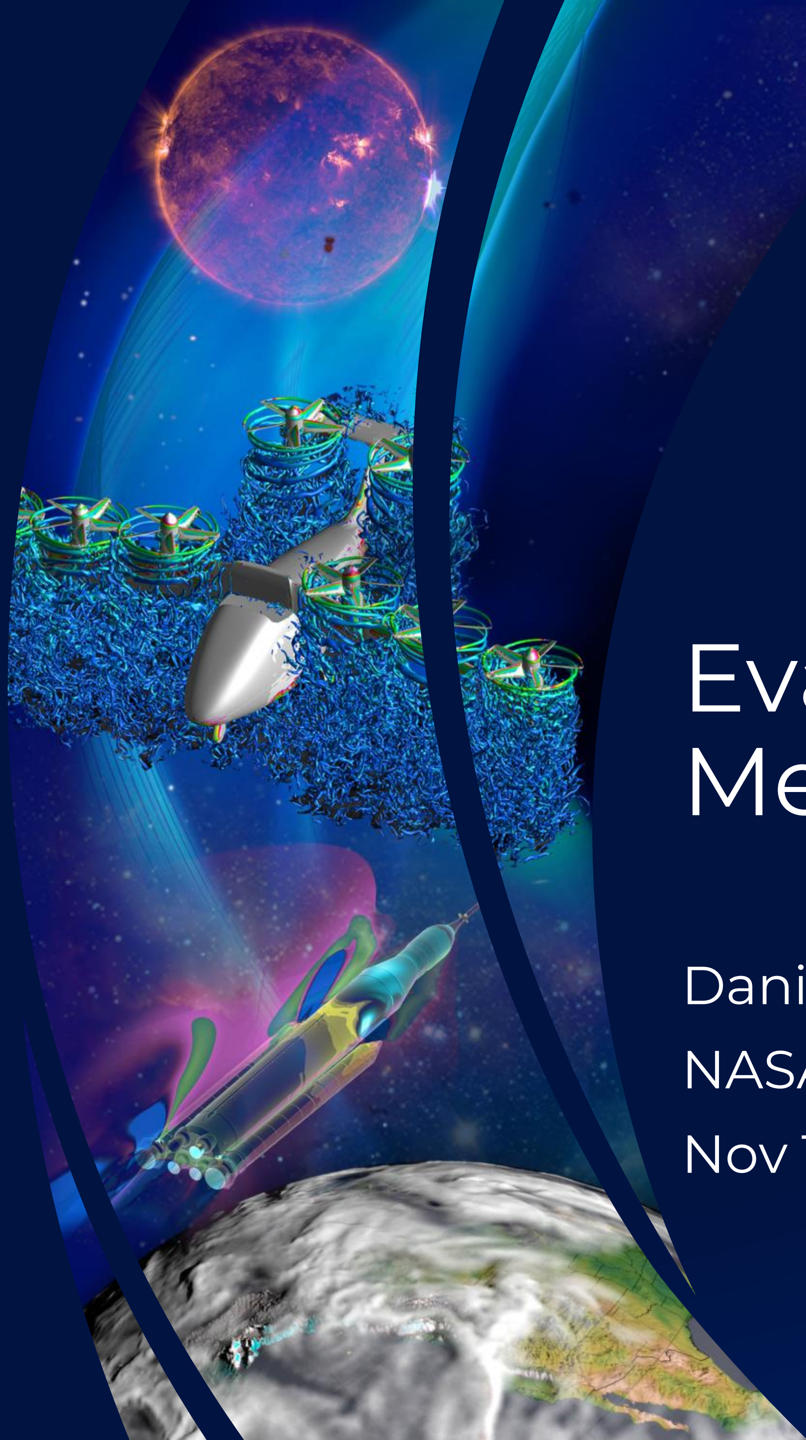


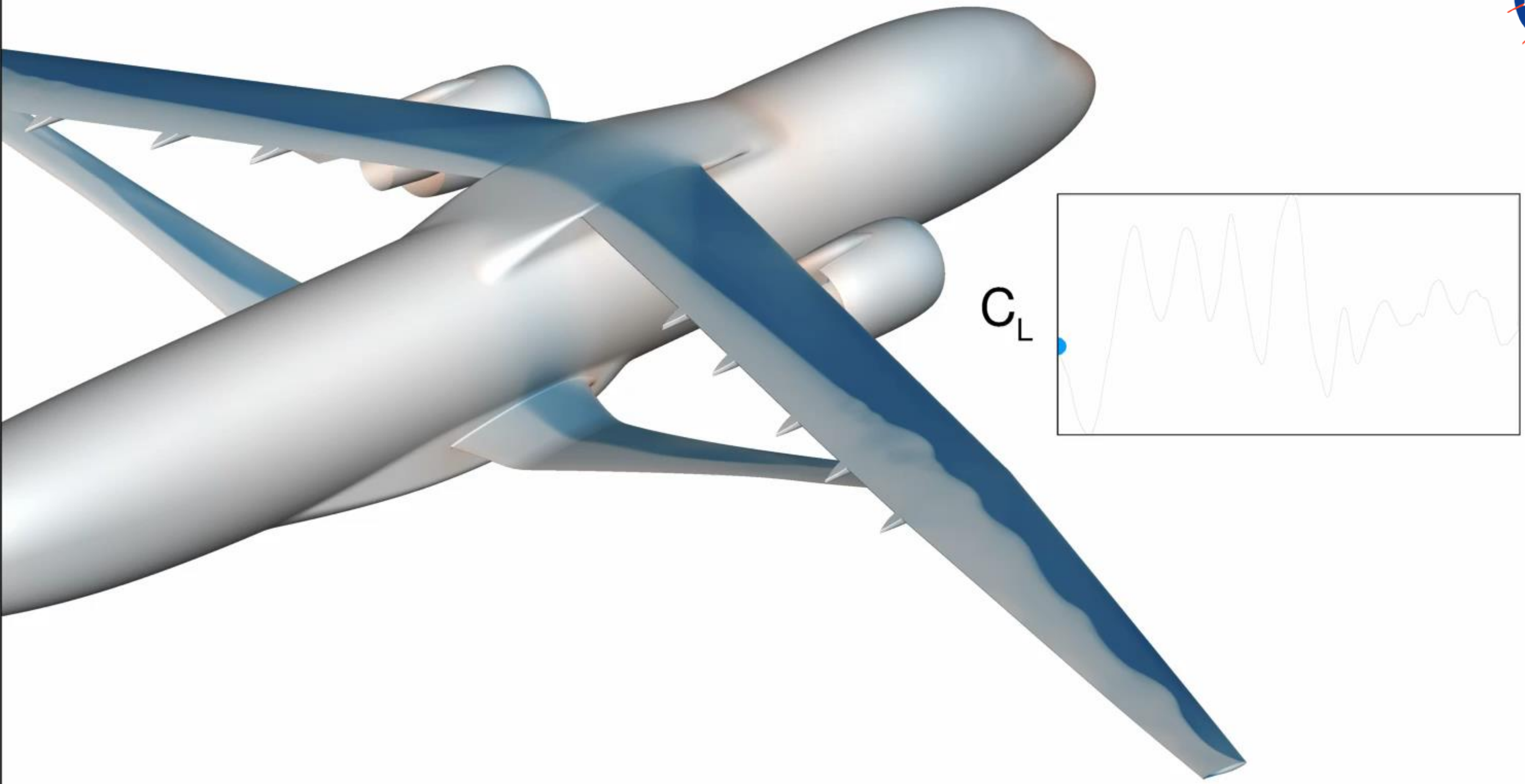
National Aeronautics and
Space Administration

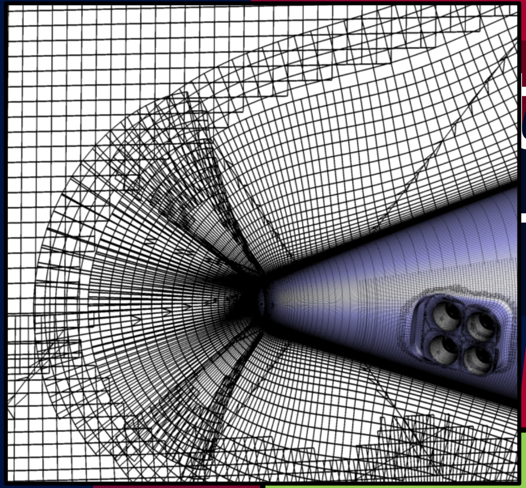
Evaluating New Computational Methods for Aerospace Simulations

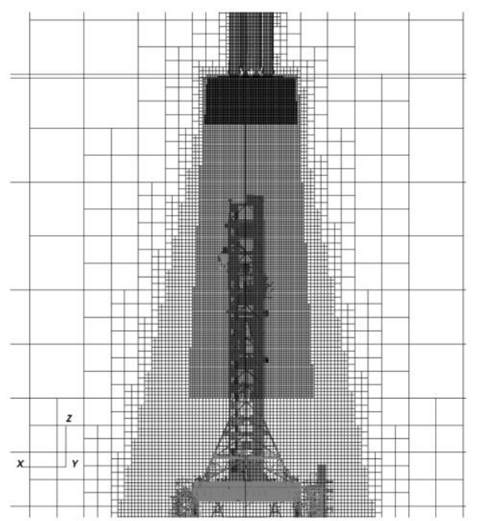
Daniel Maldonado

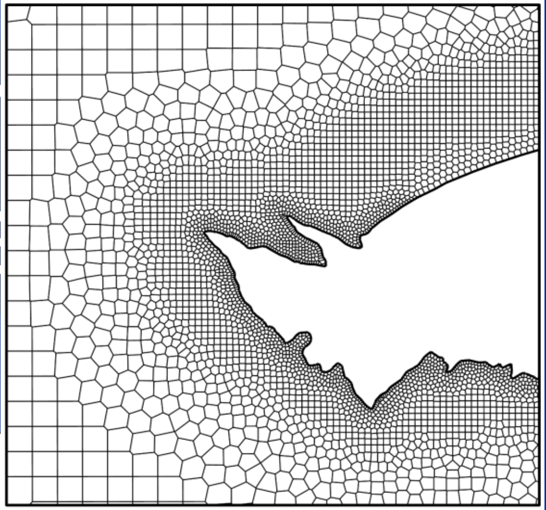
NASA Ames Research Center, TNA

Nov 18-21, 2024


C_L







tructured … near Sol…
…tured Ov… …esh Para…

Structured Curvilinear

- RANS, SA
- Rigid Body Motion

Structured Cartesian

Unstructured Polyhedral

Pre-Processing Tools

Post-Processing Tools

LAVA

C++ / Fortran / Python

MPI+OpenMP / MPI+CUDA

GitLab

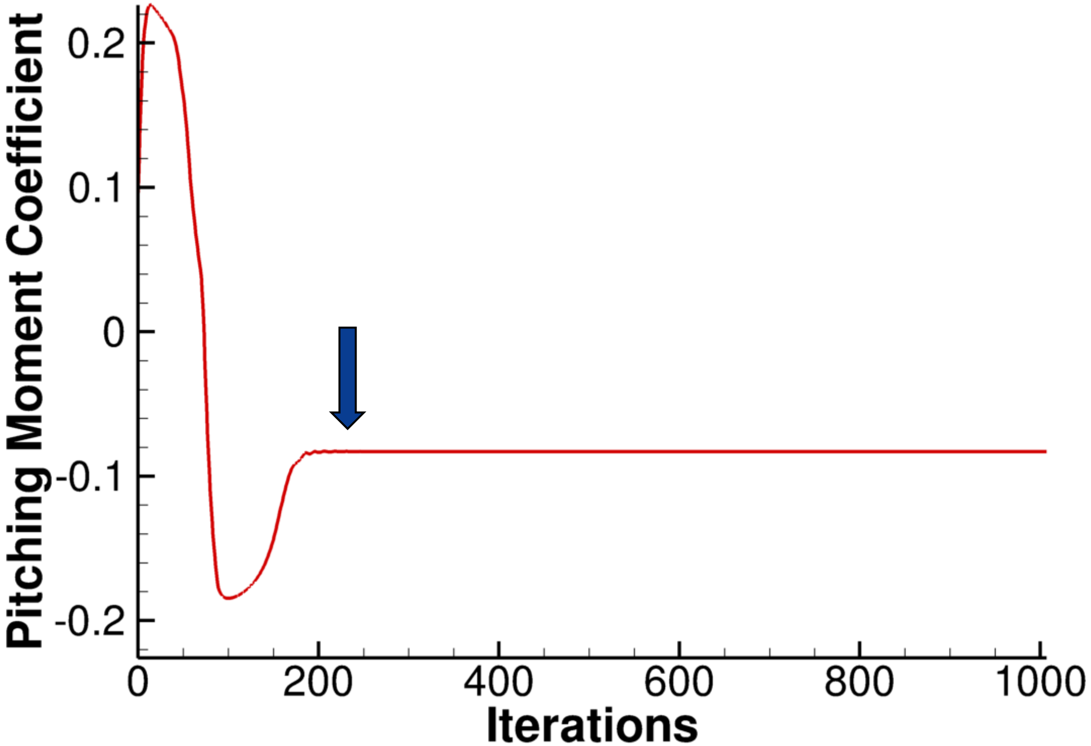
Space-Marching Propagation

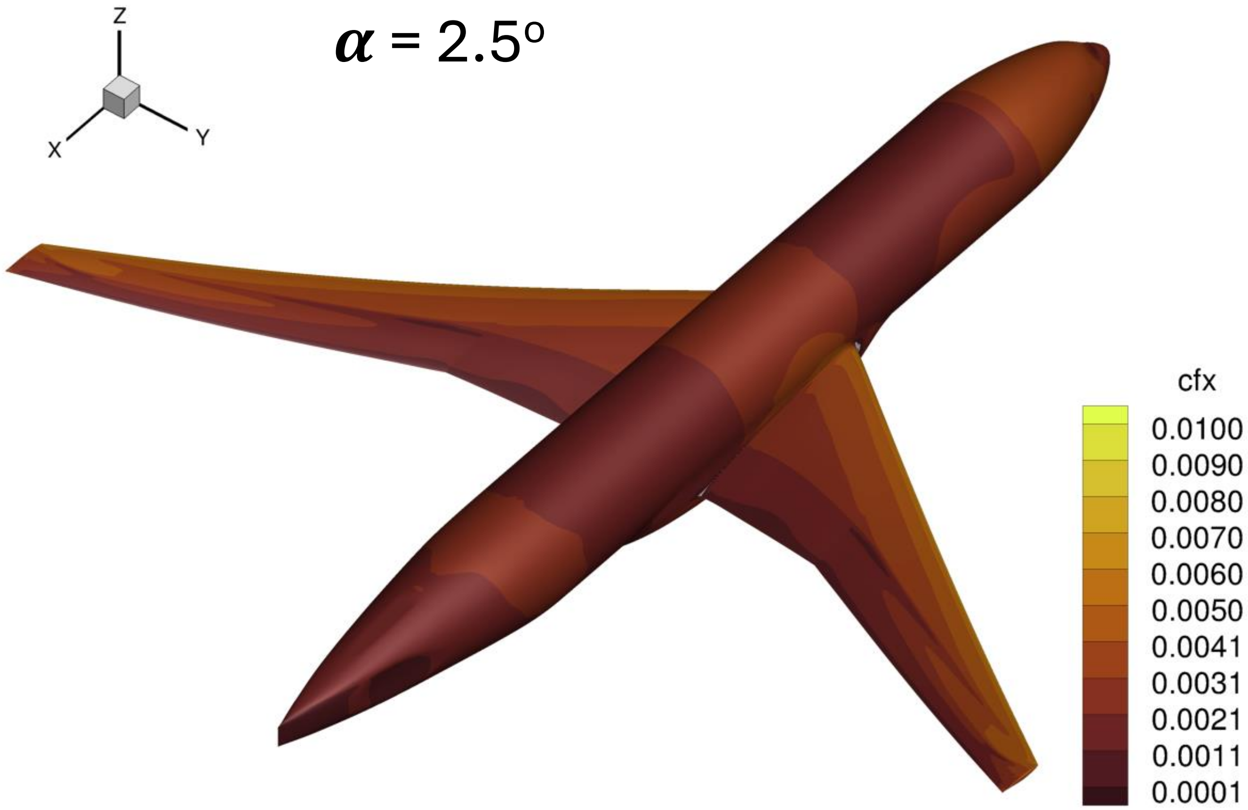
Far Field Acoustic Solver

Physics-Based Buffet Onset Prediction Method

Procedure for our application of this method

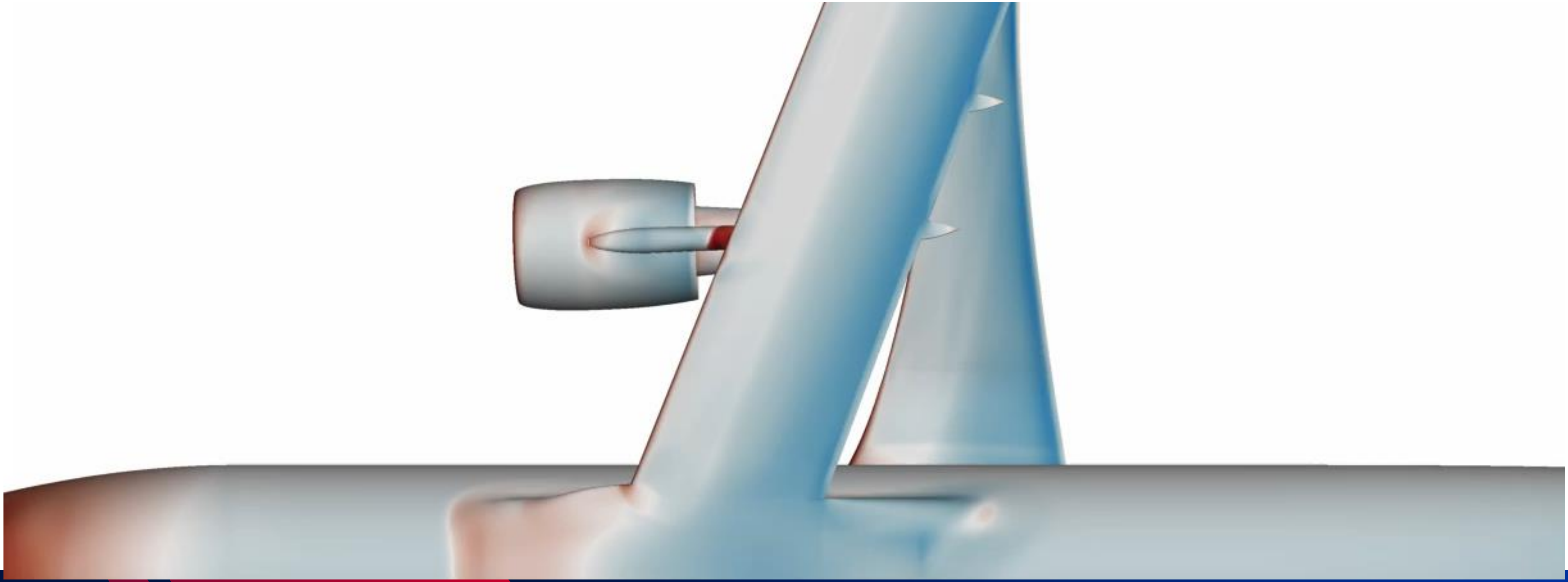
Steady-state RANS





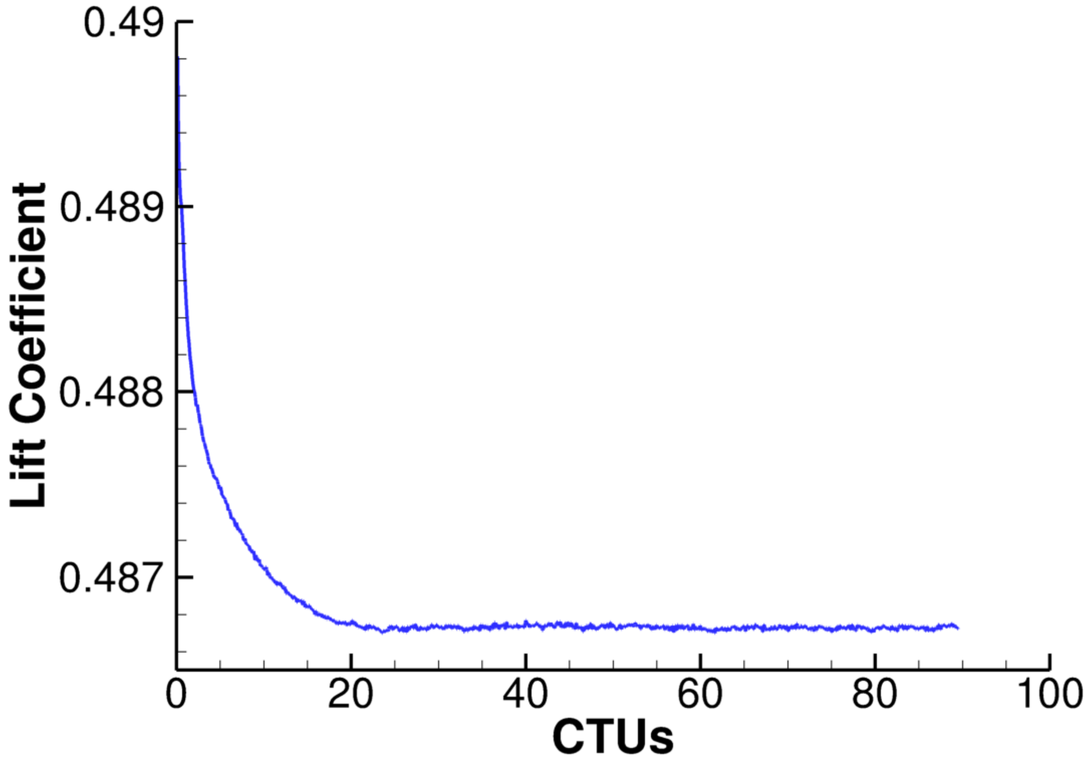
Procedure for our application of this method

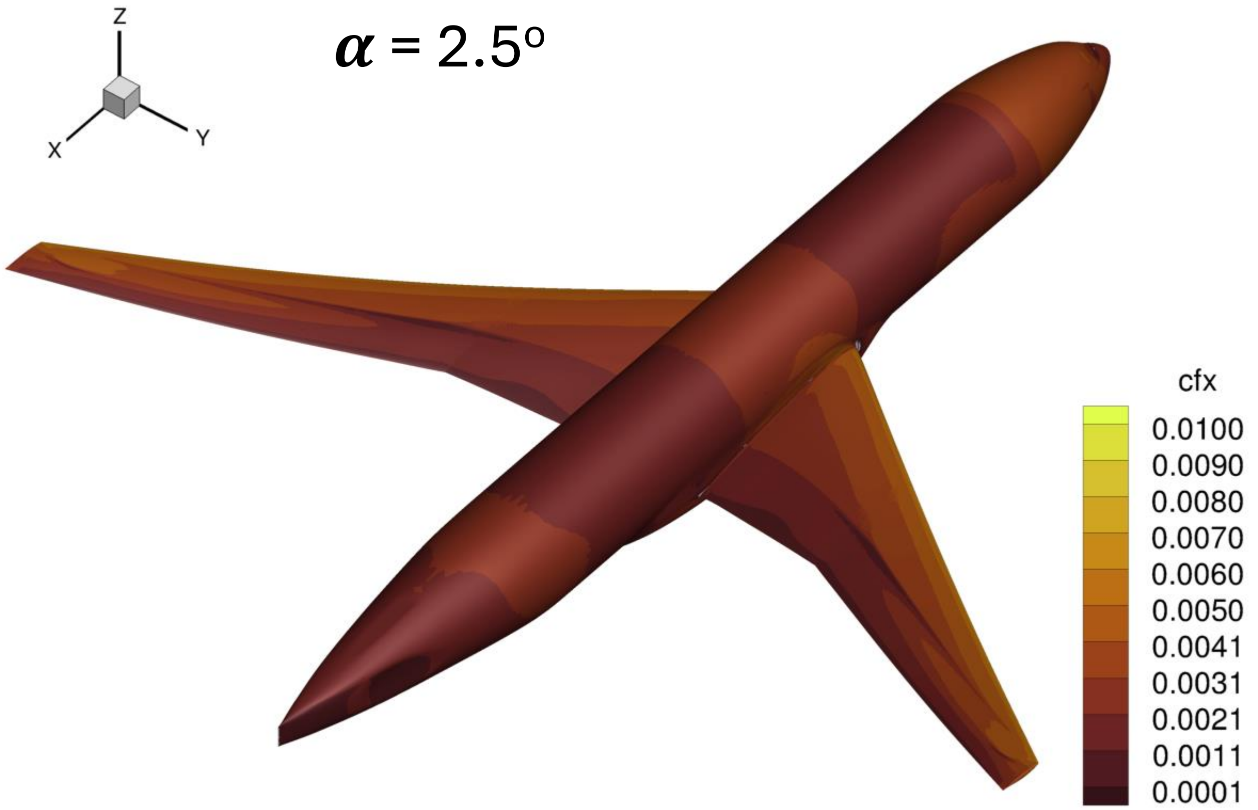
Steady-state RANS → Start-Up URANS



Procedure for our application of this method

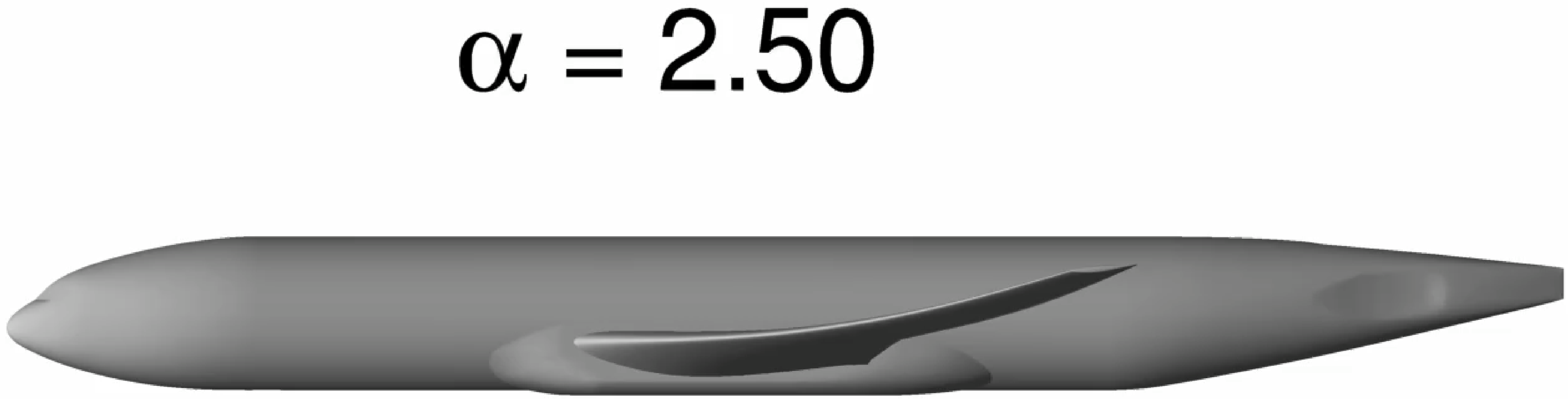
Steady-state RANS → Start-Up URANS





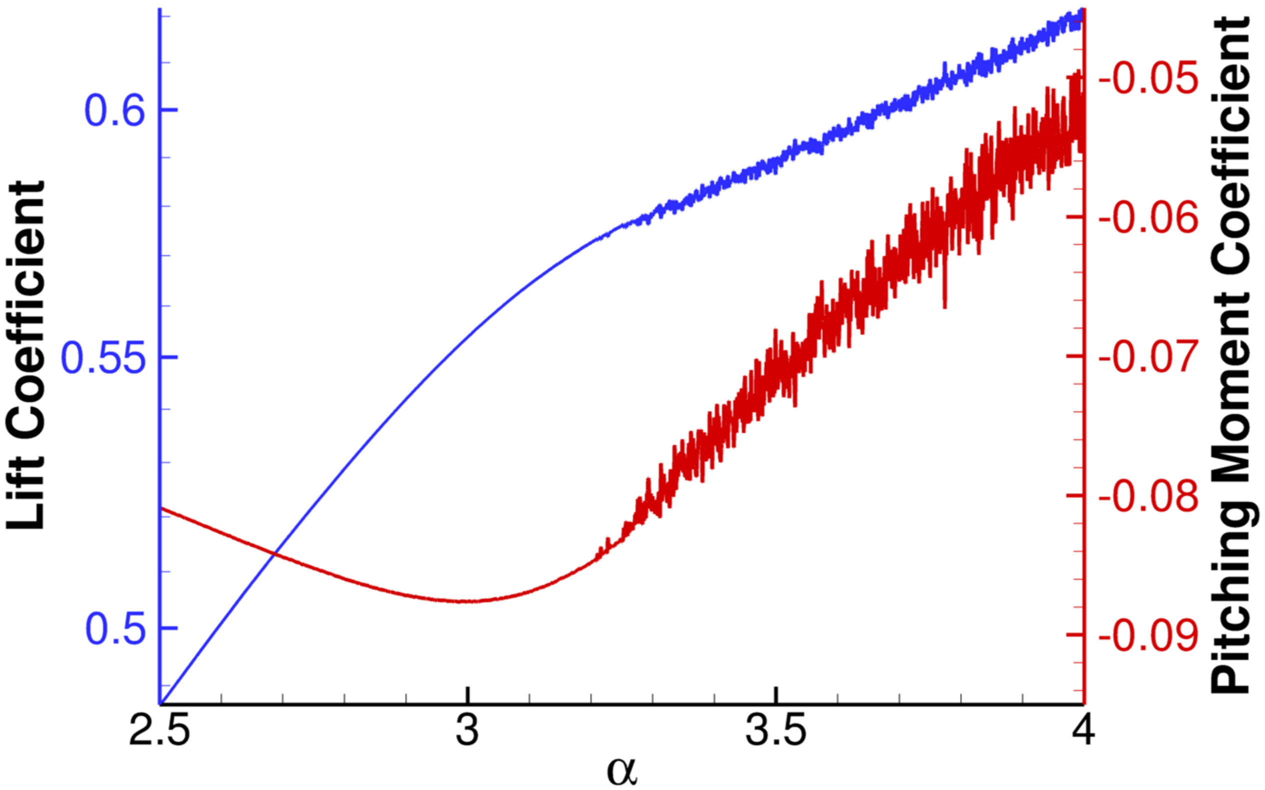
Procedure for our application of this method

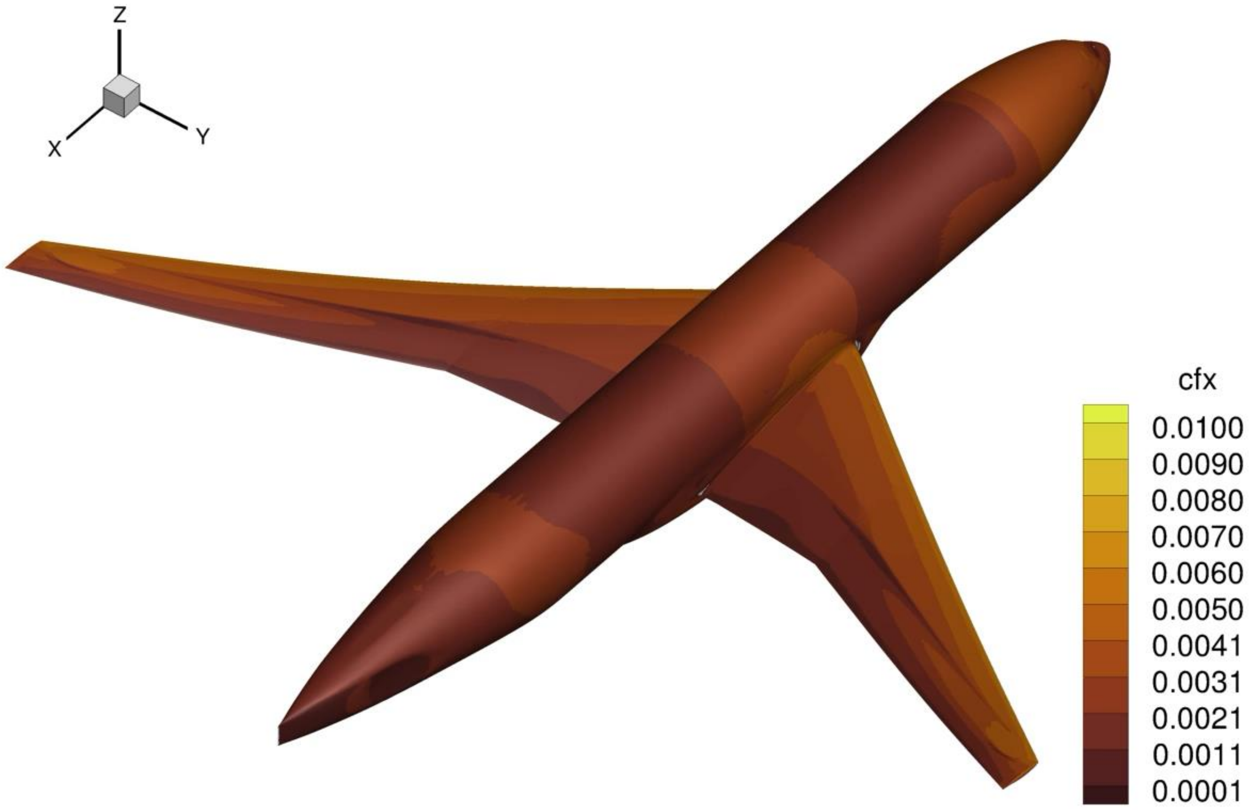
Steady-state RANS → Start-Up URANS → **Continuous Pitch**



Procedure for our application of this method

Steady-state RANS → Start-Up URANS → **Continuous Pitch**



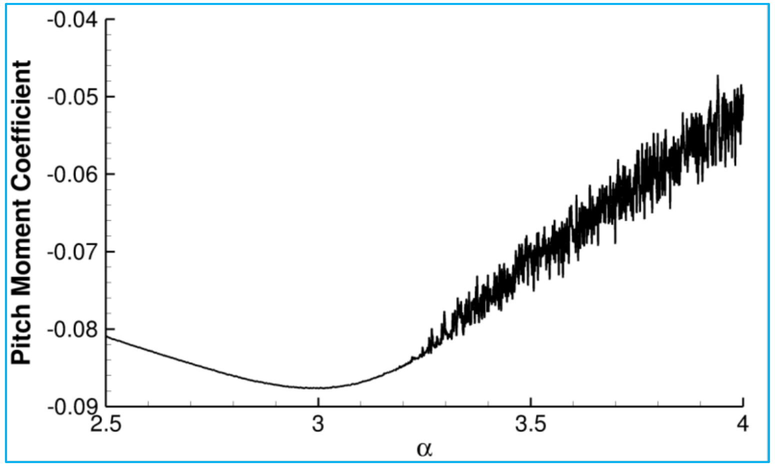


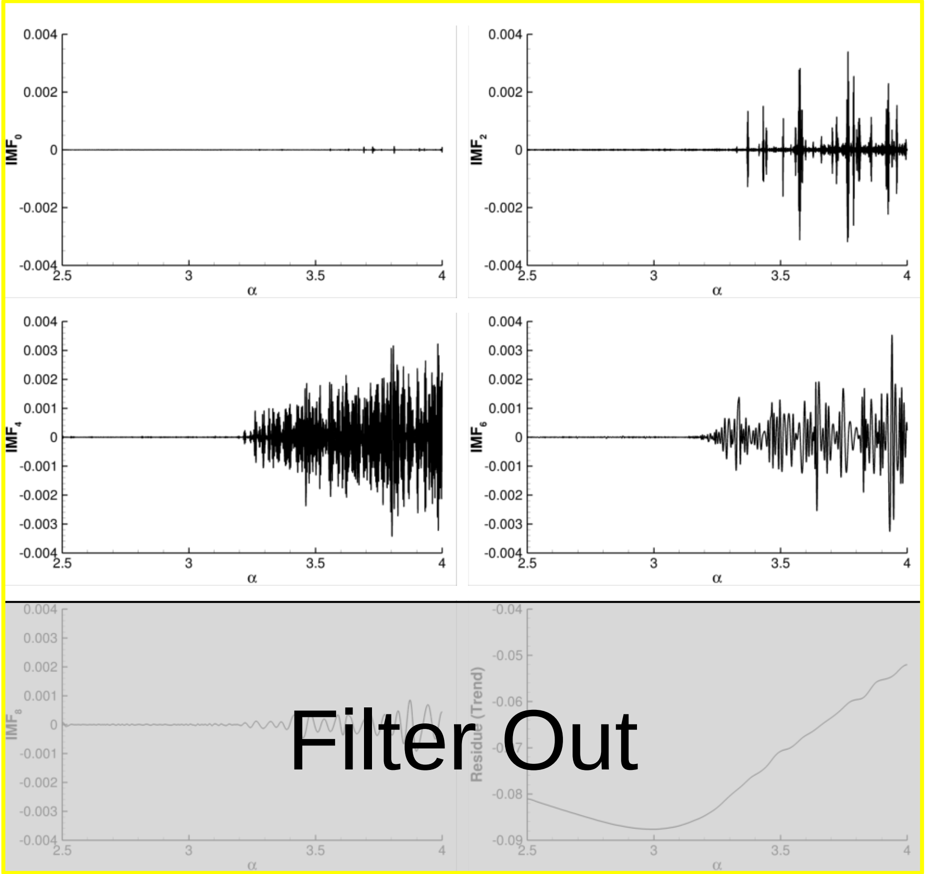
Current Buffet Onset Classification Method

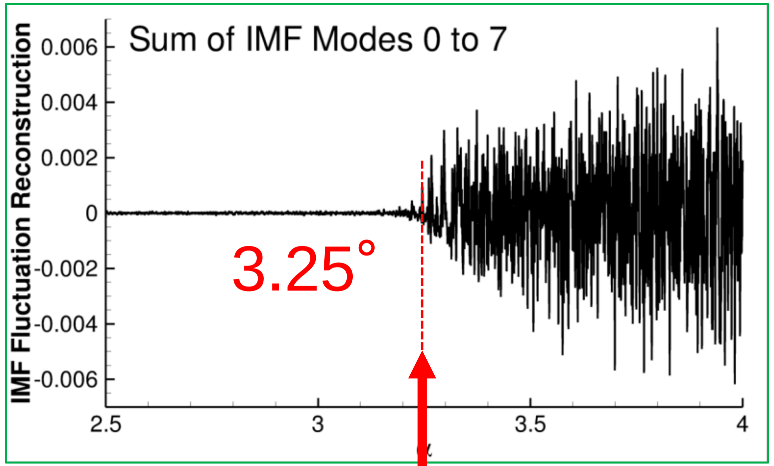
Time History

Empirical Mode Decomposition (EMD)

IMF Reconstruction



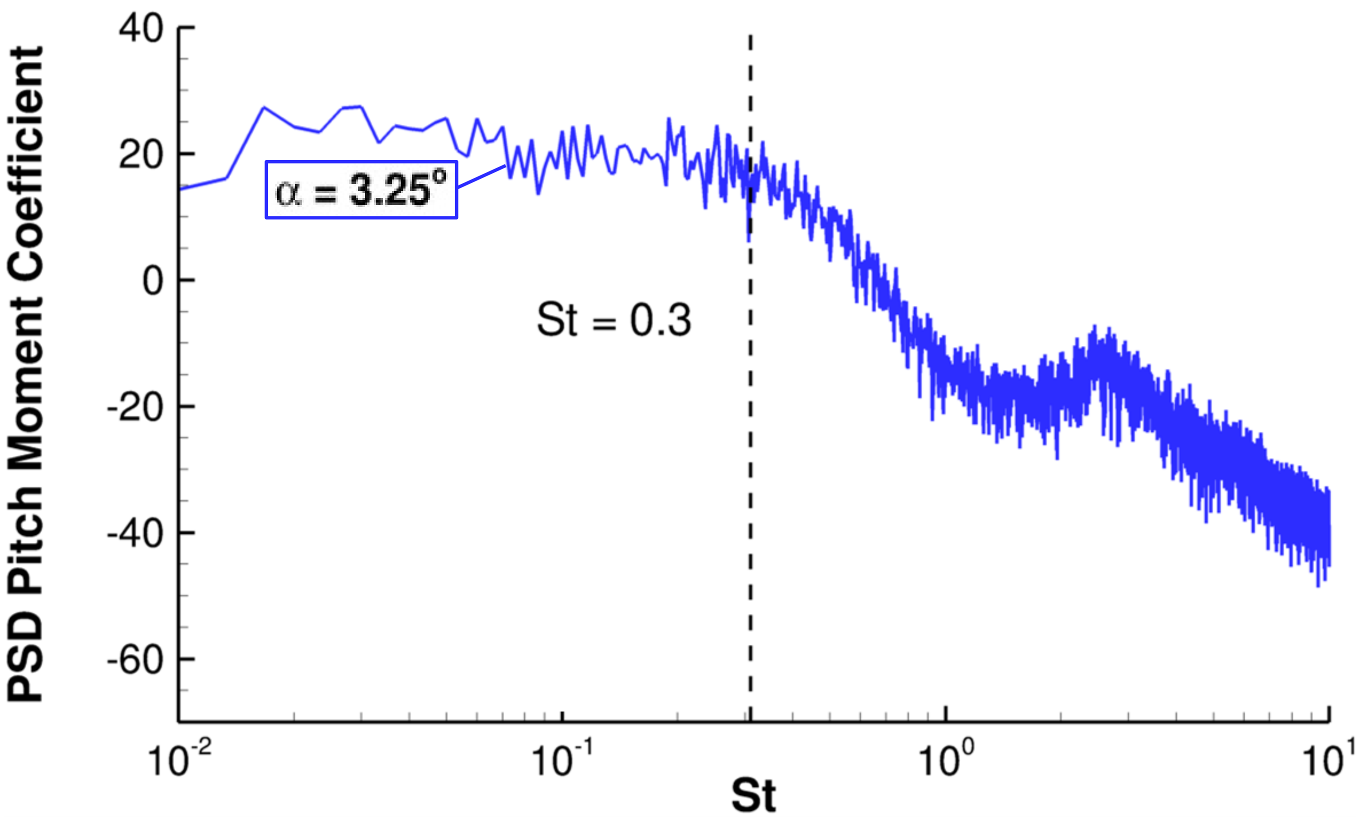


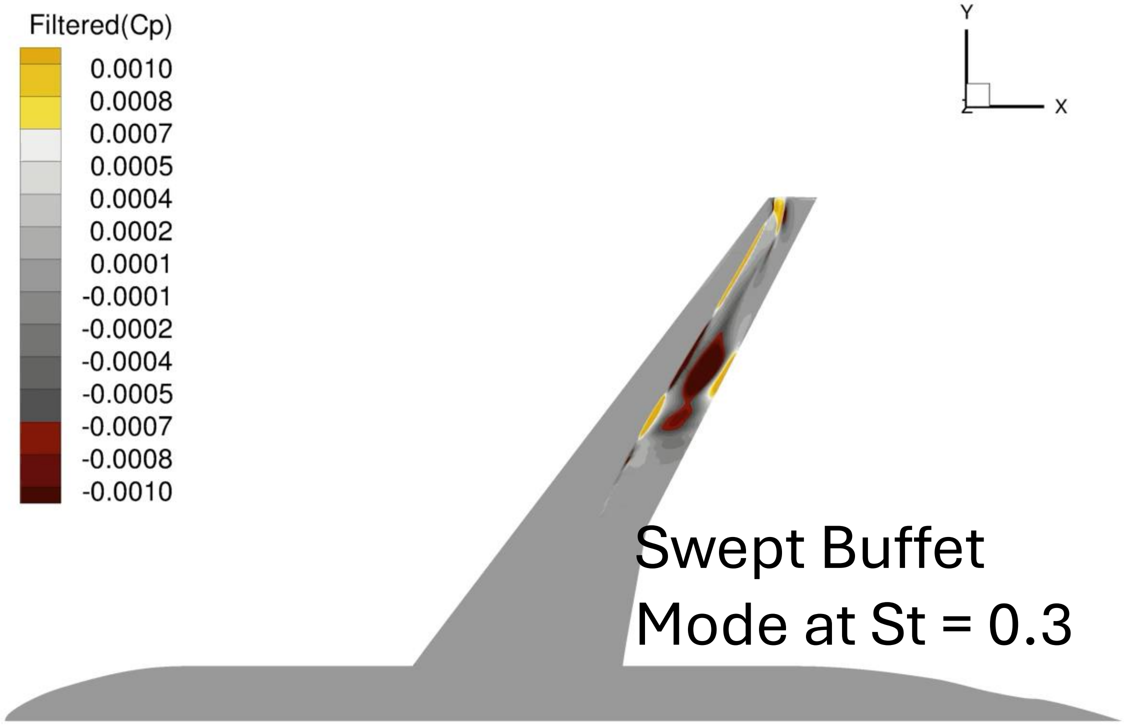


Visual Inspection for Exponential Growth

Procedure for our application of this method

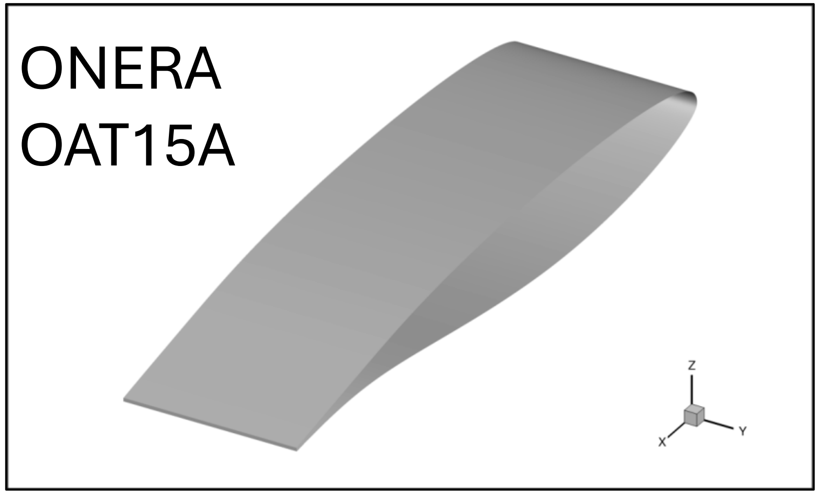
Steady-state RANS → Start-Up URANS → Continuous Pitch → **Verification of Buffet**

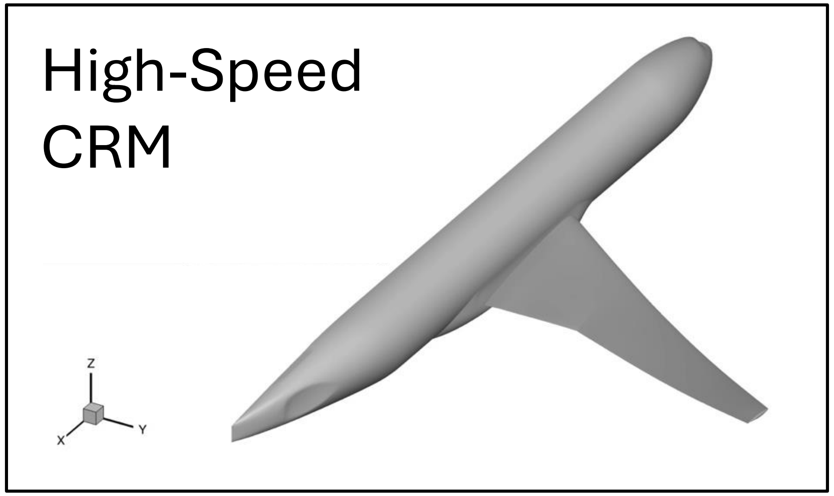


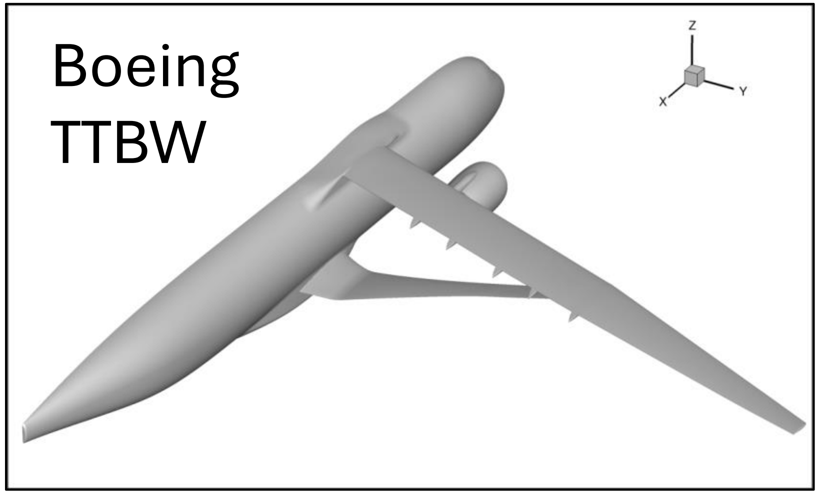


Sensitivity Studies

Sensitivities studied in this work

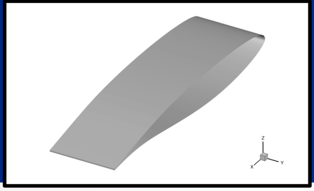


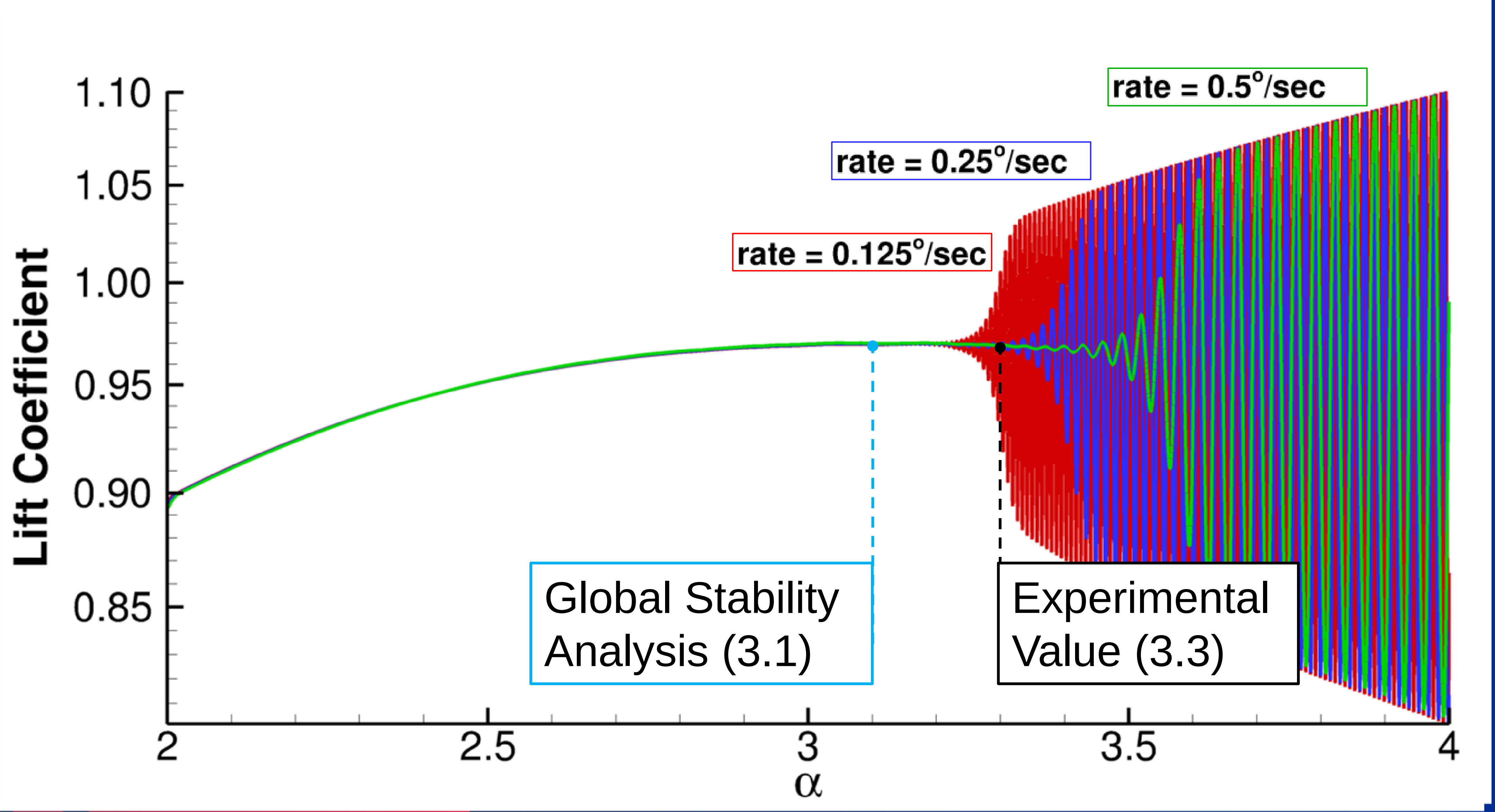




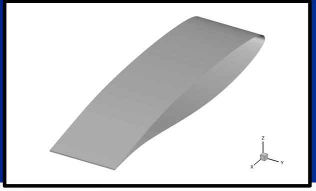
Study	Values	Configuration
Pitch Rate	0.125, 0.25, 0.5 °/sec	ONERA OAT15A

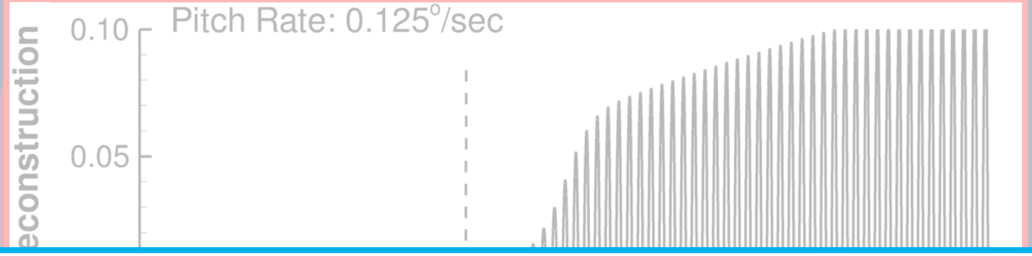
Pitch Rate Study



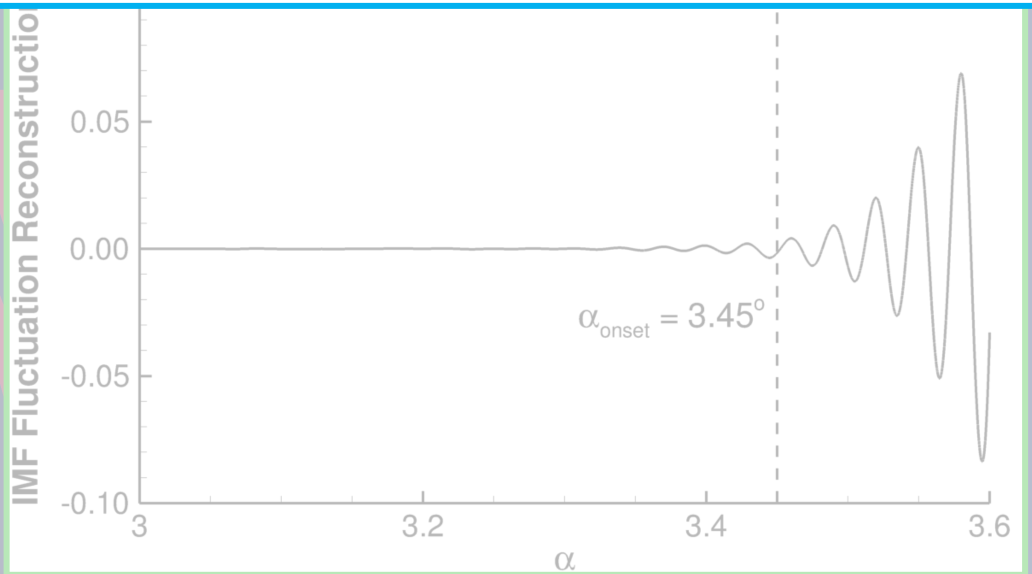


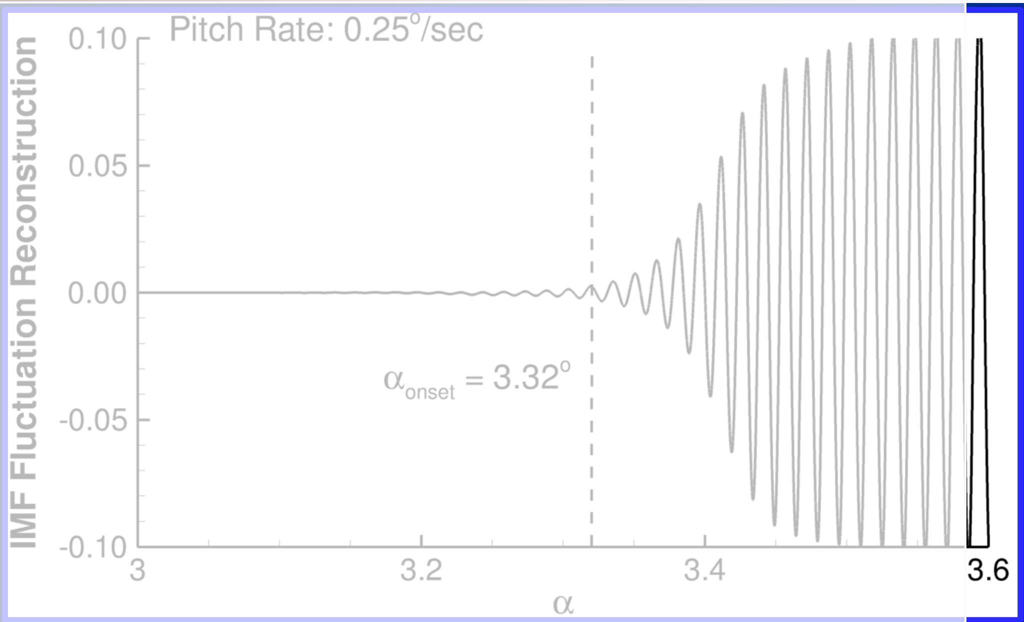
Pitch Rate Study #2





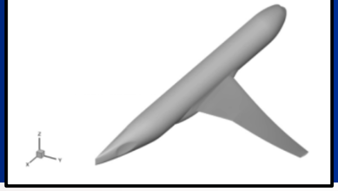
Use a relatively slow pitch rate: U_∞ /(1000c)

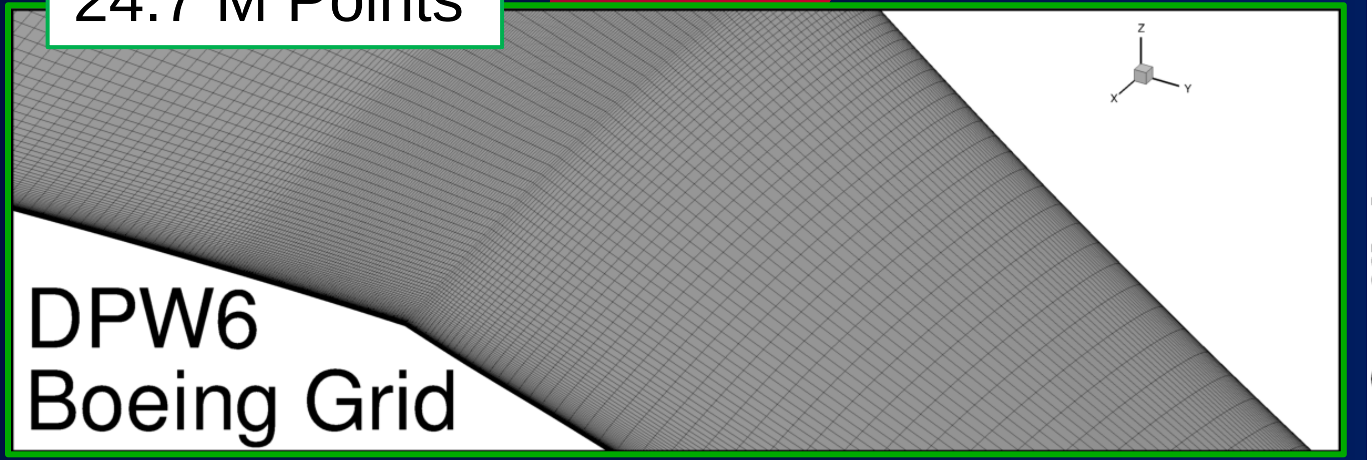


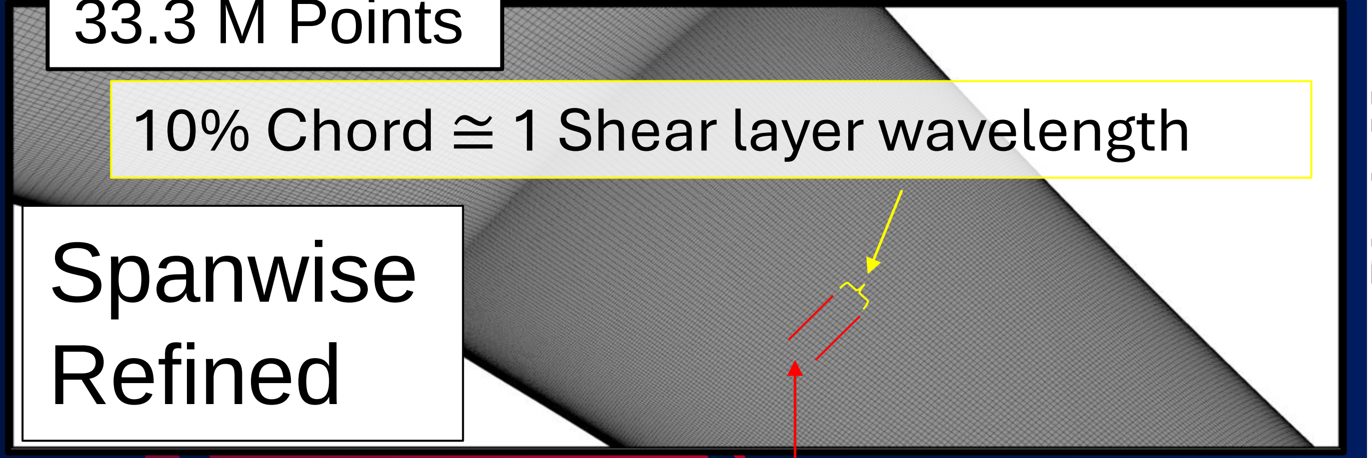


Color	Pitch Rate	α_{onset}	Difference
	0.125°/sec	3.23	2.7%
	0.25°/sec	3.32	-
	0.5°/sec	3.45	3.9%

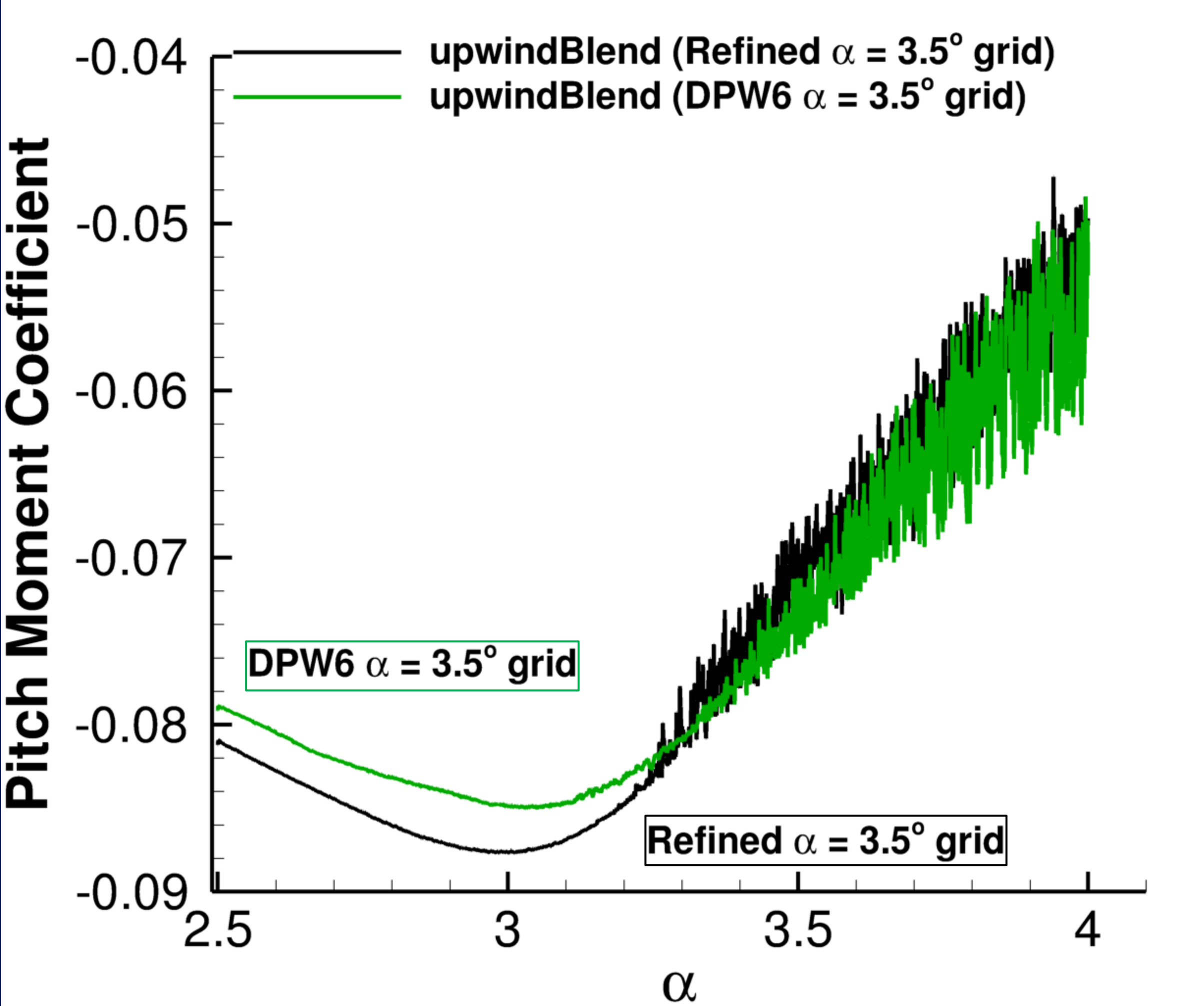
Mesh Sensitivity



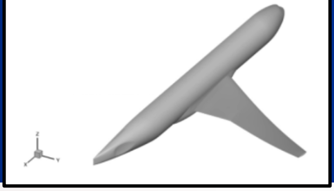


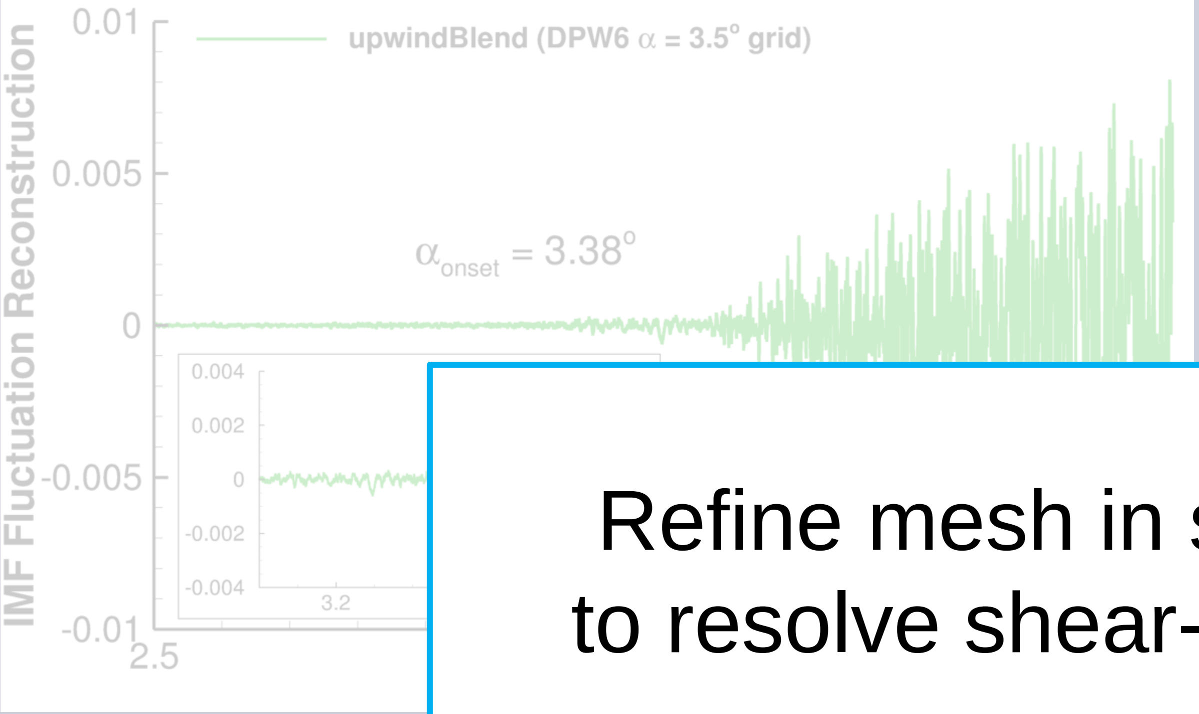


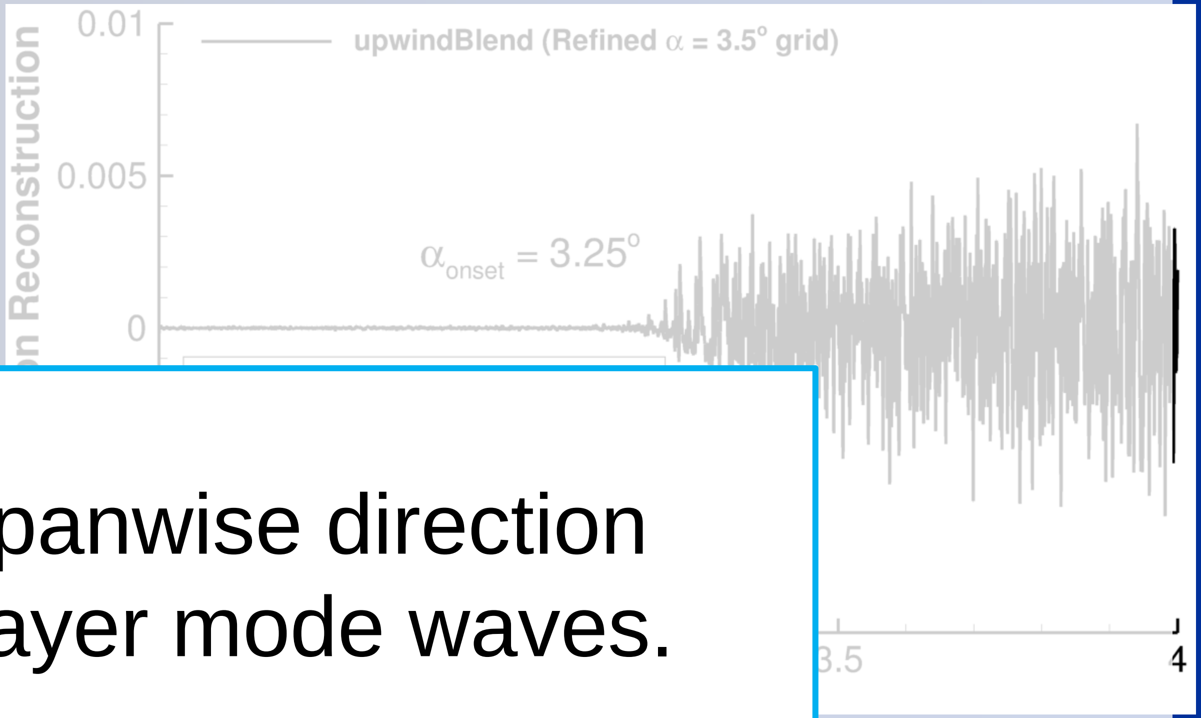
9 points/ wavelength



Mesh Sensitivity #2



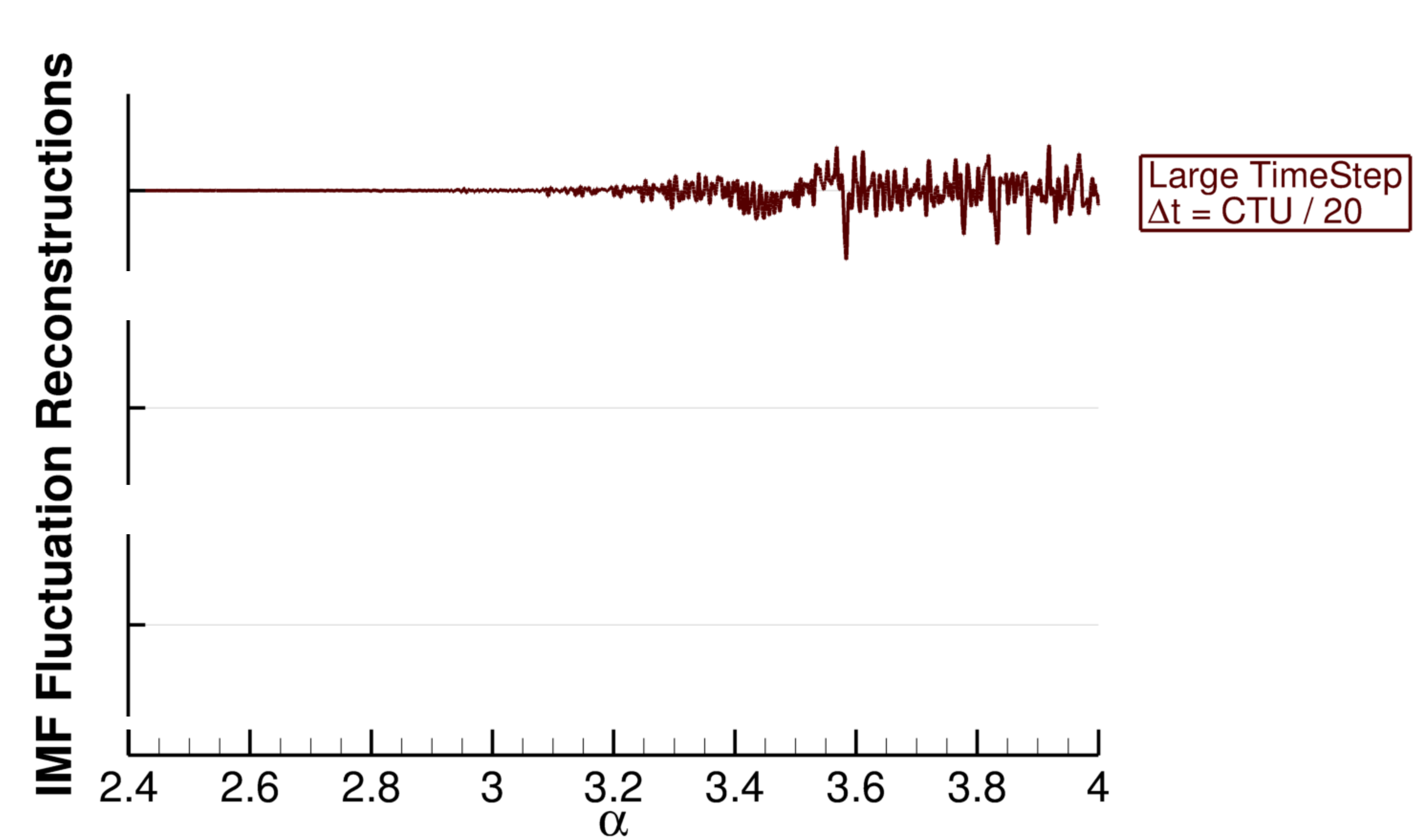




Refine mesh in spanwise direction to resolve shear-layer mode waves.

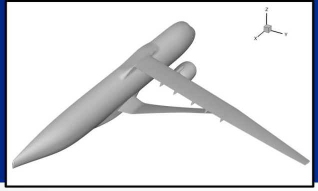
Color	Grid	α_{onset}	$C_{L\ onset}$
	DPW6	3.38	0.584
	Refined	3.25	0.576
	Delta	3.8%	1.4%

Time Step



IMF Fluctuation Reconstructions
Large TimeStep
Δt = CTU / 20
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
4
α

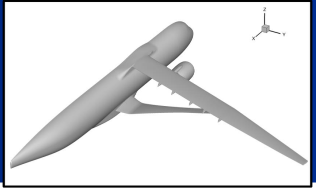
Time Step

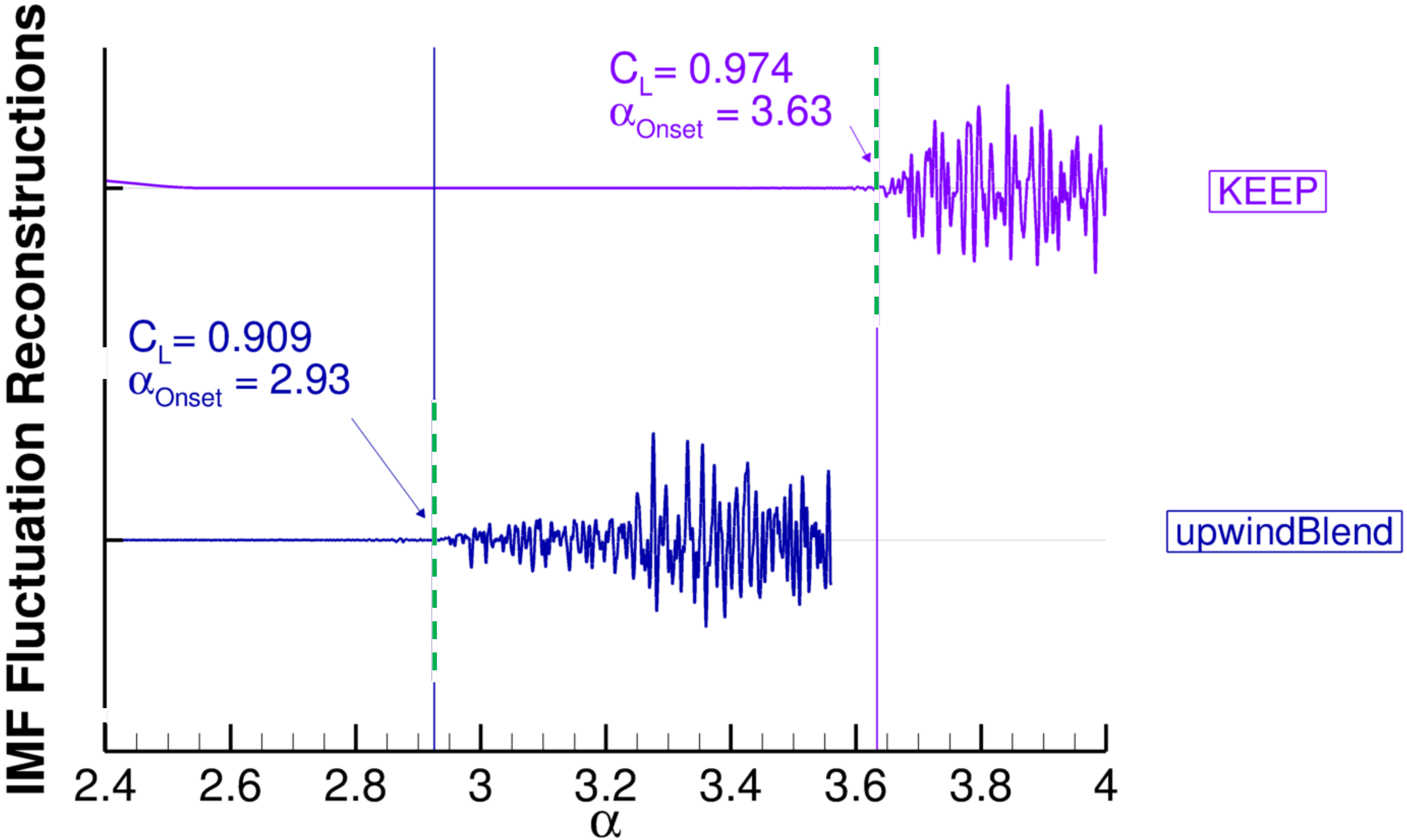


Use a timestep of CTU/100

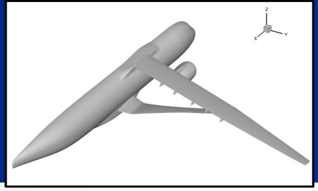
Color	Ti		$C_{L\ onset}$
	CT		.937-0.949
	CTU / 100	2.85	0.914
	CTU / 200	2.89	0.916
	Difference Between CTU/100 vs CTU/200	1.4%	0.2%

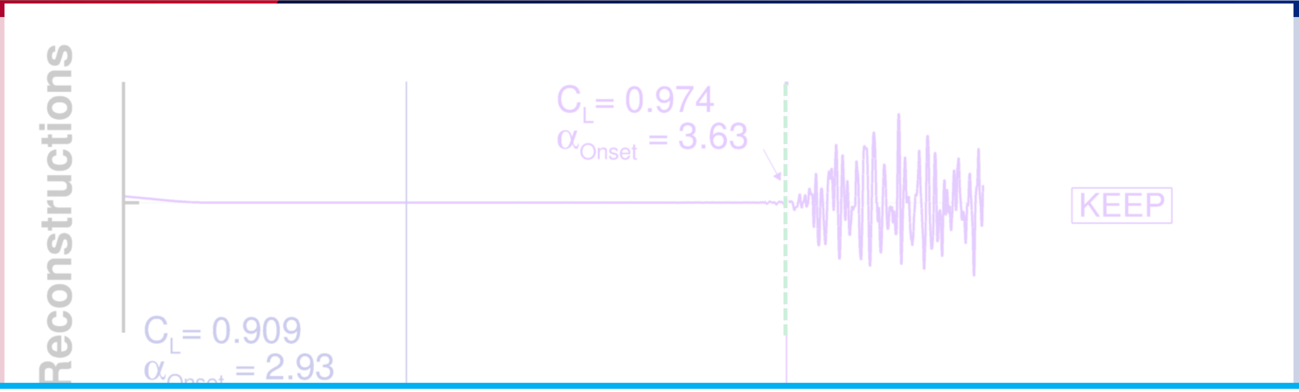
Convective Flux Discretization





Convective Flux Discretization

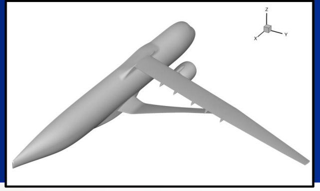


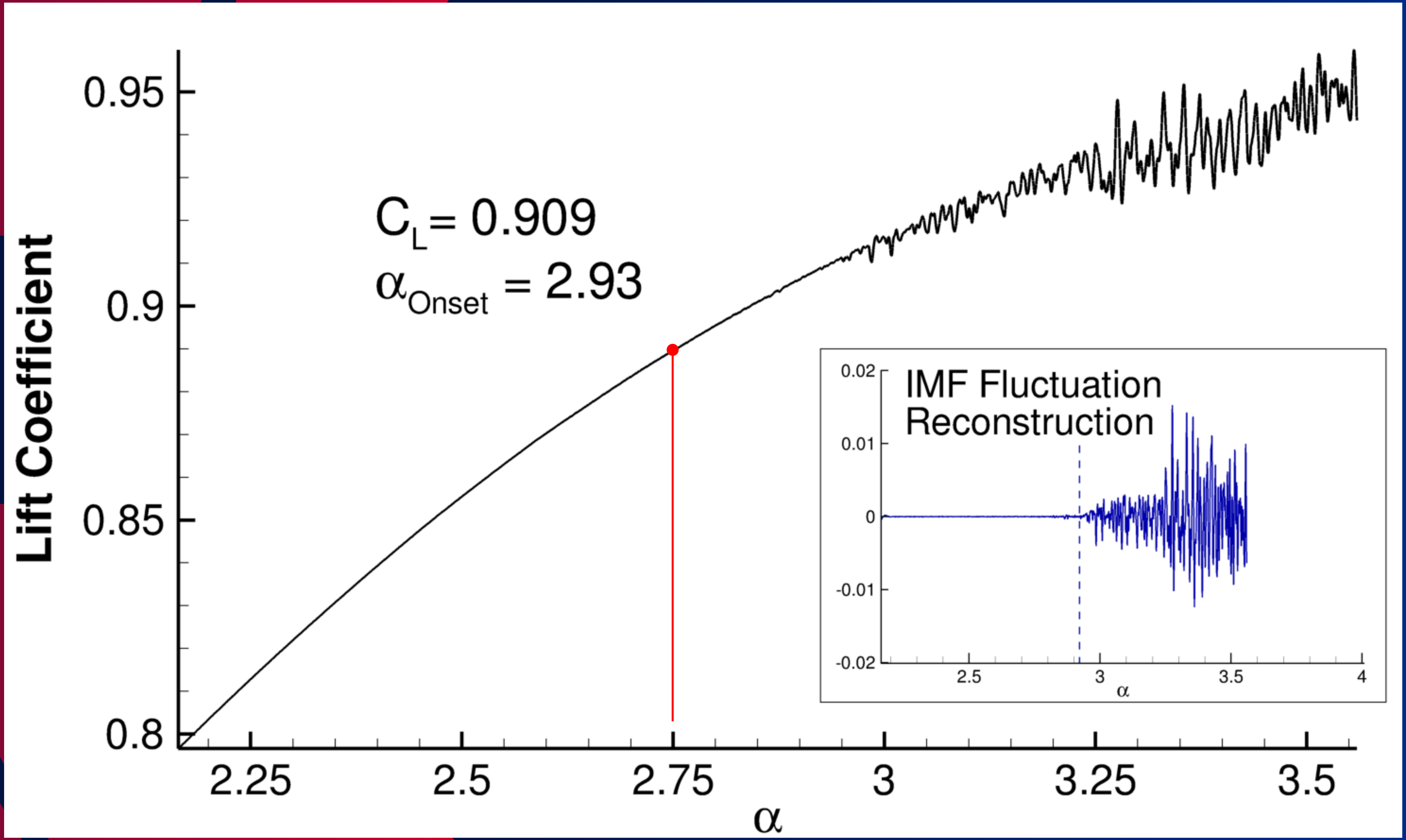


Use a low dissipation scheme that is numerically stable and able to capture physical instabilities

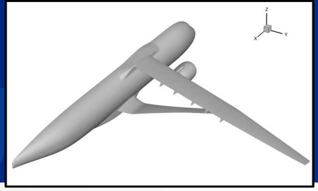
Color	Convective Flux Discretization	α_{onset}	$C_{L\ onset}$
	KEEP	3.63	0.974
	upwindBlend	2.93	0.909
	Difference	19.3%	6.6%

Continuous Pitch Initialization Angle





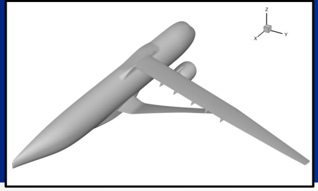
Continuous Pitch Initialization Ang



Use an initial alpha as close to buffet onset as possible

Color	Initialization α	α_{onset}	$C_{L\ onset}$
	2.0°	2.93	0.909
	2.75°	2.97	0.913
	Difference	1.4%	0.4%

Cost Breakdown



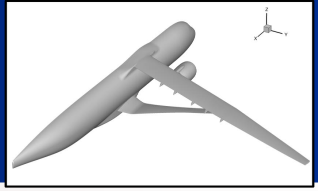
Actual cost for each step of the method

Step	Run	Node Type	Cost (CPU-hours)
1	Steady-State RANS	AMD Rome	575
2	Start-Up URANS	AMD Rome	156.7k
3	Continuous Pitch (1 Degree)	AMD Rome	853.4k
4	URANS for Verification / Run	AMD Rome	622.1k

Continuous Pitch URANS becomes cost efficient vs start-up URANS:
When desired precision of buffet onset of 0.2-degrees or less is desired

Continuous Pitch URANS is of same order cost as full static URANS:
Continuous pitch data is representative of URANS at any discrete angle and therefore potentially more benefitial

Validation



Simulations	Method	$C_{L\ onset}$
	Continuous Pitch URANS	0.909-0.913
	HRLES Kulites (Browne *et al.*)	0.925

Experiment	Method	$C_{L\ onset}$
	Pitch Break	0.76
	Trailing Edge Divergence	0.89
	Axial Force Offset	1.02
	Strain Gauge RMS	0.96-0.98
	Accelerometer	0.936-0.999
	Kulites	0.99

Conclusion

Concluding Remarks

The method was verified and validated for several configurations against experiments and other methods. Sensitivities were observed

- Suggestions Based on Sensitivities
  - Suggested pitch rate: $U_\infty/(1000c)$
  - Refine wing mesh to resolve shear layer mode waves
  - Suggested time-step: CTU/100
  - Use a stable low dissipation convective flux scheme that can pick up physical instabilities
  - Initialize continuous pitch at an angle close & prior to buffet onset.

- The method is cost efficient compared to URANS based methods.

Acknowledgements

- Funding: Advanced Air Transport Technology (AATT) and Transformational Tools & Technologies Projects (T^3) under NASA Aeronautics Research Mission Directorate.
- Computer resources were provided by the NASA Advanced Supercomputing facility, under the HECC Project.
- Contributions from: Oliver Browne for his insights and and making experimental data more accessible.
- Internal Reviewers: Luis D. Fernandes, David C. Penner, William M. Chan, Chase P. Ashby, Leonardo M. Machado, and Brandon Lowe.
- Boeing Team for guidance and research provided.
- Technical Point of Contact: Greg Gatlin for TTBW experimental unsteady data

Contact at daniel.maldonado@nasa.gov