The D8 aircraft: An Aerodynamics Study of Boundary Layer and Wake Ingestion Benefit

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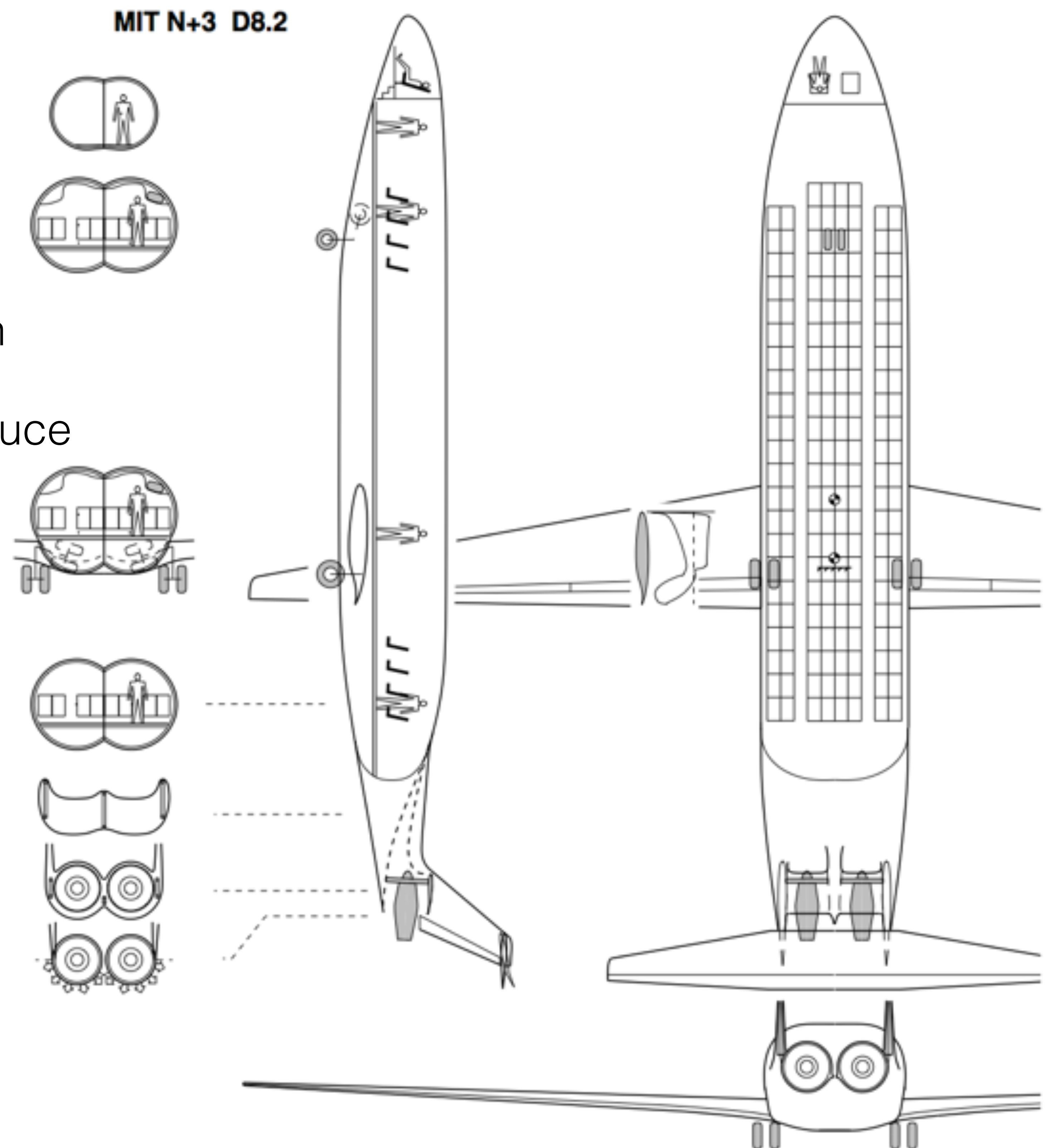
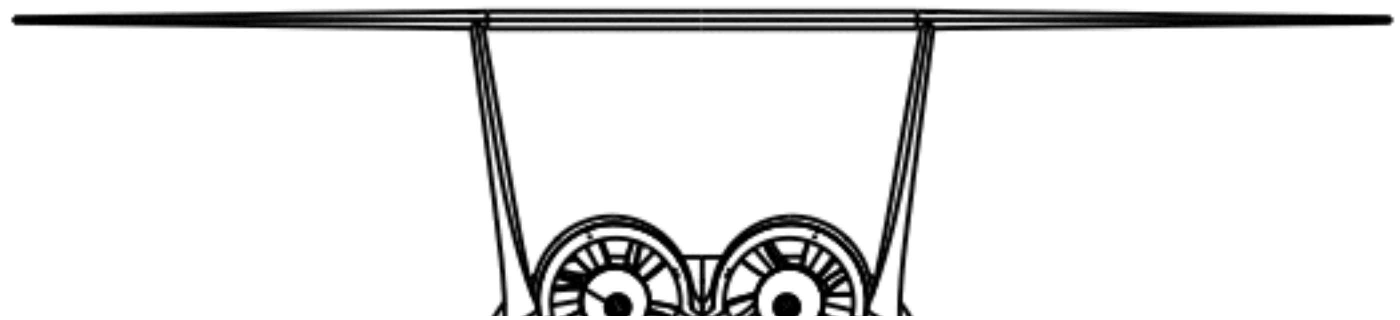
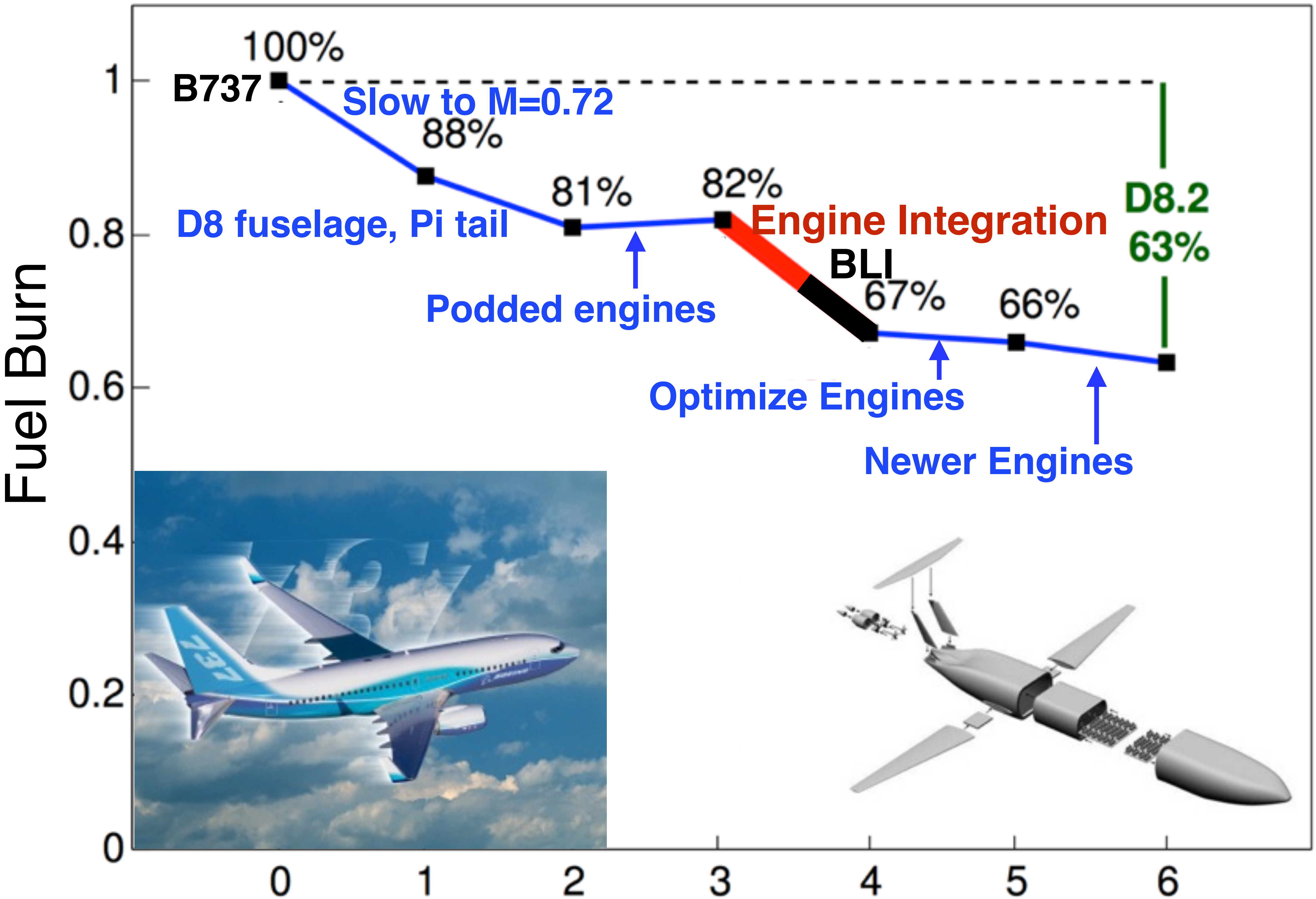
The D8 Aircraft Concept

- "Double-Bubble"
- Fundamental Aero program
  - –Fixed-wing
  - –N+3 advanced vehicle configuration
    - Lower fuel burn, lower noise, reduce emissions
- 180 passengers
- 3000 nmi range
- 118 ft span
- Boeing 737/A320 class
- Lifting fuselage, pi-tail
- Flush-mounted engines

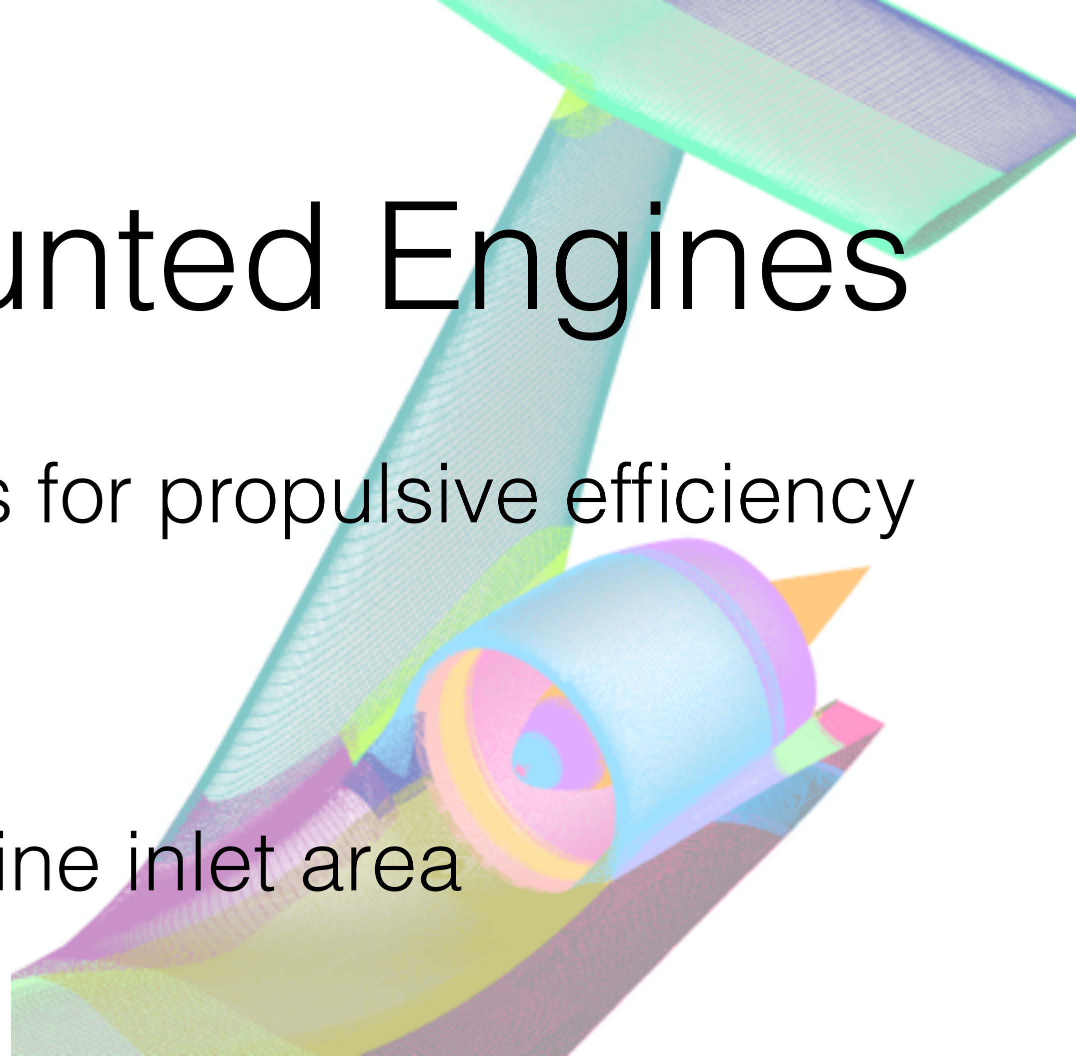


B737—>D8
Our Focus: BLI

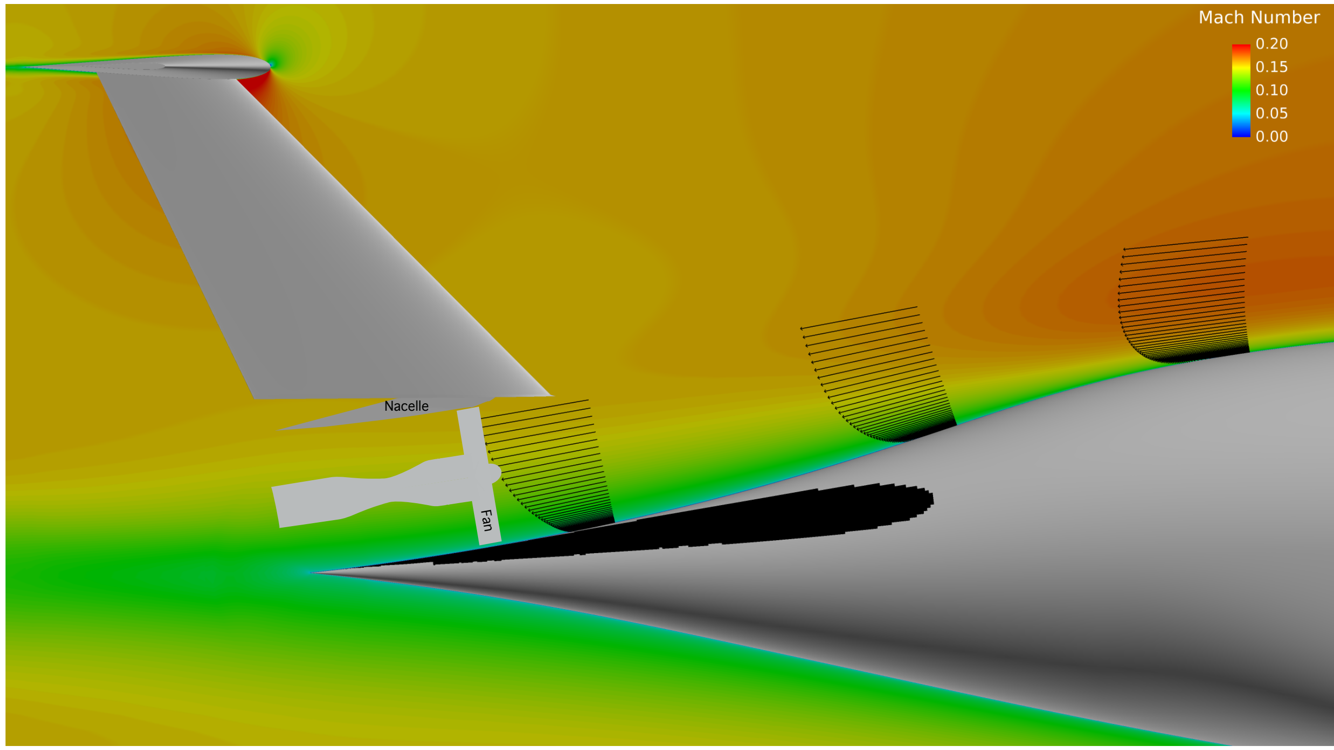




Embedded Rear-Mounted Engines



- Boundary Layer Ingesting (BLI) engines for propulsive efficiency
  - –Thicker boundary layer in the rear
  - –Designed for M=0.6 flow around engine inlet area
  - –Distortion tolerant fan
  - –High bypass ratio (~20)
- Lower engine-out yaw
  - –Reduced vertical tail size
- Noise shield



Goals and Approach

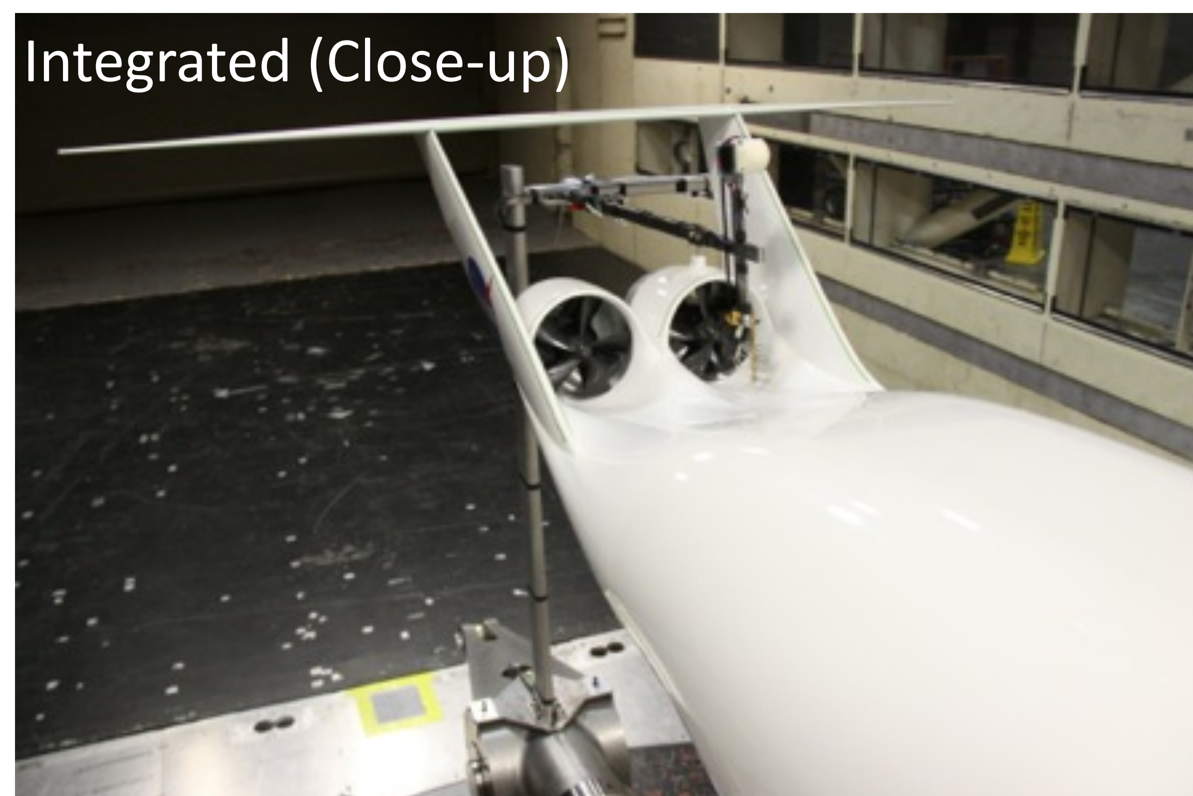
- Goal: Quantify benefits of boundary layer and wake ingestion for the D8.
- Approach:
  - Overset CFD using CGT and Overflow-2.
  - CFD validation
    - NASA LaRC 14x22 WT data for a 1:11 scale model.
  - Quantifying the BLI and wake ingestion benefit:
    - Direct Comparison between:
      - Efficient conventional (podded nacelle) configuration.
      - BLI (integrated nacelle) configuration.

WT Configurations

Unpowered

Podded

Integrated

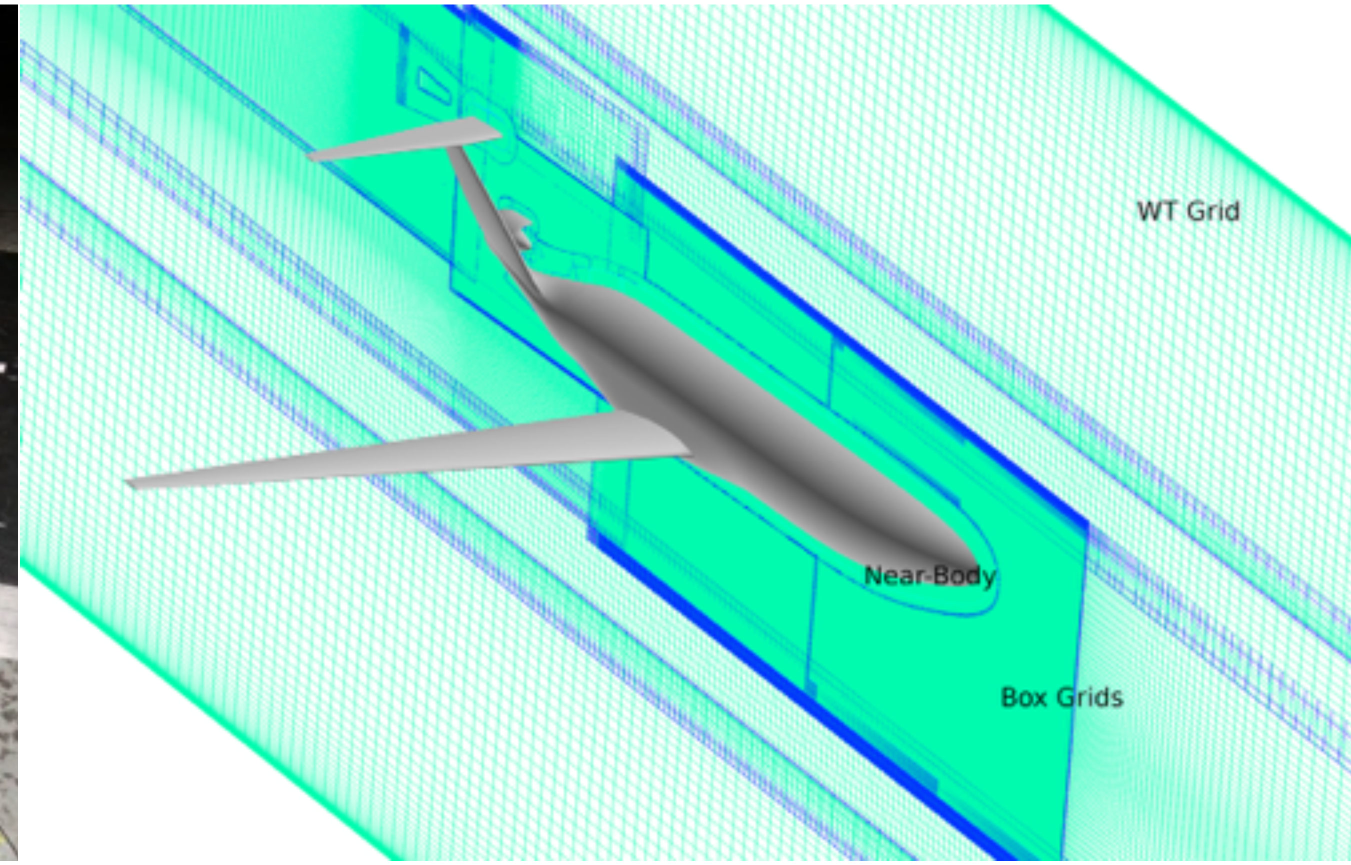


Integrated (Close-up)

Configuration Details

- WT runs at 70 mph, Re_c = 570,000.
  - lower-speed and Re compared to full-size at M=0.72.
- 1:11 Scale powered model.
- Wing designed for low Mach, low Re.
- Same wings.
- Most of fuselage is the same.
- Same propulsors plug into both podded and integrated configuration empennage sections.

D8 Model

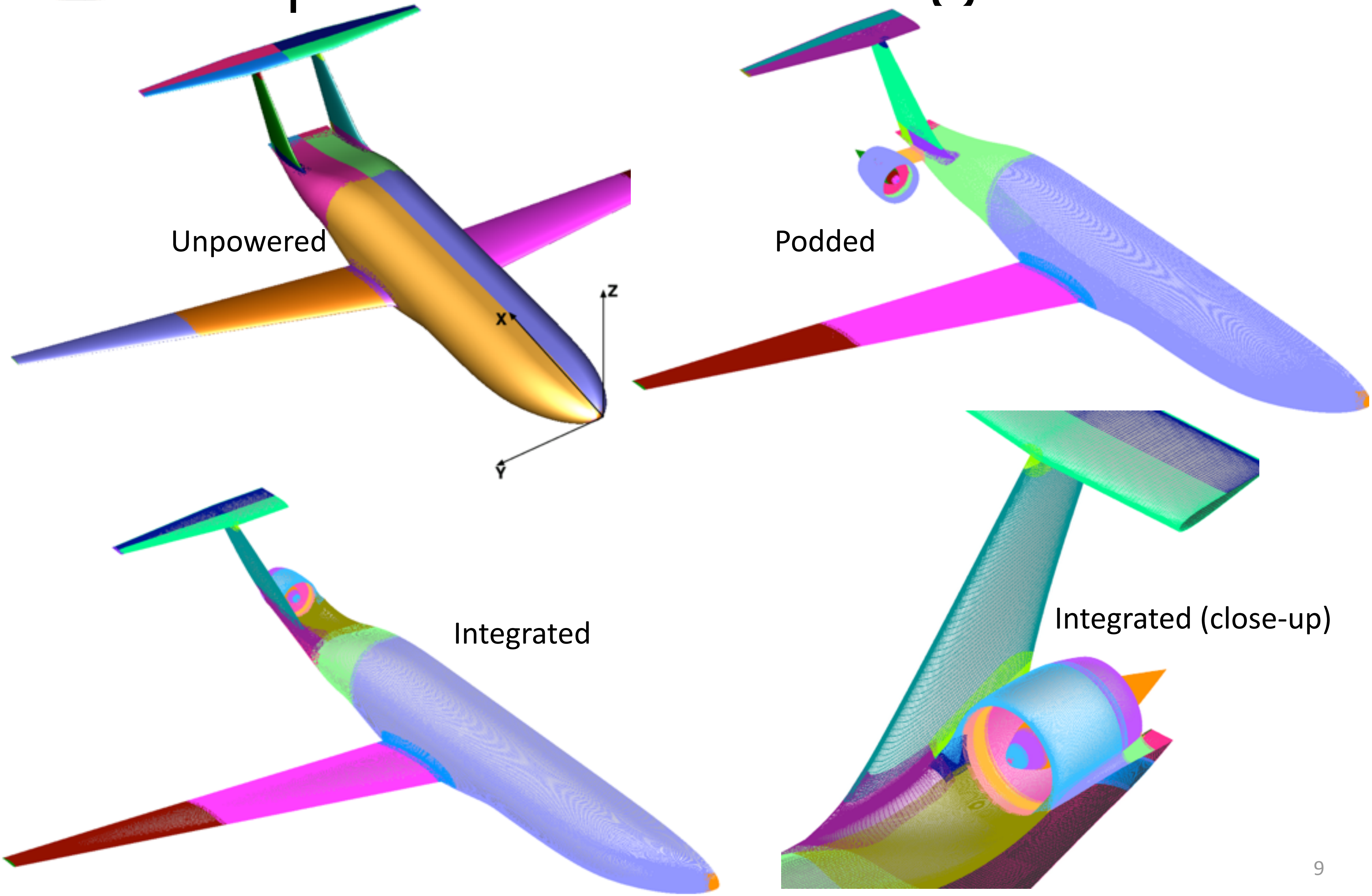


Blue indicates regions of overlap

- Larc 14x22 WT model
  - 1:11 scale, Full body
  - Mounting hardware controls AoA

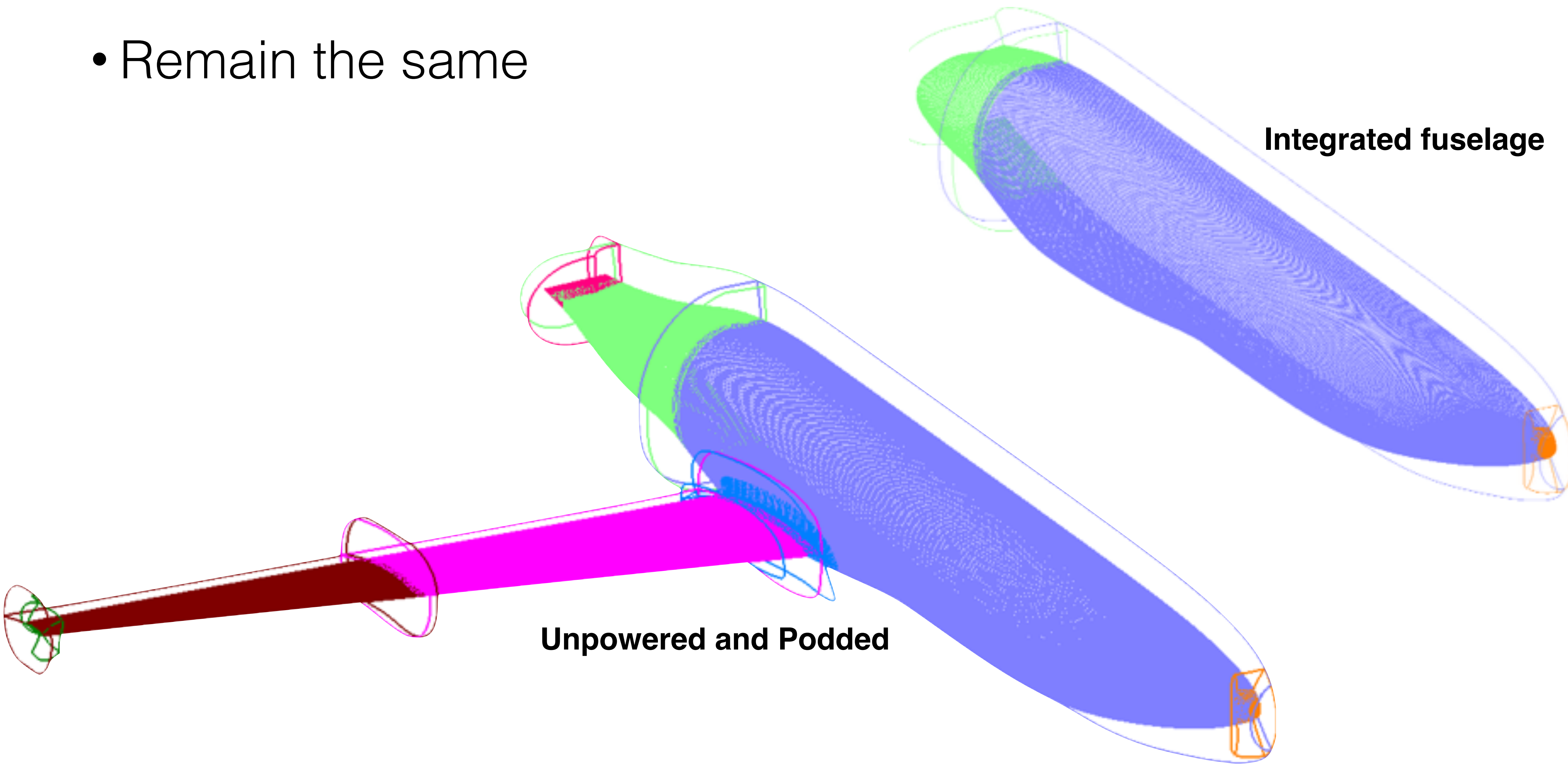
- Computational model
  - 1:11 scale, Half body
  - No mounting hardware
  - Inviscid walls

Computational Configurations

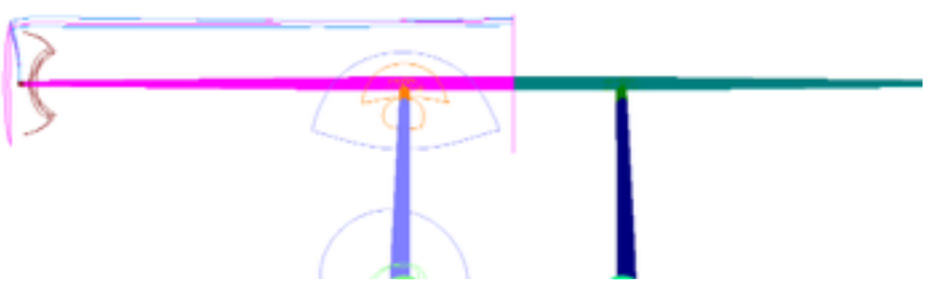


Fuselage and Wing Grids

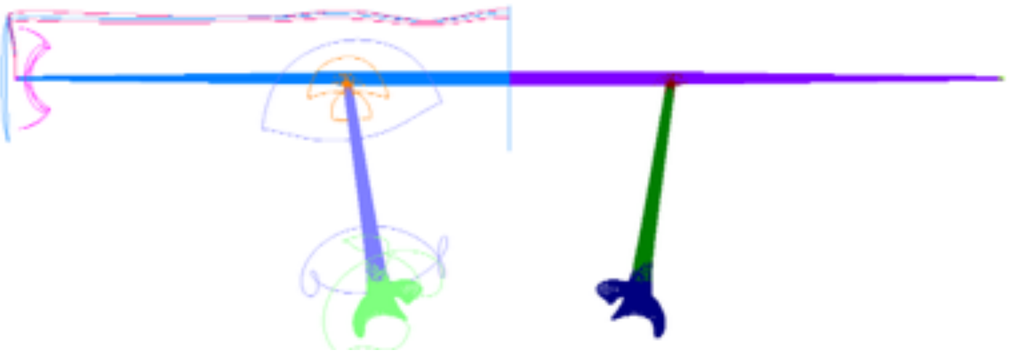
- Remain the same



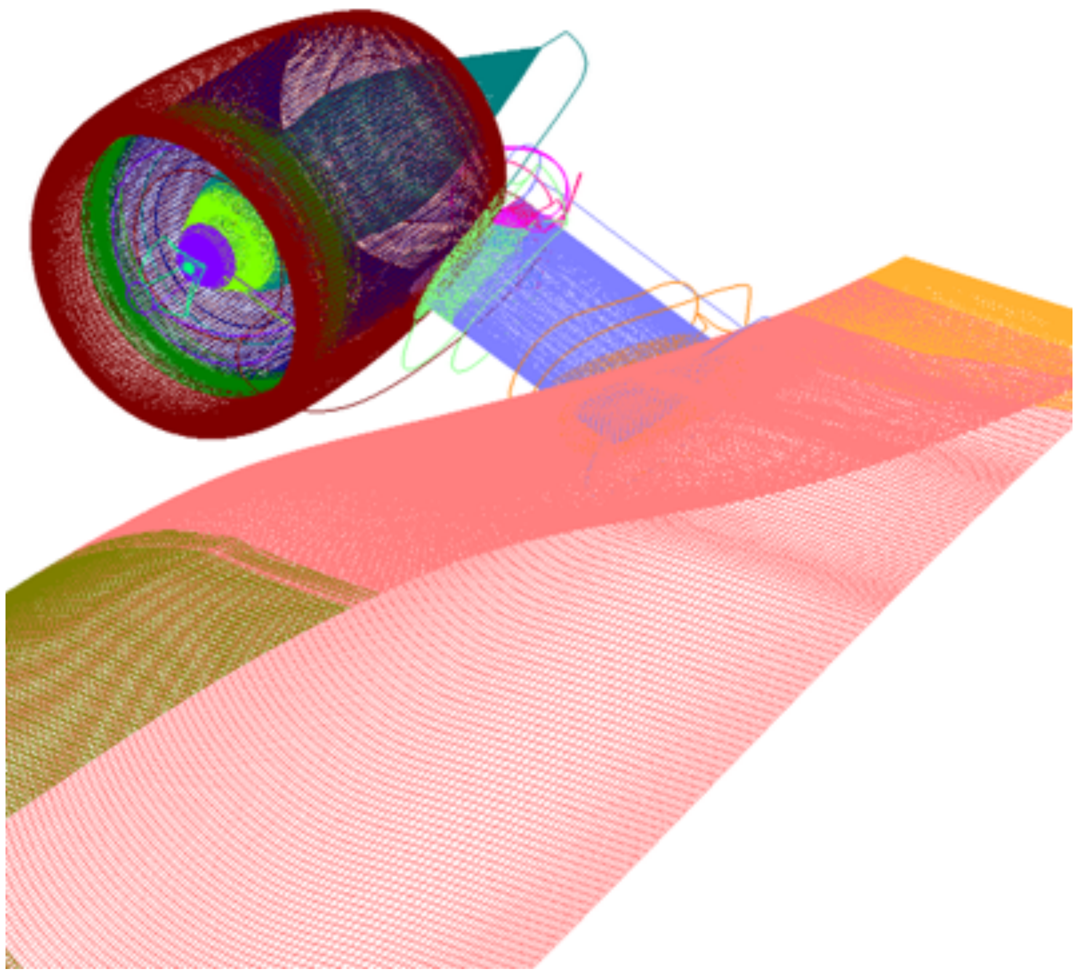
π-tail, Nacelle, Pylon

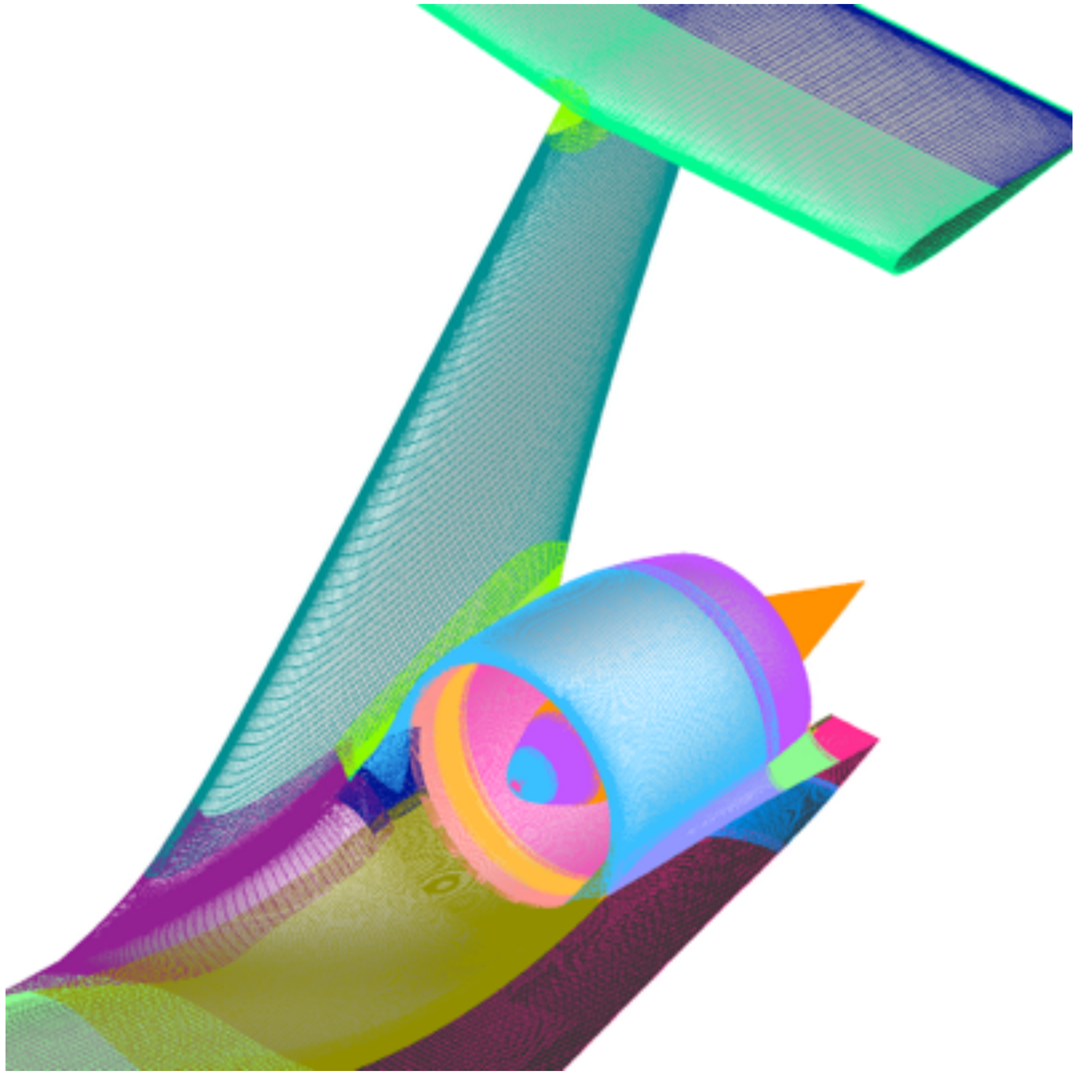


Unpowered and Podded



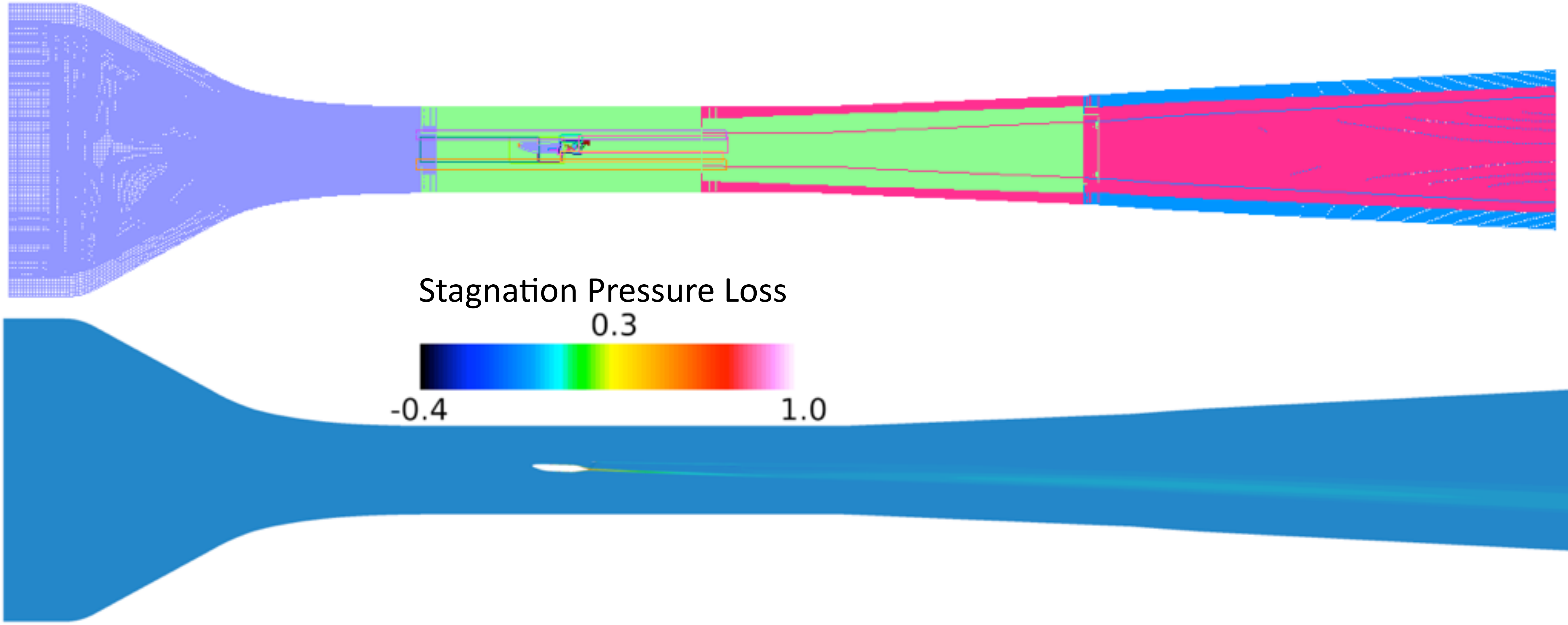
Integrated



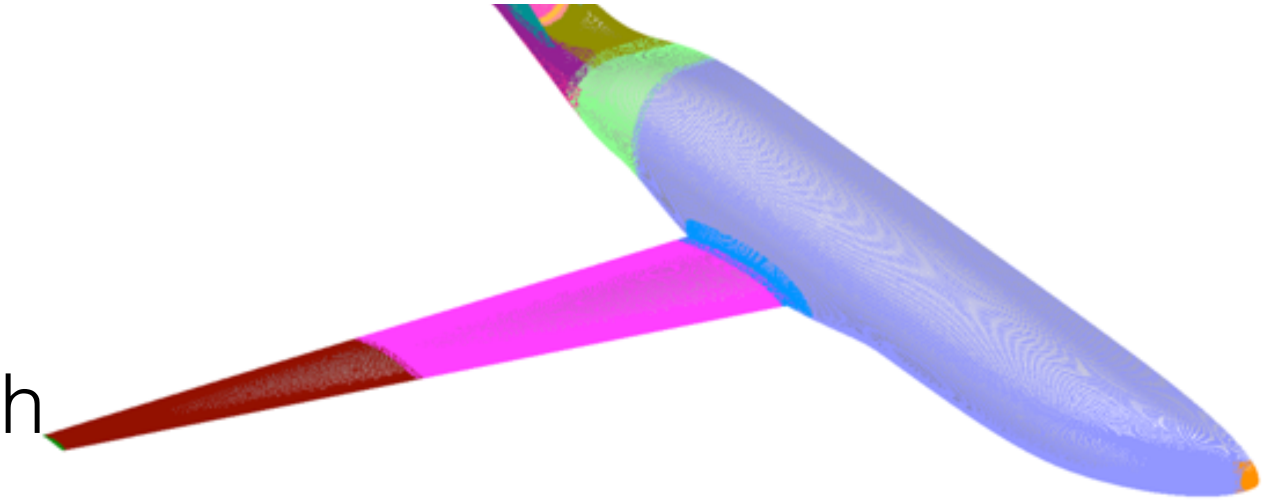


WT Grids

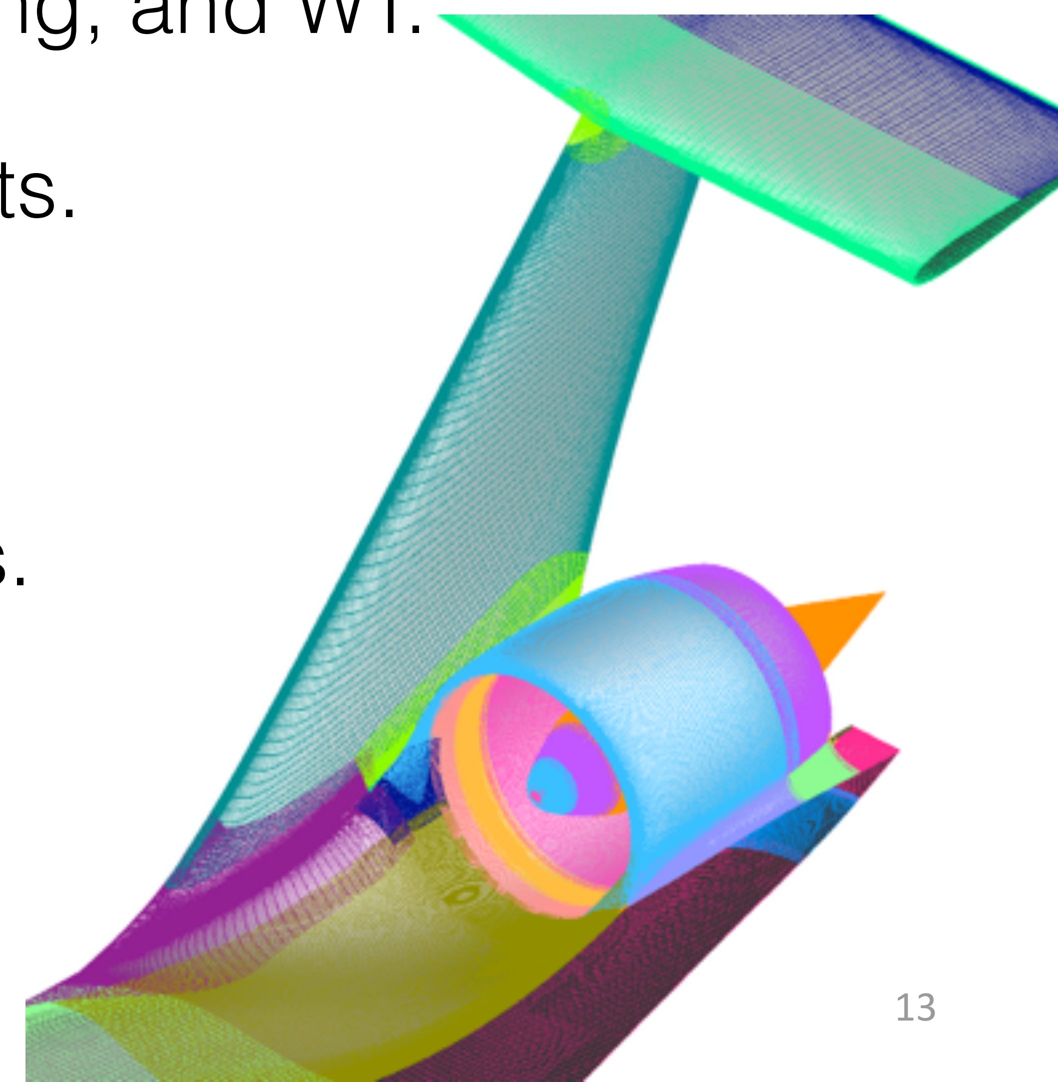
- Inviscid wall boundary condition.
- 7 grids (4 wall grids, 3 core grids) + box grids.
- Mach and Re number matched at pitot probe.



Computational Mesh



- Chimera Grid Tools
  - –Overset surface and volume mesh
    - Same grids for forward fuselage, wing, and WT.
  - –Unpowered: 36 grids, 113 Million points.
  - –Podded: 49 grids, 130 Million points.
  - –Integrated: 64 grids, 135 Million points.
  - –y+ ≈ 0.7.

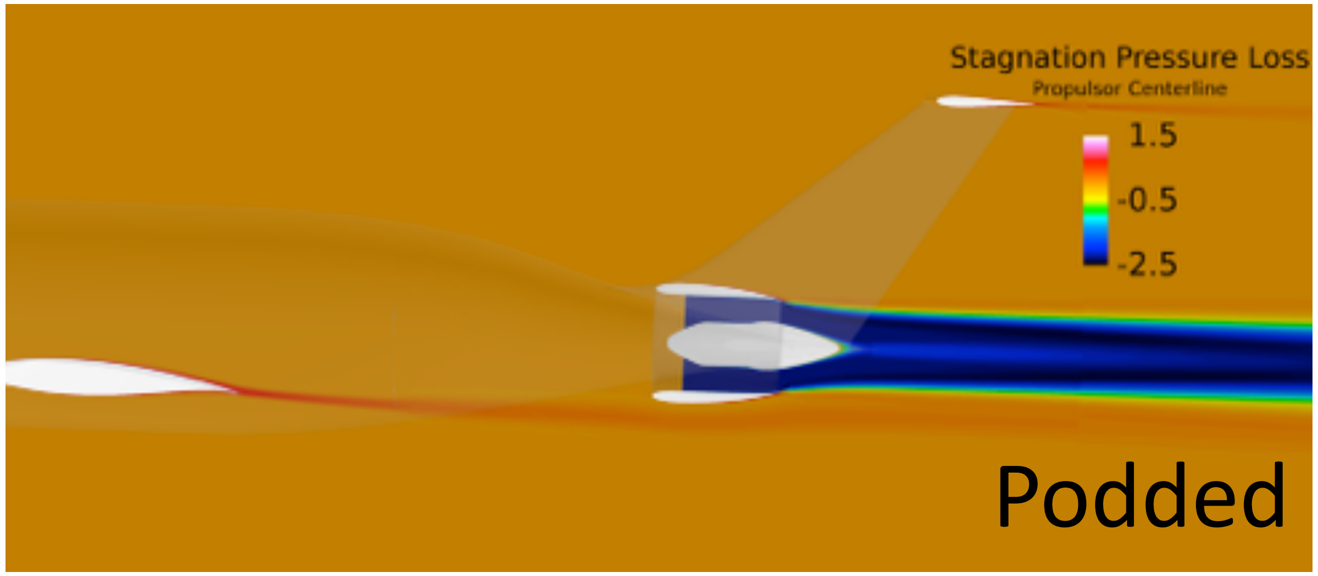


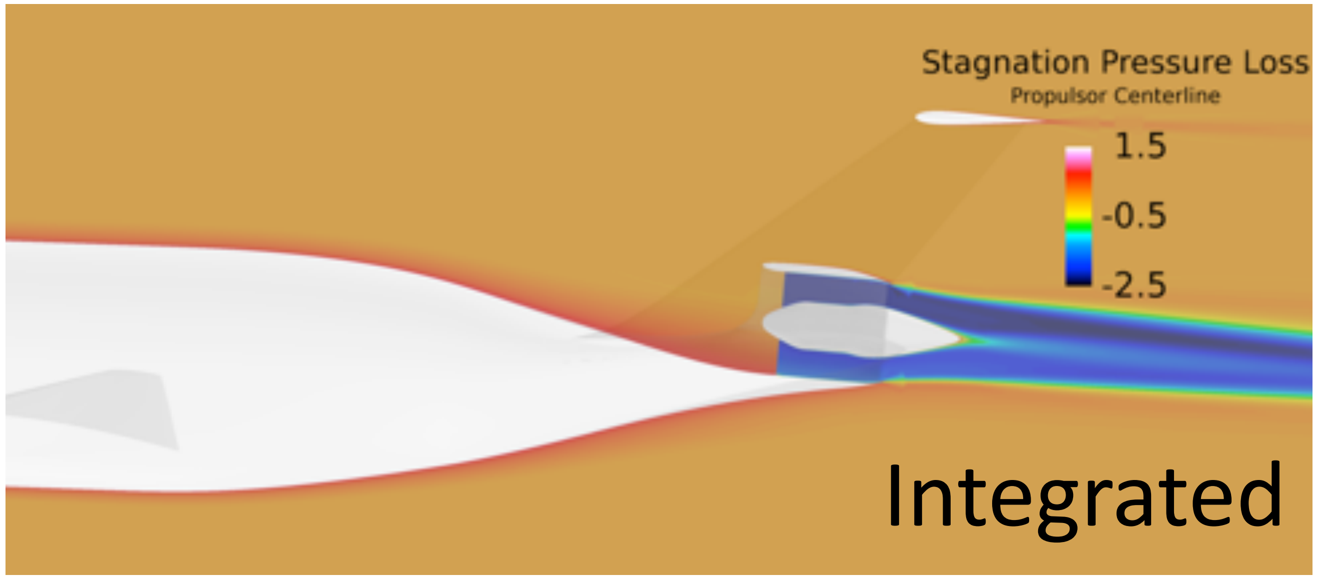
CFD Solver

- OVERFLOW
  - –3D, RANS solver for overset structured grids.
  - –Diagonalized approximate factorization Scheme.
  - –2nd order central difference + artificial dissipation.
  - –Matrix dissipation.
  - –RANS SST turbulence model.
- Flow Conditions
  - –Mach=0.088.
  - –Re = 44000/in.

Fan Model and its Effect

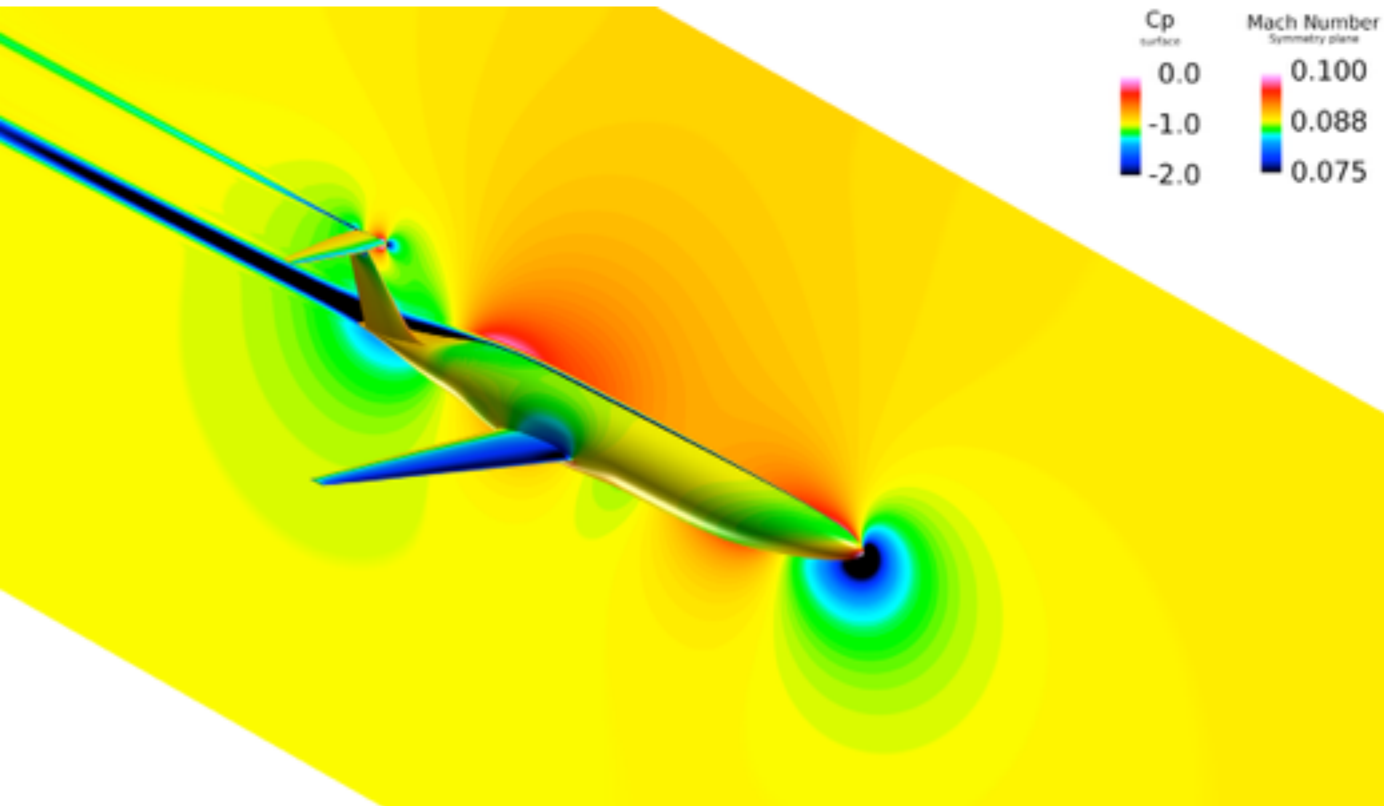
- Actuator disk
  - –Uniform pressure jump.
- Four cases with increasing pressure jump settings
  - For both podded and integrated.
  - Integrated sees a lower mass flow.

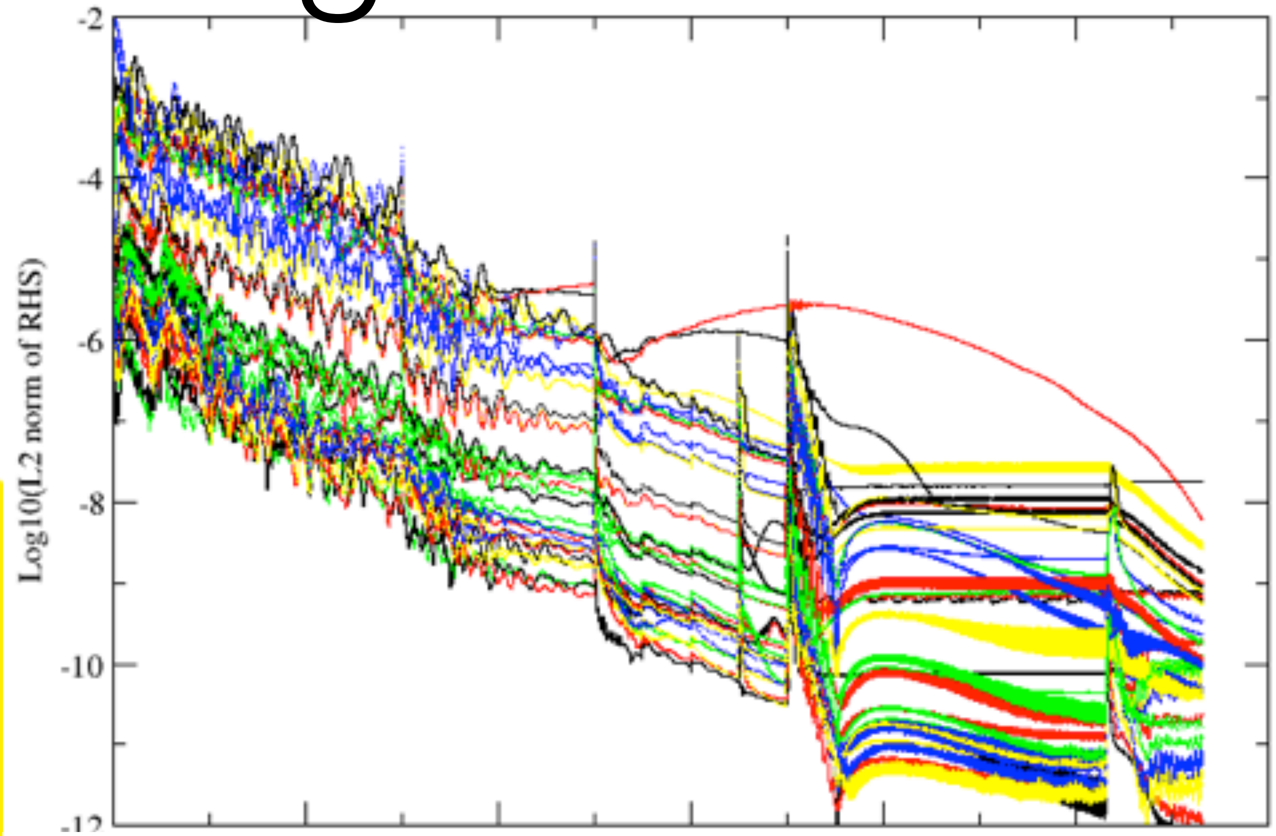


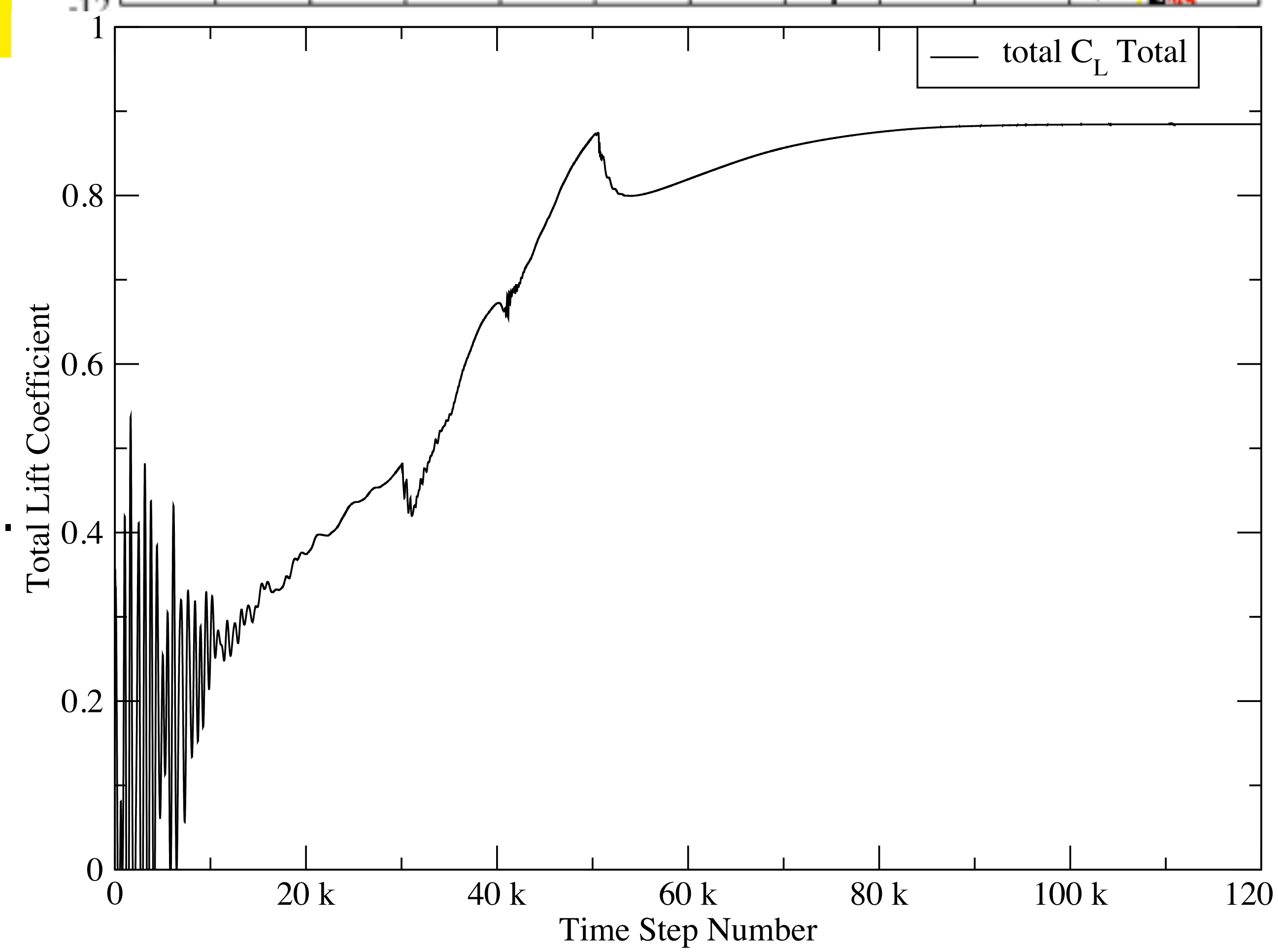


Cuts through propulsor centerline.

Typical Convergence

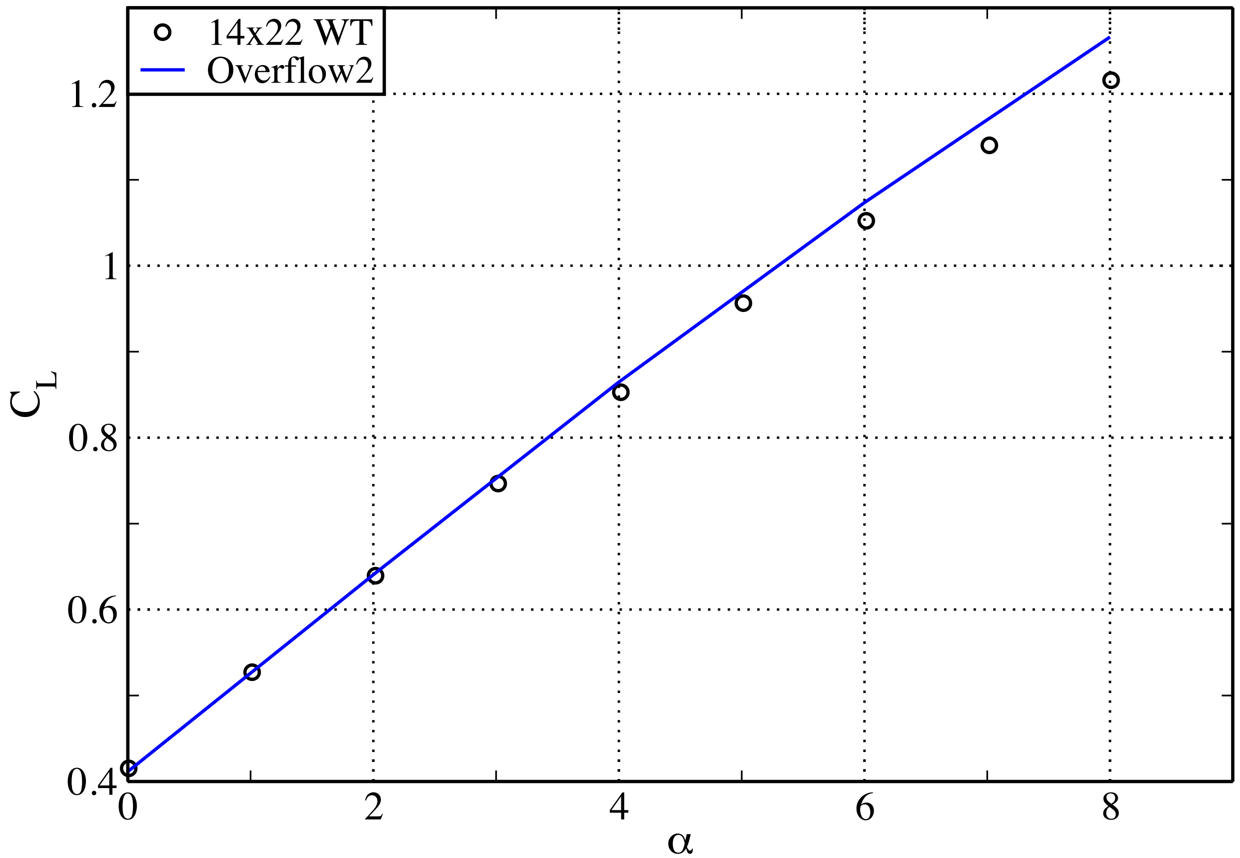


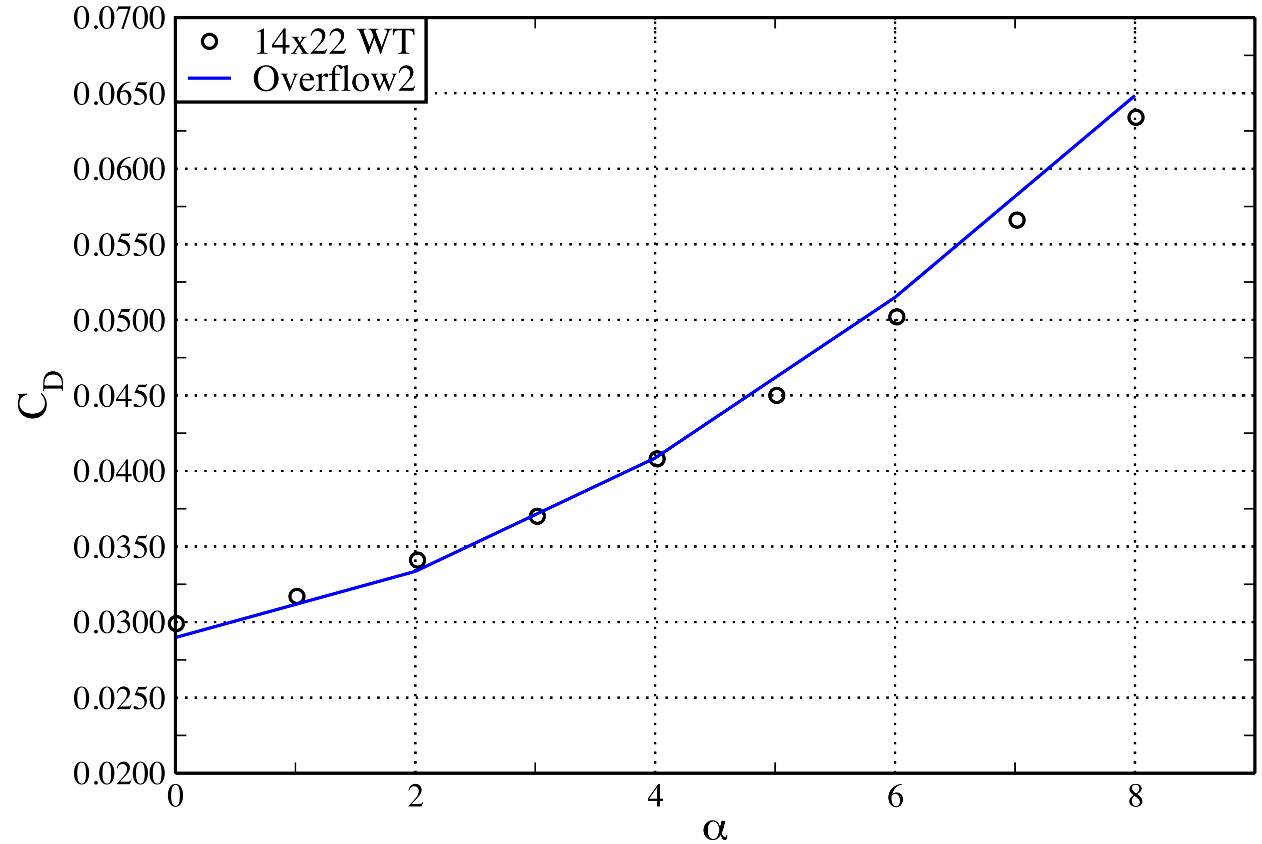


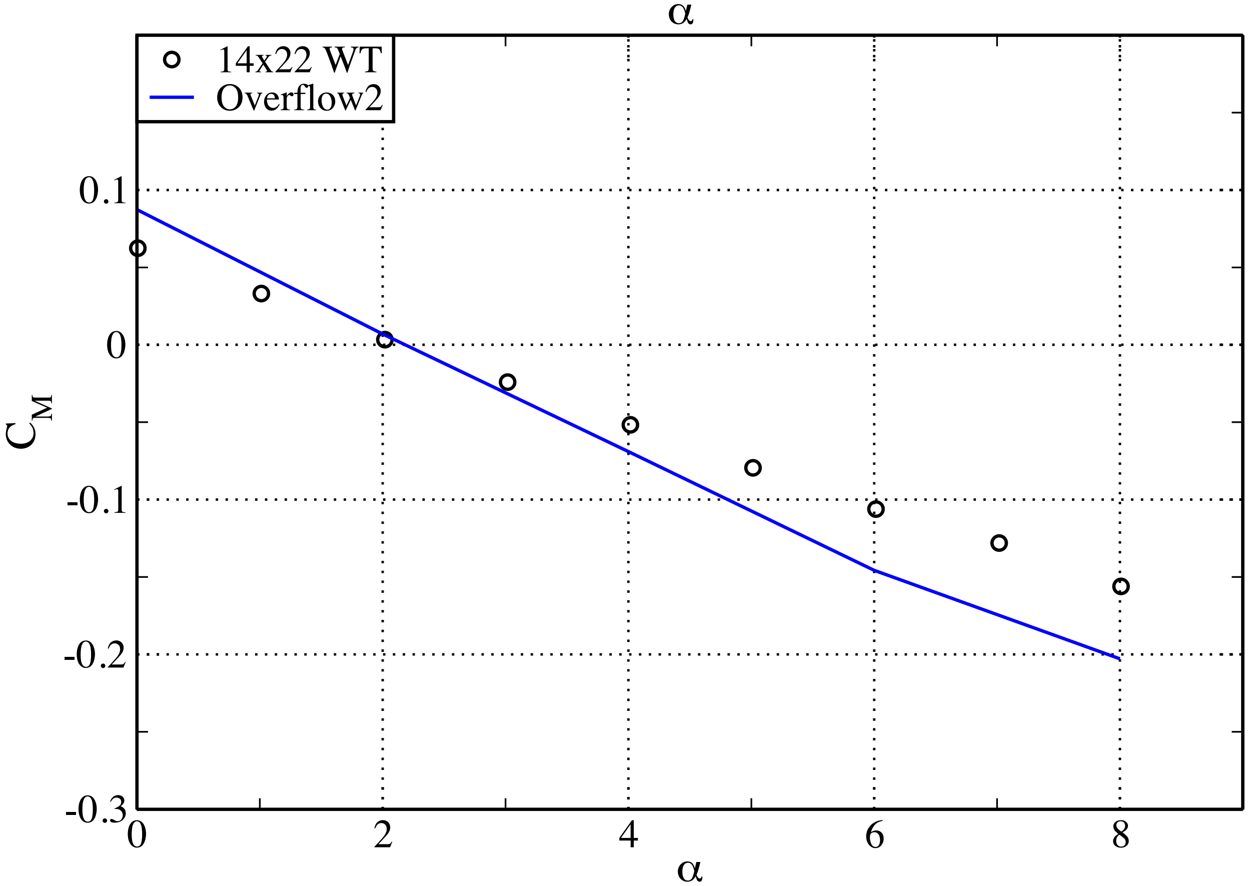


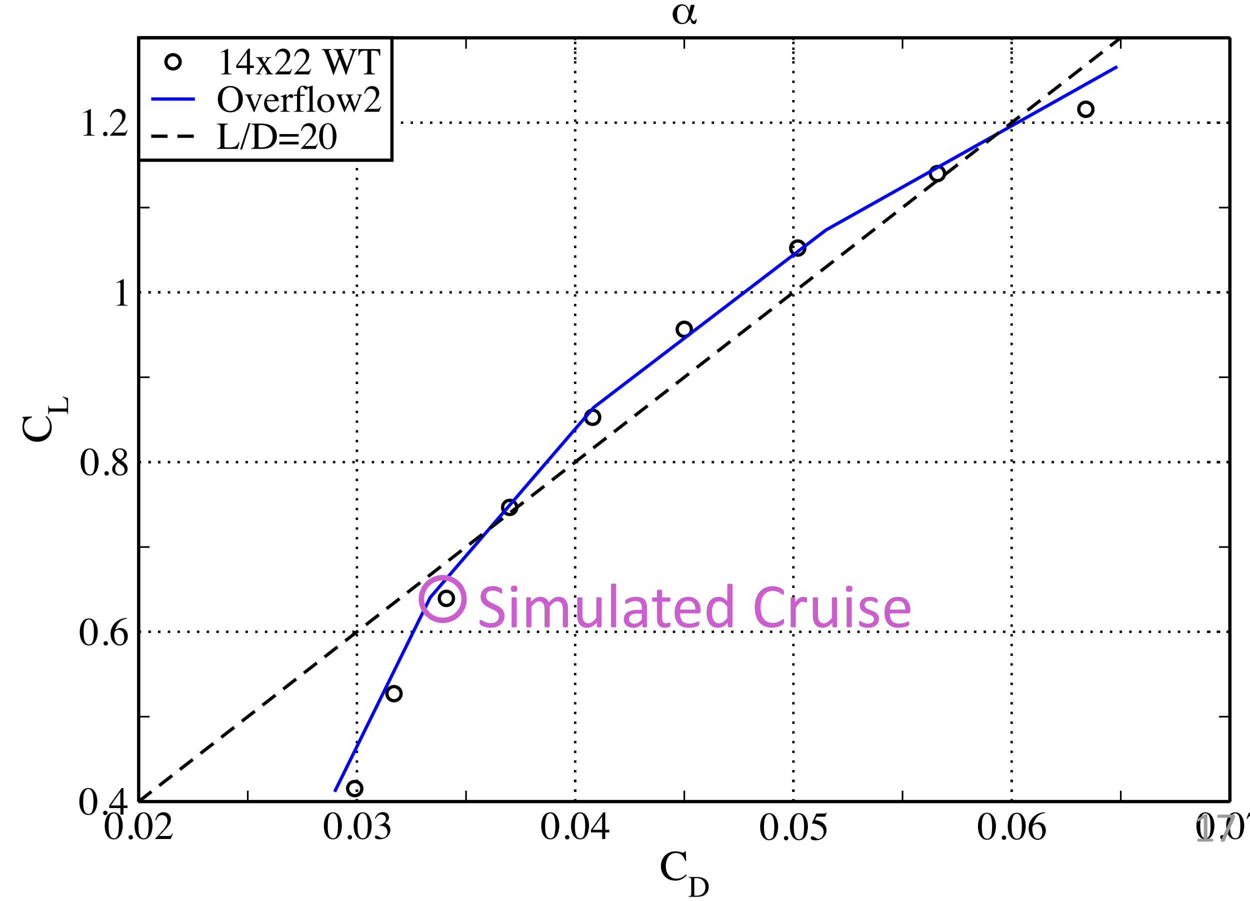
- Simulations without fans.
- Alpha sweep.
- Compare to Wind Tunnel (WT) test data.
- Iterations to match Mach & Re at pitot probe.

Validation-unpowered









Propulsor Inlet flow Comparison

Total pressure coefficient $C_{p_t} = \dfrac{p_t - p_{t_\infty}}{q_\infty}$

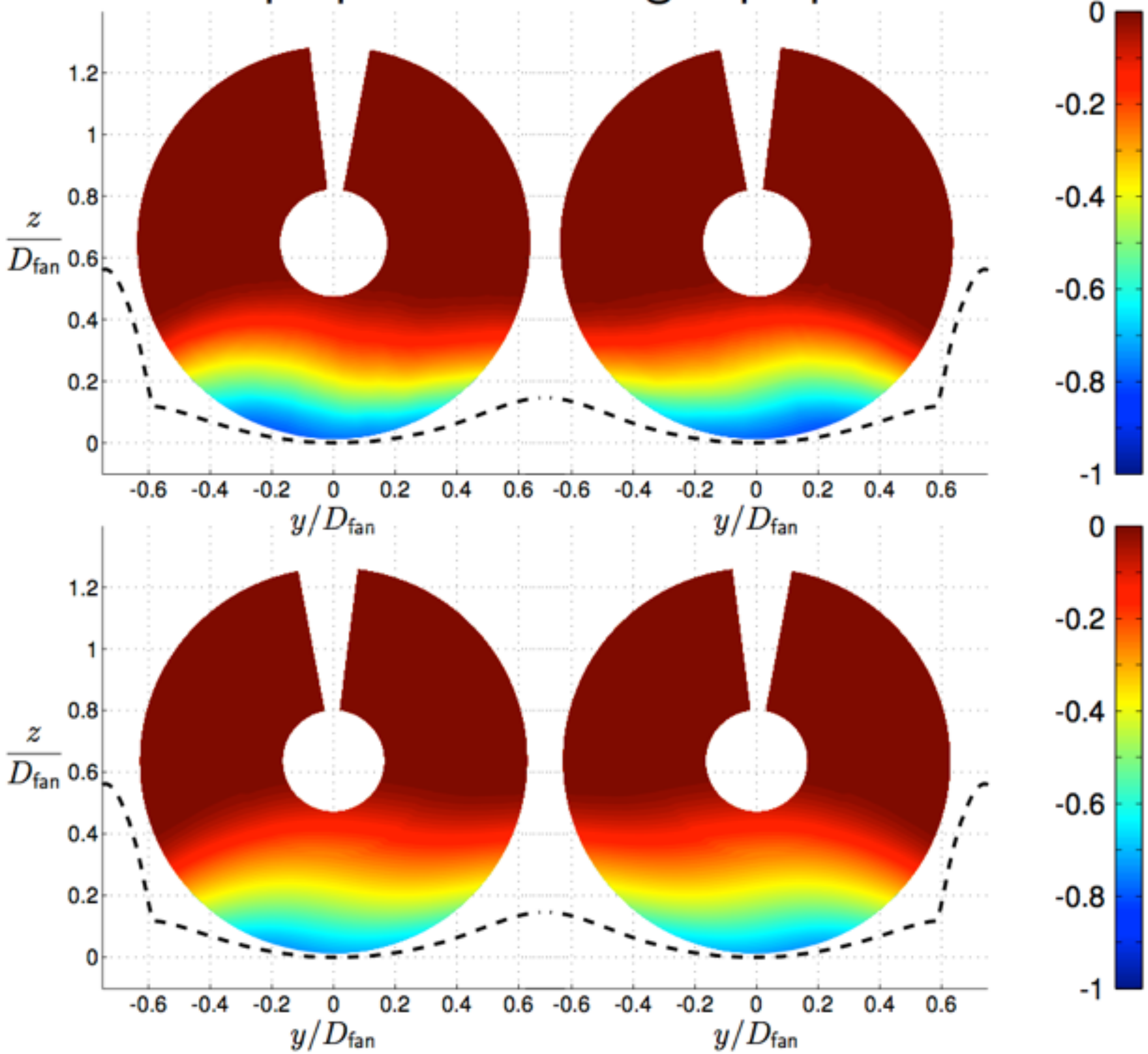
Integrated Configuration

AOA=2°

Left propulsor | Right propulsor

14x22 WT

Overflow



Propulsor Exit flow Comparison

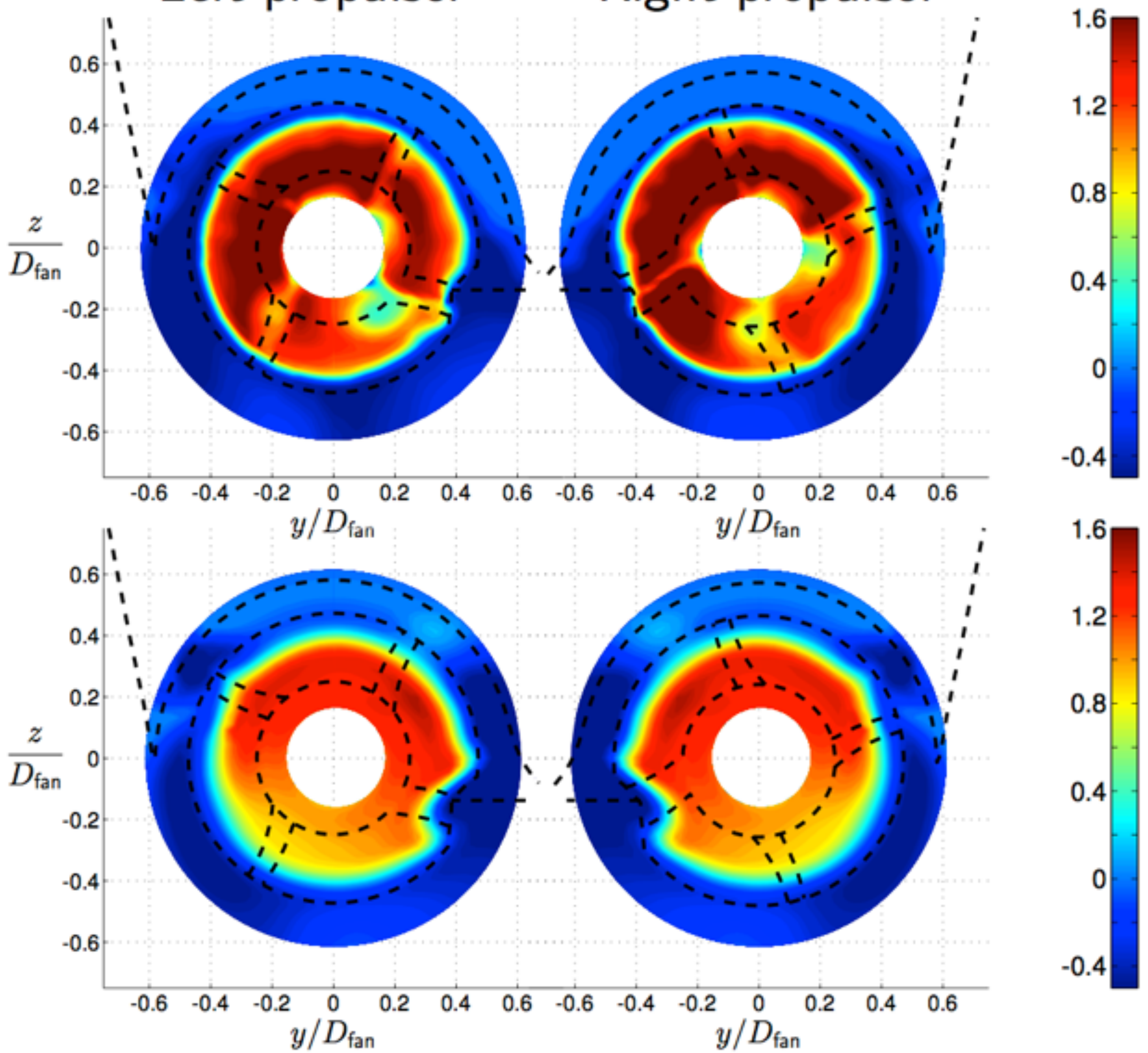
Total pressure coefficient $C_{p_t} = \frac{p_t - p_{t_\infty}}{q_\infty}$

Integrated Configuration

AOA=2°

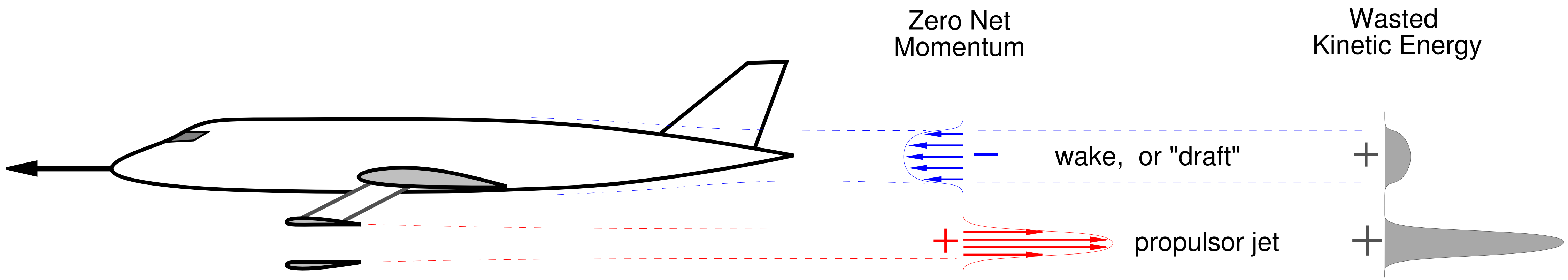
14x22 WT

Overflow



BLI

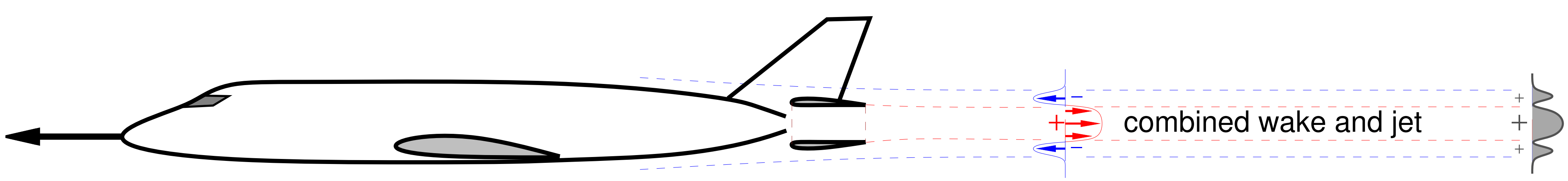
- Conventional: wake/BL energy lost.



- BLI: Fuselage boundary layer ingested by propulsor.

  –> Reduced viscous dissipation in combined wake + jet.

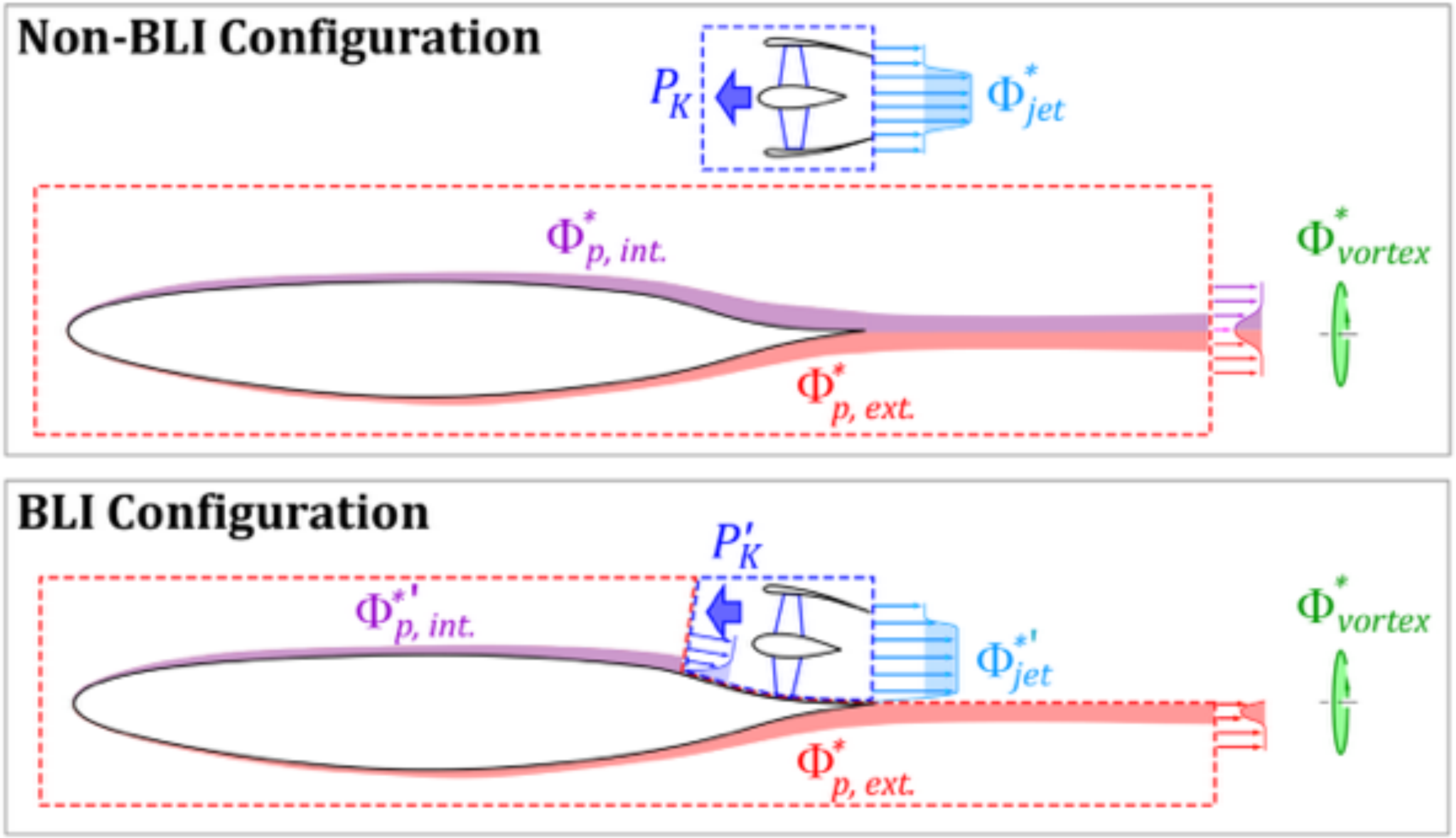
  –> Reduced flow power required from propulsor.



- Use Power-balance method (Drela, 2009, AIAA J.).

Power Balance Method

- Mechanical energy sources and sinks.



- Power-in = Dissipation.

BLI Benefit

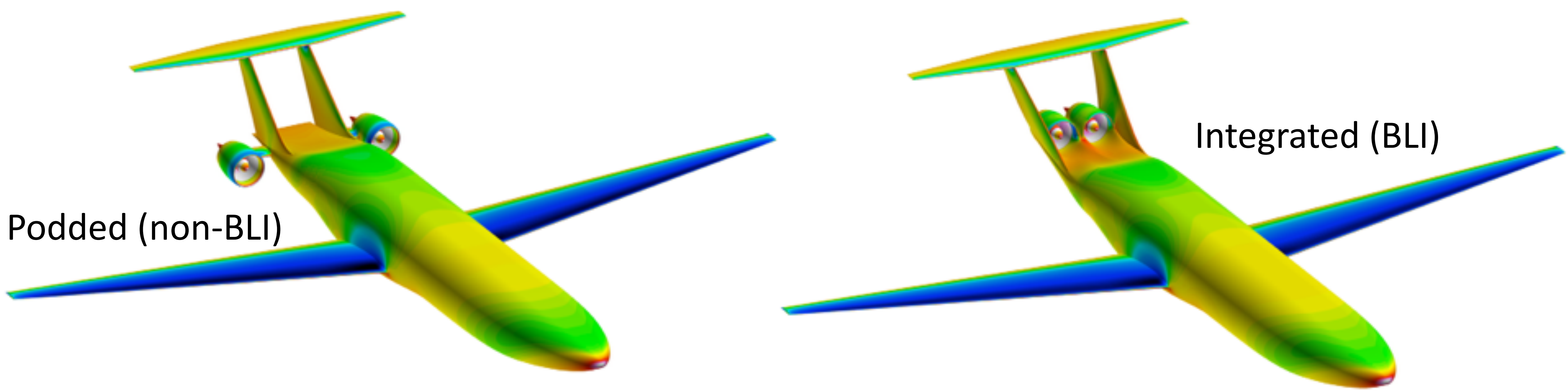
- Compare mechanical flow power:

$$P_K = \oint_{propulsor} (p_{t,\infty} - p_t)\,(\mathbf{V} \cdot \hat{\mathbf{n}})\,\mathrm{d}A\ .$$

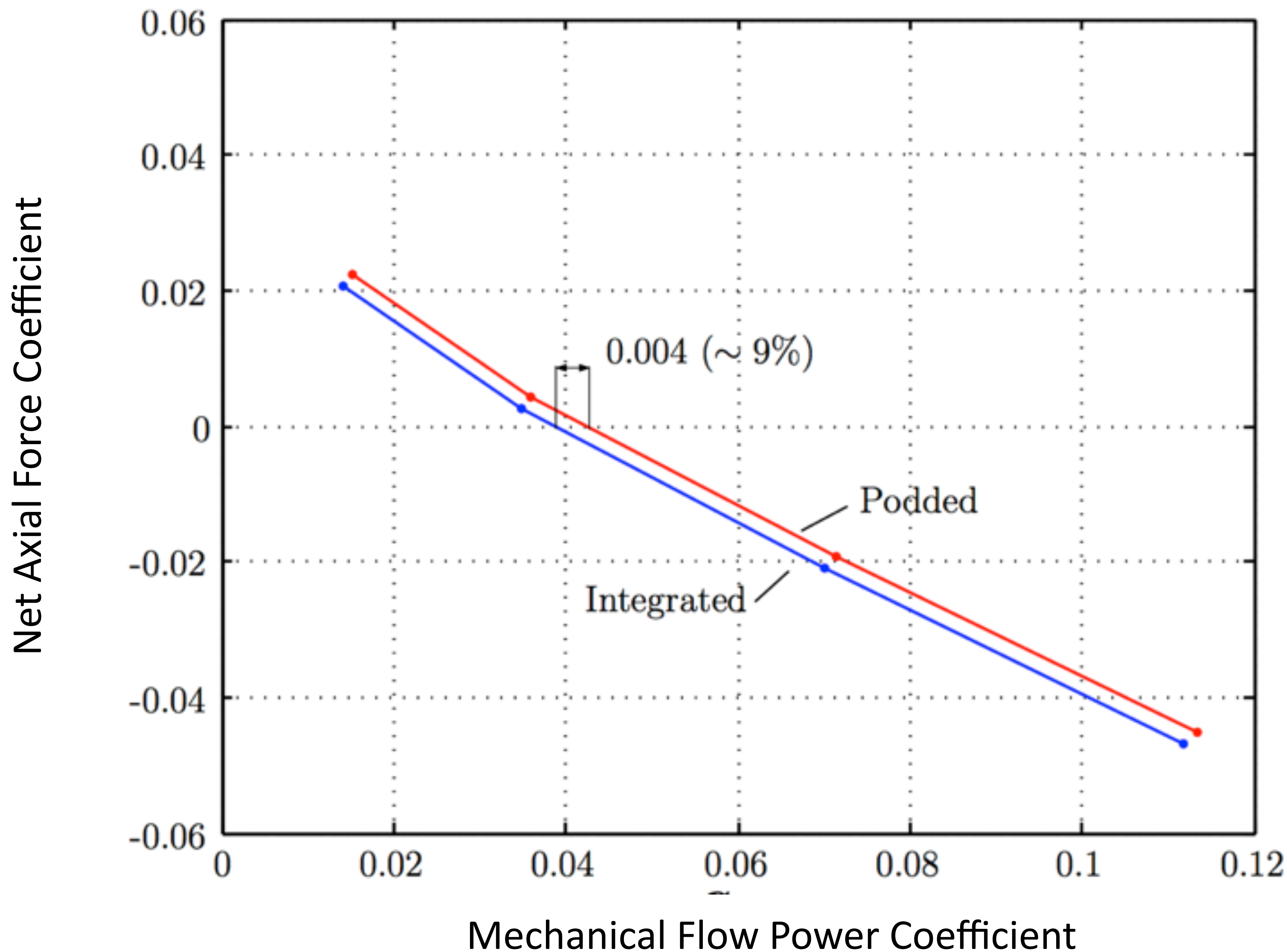
  – Power transmitted by propulsor to the flow.

- Savings in power required: integrated vs. podded.

$$\text{BLI benefit} \equiv \left.\frac{P_{K_{\text{non-BLI}}} - P_{K_{\text{BLI}}}}{P_{K_{\text{non-BLI}}}}\right|_{\text{at given } F_X}$$

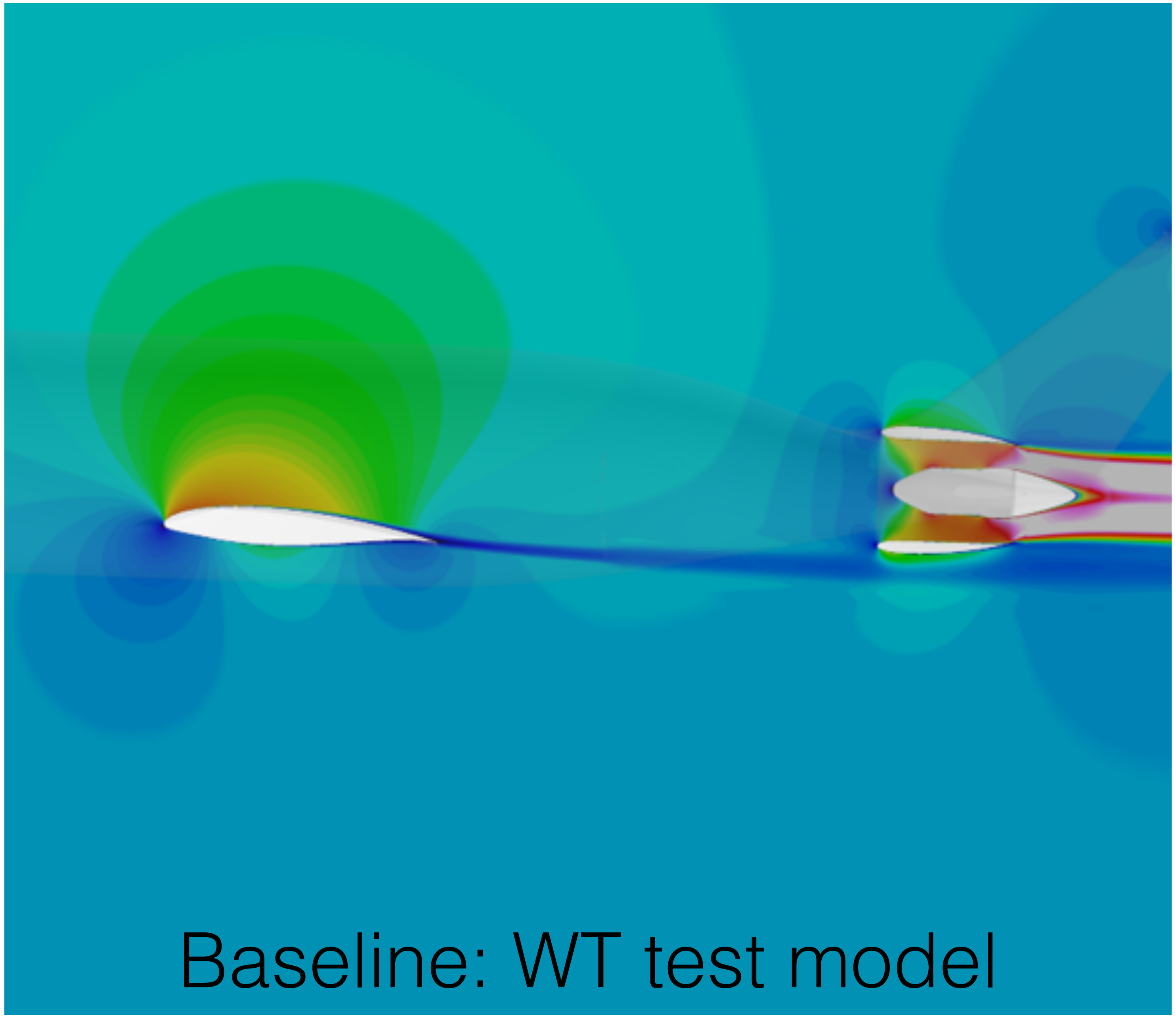


Benefit of BLI (Computational)



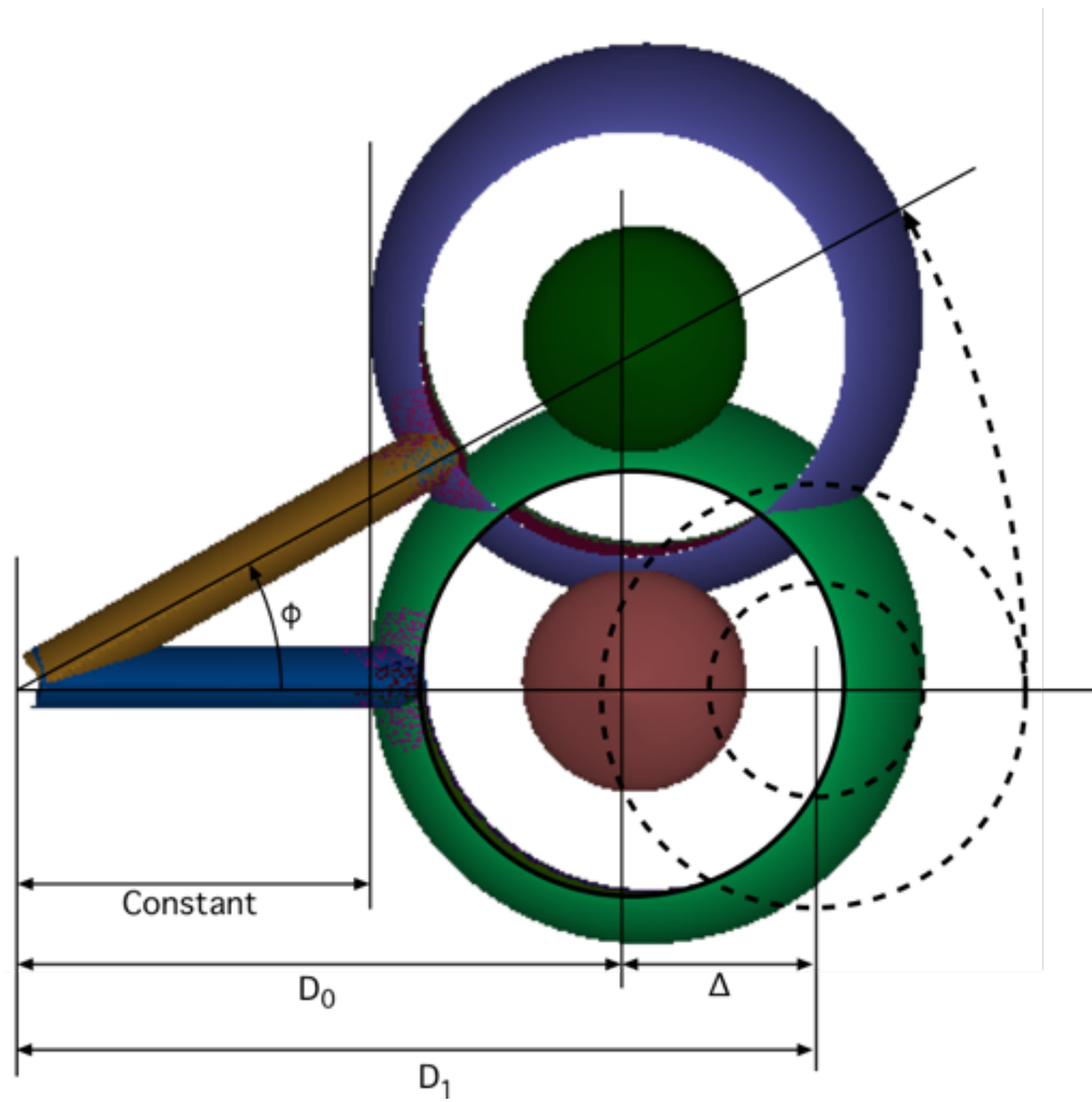
Wake Ingestion

- Previous podded nacelle almost ingested the wing wake
- Can we move the nacelle out of the way?
- What is the effect of nacelle movement on BLI?

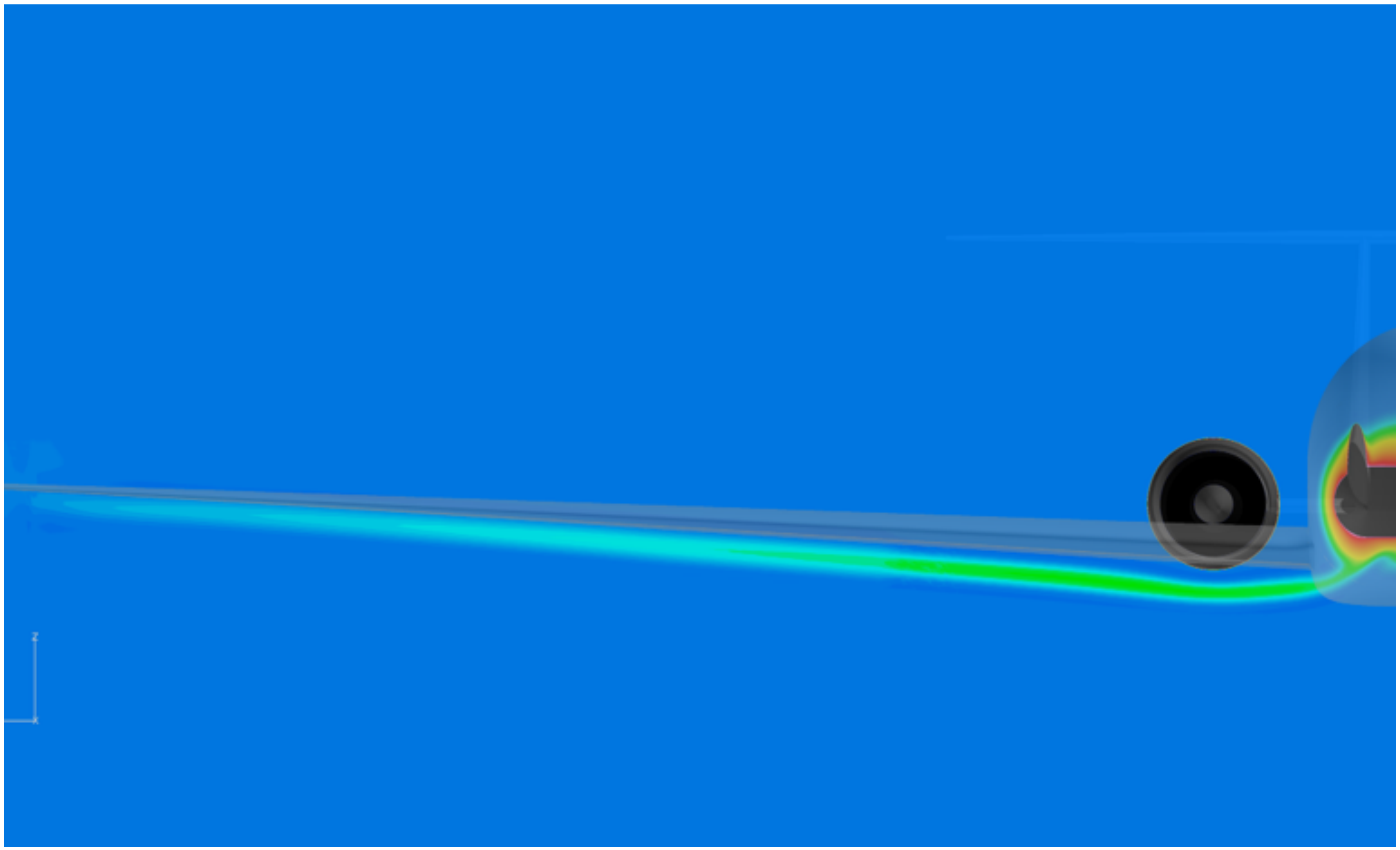

Baseline: WT test model

Test Matrix

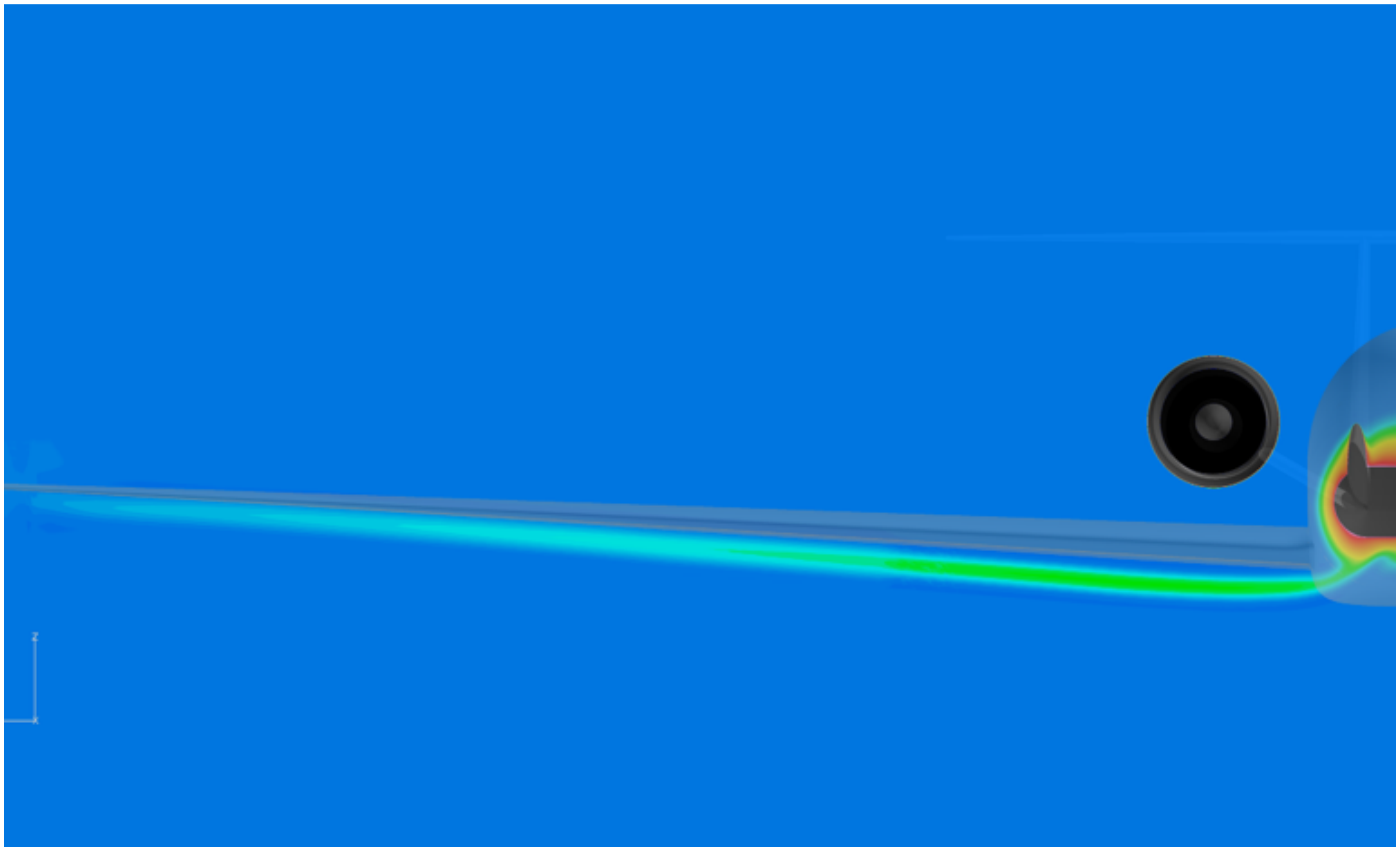
- Deflect the nacelle up and down (-20°,-10°,0°,10°,20°,30°).
- Power setting: closest to WT test setting.
- Keep the outboard position and toe angle unchanged.
- Compare to the baseline case.
- $\Delta = D_1 - D_0 = D_0(1/\cos\theta - 1)$.
- Translate by Δ, then rotate by θ.



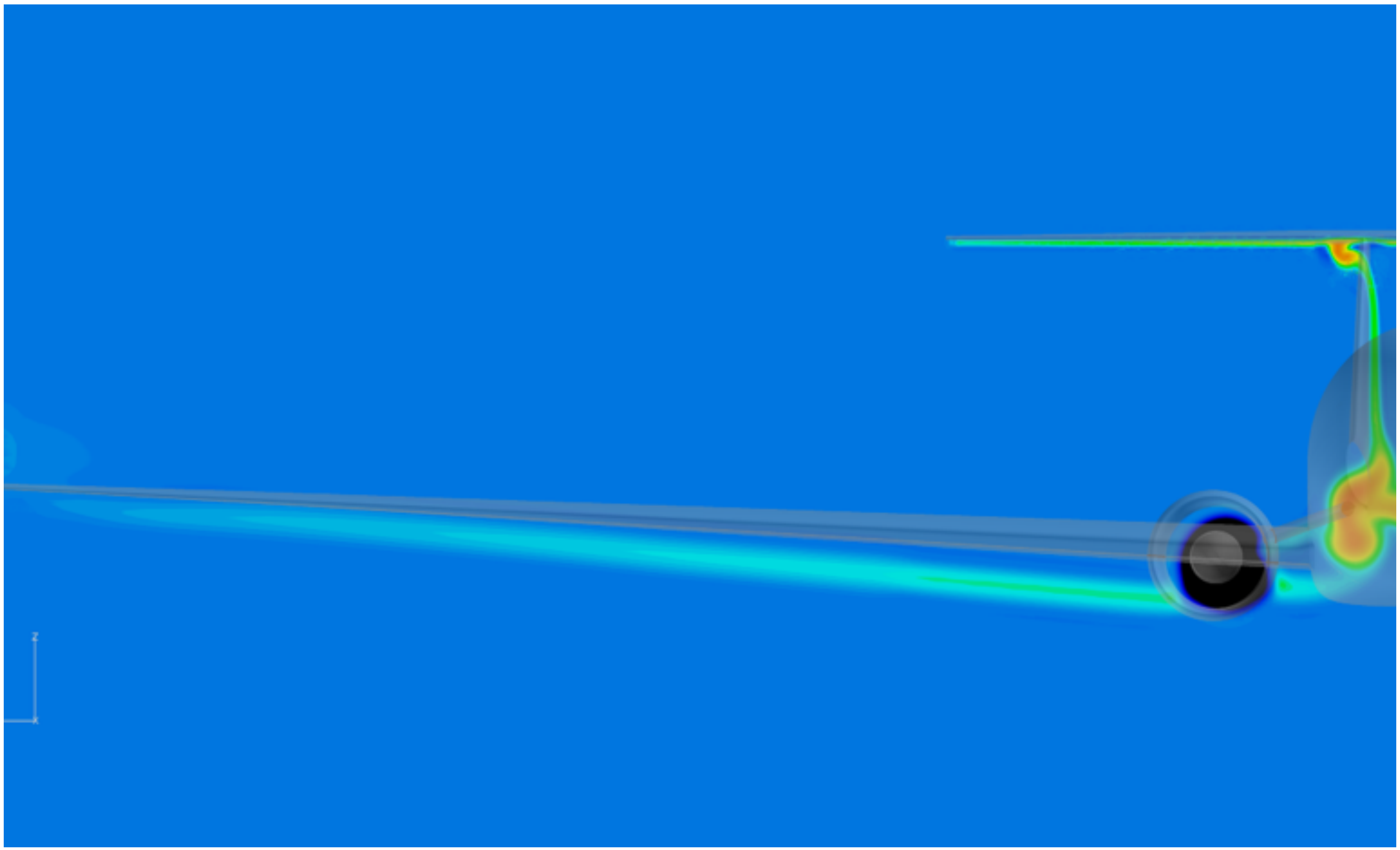
Stagnation Pressure Loss ($\phi=0°$) prior to entering the nacelle

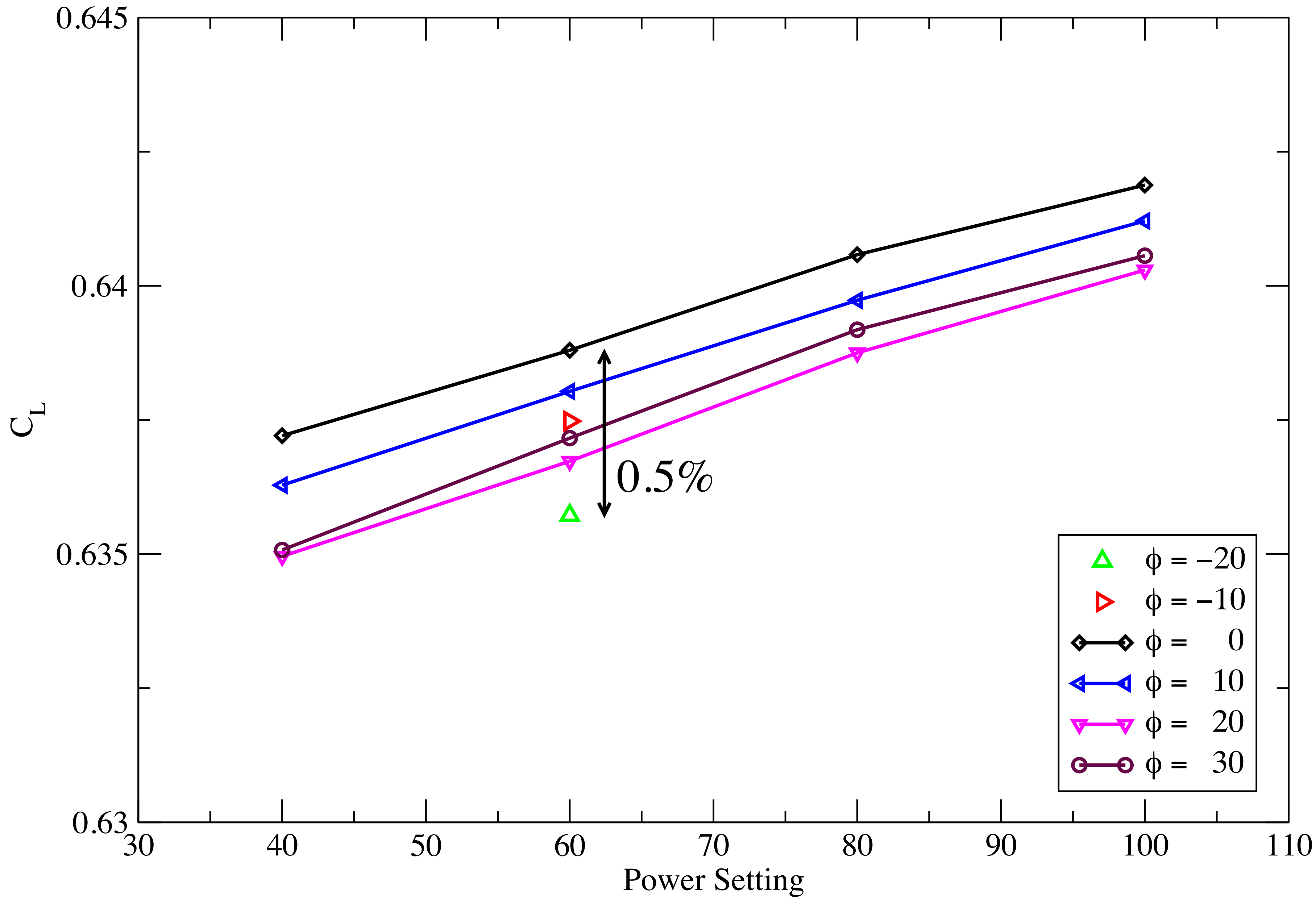


Stagnation Pressure Loss (ϕ=30°) prior to entering the nacelle



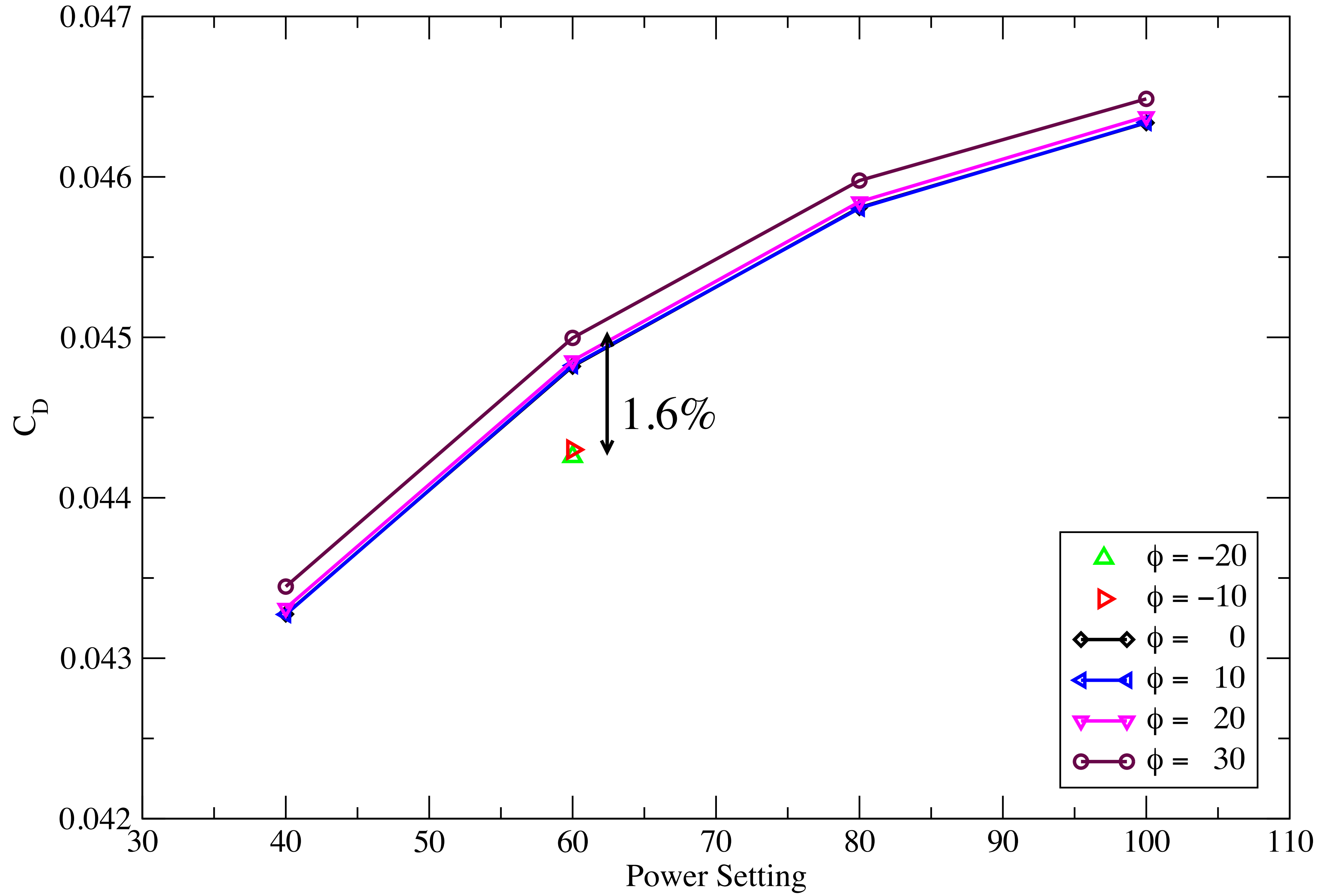
Stagnation Pressure Loss (ϕ=-20°) behind the nacelle





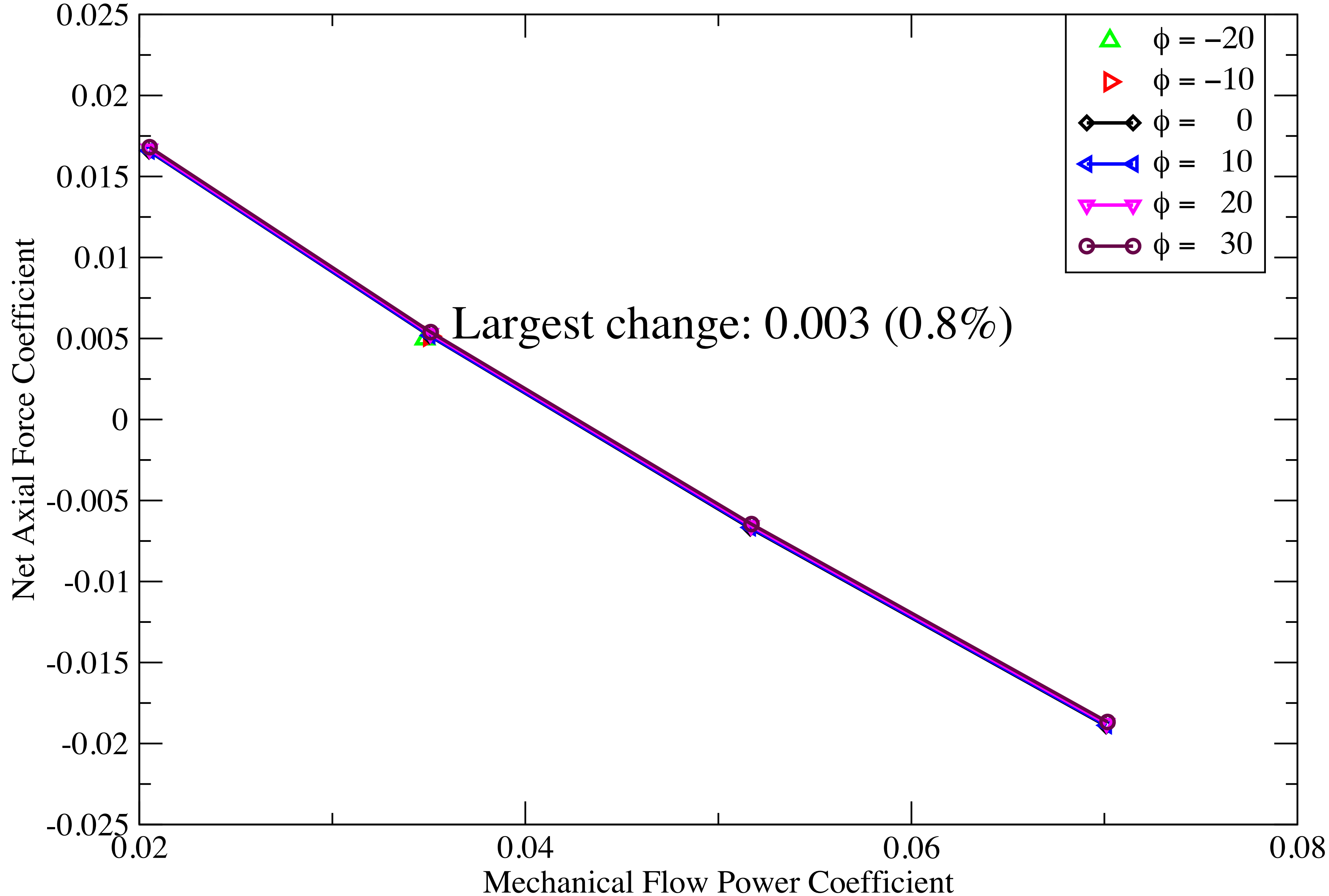
Effect of Pylon Deflection

Lift



Effect of Pylon Deflection

Drag



Effect of Pylon Deflection

Axial Force vs. Mech. Flow Power with power settings of 40, 60, 80 and 100%

Concluding Remarks

- BLI benefit is:
  - 9% less Mechanical flow power with BLI
- Wake ingestion benefit is:
  - 0.8% less Mechanical flow power with wake ingestion
- BLI has the potential to reduce fuel burn
- Wake Ingestion is not worth pursuing
- Future Work:
  - Full scale aircraft at cruise Ma, and Re.
  - Other operating conditions
  - Improve actuator disk model

Acknowledgements

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