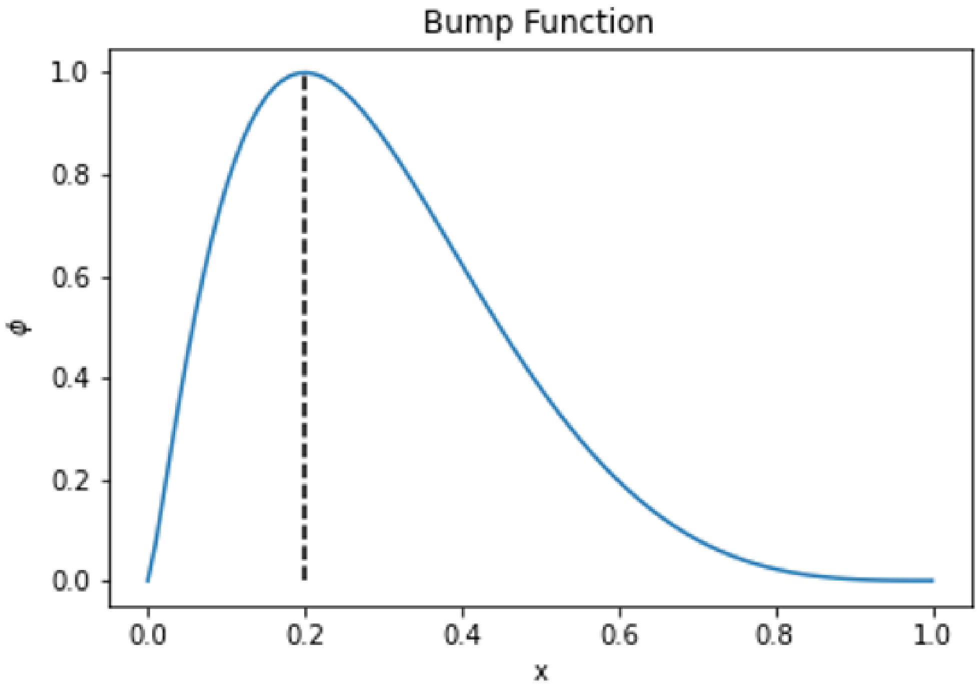
Framework for 2D ASO

Some of the methods used here are directly inspired from Sachit Vekaria's work on "Multi-disciplinary Design Optimization for Aerodynamic Efficiency and RCSR" under the guidance of Professor Avijit Chatterjee, Professor Bharat Adsul and Professor Hemandra Arya.



Common Parameters

Parameters	Methods/Values
Optimization Algorithms	SLSQP
Tolerance	10E-6
Gradients	Finite Differencing
Mesh Strategy	Remesh the entire domain
Geometry Parameterization	Bump Function



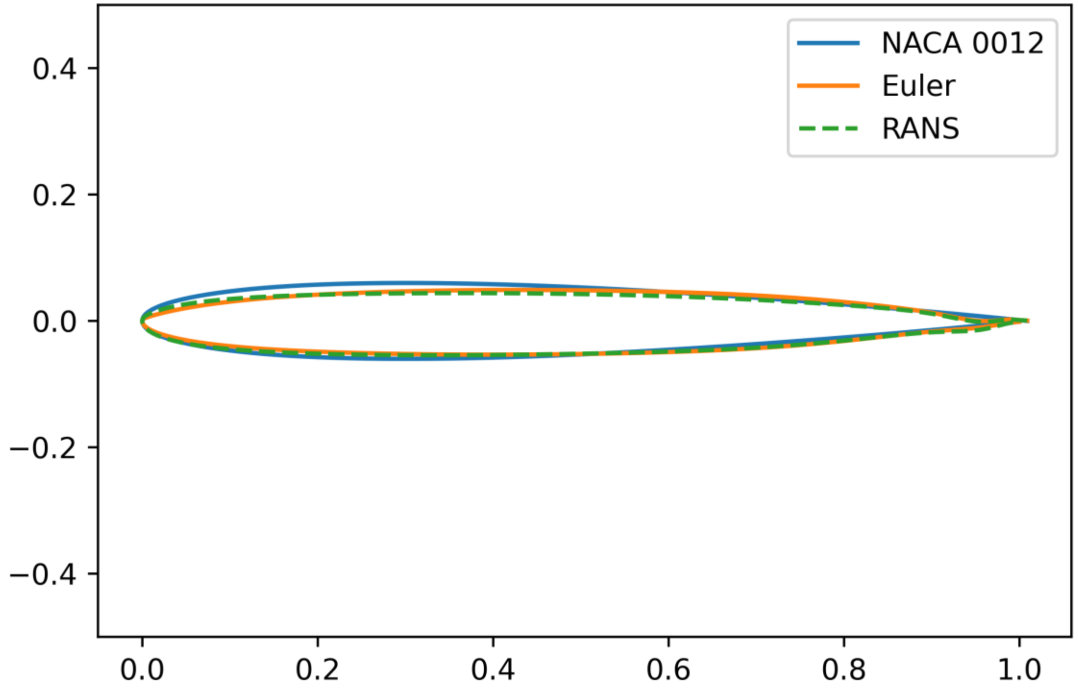
Benchmarking with SU2 Test Case

Problem Setup	
Obj Fn	Min. Cd
DV	20 shape amplitudes
Constraints	None

Parameters	Values
Mach no.	0.8
AoA	1.25deg
Flow	Inviscid
Solver	Euler

Benchmarking with SU2 Test Case

Results	
Baseline Cd	209.95
Optimized Euler	4.39
Optimized Test Case	4.5
Optimized RANS	27.47

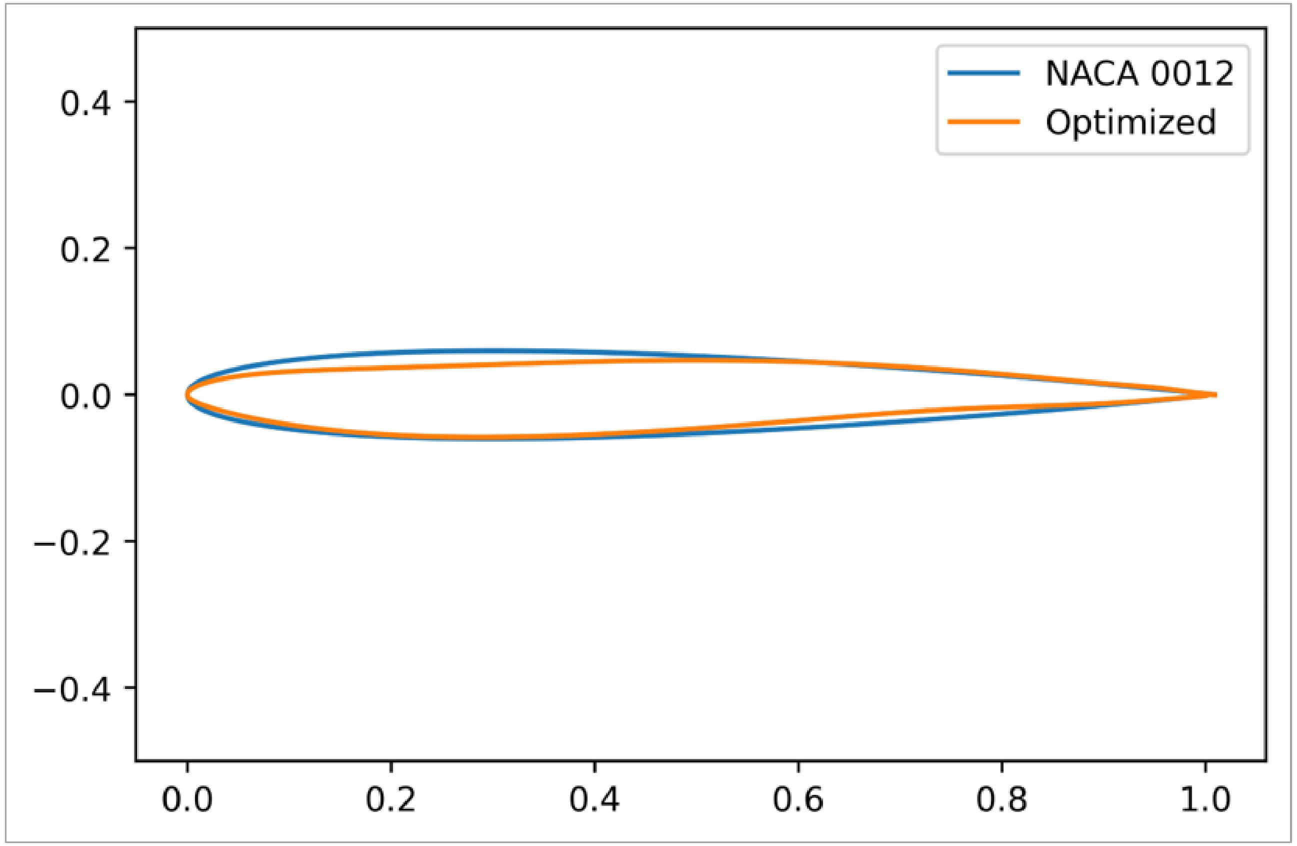


Results – 2D | Constrained Optimization

Constrained Problem
M = 0.8
AOA = 1.25 degrees

Problem Setup	
Obj Fn	Min. Cd
DV	20 shape amplitudes
Constraints	Cl*>0.4 A*/A > 0.85

Function	OpenMDAO Optimized
Cd	0.0025126 (88%)
Cl	0.4



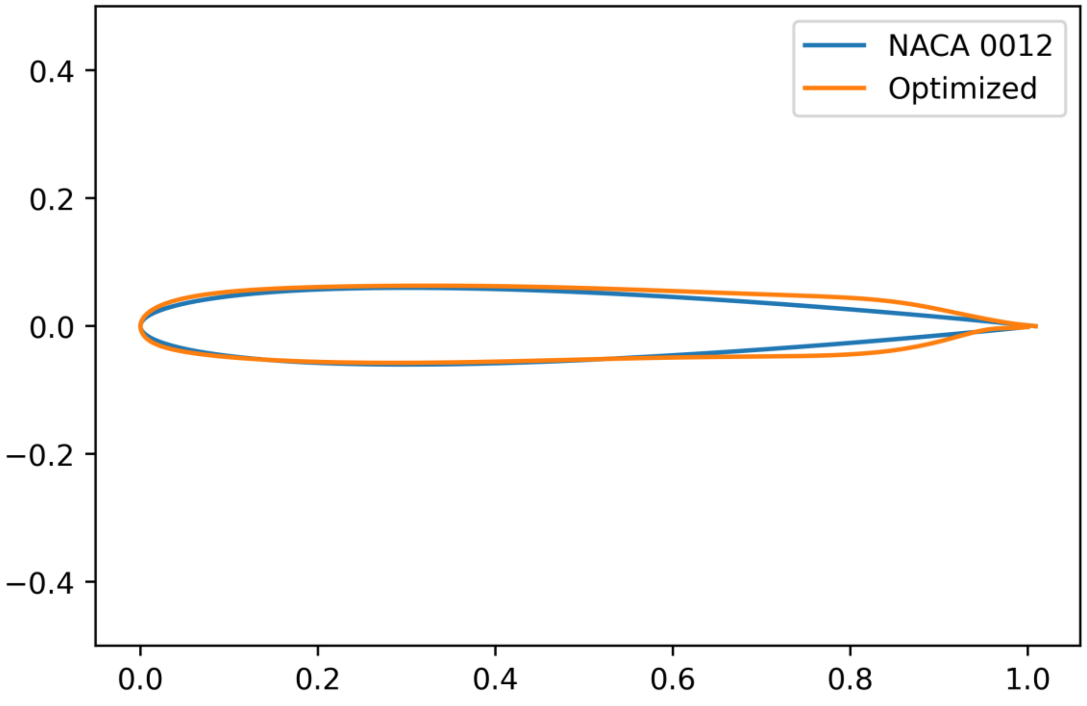
Benchmarking with ADODG Test Case-1

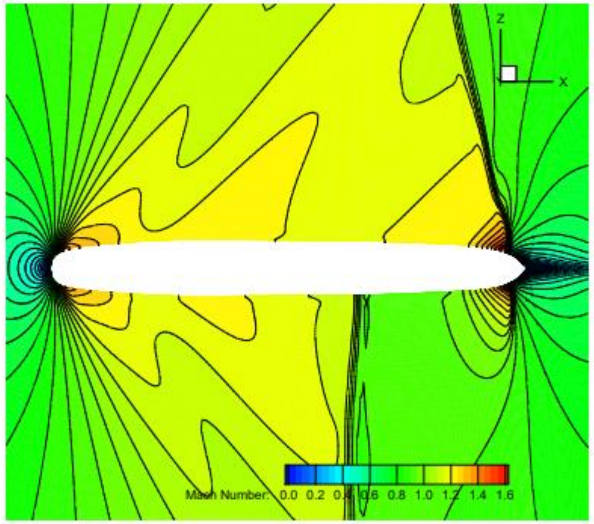
Problem Setup	
Obj Fn	Min. Cd
DV	20 shape amplitudes
Constraints	Thickness > Baseline's

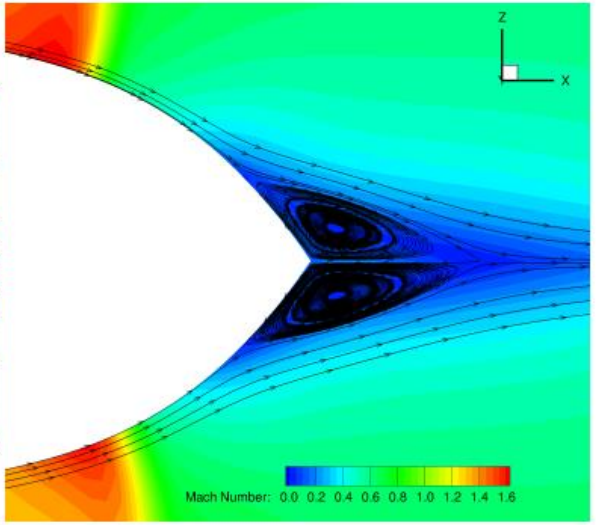
Parameters	Values
Mach no.	0.85
AoA	0 deg
Flow	Inviscid
Solver	Euler

Parameters	ADODG Results	Current Framework Results
Optimized C_d	143.64	239.87
Optimizer	SNOPT	SLSQP
Mesh	Structured	Unstructured
Parameterization	FFD	Bump Function

Benchmarking with ADODG Test Case-1



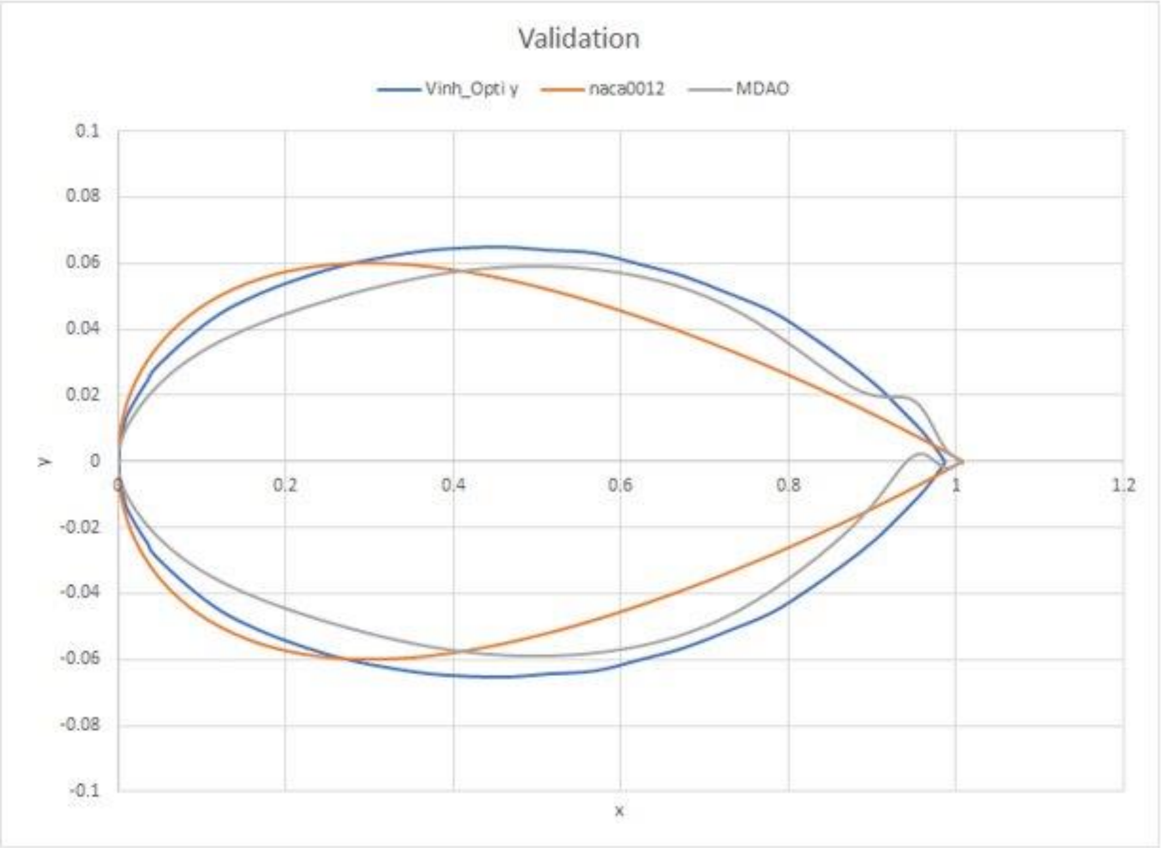




RCS + CFD

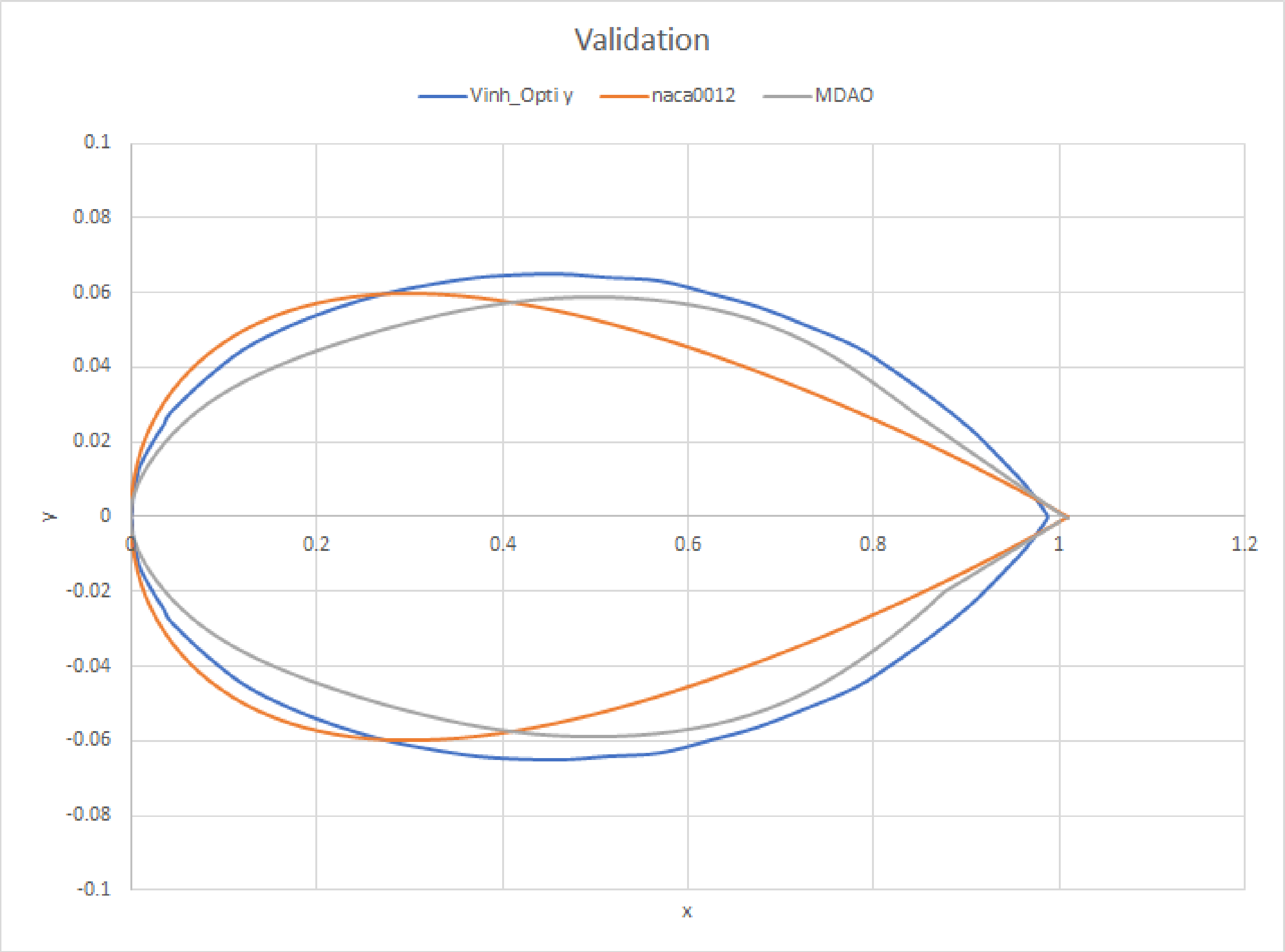
Obj Fn	Min. Cd
DV	20 shape amplitudes
Constraints	A*/A >1 RCS*/RCS < 0.7
Cd baseline	92
Cd optimized	84
Cd optimized Vinh	71

Parameters	Values
Mach no.	0.8
AoA	1.25deg
Flow	Inviscid
CFD Solver	Euler
CEM Solver	MLFMM*



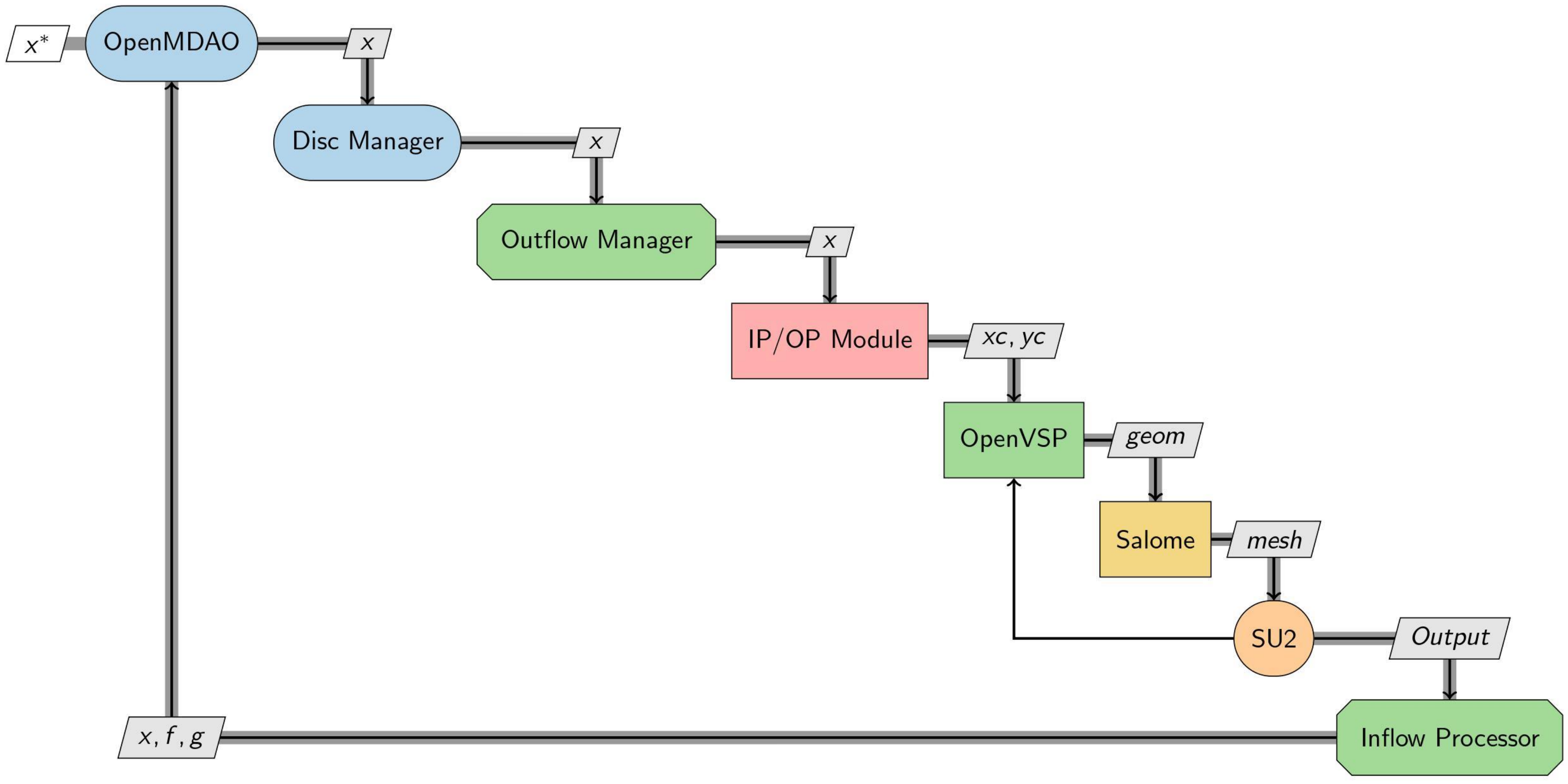
Multi-Level Fast Multipole Method

RCS + CFD



Validation
Vinh_Opti y
naca0012
MDAO
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
y
0
0.2
0.4
0.6
0.8
1
1.2
x

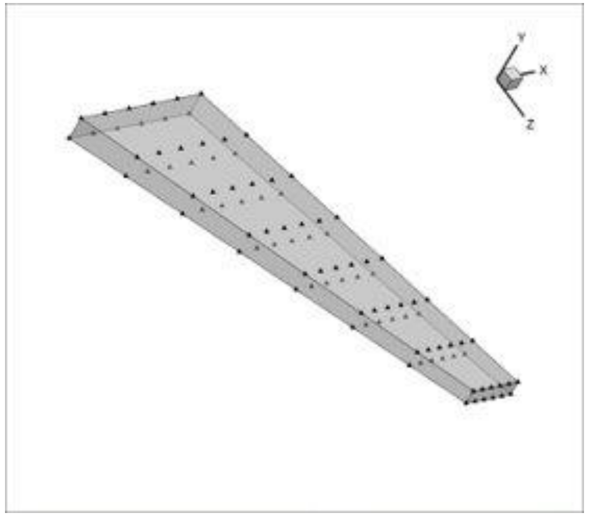
Framework for 3D ASO

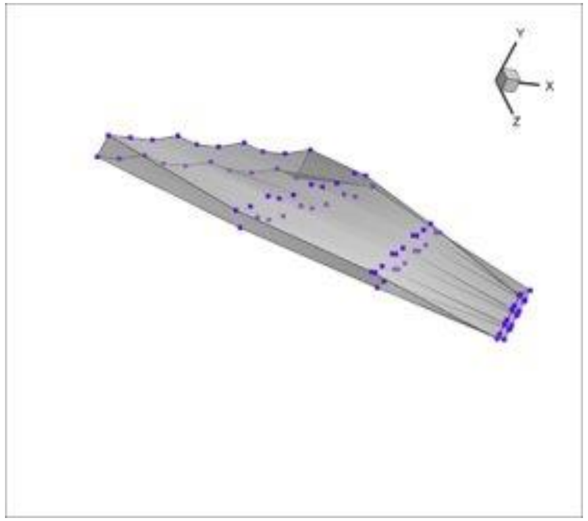


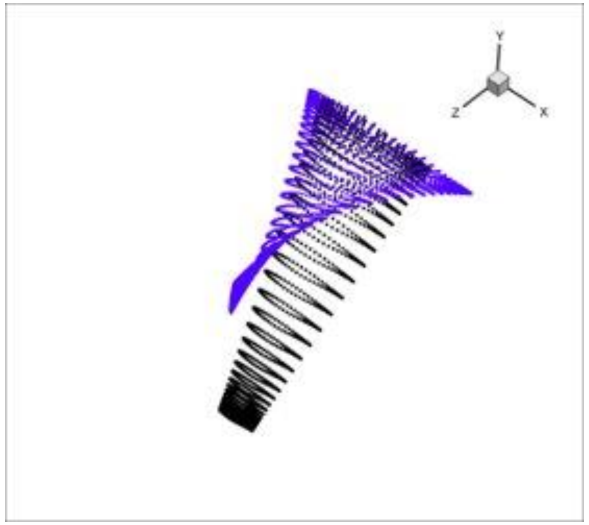
Challenges

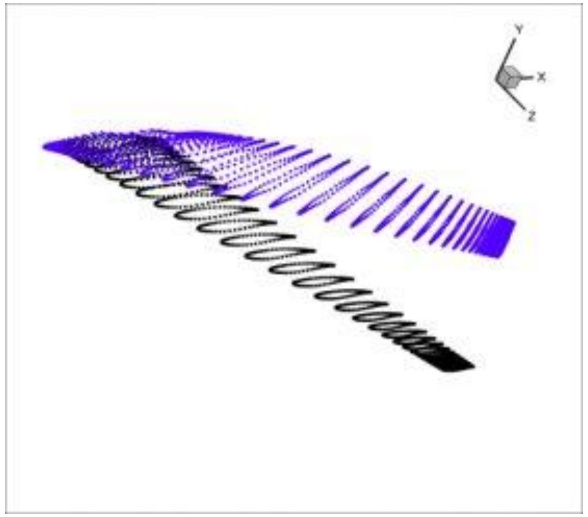
- Ad-hoc constraint implementation to prevent wiggly designs may not always work
- Finite Differencing is very time consuming
  - 1 CFD run takes about 5 mins
  - For 20 Design Variables time taken is about 100 mins for 1 gradient calculation
  - 100 function evaluations takes about 10,000 mins!
  - Adjoint based derivative take less than 5 mins for 1 gradient evaluation
- Meshing strategy – Remesh entire volume
  - 1 million nodes take 2-3 mins
  - 100 function evaluation take 200-300 mins
  - Mesh deformation take 4-5 seconds
- Previous framework was not SCALABLE to 3D ASO problems

MDO Lab Tools



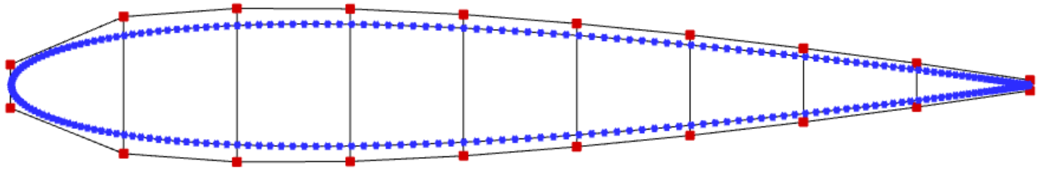




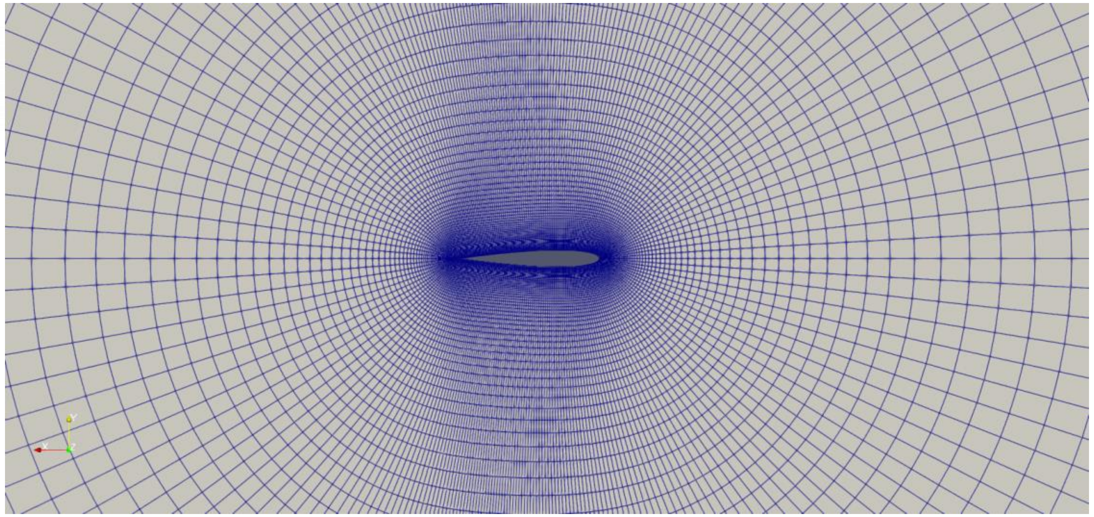


Framework Testing | Case1

$$\begin{aligned} \textit{minimize} \quad & C_d \\ \textit{with respect to} \quad & -2.5\% \leq x \leq 2.5\% \\ \textit{subject to} \quad & z_i \geq z_{i,baseline} \end{aligned}$$

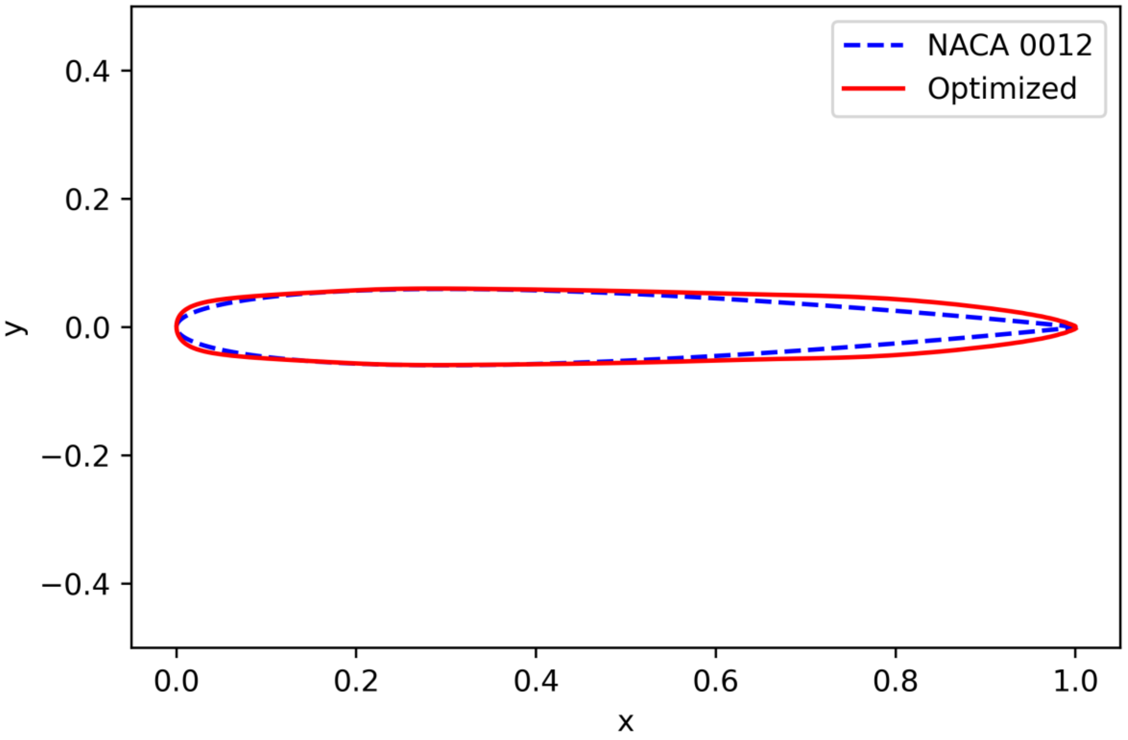


Parameters	Values
Mach no.	0.85
AoA	0 deg
Flow	Inviscid
Solver	Euler

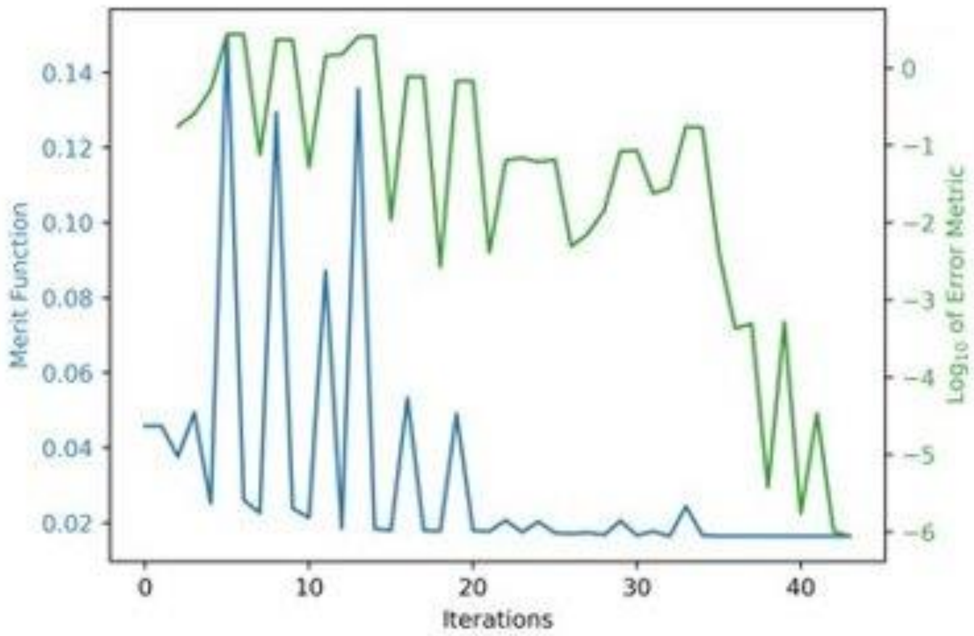


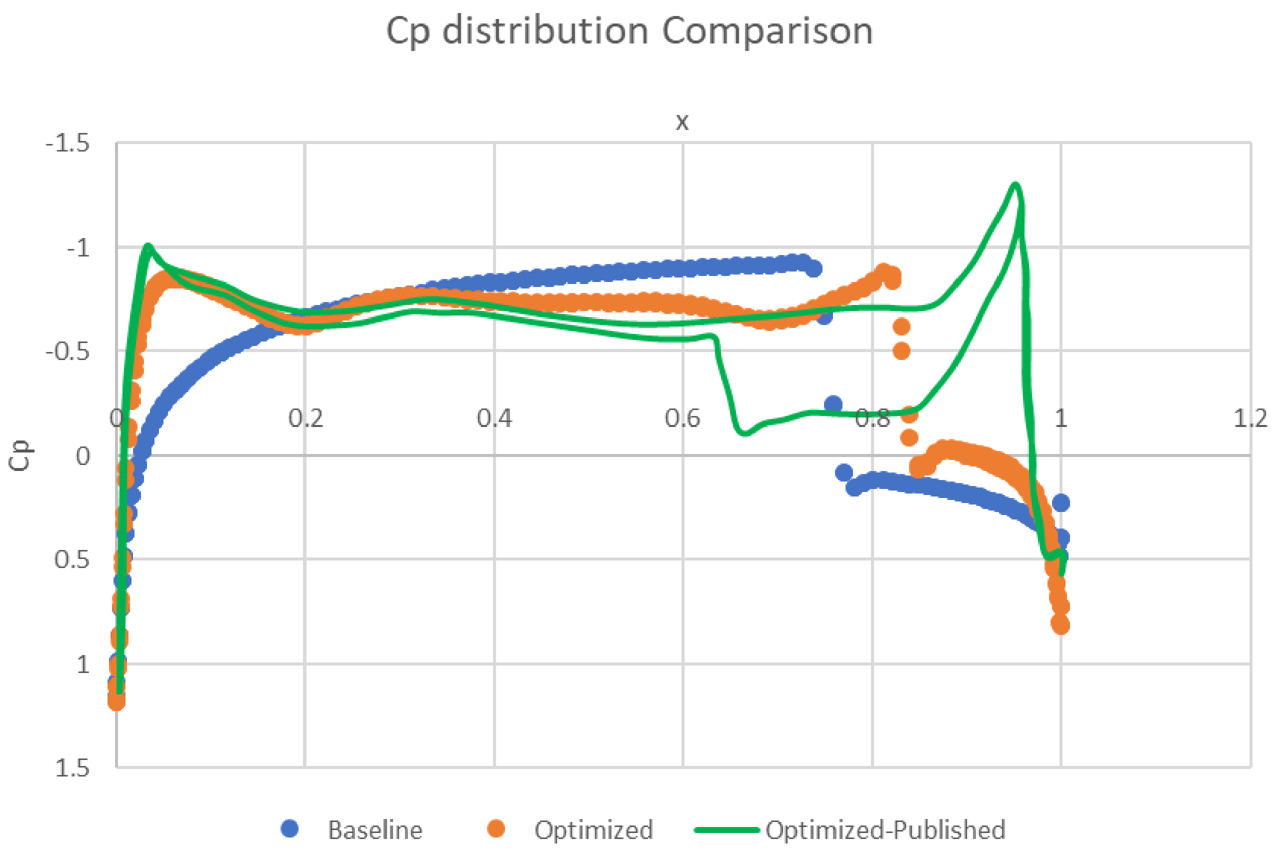
Result | Case-1

	ADODG	Current Setup
Mesh Type	H grid	O grid
Grid level	Coarse	Coarse
Nodes (2D)	12,760	31,605
Off-wall spacing	0.008	0.002
Baseline C_d	461.29	458.96
Solver	Jetstream	ADflow
Flowsolve	Coarse	Medium
Algorithm	SNOPT	SLSQP
FFD points	20	20
Convergence tol.	10^{-6}	10^{-6}
Optimized C_d	143.64	166.22



Result | Case-1

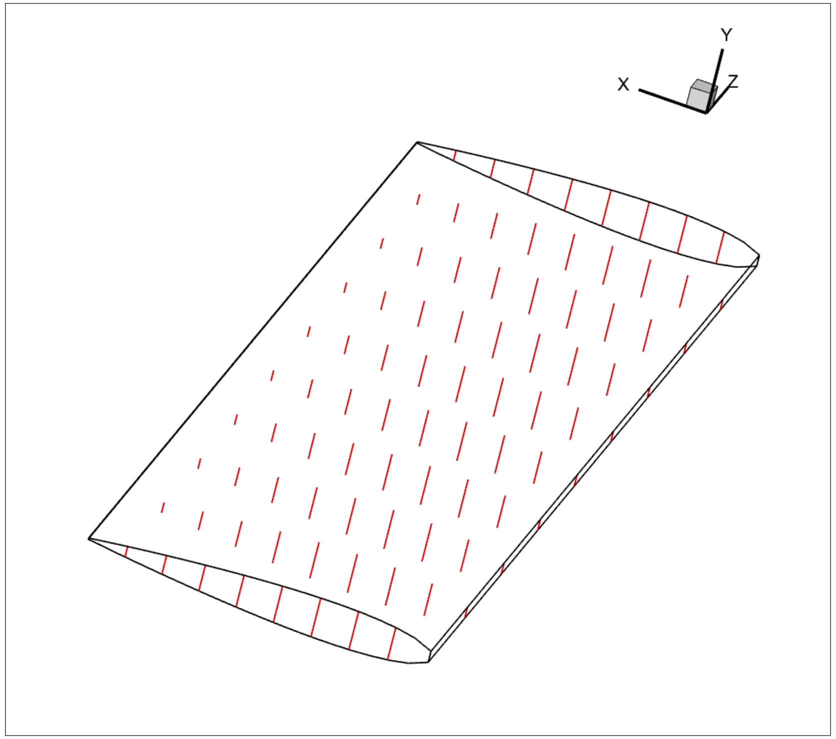




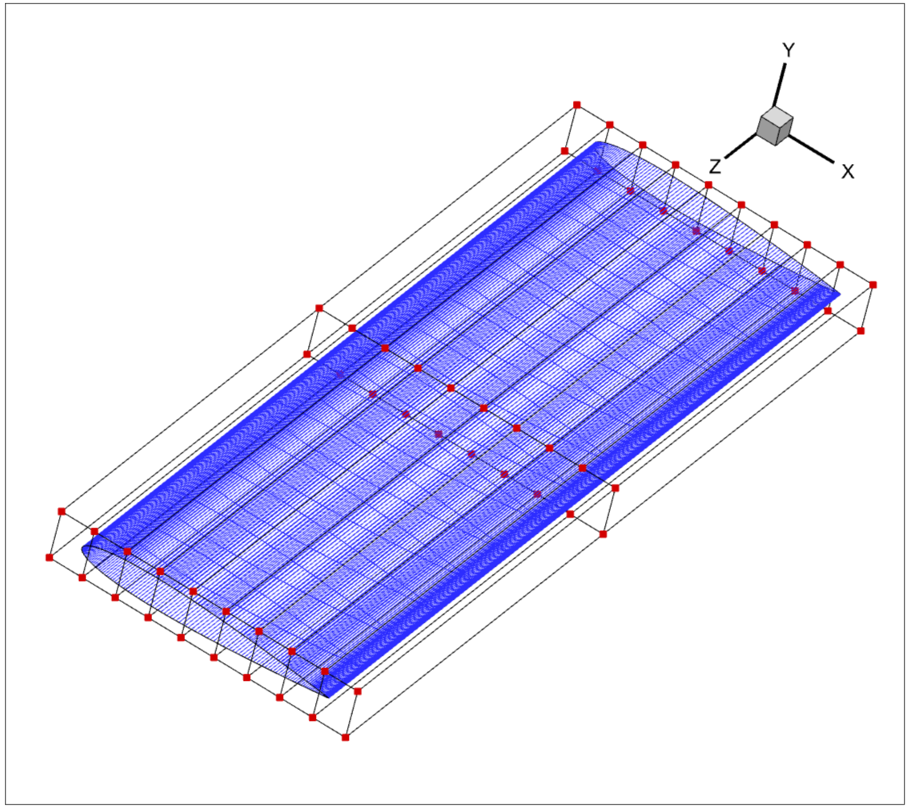
Framework Testing | Case2

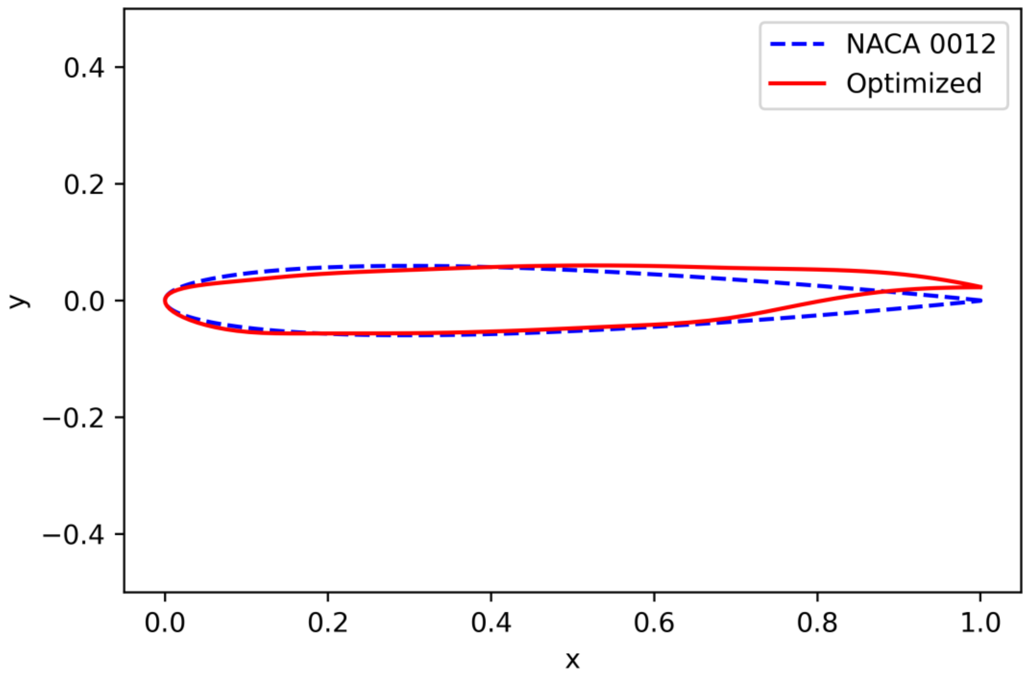
$$
\begin{aligned}
\textit{minimize} \quad & C_D \\
\textit{with respect to} \quad & -2.5\% \leq x \leq 2.5\% \\
\textit{subject to} \quad & C_L = 0.284 \\
& C_{M,c/4} \leq -0.12 \\
& z_i \geq z_{i,baseline}
\end{aligned}
$$

Parameters	Values
Mach no.	0.85
AoA	2.79 deg
Flow	Turbulent – 20 Million Re
Solver	RANS
Cd reduction	49%



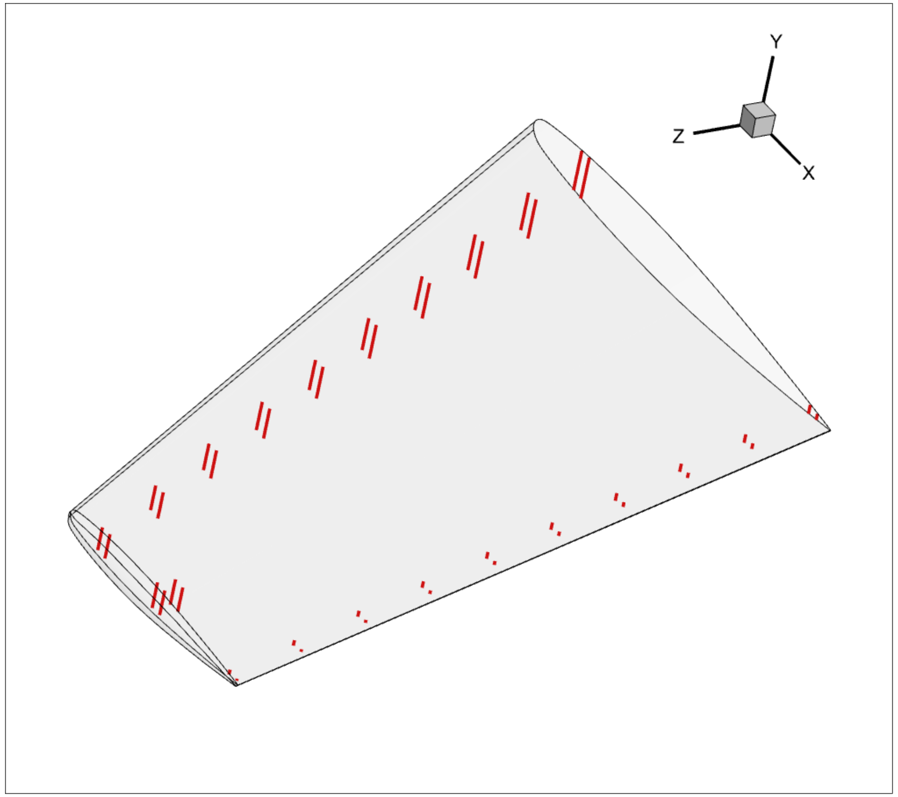
Framework Testing | Case2





Framework Testing | Case 3

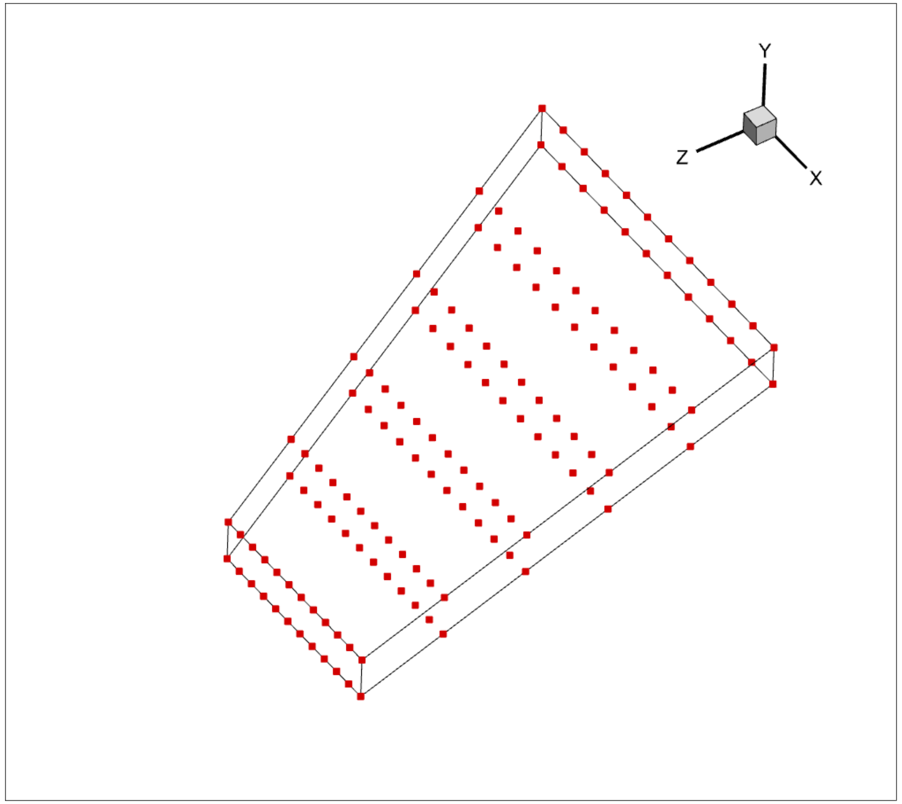
$$
\begin{aligned}
\textit{minimize} \quad & C_D \\
\textit{with respect to} \quad & -2.5\% \leq x \leq 2.5\% \\
\textit{subject to} \quad & C_L = 0.271 \\
& z_{i,0.15c} \geq z_{i,0.15c,baseline} \\
& z_{i,0.99c} \geq z_{i,0.99c,baseline} \\
& z_{\frac{c}{2}tip} \geq z_{\frac{c}{2}tip,baseline} \\
& V \geq V_{baseline}
\end{aligned}
$$



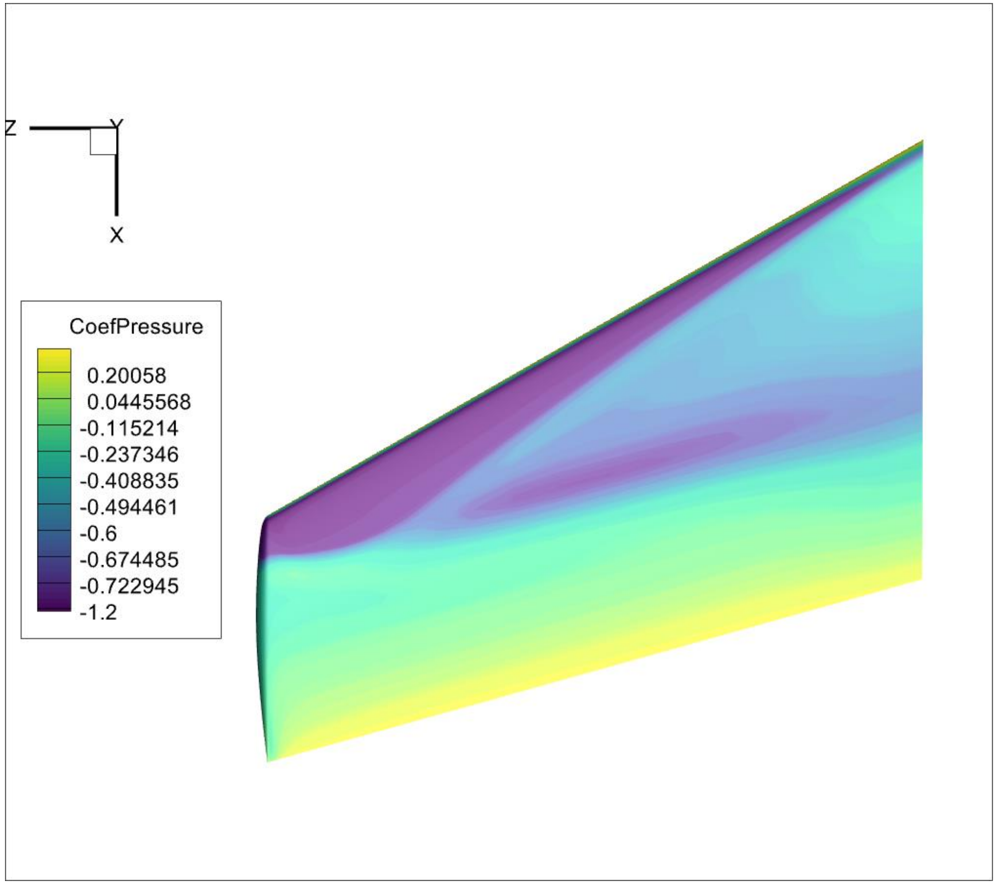
Parameters	Values
Mach no.	0.839
AoA	3.06 deg
Flow	Turbulent – 11 Million Re
Solver	RANS
DV	144 shape + 6 twist

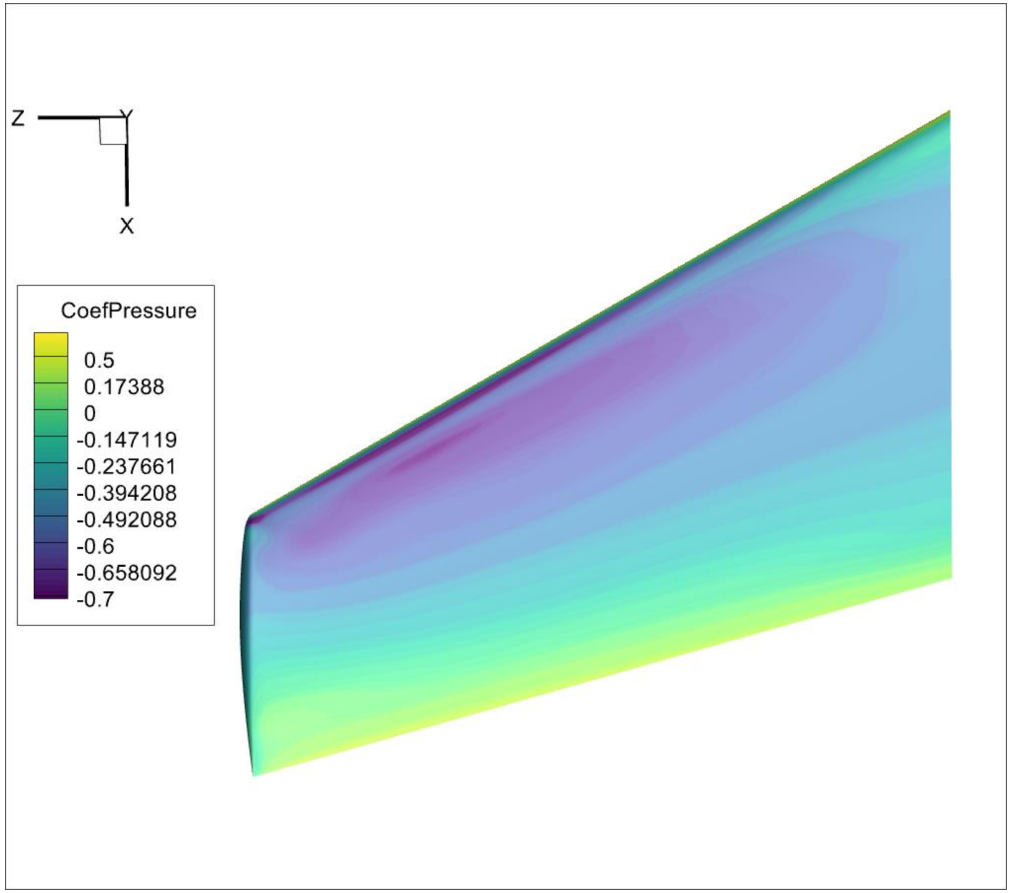
Framework Testing | Case 3

	ONERA-M6 [21]	Current Setup
Cells	10,32,192	3,63,840
Off-wall cells	64	49
Off-wall spacing	1.5×10^{-6}	1×10^{-6}
$y+$	0.67	0.365
Baseline C_D	172.5	179.3
C_L	0.2710	0.2682
Solver	SUmb	ADflow
Algorithm	SNOPT	SLSQP
FFD points	150	150
LE & TE clustering	Present	Absent
Thickness Constraints	21	44
Convergence tol.	10^{-6}	10^{-6}
Optimized C_D	140.00	149.43

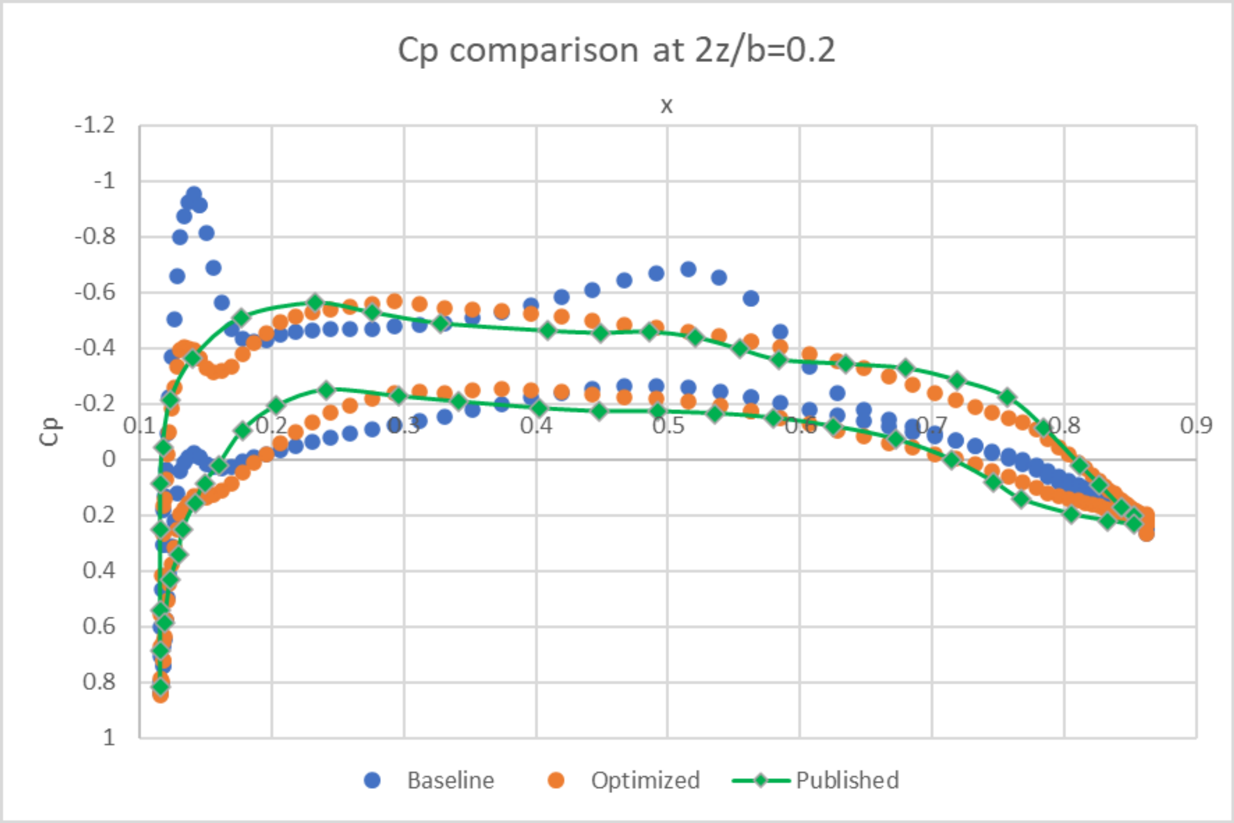


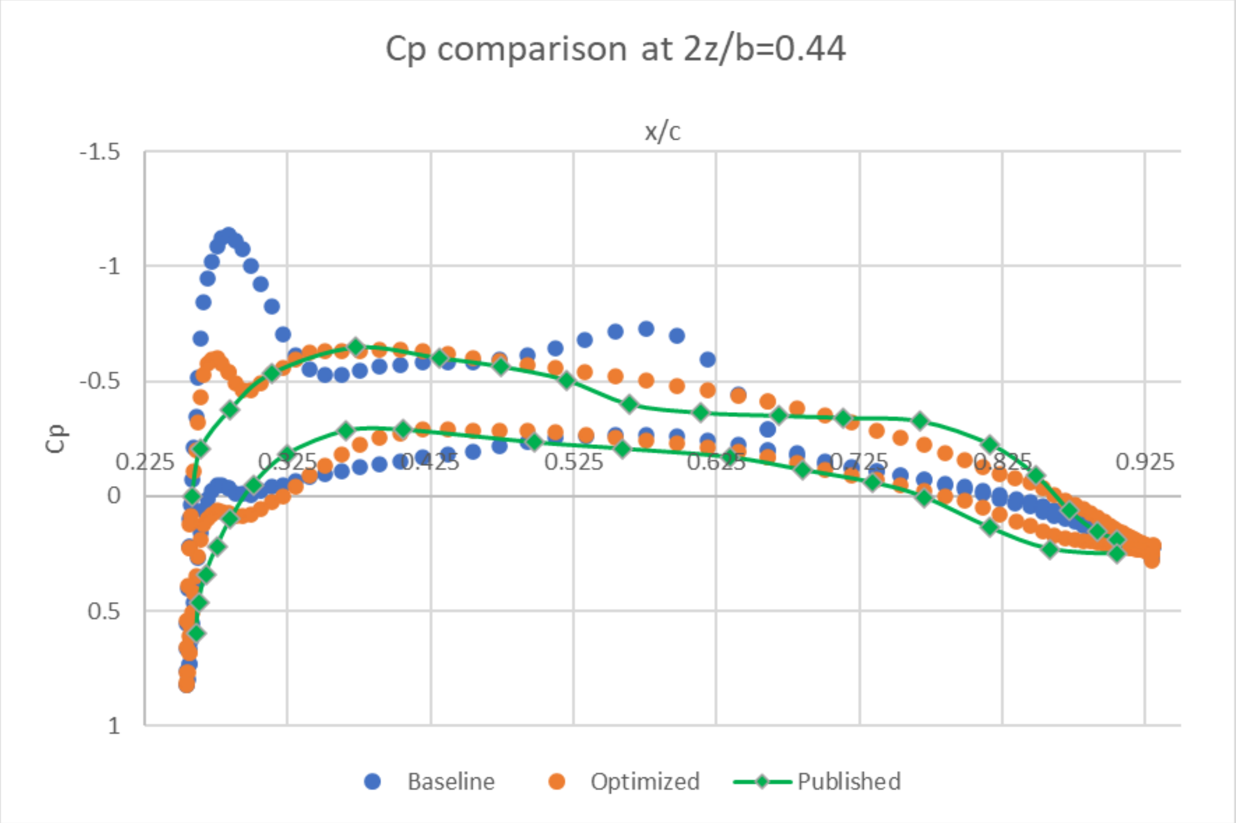
Framework Testing | Case 3



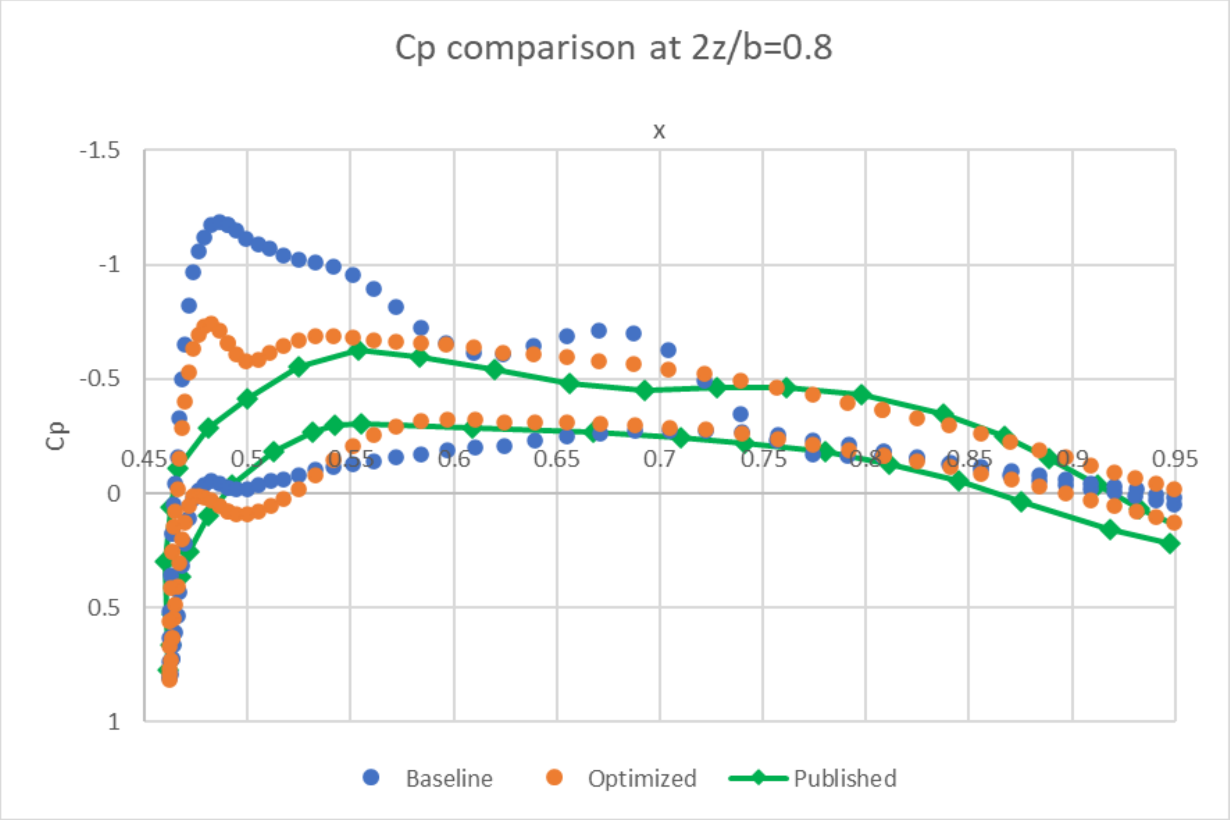


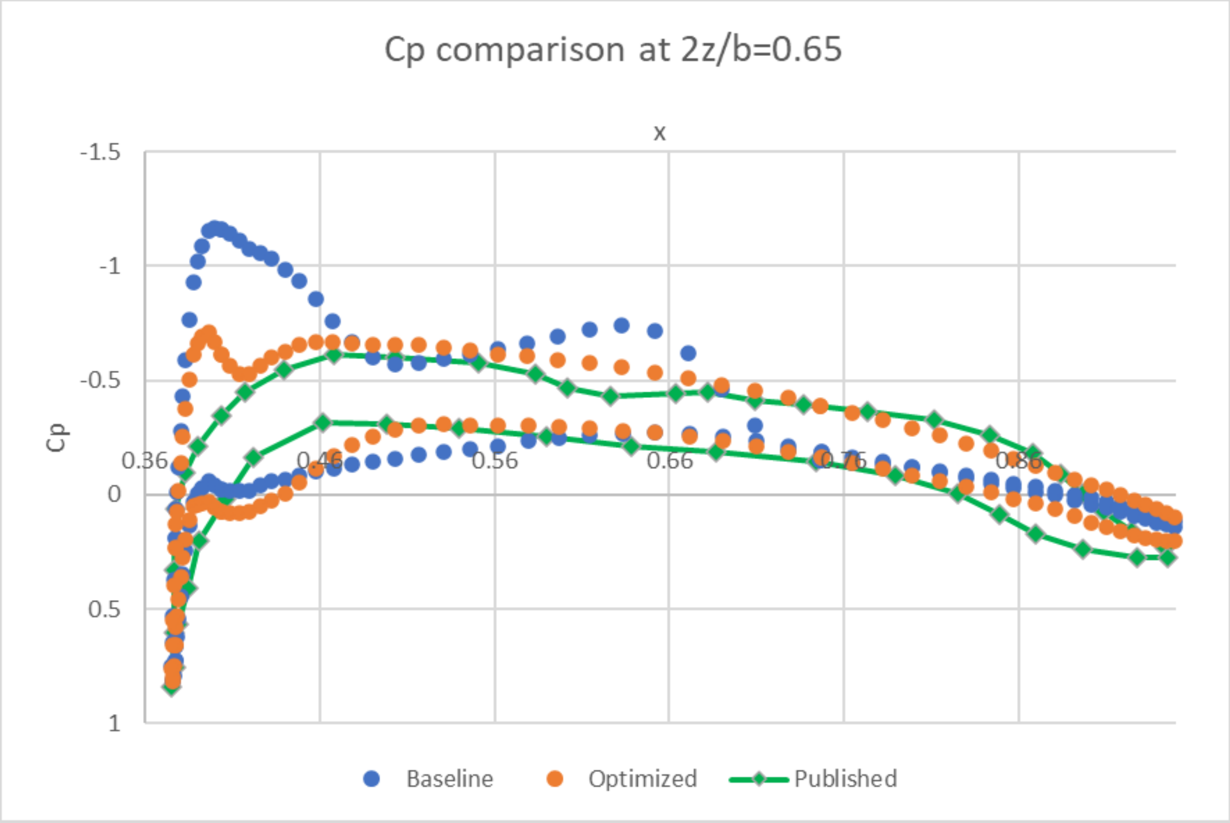
Framework Testing | Cp Distribution



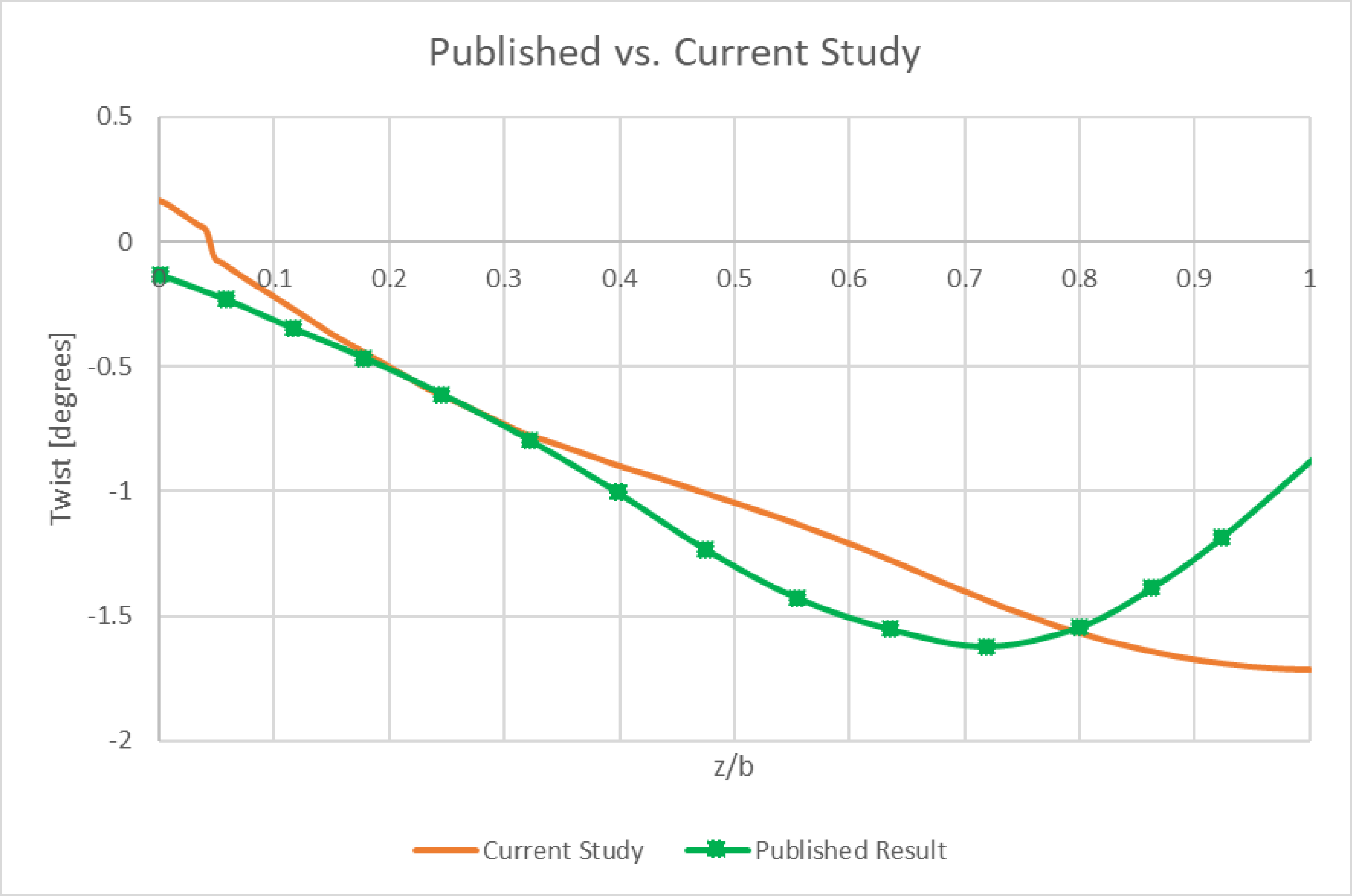


Framework Testing | Cp Distribution





Framework Testing | Case 3



Conclusion and Future Work

- Created a MDO framework
- Specifically vetted for 2D and 3D ASO problems
- It is generalizable to incorporate other disciplines
- RCS module is still in process

APPENDIX