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Impact of the Propulsion Modeling Approach on High-Lift Force Prediction of Propeller-Blown Wings

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Outline

1. Introduction
2. Isolated Propeller Results
3. Propulsion Models
4. 2D Model Problem + Full 3D
5. Conclusions

Introduction

Primary motivation for this work:

Enable SSTOL

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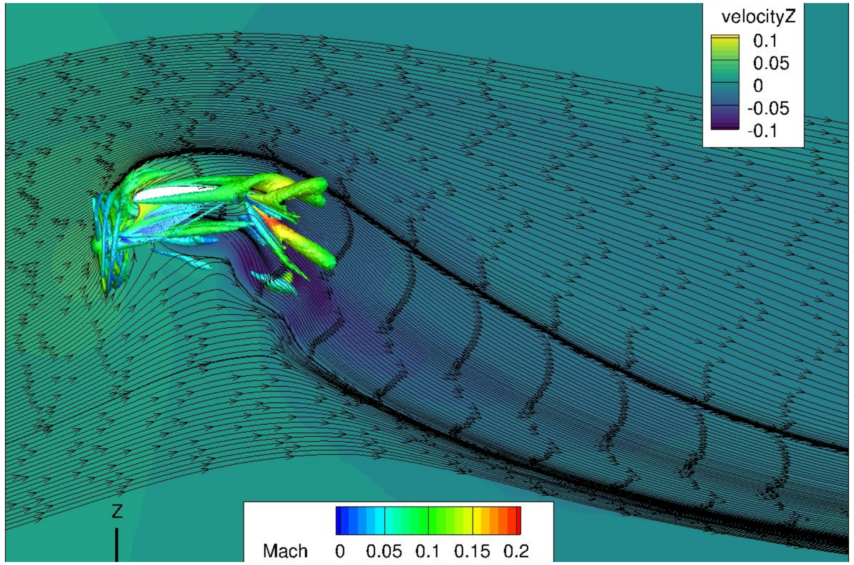
Enable SSTOL

Achieved through **Blown-wing concept**

- Distributed electric propulsion
- High lift devices

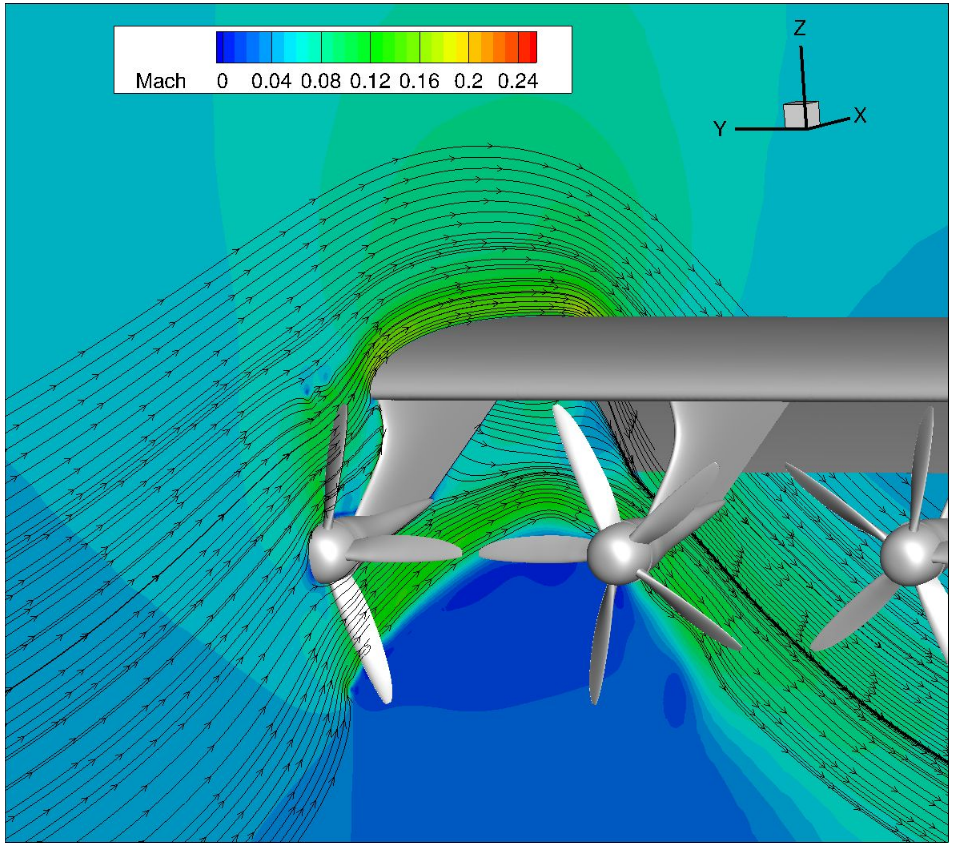


Increased wing lift!

Introduction

- Primary difficulty:

Many design considerations



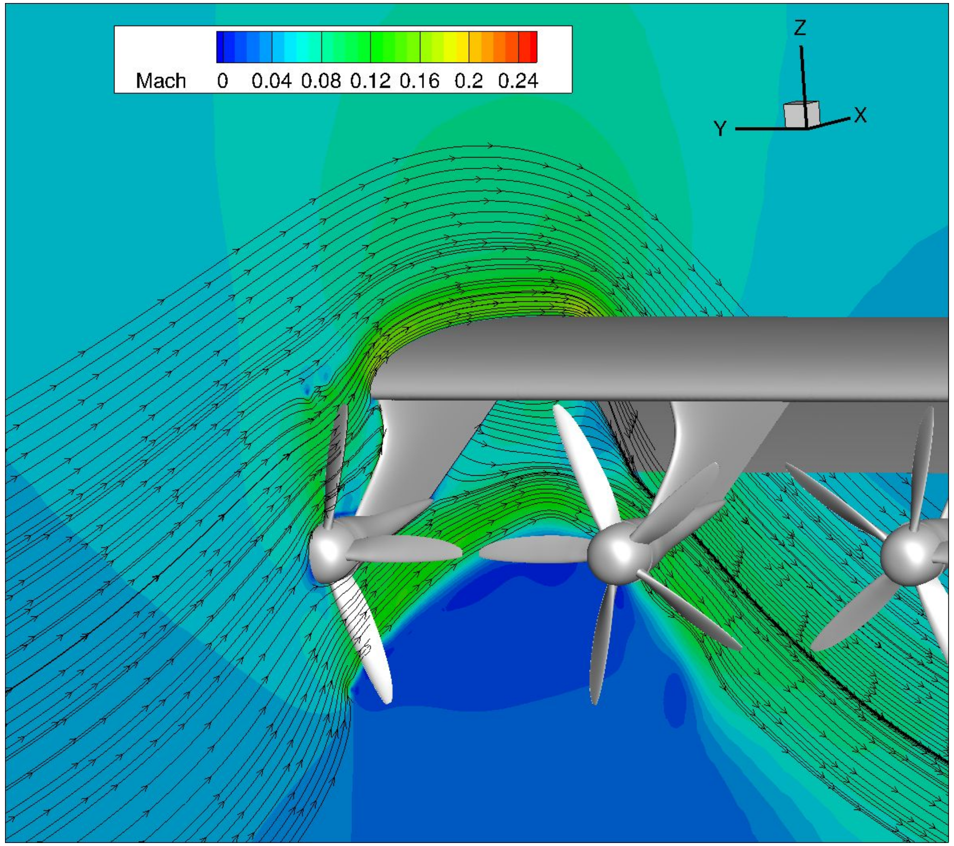
Introduction

- Primary difficulty:

Many design considerations

- Objective of current work

Investigate approaches to reduce computational costs of fully-resolved 3D aircraft CFD simulations



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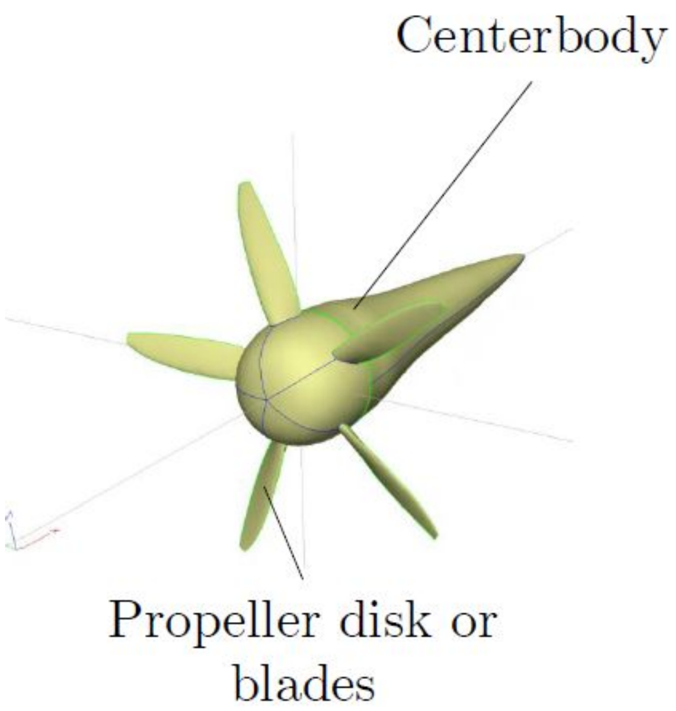
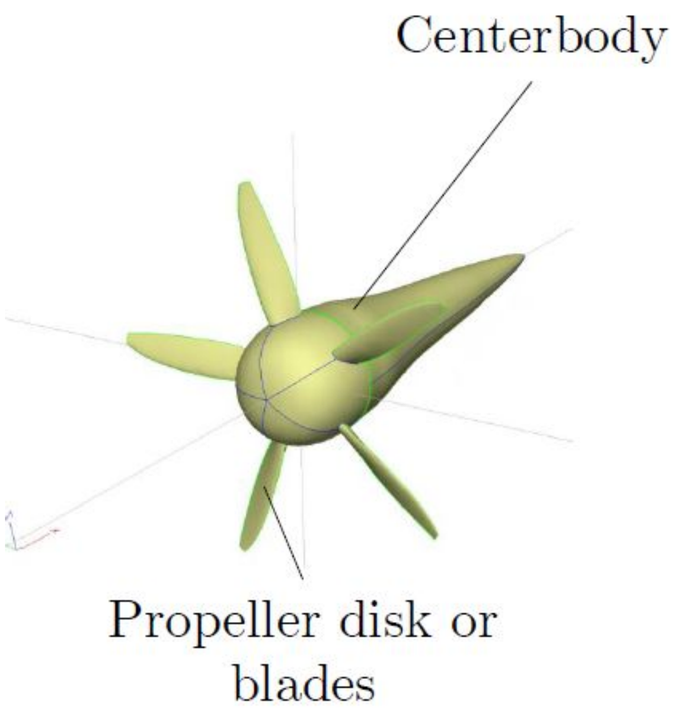
Isolated Propeller – Case Setup



Aim: to assess different propulsion models for a simple configuration

Isolated Propeller – Case Setup



- Mesh refinement + disk thickness study shown in paper
- Final mesh 6.9M points with 13.5%R disk thickness for AD + BET
- 18M points for Unsteady

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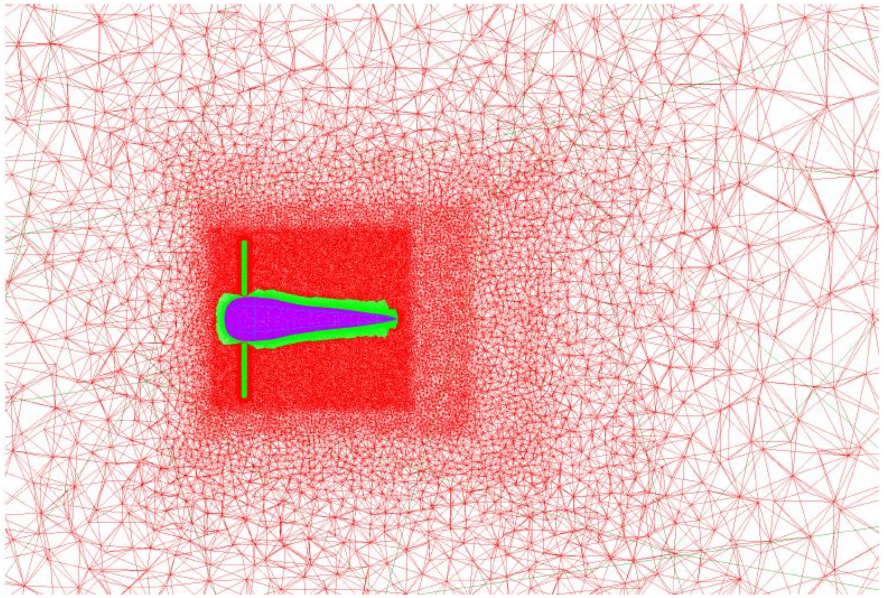
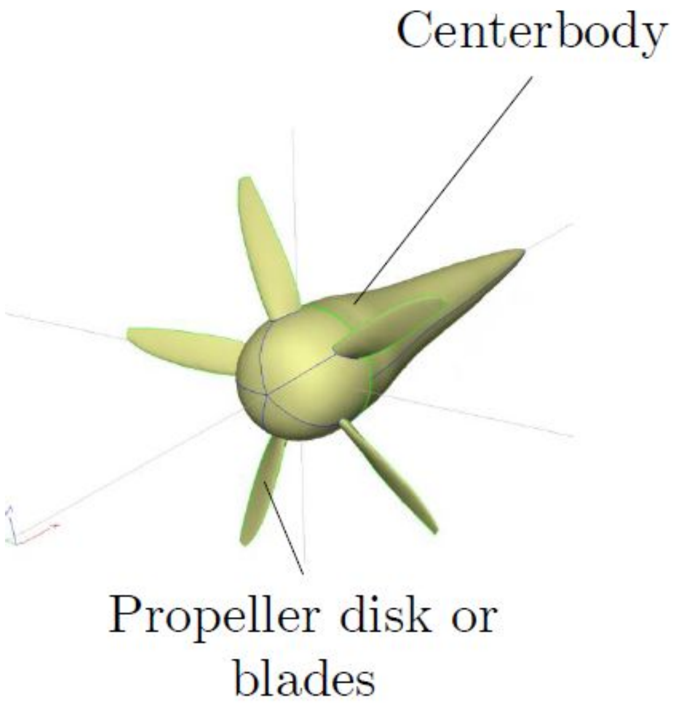


Isolated Propeller – Case Setup



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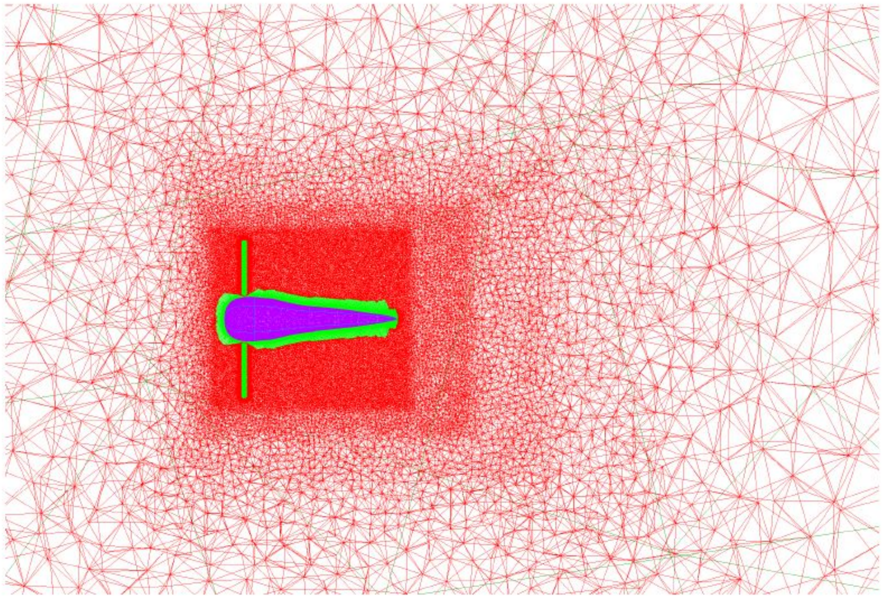
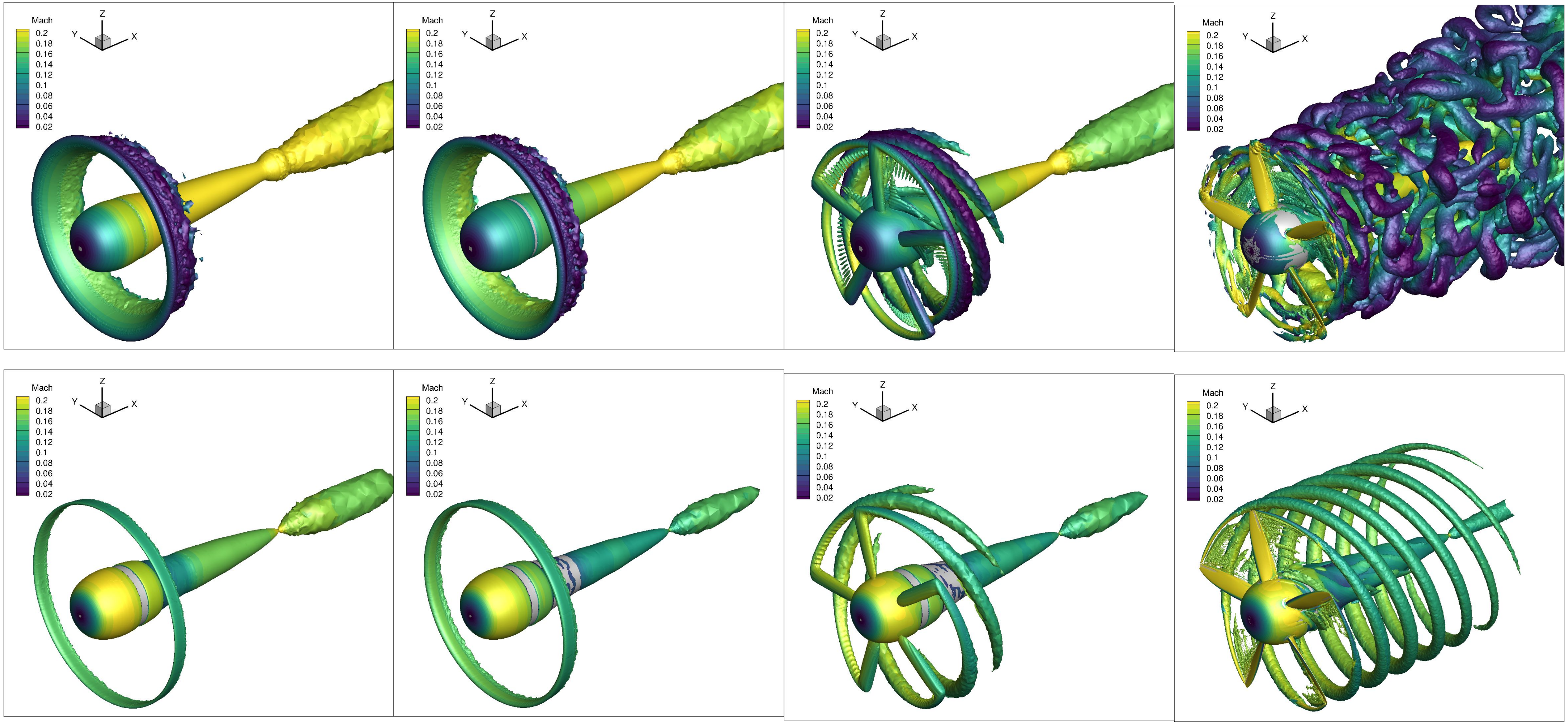


α (deg)	[0, 10]
RPM	4000
V_∞ (m/s)	[6.12, 9.53, 14.97, 20.08, 28.58, 47.64]
λ	[0.032, 0.050, 0.079, 0.105, 0.150, 0.184, 0.250]

Isolated Propeller – Propulsion Models

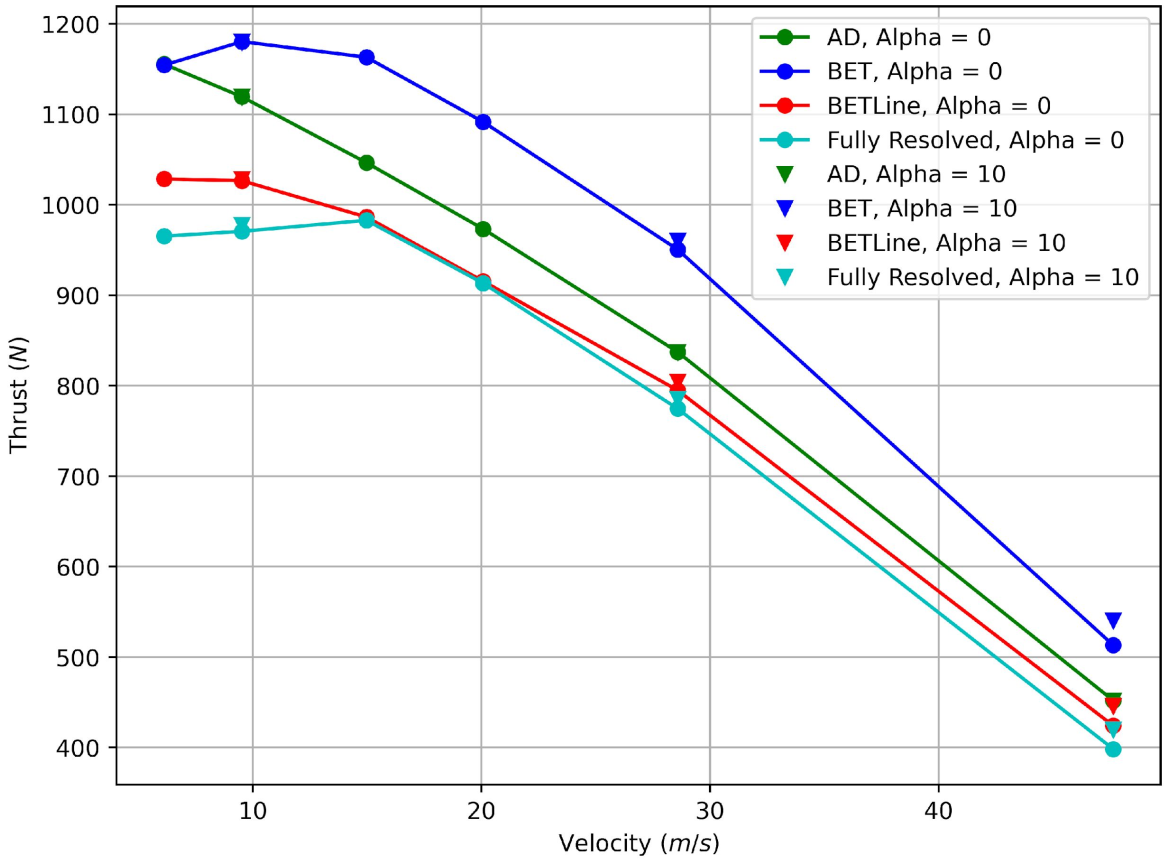
V=9.5282 m/s

V=47.6412 m/s

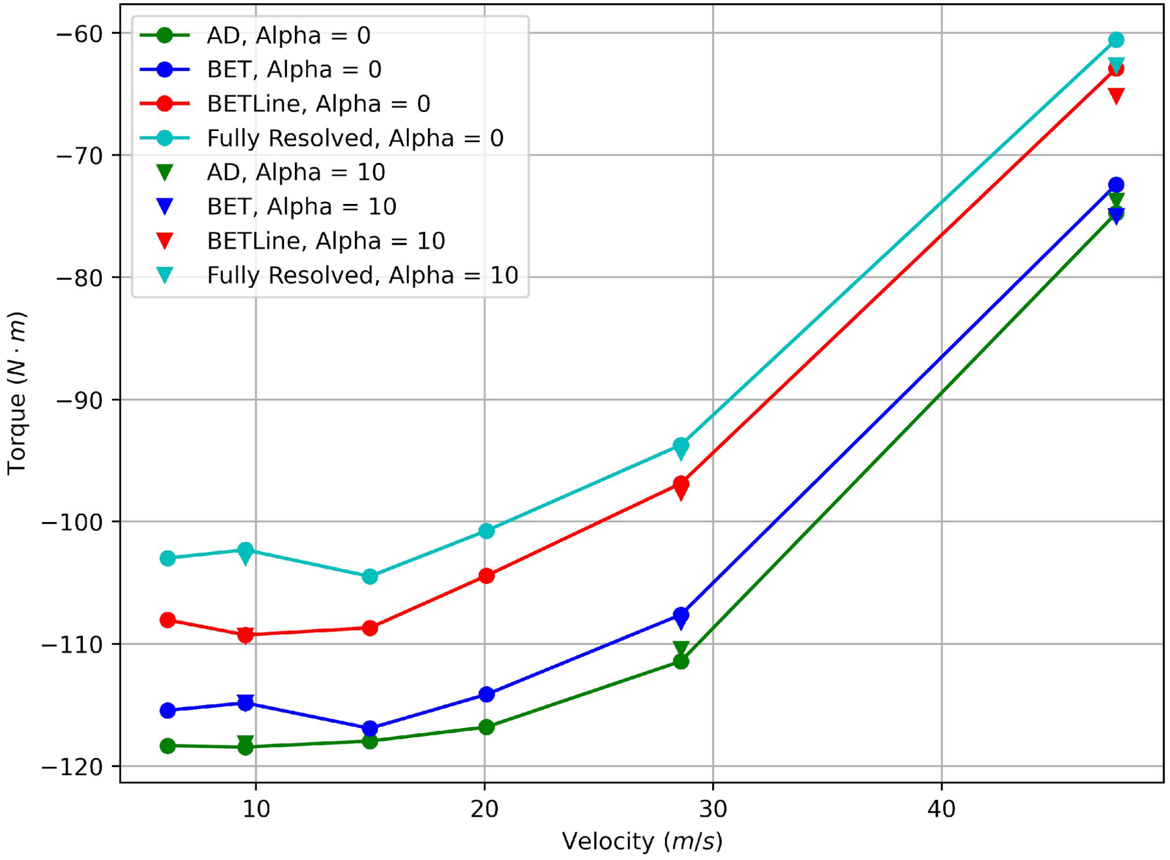


AD **BET Disk** **BET Line** **Fully-Resolved**

Isolated Propeller - Results



Thrust vs Velocity



Torque vs Velocity

Isolated Propeller - Results

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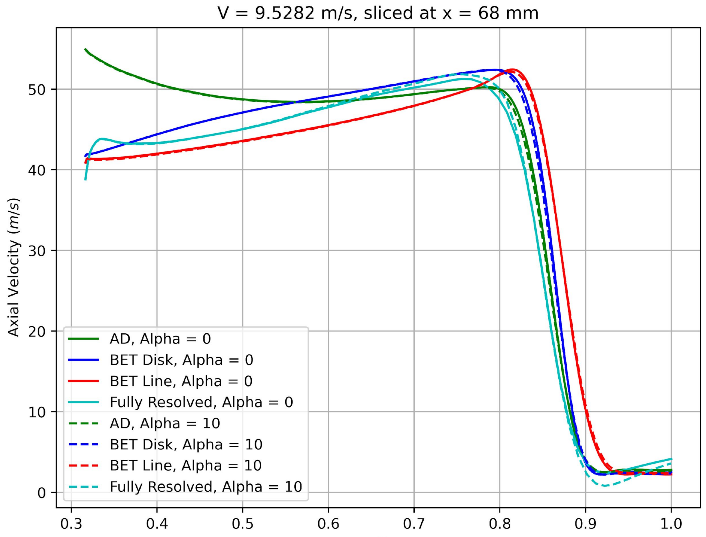

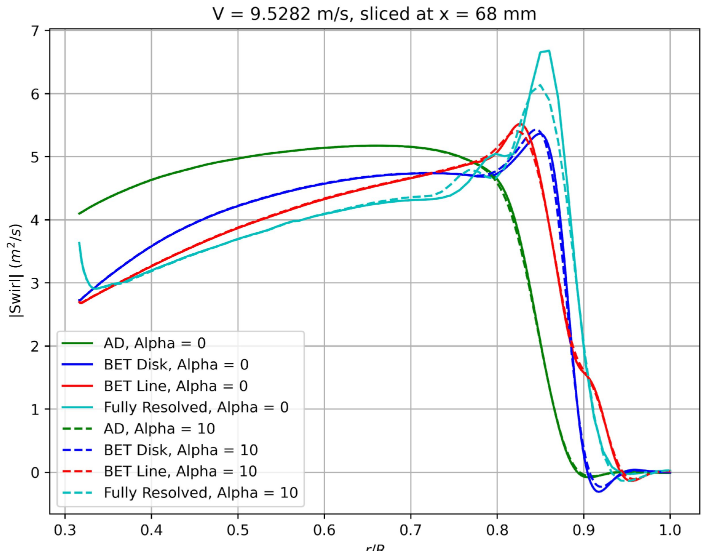

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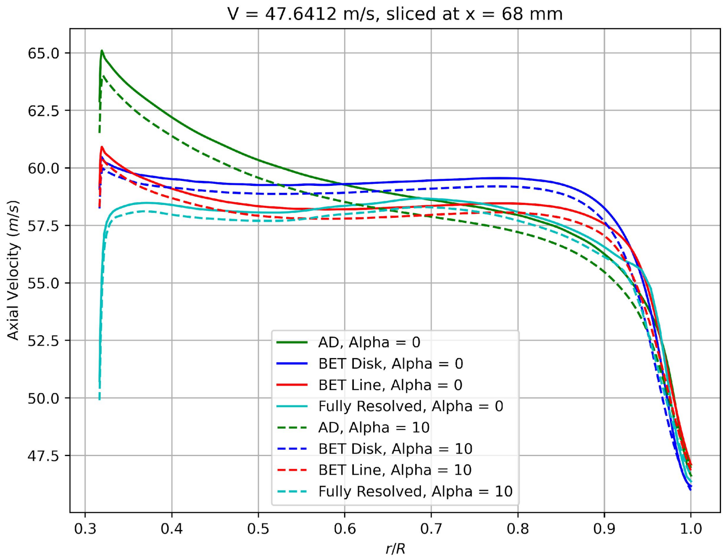

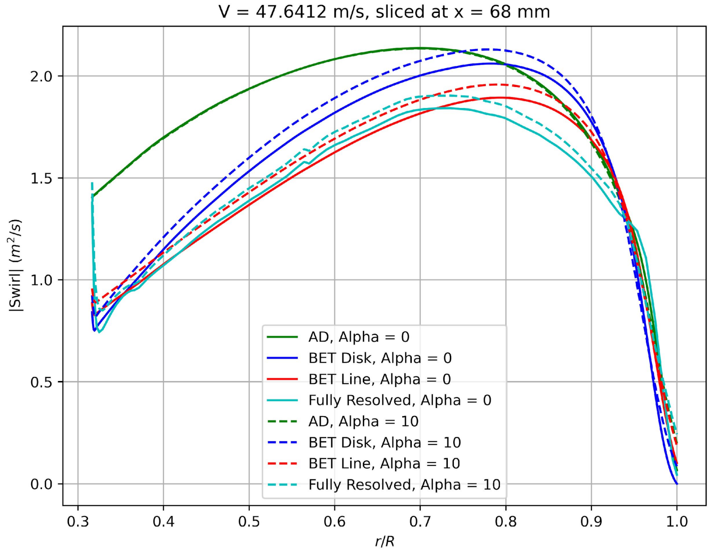

Axial Velocity **Swirl**

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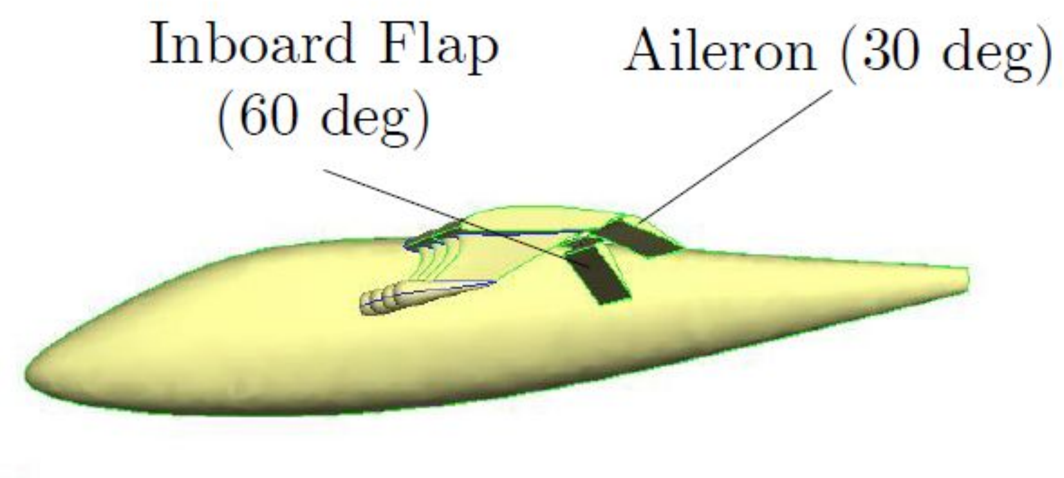
Propulsion Models

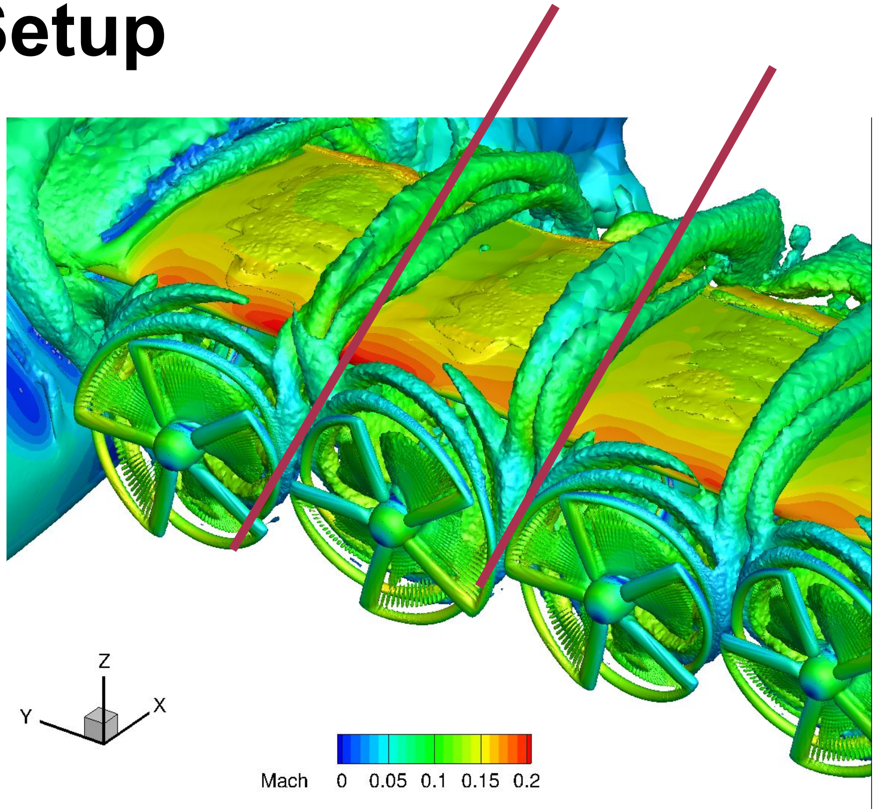
Actuator Disk	Blade-Element Disk	Blade-Element Line	Fully-Resolved
• Steady in time • No need to mesh the blades • Rotor forces largely defined by user • Cheap computationally	• Steady in time • No need to mesh the blades • Rotor forces calculated from inputs and velocity field • Cheap computationally	• Unsteady in time • No need to mesh the blades • Rotor forces calculated from inputs and velocity field • Moderate computational expense	• Unsteady in time • Need to mesh the blades • Rotor forces calculated by solving the NS equations around the wall sufaces • High computational expense

Blades modelled as a body force source term in the NS equations (Actuator Disk, Blade-Element Disk, Blade-Element Line)

Blades directly resolved (Fully-Resolved)

3D Geometry + 2D Model Problem – Case Setup





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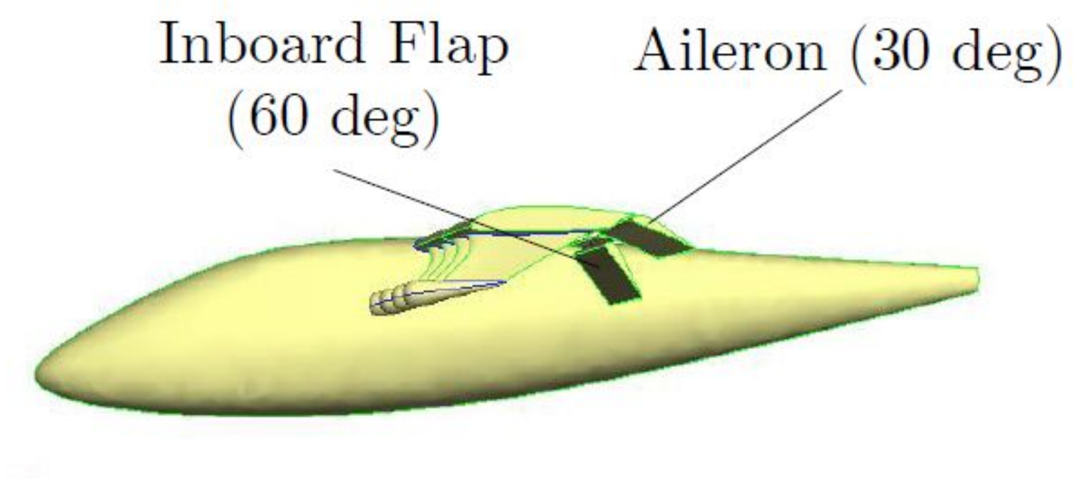
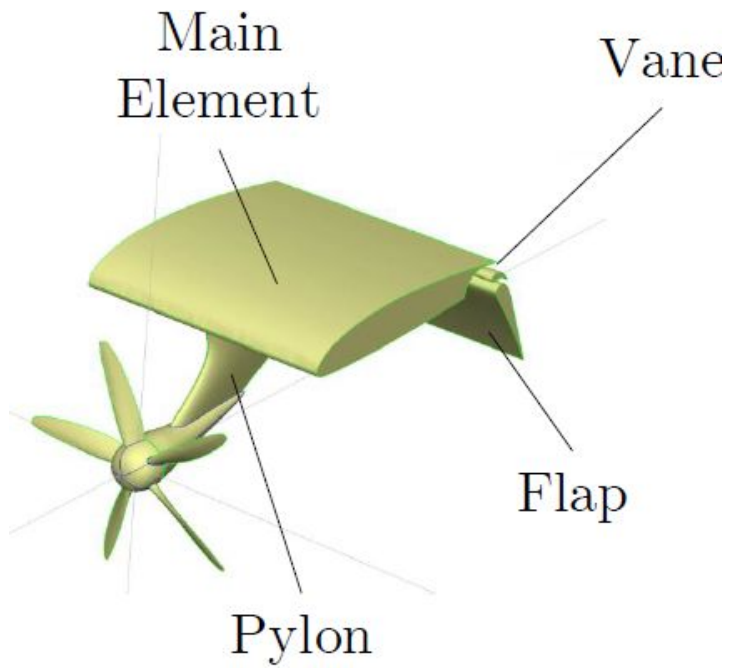


Mesh: 47.3M points



12.2M points (after mesh refinement study)

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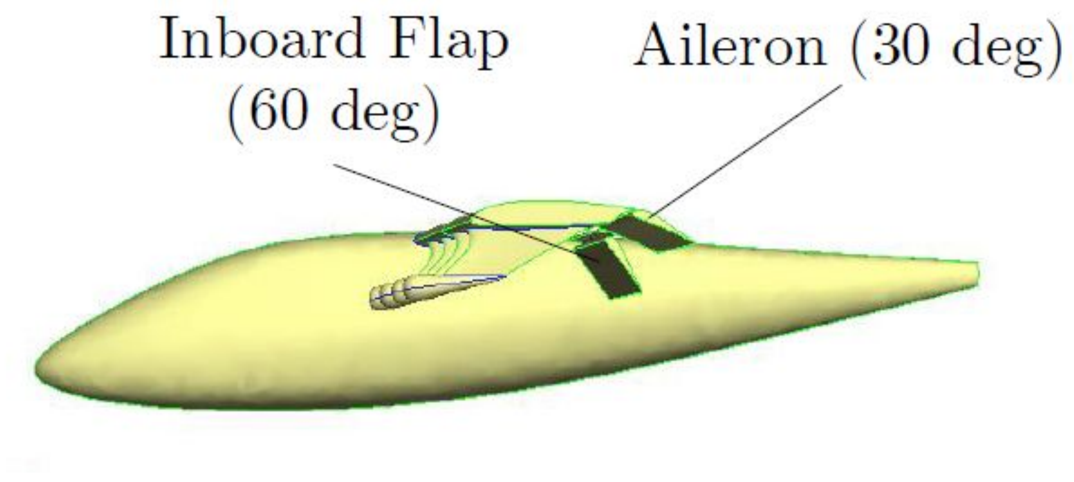

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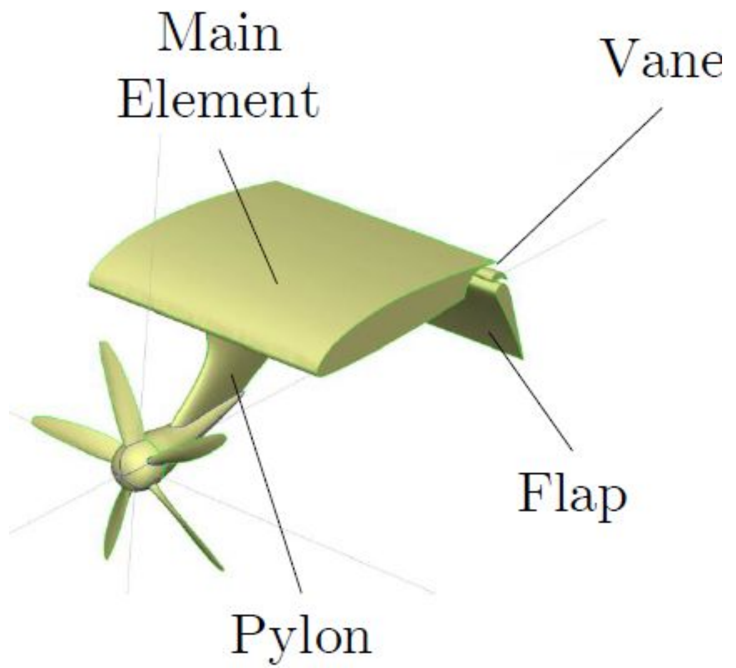
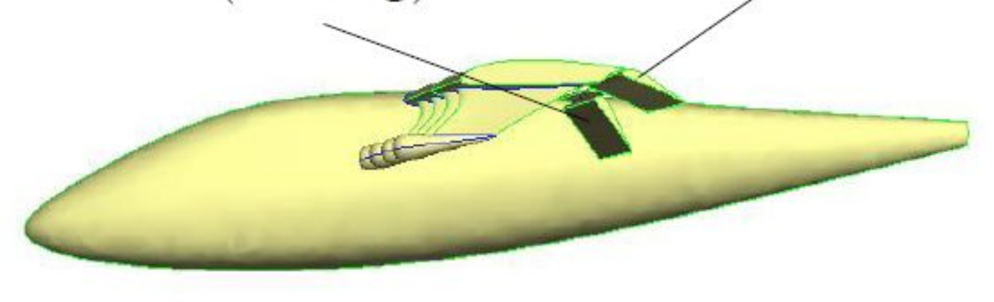


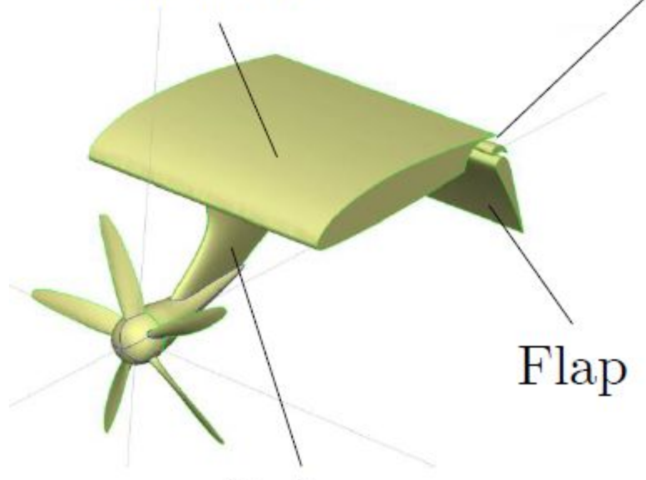
12.2M points (after mesh refinement study)

Aims:

- **Establish the validity of the 2D model problem**
- **Assess different propulsion models for 2D model problem and 3D geometry**

3D Geometry + 2D Model Problem – Case Setup





Mesh: 47.3M points

	AD, and, BET disk	BET line
α (deg)	[10, 15]	15
T_c	[2, 3]	2
V_∞ (m/s)	15.433	15.433

12.2M points (after mesh refinement study)

	BET disk	AD, BET disk, and BET line
α (deg)	[-10, -5, 0, 5, 10, 15]	[-10, -5, 0]
T_c	[2]	[1, 2, 3]
V_∞ (m/s)	15.433	15.433
λ	0.11	[0.149, 0.114, 0.096]

Based on results 3D geometry α=15° corresponds to α= -5° for 2D geometry

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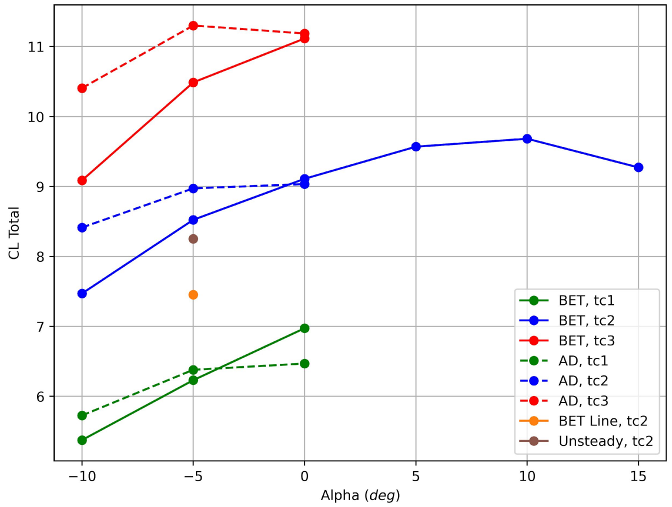
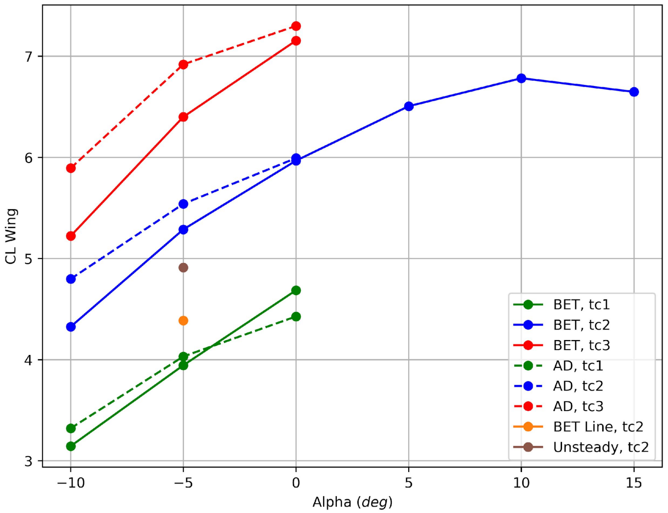
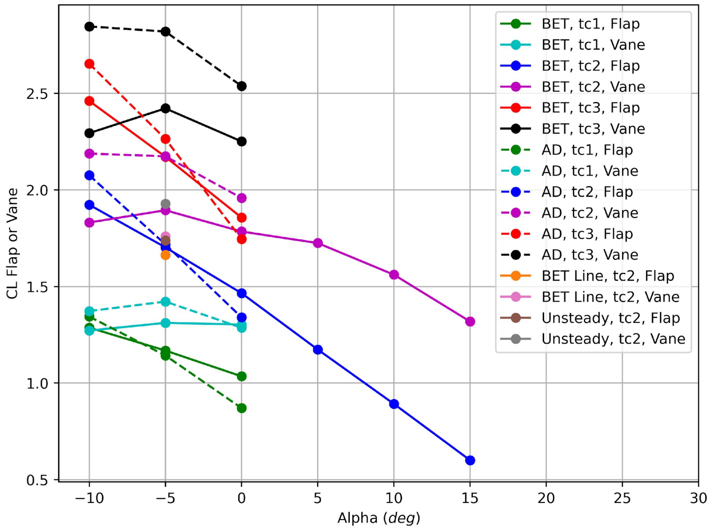
2D Model Problem Results

- Effect of test condition and propulsion model

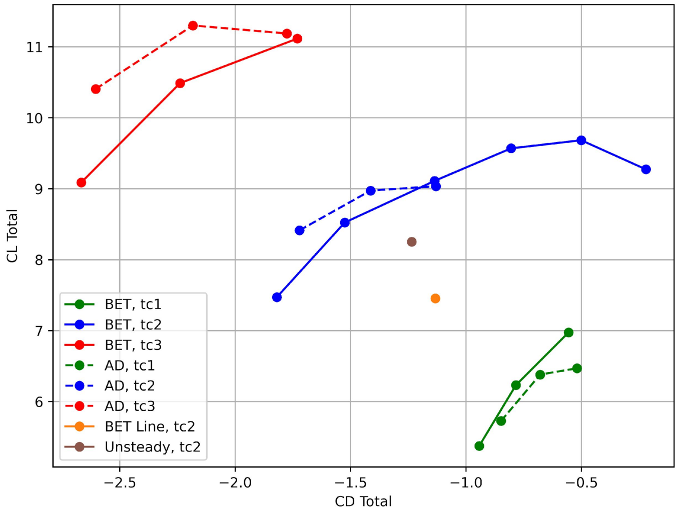
CL vs Alpha

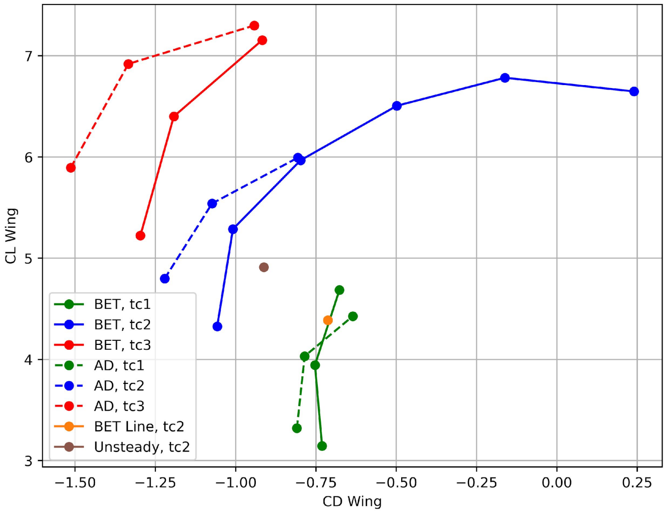


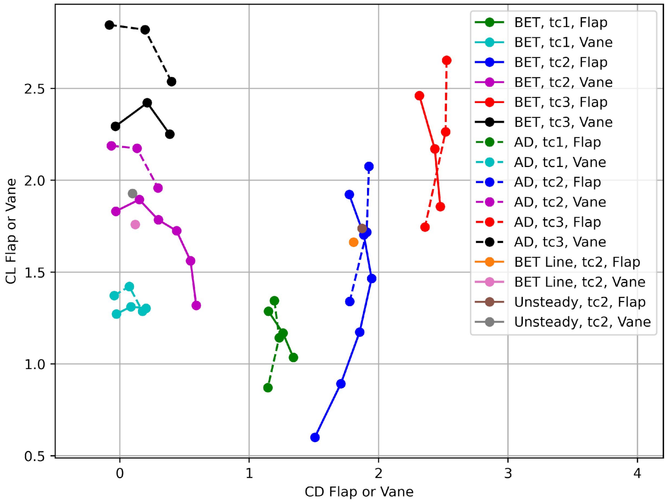




CL vs CD







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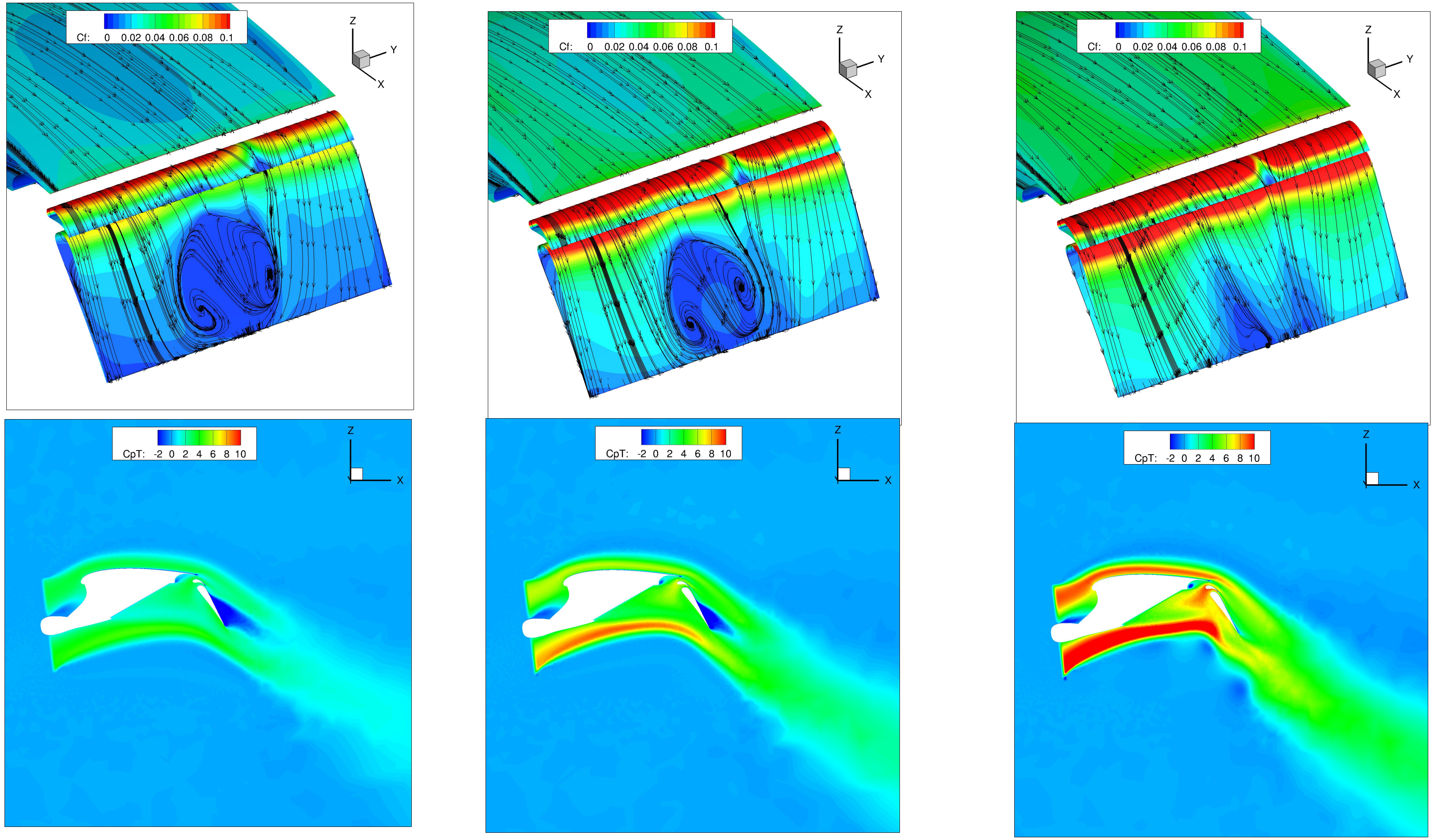
2D Model Problem Results

- Effect of test condition (BET Disk) at alpha = -5



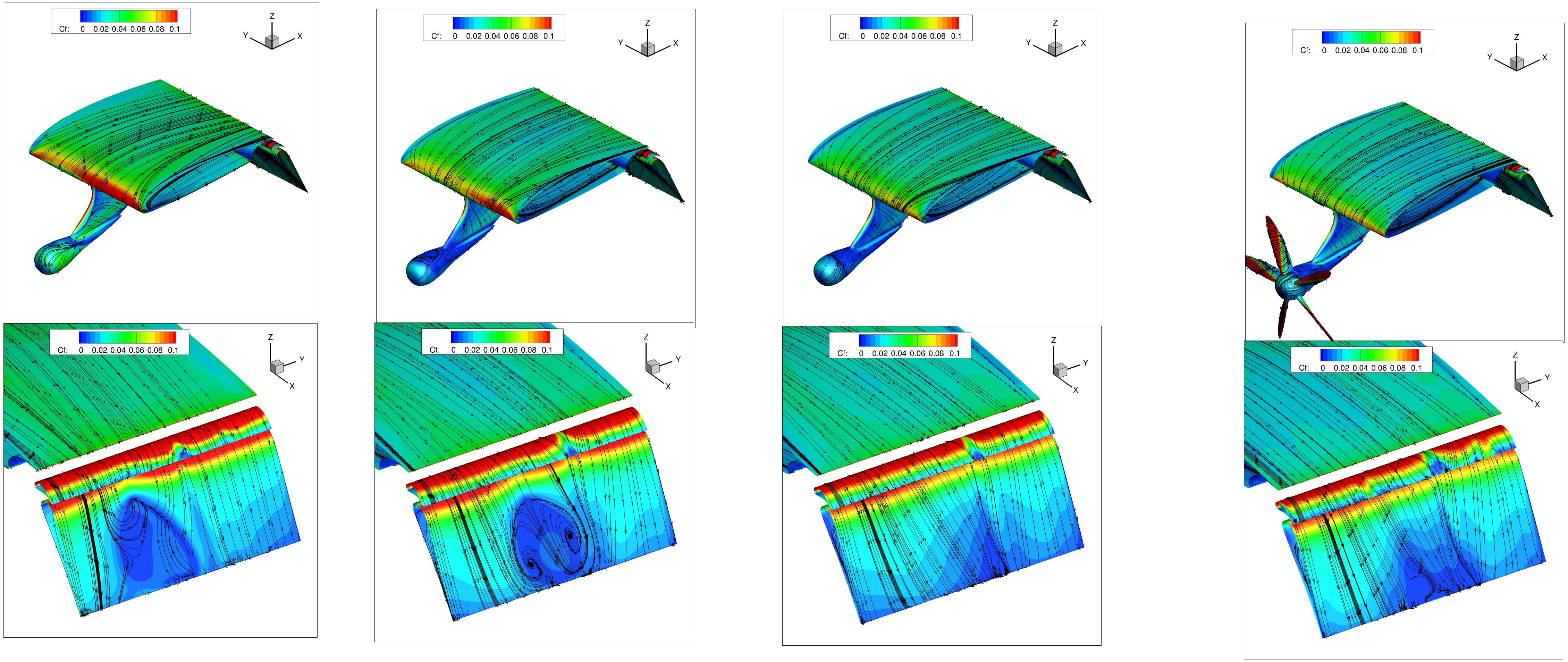
Flap Skin Friction

Contour of total pressure along centreline

Tc1 **Tc2** **Tc3**

2D Model Problem Results

- Effect of propulsion model at alpha = -5



AD Disk **BET Disk** **BET Line** **Fully-Resolved**

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2D Model Problem Results

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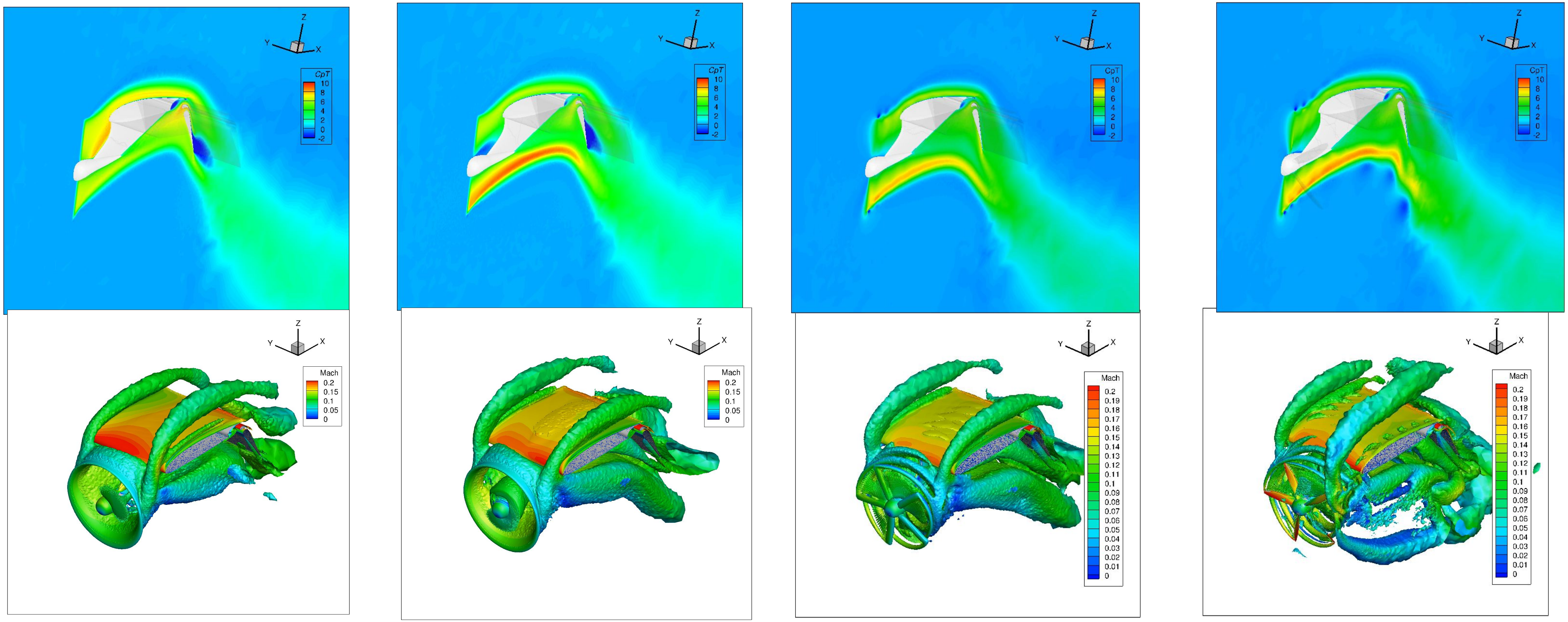
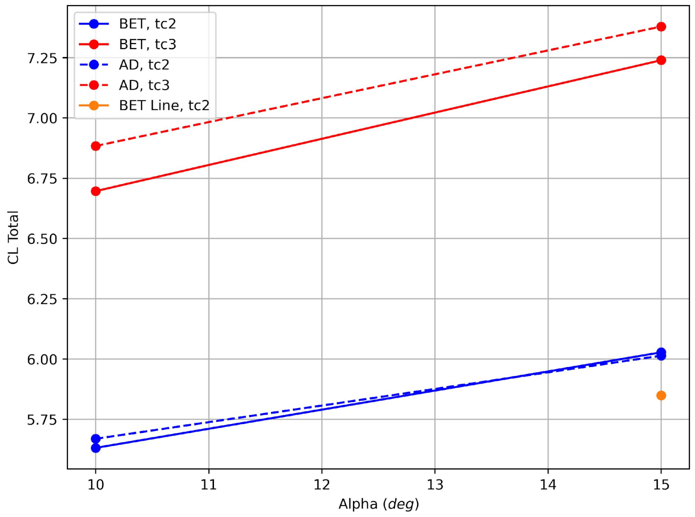
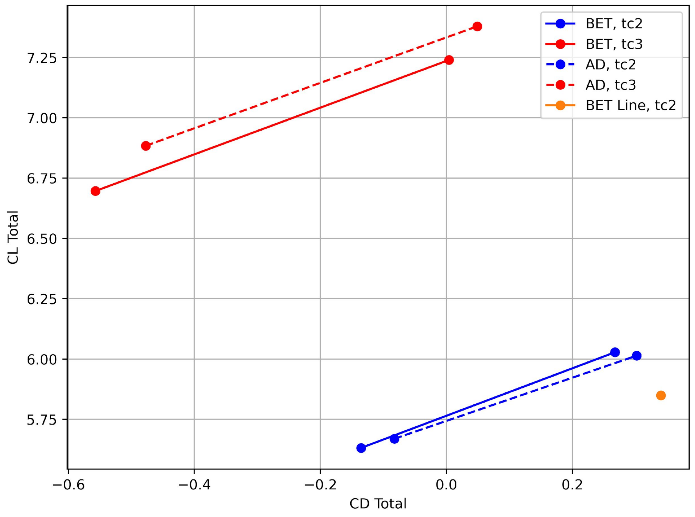


AD Disk **BET Disk** **BET Line** **Fully-Resolved**

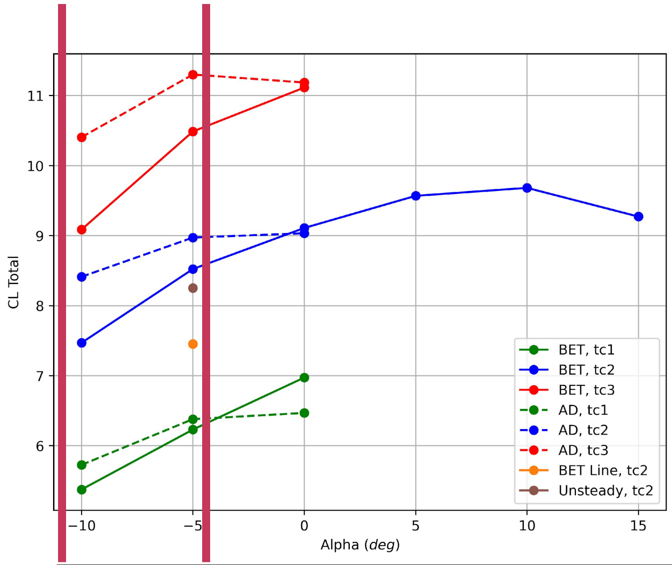
3D geometry vs 2D model problem

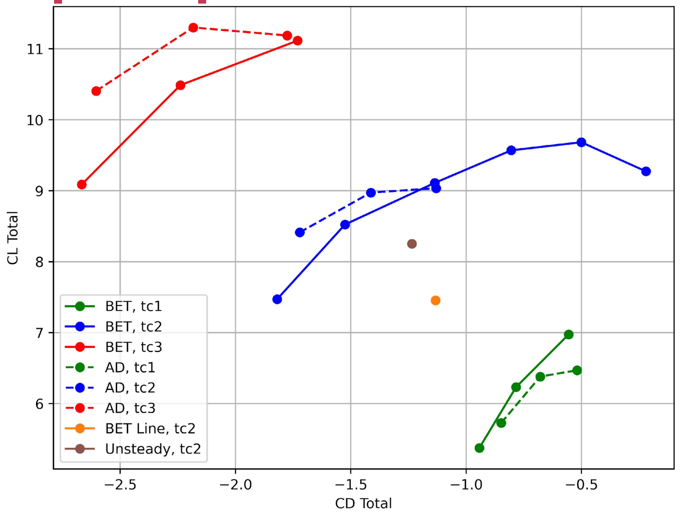
3D geometry





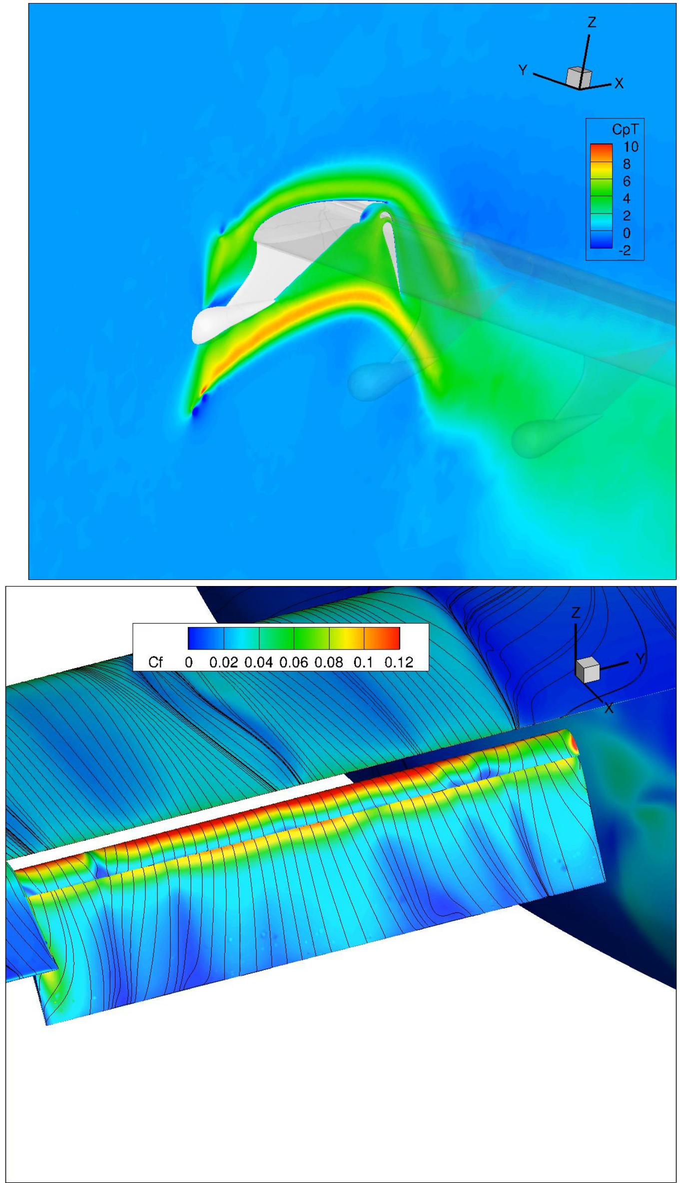
2D model problem

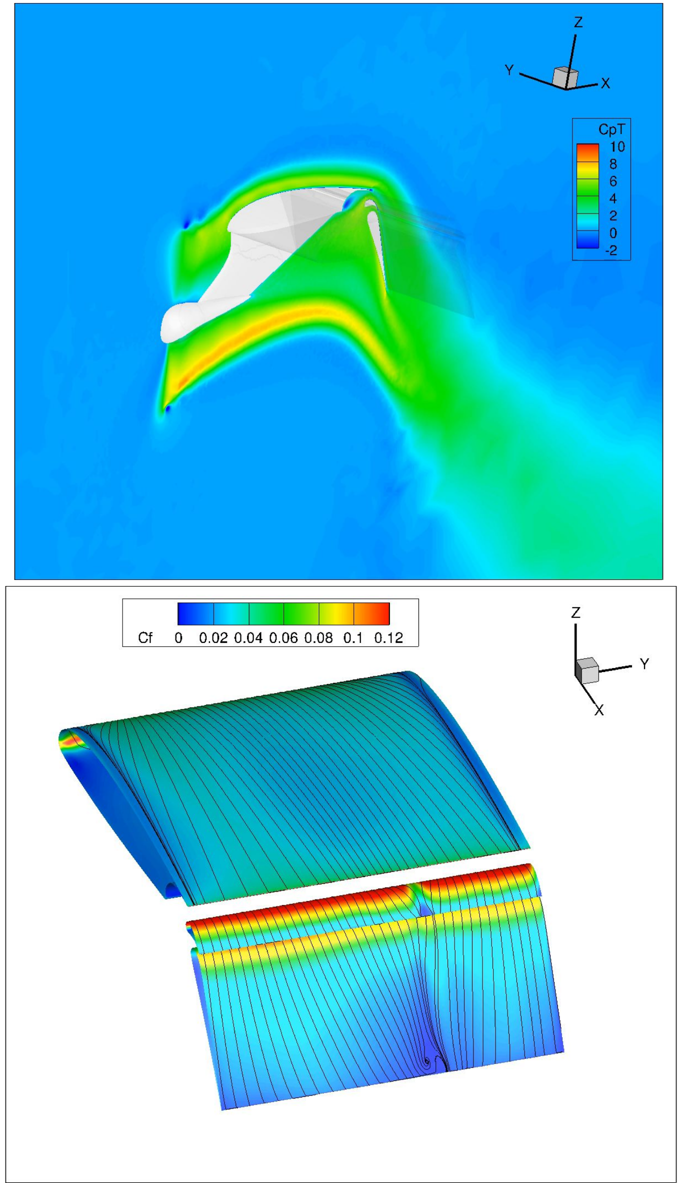




3D geometry vs 2D model problem

3D geometry





2D model problem

Computational Cost

	AD/BET Disk	BET Line	Blade-resolved
Isolated Propeller	1	6-12	40-60
2D model problem	3-4	80(*)	280
3D geometry	25	320(*)	-

80x speed up is achieved by combining 2D model problem + BET disk compared to a 3D blade-line simulation

Conclusions

- The isolated propeller simulations showed the BET Disk and BET Line models were able to capture the correct trends.
- The 2D model problem accurately captured the effects of the 3D geometry with similar trends of alpha and thrust conditions predicted by the BET disk model.
- The BET disk model showed good correlation with resolved-blade results at a fraction of the computational costs permitting design exploration studies.
- Further unsteady simulations could be performed to assess the accuracy of BET disk results across different alpha's and thrust conditions.

Questions?