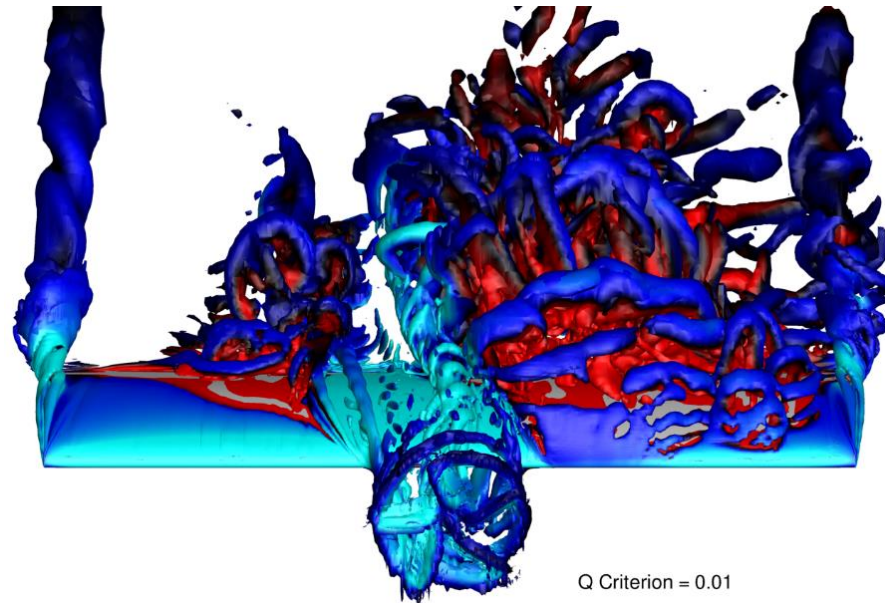


AIAA SCITECH 2023

COMPARISON OF AERODYNAMIC ANALYSIS TOOLS APPLIED TO A PROPELLER-BLOWN WING



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- Co-founder Research in Flight
- Head of FlightStream R&D
- Developed FlightStream aerodynamics tool in extensive use in industry, government & NASA
- 15 years of R&D experience in aerodynamics & aerospace vehicle design
- PhD in Aerodynamics from Auburn University

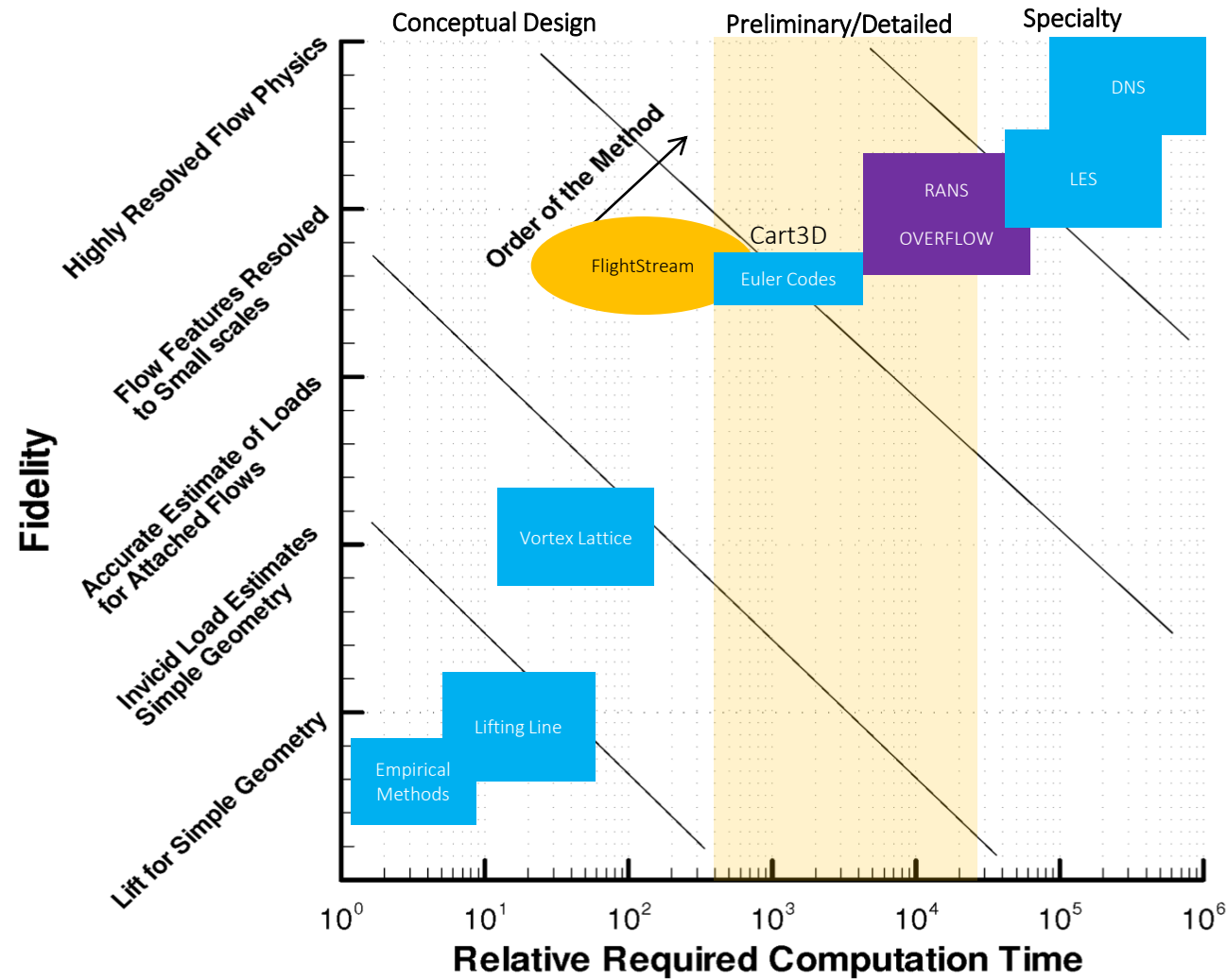


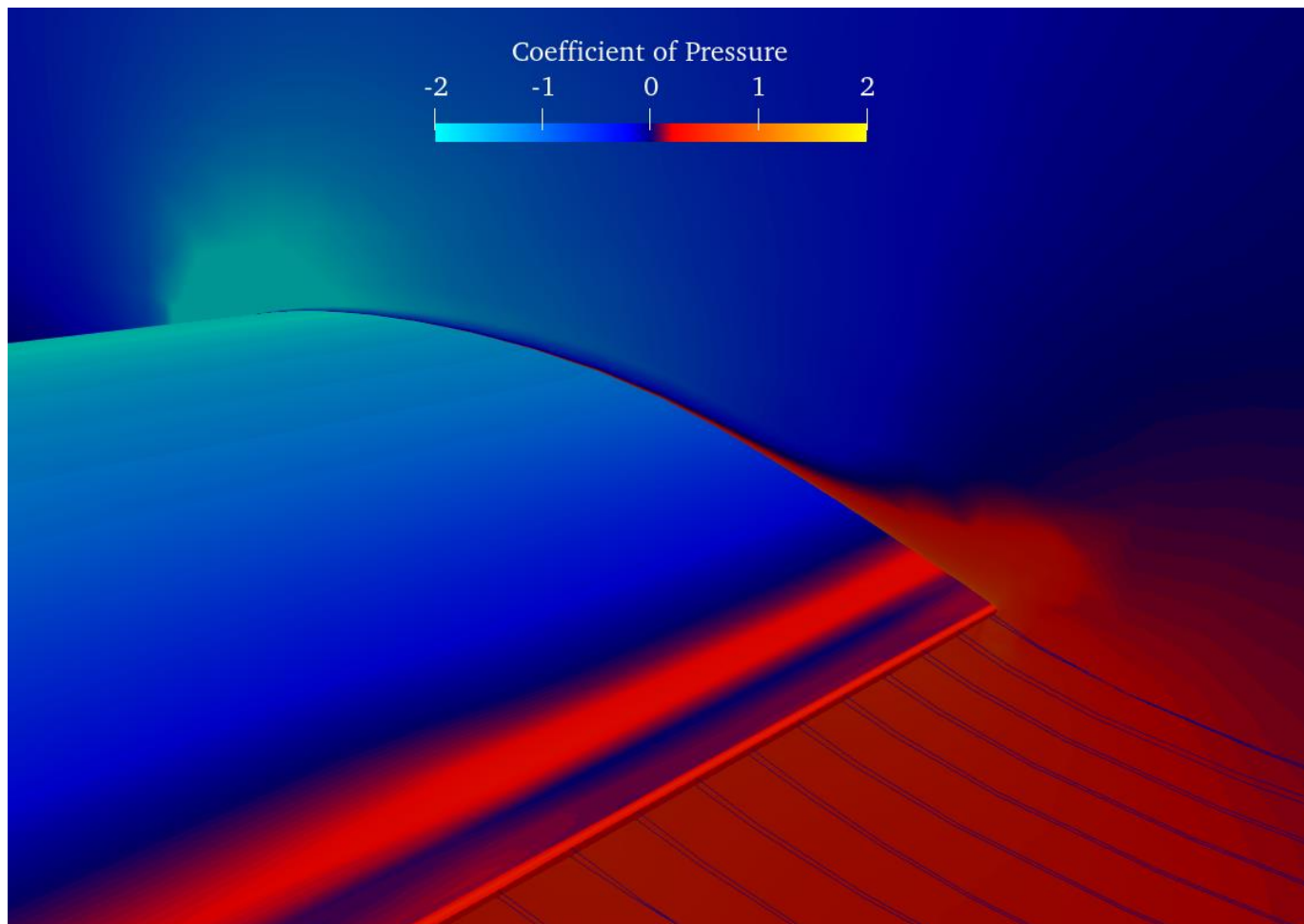
Brandon Litherland
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- Vehicle Design and Systems Analysis in Aeronautics Systems Analysis Branch
- Developed novel folding conformal high-lift propeller for NASA's X-57 Maxwell
- Lead developer of OpenVSP Ground School training library
- BS AE from UIUC, MSAE from GA Tech ASDL

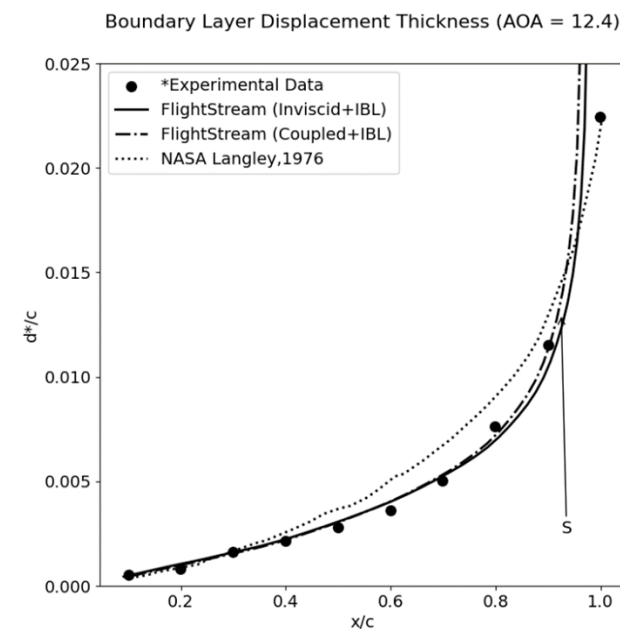
FLIGHTSTREAM[®] & OVERFLOW

SIMULATION LANDSCAPE

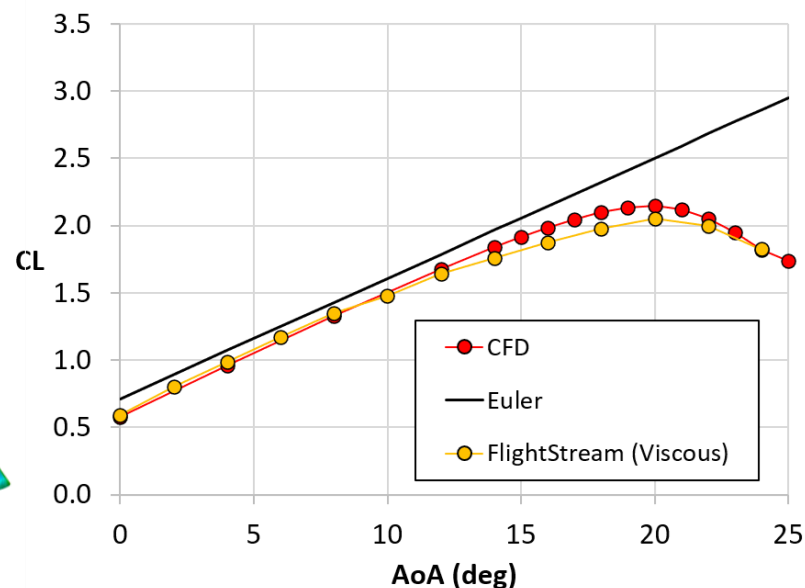
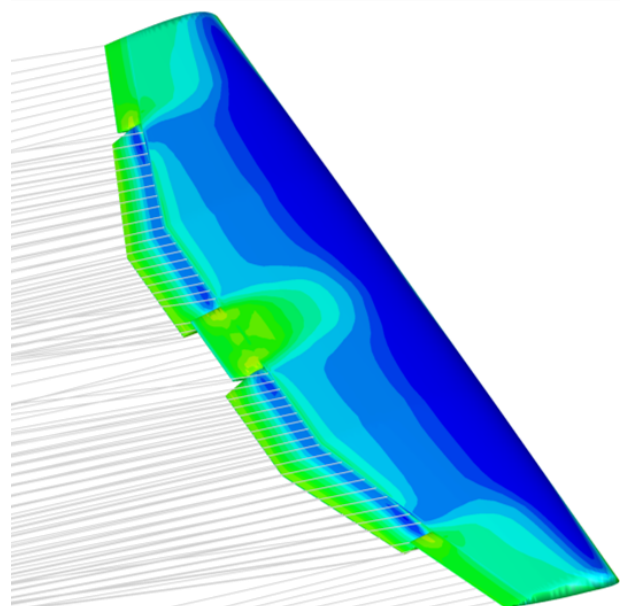
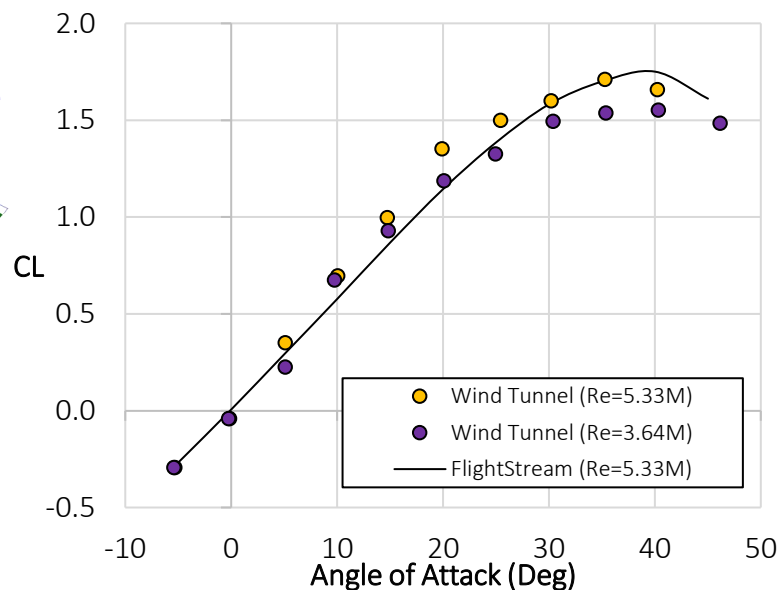
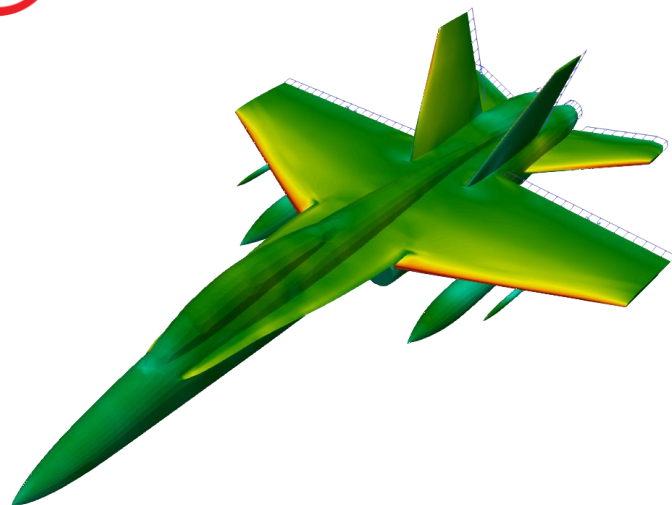




- FlightStream® has a fully viscous-coupled non-linear flow solver that allows the accurate physics-based capture of boundary layer flow and its impact on the vehicle aerodynamics.
- Laminar transition & instabilities.
- Non-linear lift and moment distributions.
- Viscous-flow ingestion physics modeling on affected propulsors and BLI-configured aircraft.

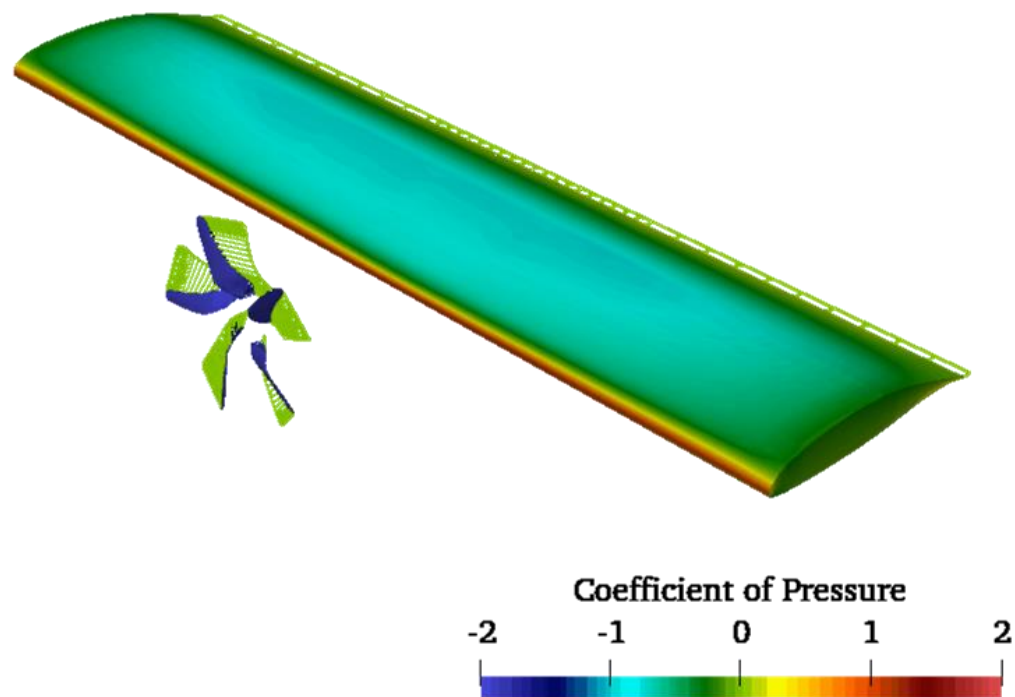


FLIGHTSTREAM FLOW SEPARATION & STALL



- Fully viscous-coupled non-linear flow solver that allows the accurate physics-based capture of boundary layer aerodynamics, flow separation and post-stall aerodynamics.
- Generalized, compressible subsonic flow.
- Separation line contours.
- Laminar separation bubble capability.
- Post-stall aerodynamic loads and moments.
- CL_{MAX} and stall angle predictions.

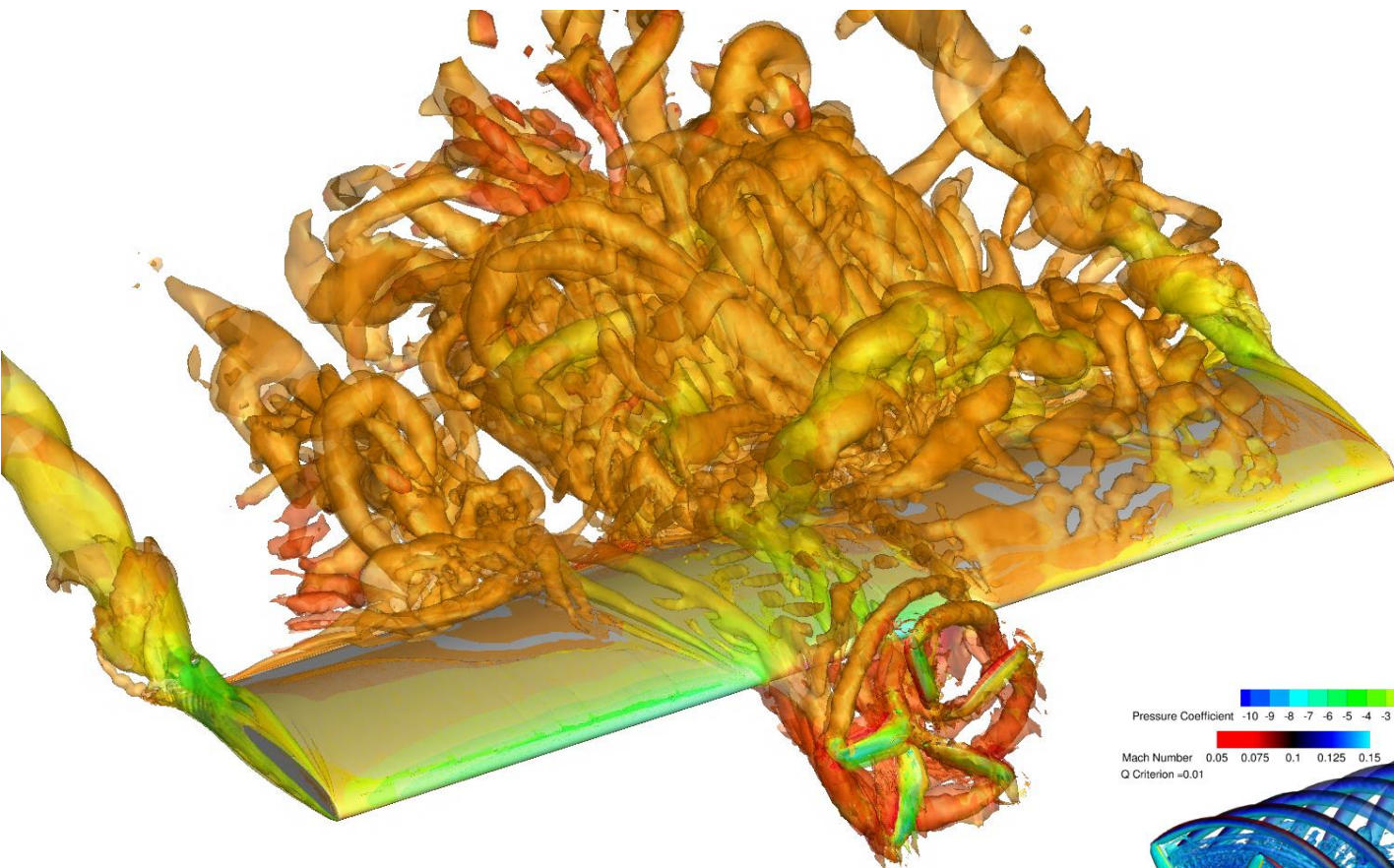
FLIGHTSTREAM UNSTEADY SOLVER



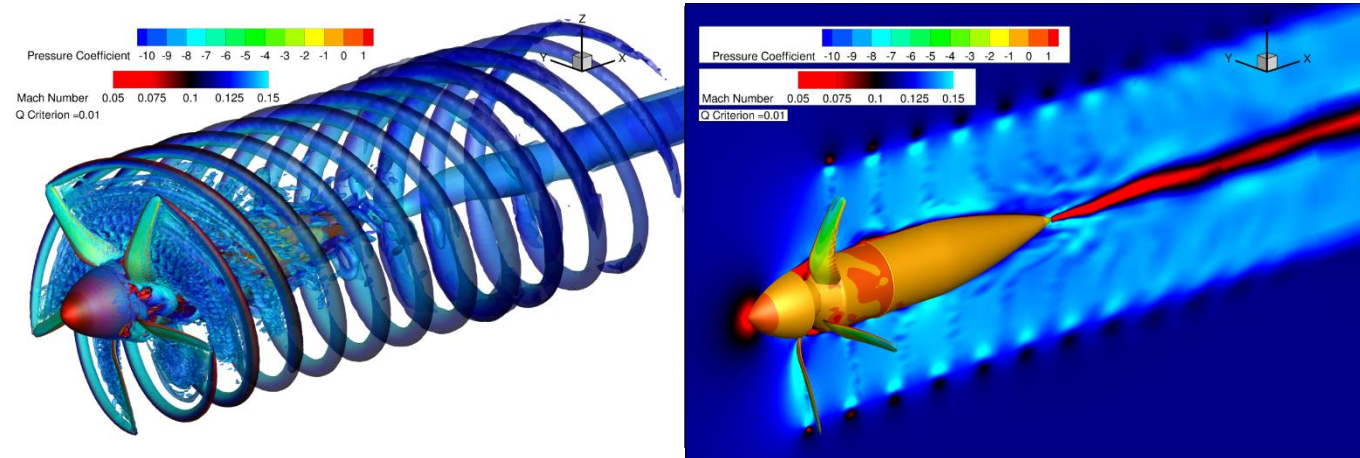
- Simulate arbitrary motion definitions of all kinds: rotation, translation, accelerations, flapping, and morphing.
- Full-unsteady, time-evolving relaxed wake model.
- Ability to resolve around solid bodies.
- Vortex stretching, disintegration models.
- Ability to enable/disable wake relaxation.
- Full volumetric effects (including viscous flow).
- Solver run-time in minutes.

OVERFLOW SOLVER

- NASA's OVERFLOW is a 3D time-marching implicit Navier-Stokes code leveraging overset grid systems that can also operate in 2D or axisymmetric modes.
- Multiple inviscid flux and implicit solution algorithms are included along with algebraic, one-equation, and two-equation turbulence models.
- Wide variety of boundary conditions available.
- Supports relative body motion including six-degree-of-freedom models and collision detection.



Blown wing stall at 25° angle of attack. Iso-surfaces defined at Q Criterion = 0.01



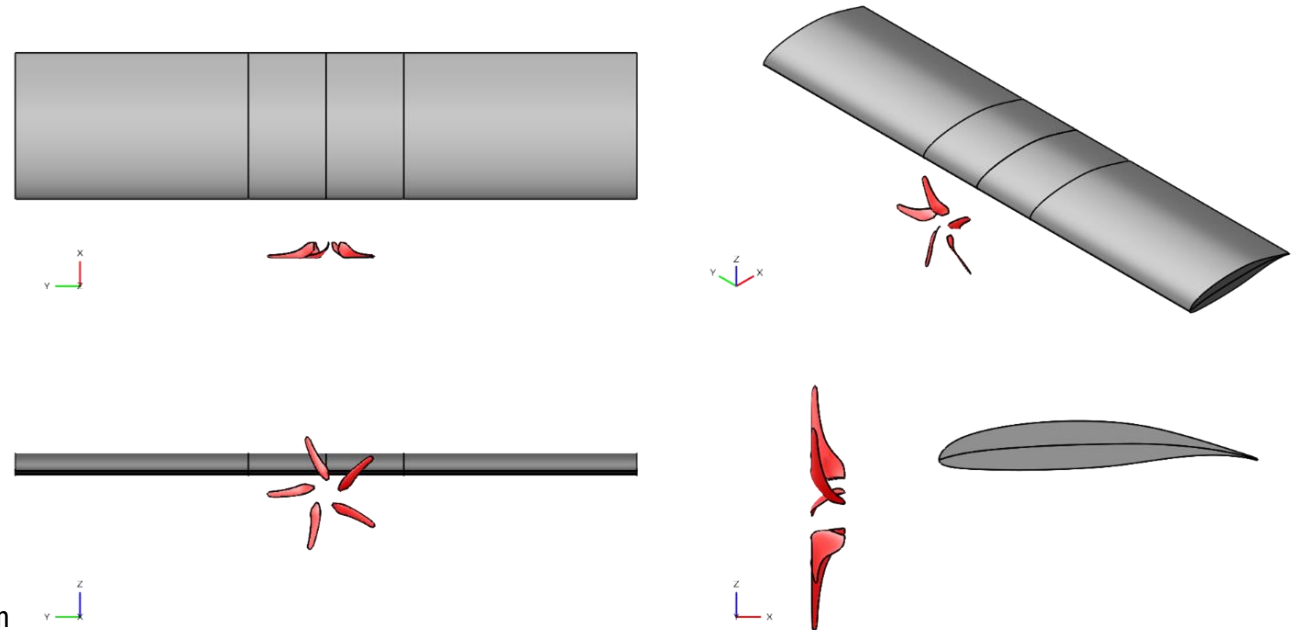
From X-57 "Maxwell" High-Lift Propeller Test for Improved Thrust Measurements and Slipstream Velocities, with permission

MODEL GEOMETRY

- This work is a continuation of prior OVERFLOW analyses and comparisons performed in 2020-2021*. The wing and propeller geometry have remained the same.
- The OpenVSP model of this configuration is publicly available on the OpenVSP Hangar model library.
 - <https://hangar.openvsp.org/vspfiles/526>
- The wing along with the high-lift propeller is a rectangular section with a constant airfoil based on the X-57 main wing root airfoil with no twist, dihedral, or taper.

Parameter	Value
Wing Chord	0.7141 m
Wing Span	3.048 m
Wing Area	2.1767 m
Wing Leading Edge Center, XYZ	0.2588 m, 0.000 m, 0.1241 m
Wing Quarter Chord Location, XYZ	0.4376 m, 0.000 m, 0.1241 m

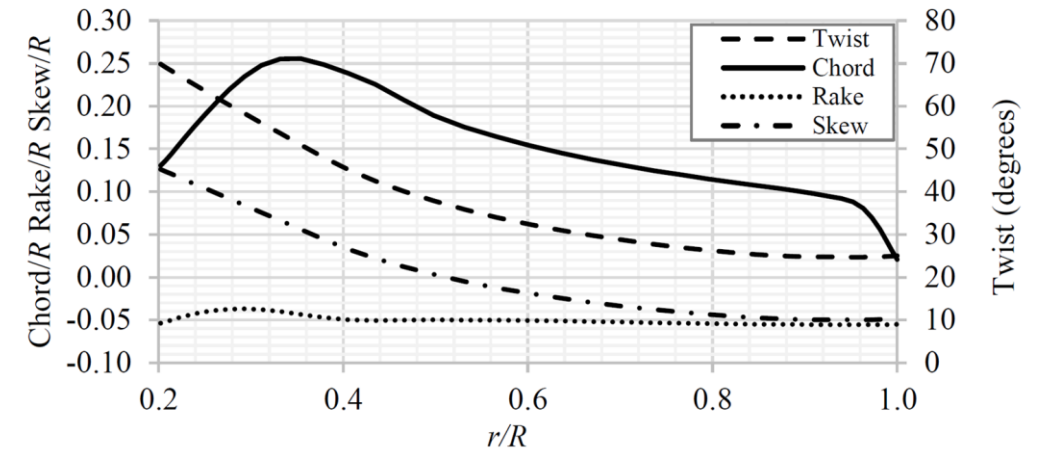
Midspan high-lift propeller and wing geometry.



*C. N. Sheridan, D. D. Pham and S. Whiteside, "Evaluation of VSPAERO Analysis Capabilities for Conceptual Design of Aircraft with Propeller-Blown Wings," in AIAA Aviation 2021 Forum, American Institute of Aeronautics and Astronautics, AIAA 2021-2510.

HIGH-LIFT PROPELLER GEOMETRY

- The X-57 high-lift propeller is designed to have a relatively constant induced velocity aft of the propeller according to the methods described by Patterson, Borer, and German*.
- The propeller root chord was modified from the original design to accommodate folding and stowage along the nacelle by removing material from the root leading edge to avoid cutting into the spinner.
- The blades have a constant MH114 airfoil from root to tip, which was modified to include a 0.020- inch blunt trailing edge thickness for manufacturability by relofting the airfoil upper surface along the blade.



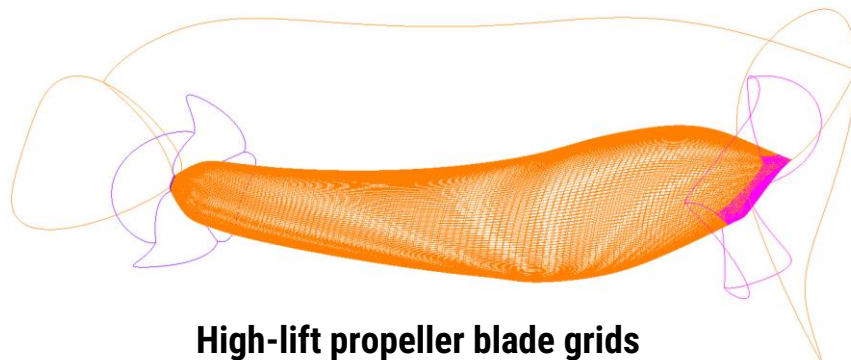
Parameter	Value
Radius (R)	0.28769 m
Blade Root Radius (r_0)	0.0583 m
3/4 Pitch ($\beta_{3/4}$)	27.4°
Number of Blades	5
Rotational Speed	4549 RPM
Power (electric)	10.5 kW
Thrust	220 N
Flight Velocity	29.9 m/s (58 KTAS), Sea Level
Center Location, XYZ	-0.000 m, 0.000 m, -0.000 m

*M. D. Patterson, N. K. Borer and B. German, "A Simple Method for High-Lift Propeller Conceptual Design," in 54th AIAA Aerospace Sciences Meeting, American Institute of Aeronautics and Astronautics, AIAA 2016-0770.

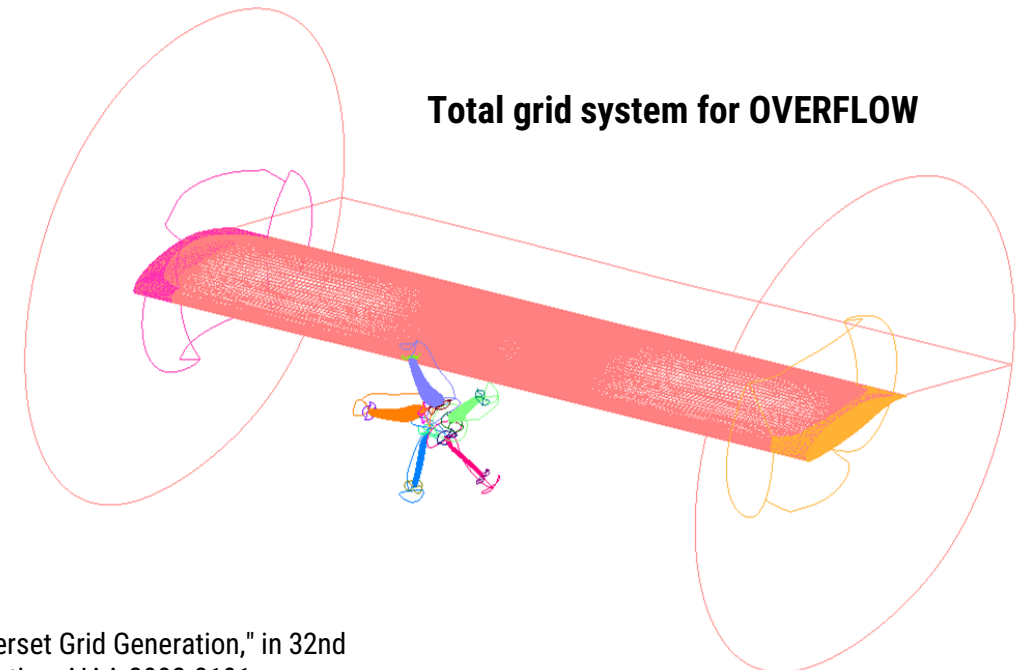
OVERFLOW SETUP

- The overset grid systems required to perform CFD analyses were created in Chimera Grid Tools (CGT) according to the best practices established by Chan, Gomez, Rogers, and Buning*.
- The wing and blades are O-type grids wrapping around the geometry in the chord direction and several planar edges are removed from the grid ends to avoid coincident edges with the square caps.
- The caps for each geometry are also O-type grids generated from the leading edges, camber lines, and trailing edges.
- All surface and volume grids were generated with hyperbolic growth ratios of approximately 1.1 or less.

Parameter	Wing	Blade
Number of Chordwise Points	221	201
Number of Spanwise Points	393	181
Near-Body Distance (Number of Points)	0.9144 m (181)	0.0914 m (91)
Parameter	Value	
Viscous y+ spacing (y distance)	0.5 (3.048×10^{-6} m)	
Off-Body Grid Distance	60.96 m	
Minimum Off-Body Grid Spacing	0.0209 m	
Unblown Total Vertex Count	24,296,367	
Blown Total Vertex Count	44,457,872	



High-lift propeller blade grids

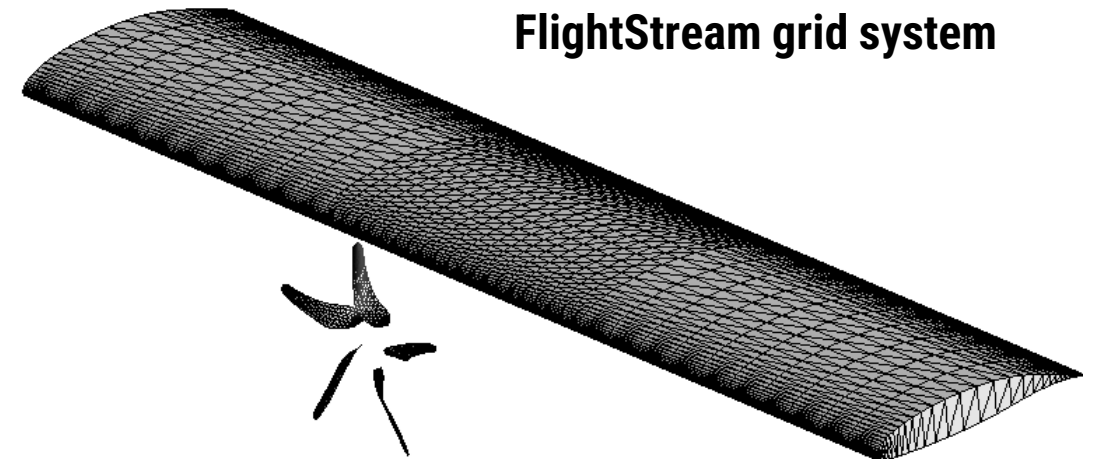


Total grid system for OVERFLOW

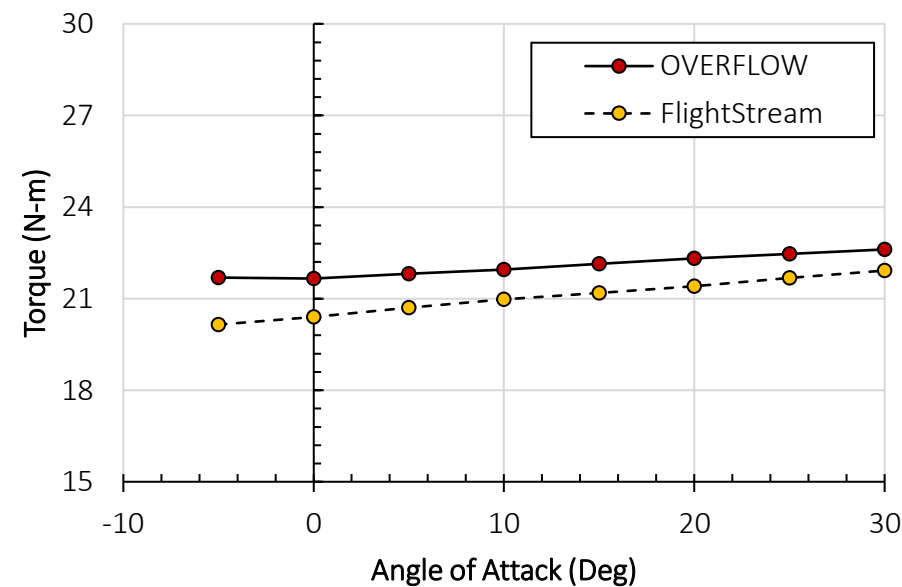
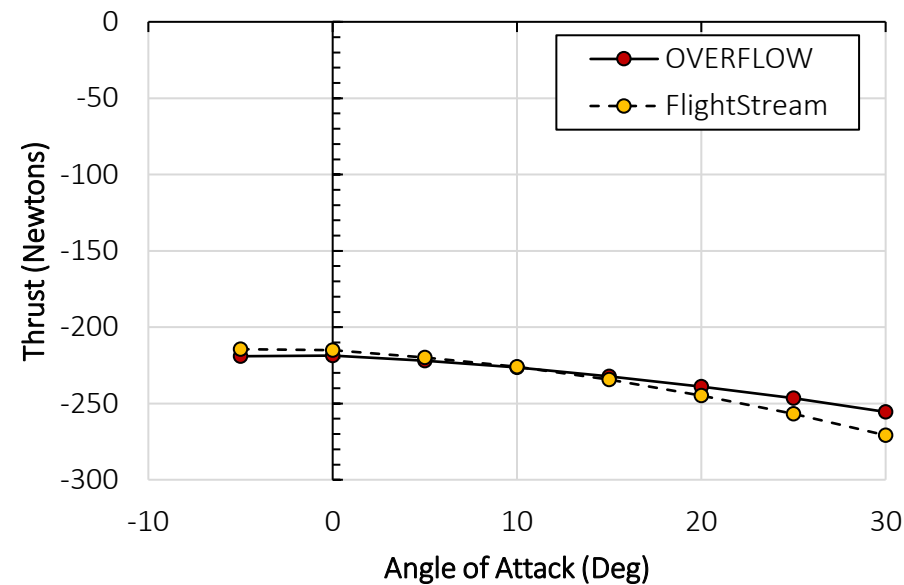
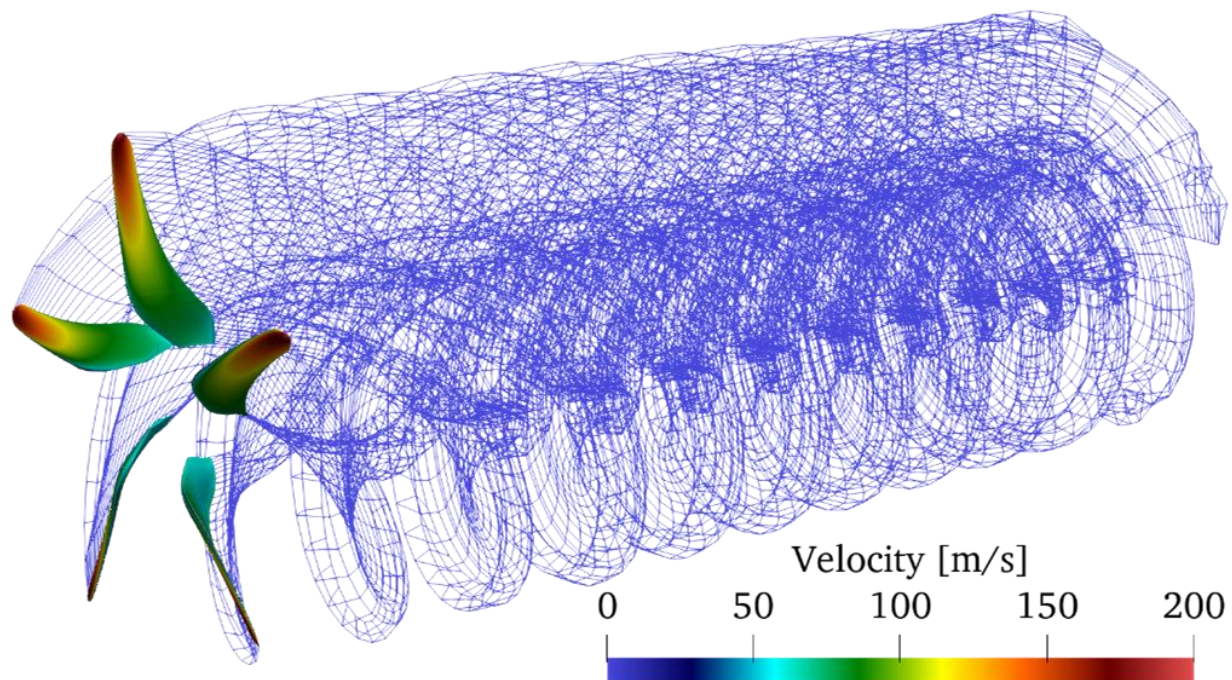
FLIGHTSTREAM SETUP

- The FlightStream solver requires a surface grid only and this grid was generated using the surface gridding tools available within FlightStream.
- Primarily, the aligned meshing tool was used to generate a structured, anisotropic quad surface grid using directional refinements in the chordwise and spanwise directions, according to the best practices established by Ahuja et.al*.
- Anisotropic ratios are defined as the mid-chord spanwise-to-chordwise parameter, and values between 2.5-3.5 were chosen for both the blown and unblown components.
- The blown section of the wing was provided a spanwise refinement with anisotropy ratios of 1.0 for 1.5R spanwise distance on either side of the propeller centerline.
- The blades were modeled using the solid body representation similar to the Overflow setup described previously.

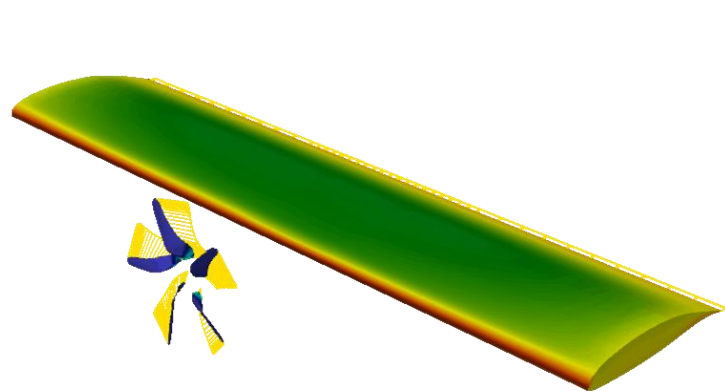
Parameter	Wing	Blade
Chordwise Points	82	30
Spanwise Points	40	25
Surface Directional Growth Rate	1.1 (Dual-sided)	1.1 (Dual-sided)
Parameter	Value	
Unblown Total Face Count	6,600	
Blown Total Face Count	8,100	



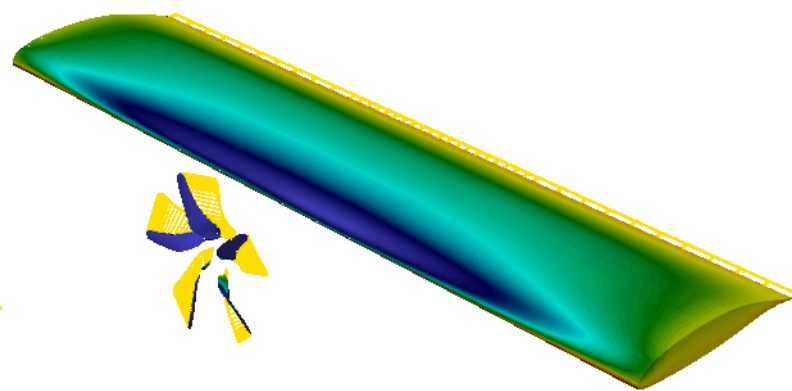
HLP PROPELLER MODELING & RESULTS



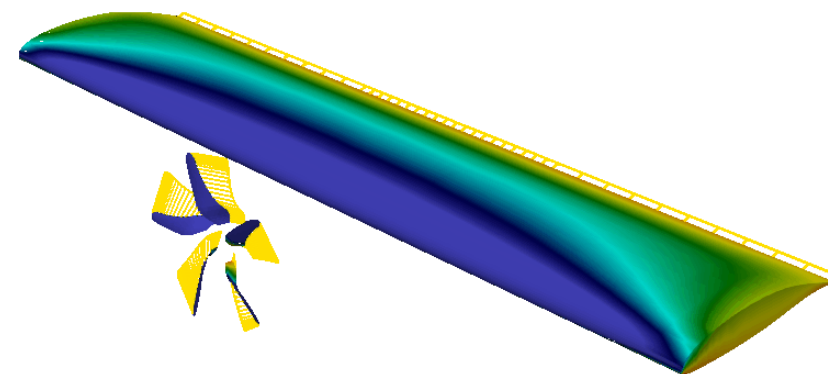
FLIGHTSTREAM TIME-VARYING SLIPSTREAM



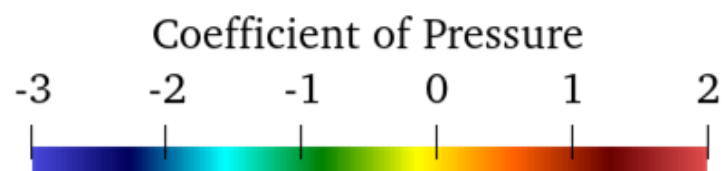
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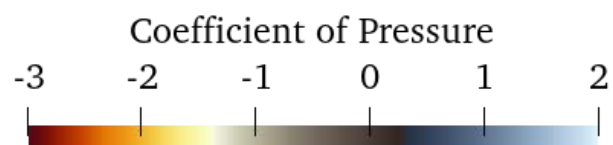
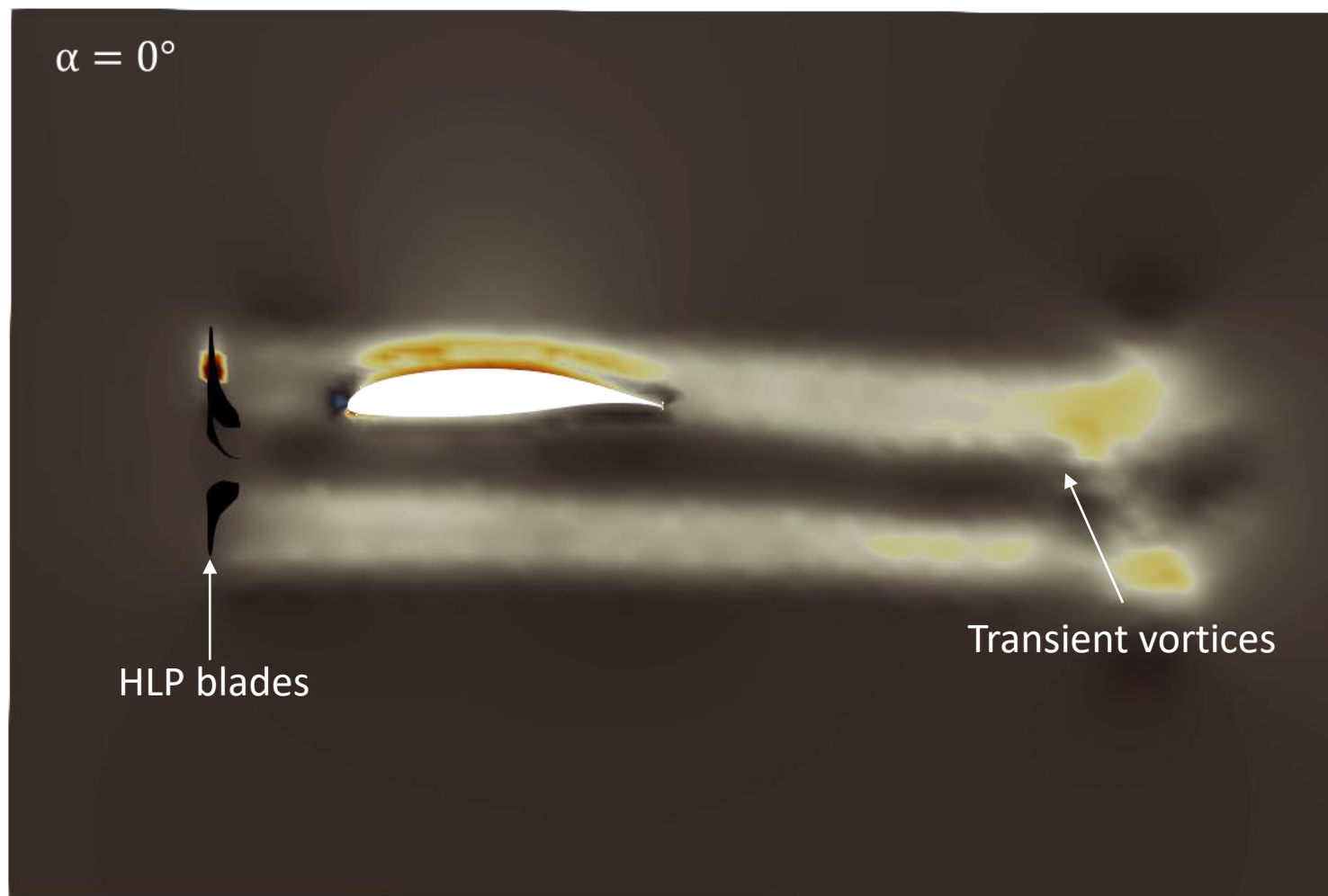
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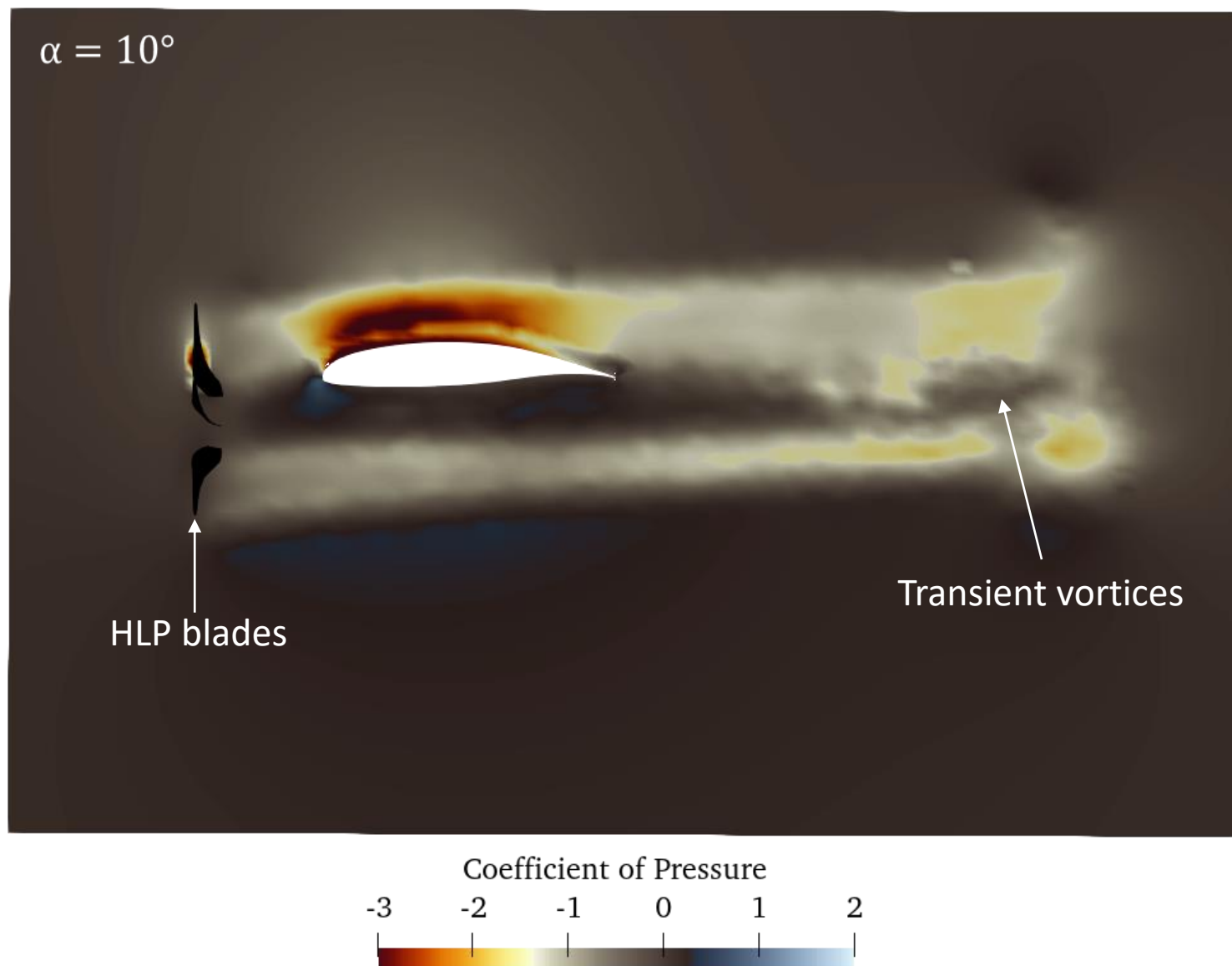
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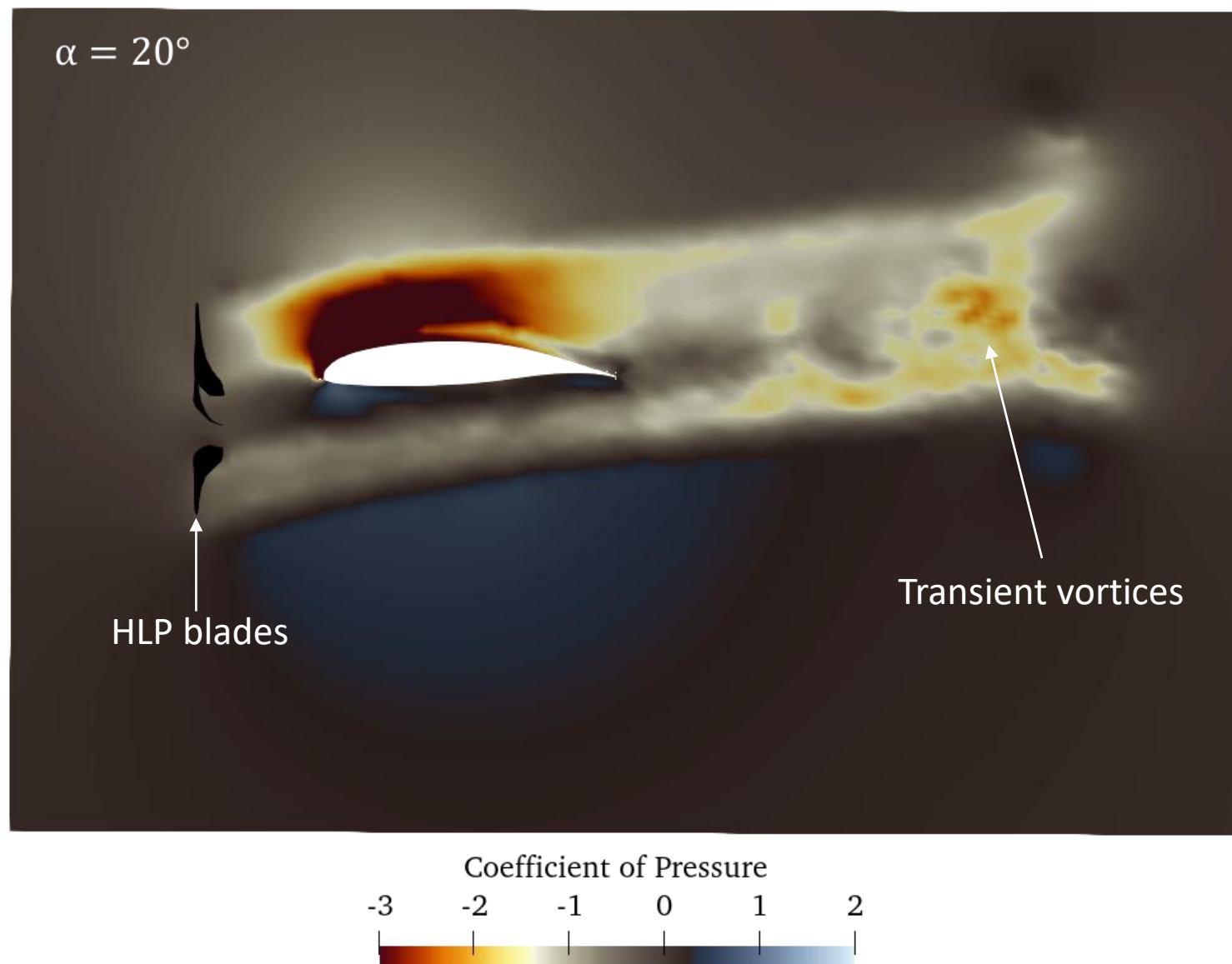
FLIGHTSTREAM TIME-VARYING SLIPSTREAM



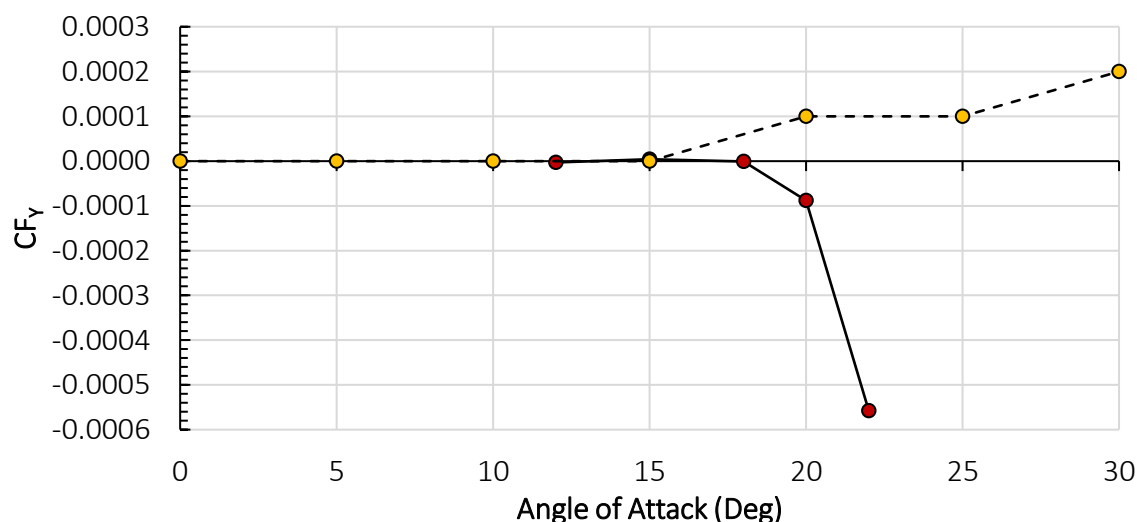
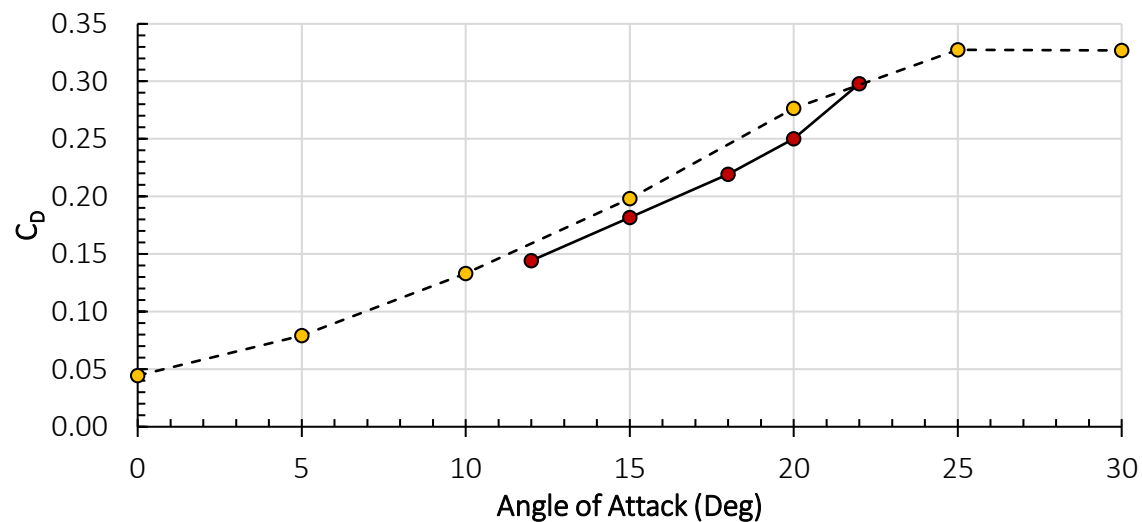
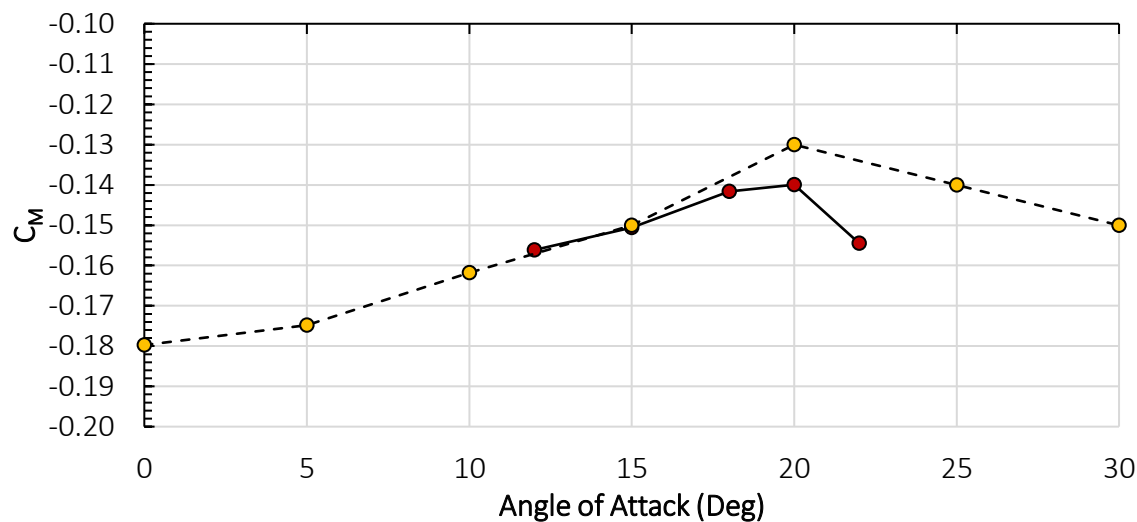
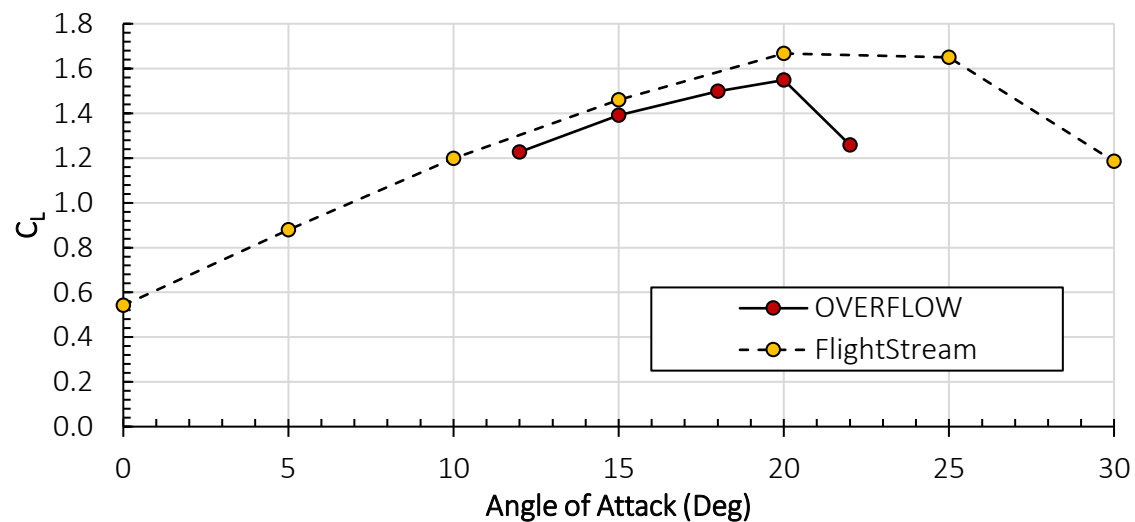
FLIGHTSTREAM TIME-VARYING SLIPSTREAM



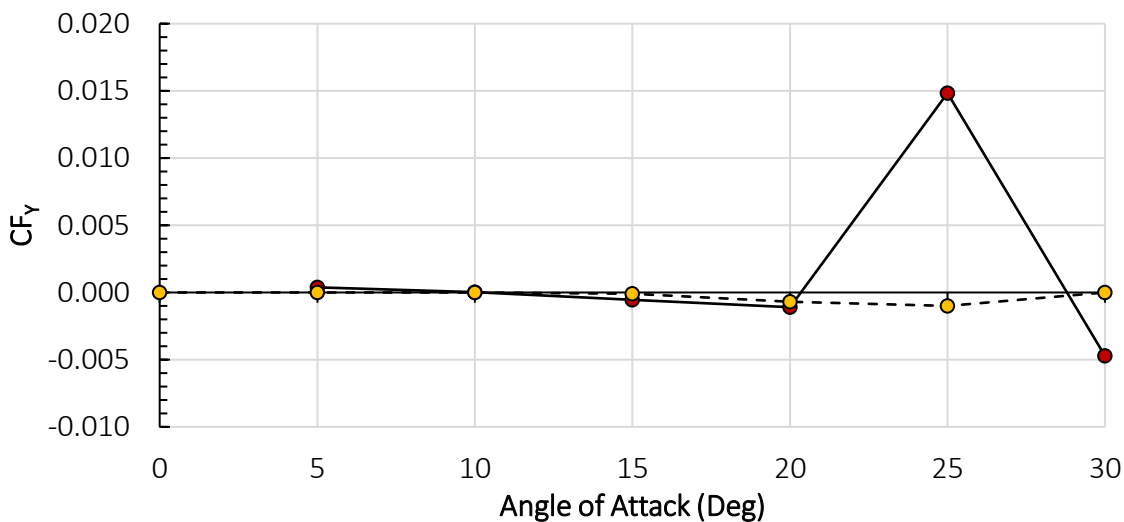
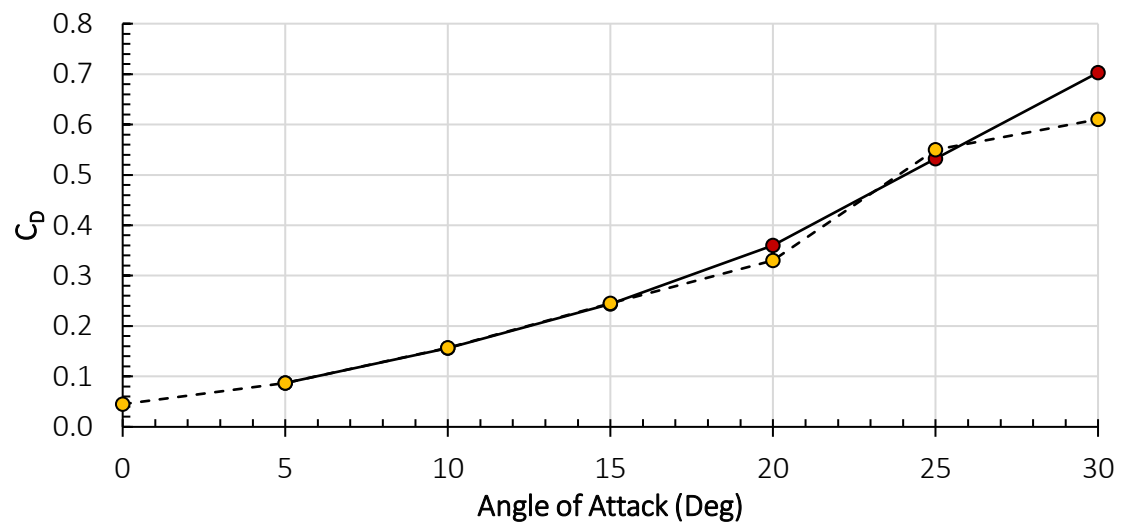
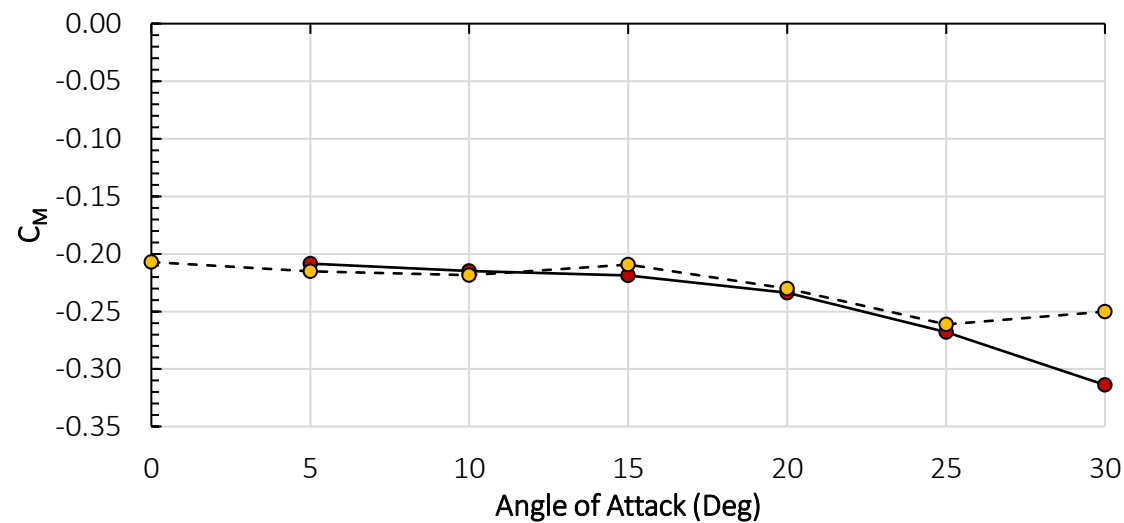
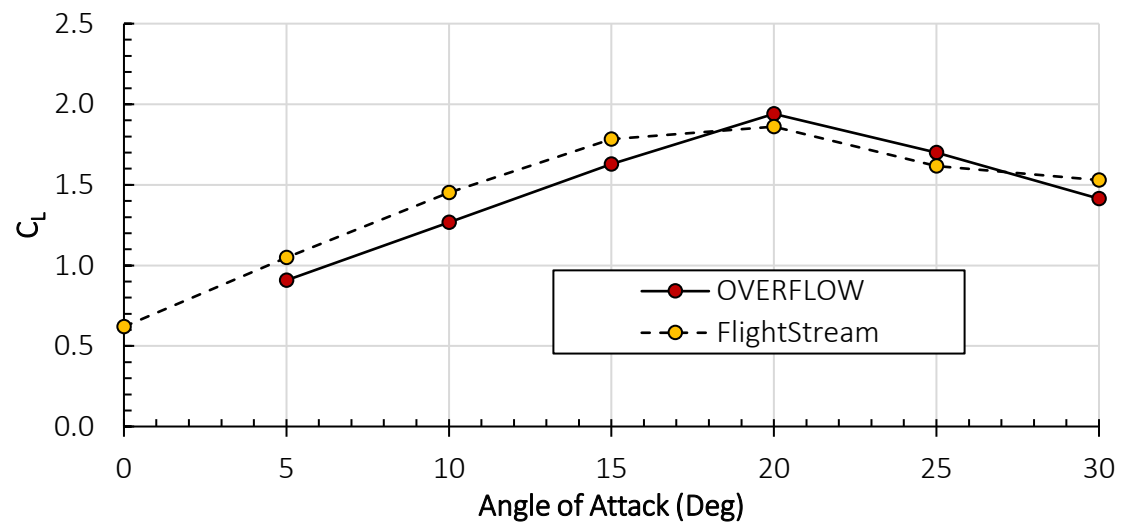
FLIGHTSTREAM TIME-VARYING SLIPSTREAM



UNBLOWN WING COMPUTATIONAL RESULTS



HLP+WING COMPUTATIONAL RESULTS



CONCLUSIONS

- This paper is a summary of the ongoing activity.
- Initial results support the validity of applying mid-fidelity tools like FlightStream in early-design stages alongside more detailed CFD tools for complex cases, such as propeller-blown wings.
- Future work is focused on the comparison of flow data, in the form of surface pressure and velocity contours, and the comparison of predicted flow separation characteristics in both tools.
- The OVERFLOW data will be expanded to include a closer resolution of the near-stall incidence angle regimes, a broader range of angle of attack both pre- and post-stall, as well as a closer investigation of some of the observed separated flow characteristics.
- Continued investigation of the recommended methods for simulating in OVERFLOW is also planned to evaluate the validity of the approach and to quantify any improvements in convergence or computational efficiency.

Special Thanks and Acknowledgments

- FlightStream developmental work performed with the cooperation and support of the NASA SBIR Office and Transformational Tools and Technologies (TTT) Project.
- OVERFLOW aspects supported by the NASA Langley Research Center Innovation Fund for Internal Research and Development, the Flight Demonstrations and Capabilities (FDC) X-57 Maxwell Subproject, the TTT Project, and the Revolutionary Vertical Lift Technologies (RVLT) Project.
- Special thanks to Joseph Derlaga, Pieter Buning, Sally Viken, Karen Deere, Neal Chaderjain, and Patricia Ventura-Diaz for supporting the OVERFLOW simulations and to Siena Whiteside for coordination of the study.



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