Flight Control Research at NASA Ames

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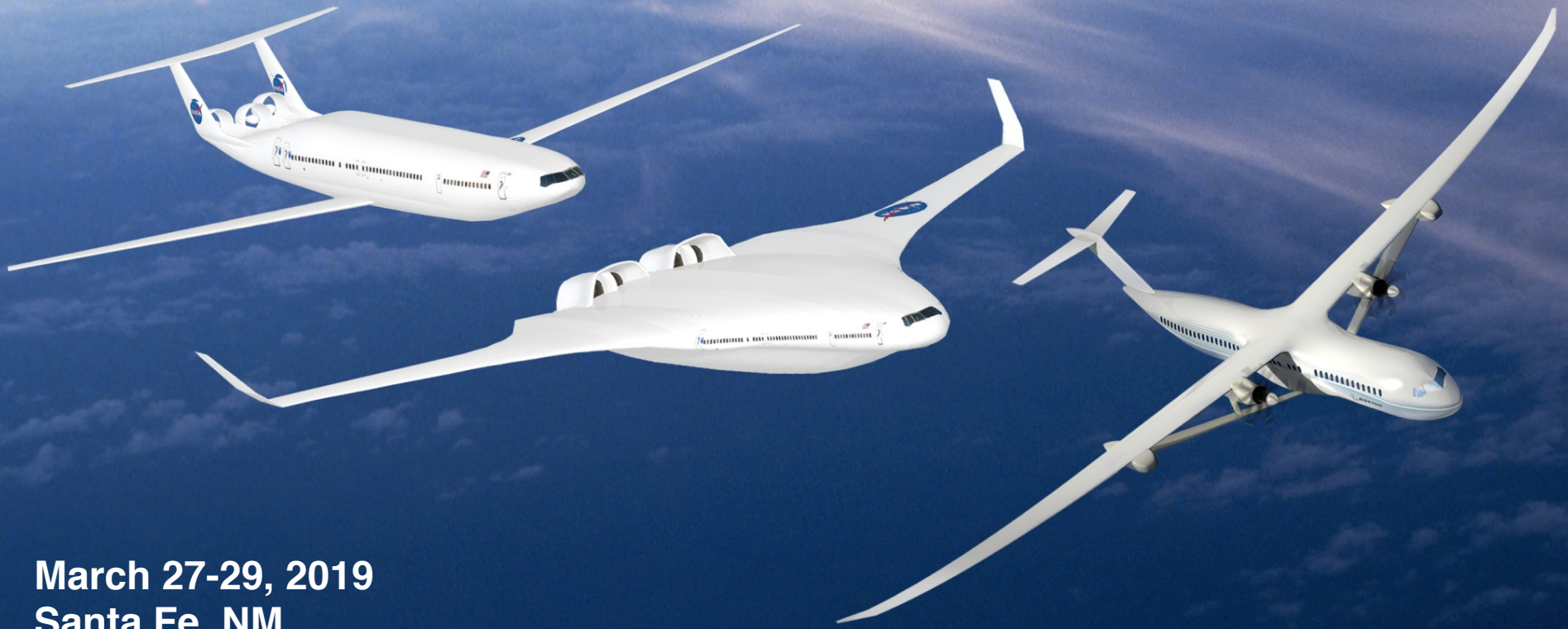
NASA Ames Research Center

ACGSC Meeting



March 27-29, 2019
Santa Fe, NM

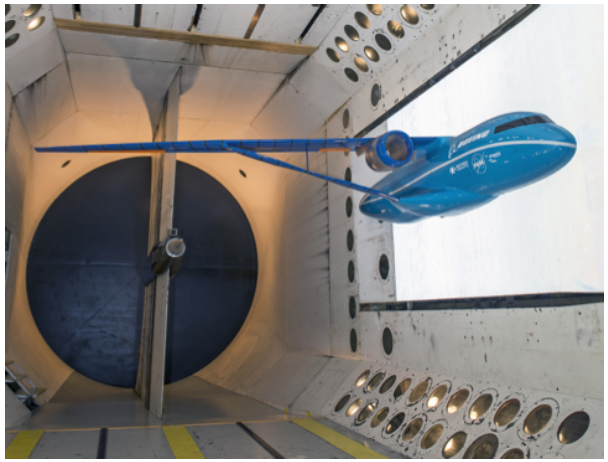
Flight Control Research at NASA Ames

Intelligent Systems Division: Advanced Control and Evolvable Systems Group (ACES)

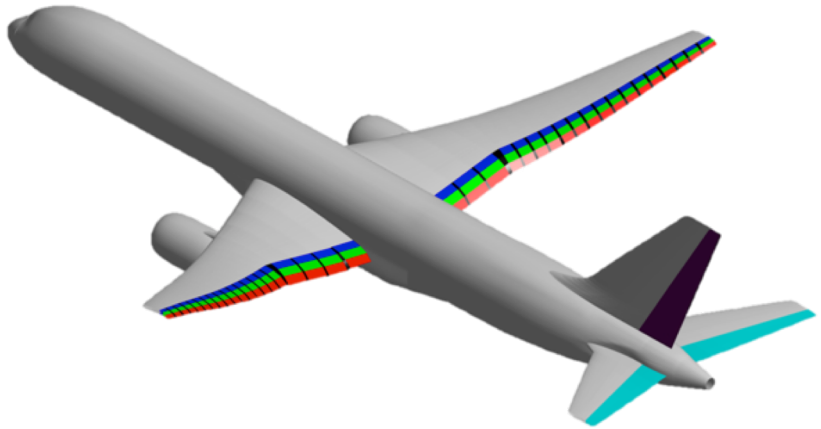
- Adaptive, robust, and optimal control
- Unmanned Aerial System autonomous operation
- Avionics architectures and processes

Elastically shaped aircraft concepts

- **Truss-braced wing ASE model development**
- **Real-time drag optimization control**
- **Multi-objective gust load alleviation control**
- **Wind tunnel demonstrations**



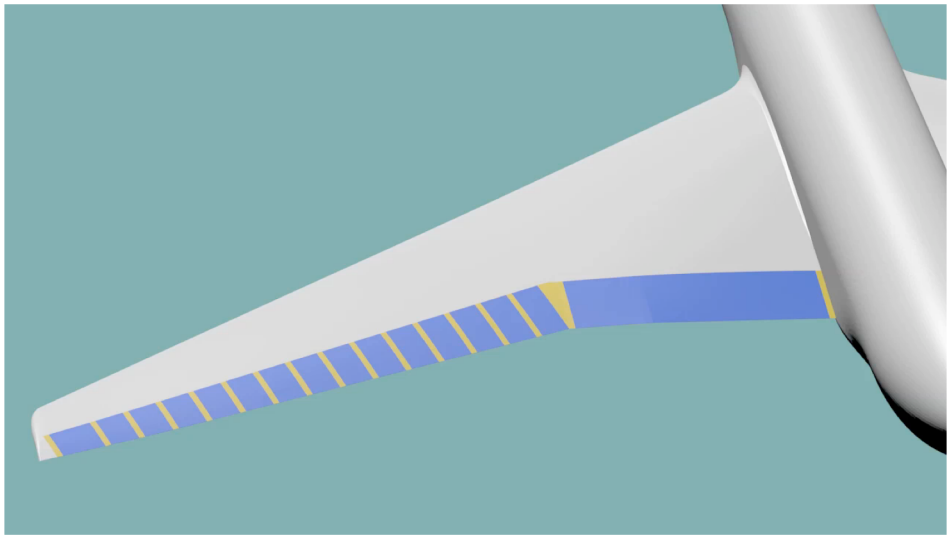
Truss-braced wing



Variable Camber Continuous Trailing Edge Flap (VCCTEF)

Elastically-shaped Aircraft Research

Variable Camber Continuous Trailing Edge Flap (VCCTEF) as a performance adaptive aeroelastic wing technology funded by ARMD since 2010



Partnership and collaboration

- External partners include Boeing, SSCI (Scientific Systems Company, Inc.), and University of Washington (UW)
- Cross center collaboration with NASA LaRC

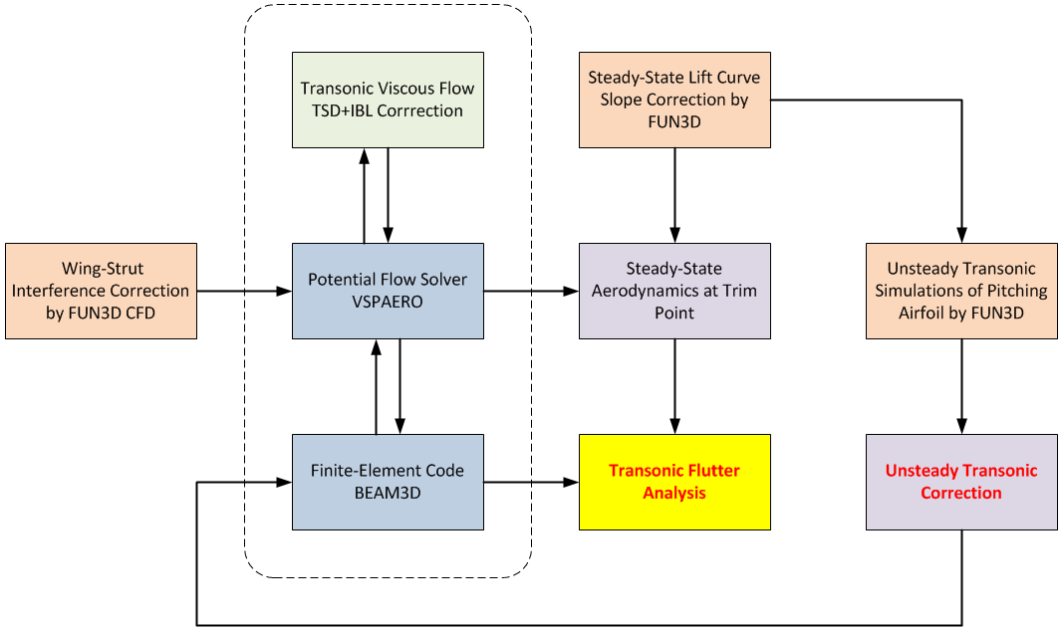
Research elements in FY 2019

- Multi-objective control for gust load alleviation (GLA) / drag optimization and wind tunnel validation
- Drag optimization of Boeing CRM (Common Research Model) aspect ratio 13.5
- Coupled aeroservoelastic flight dynamic modeling of Boeing Transonic Truss-Braced Wing (TTBW)

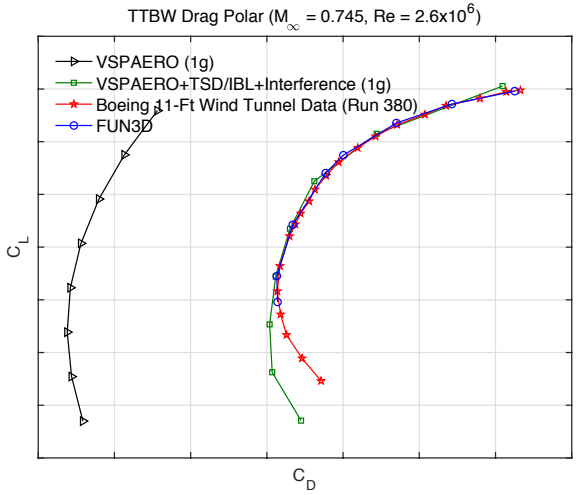
Advancing technology to TRL 5 through five wind tunnel test validation campaign

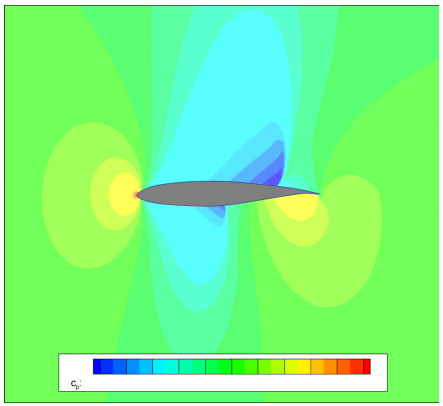
- Aerodynamic cruise drag test at UW (2013) and high lift test at UW (2014)
- Active Real-time drag optimization control test at UW (Jun 2018)
- Active GLA control tests at UW (May 2019) and in NASA LaRC Transonic Dynamic Tunnel

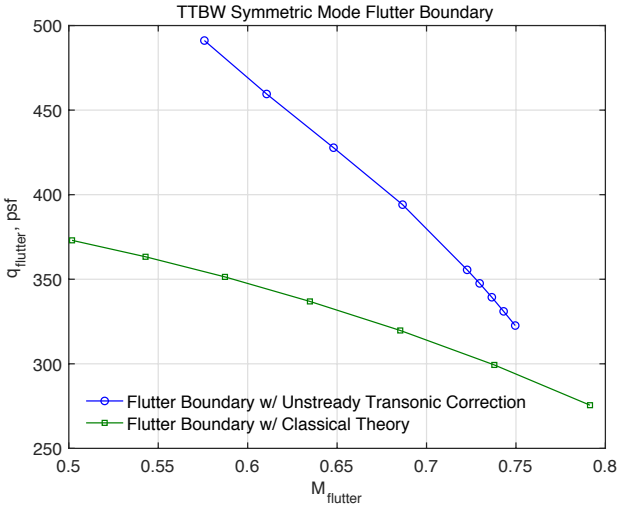
Truss Braced Wing Multi-Fidelity Modeling



- Rapid nonlinear ASE modeling technique enables transonic flutter analysis for design optimization
- Wing-strut interference requires aerodynamic correction
- The multi-fidelity modeling framework provides a means of interference correction using FUN3D CFD



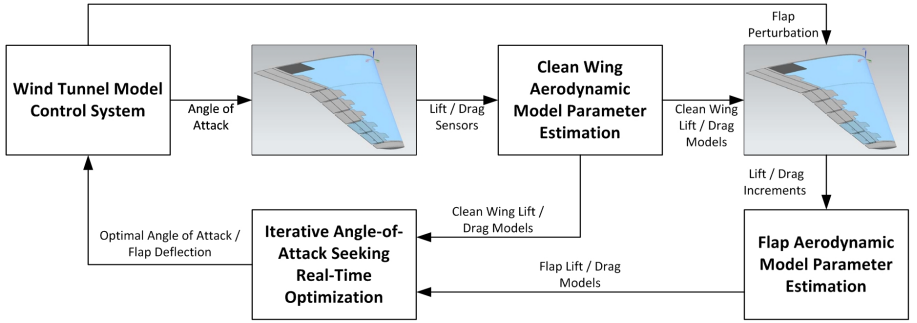




Real-Time Drag Optimization Wind Tunnel Test

- Wind tunnel CRM model
- Aerodynamic model parameter identification by least-squares
- Real-time optimization by iterative angle-of-attack seeking method
- Algorithm identified **3.9% drag reduction at off-design CL = 0.65**

	Design $C_L^* = 0.5$		Off-Design $C_L^* = 0.65$		Off-Design $C_L^* = 0.7$	
Run	C_D	ΔC_D	C_D	ΔC_D	C_D	ΔC_D
Clean Wing Run 56	253	0	330	0	382	0
Optimal Solution 1 Run 53	248	5	317	13	364	18
Optimal Solution 3 Run 54	255	-2	321	9	367	15
Optimal Solution 9 Run 55	256	-3	329	1	376	6
Pseudo-Inverse Solution 1 Run 57	259	-6	322	8	360	22
Pseudo-Inverse Solution 3 Run 58	252	1	321	9	346	36



- **<u>Impact:</u> Technology can achieve drag optimization at off-design cruise, enabling mission-adaptive wing capabilities**

Multi-Objective Control Architecture

Incremental controller development

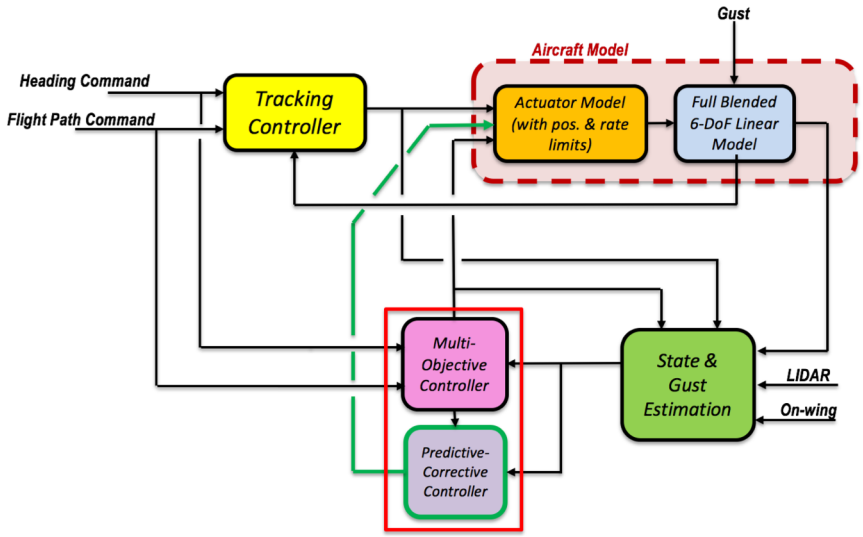
- 6-DoF tracking controller
- Multi-objective controller
- Gust prediction corrector control

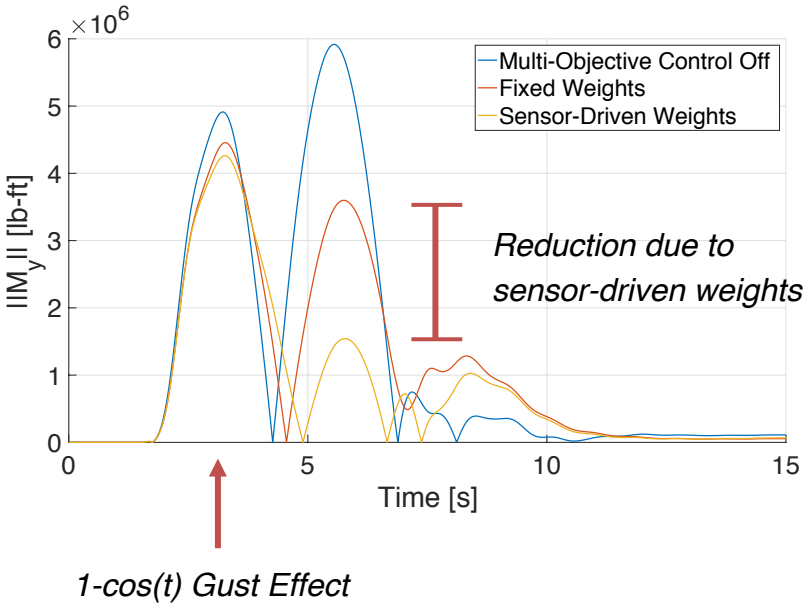
$$J = \lim_{t_f \to \infty} \frac{1}{2} \int_0^{tf} \left(x^T Q(x) x + u^T R u + q_M(x) M_y^2 + q_D(x) \Delta C_D \right) dt$$

- $q_M(x) M_y^2$: Sensor-Driven Mode Suppression
- $q_D(x) \Delta C_D$: Sensor-Driven Drag Minimization
- $x^T Q(x) x + u^T R u$: Sensor-Driven Load Alleviation

State and gust estimation methods

- On-wing reactive vs. look-ahead predictive
- Adaptive estimation
- Incorporation of FOSS measurements

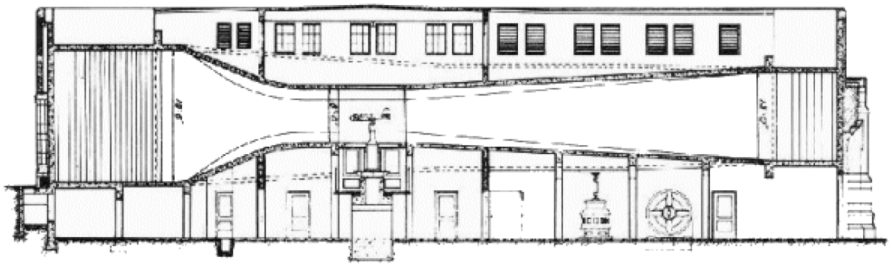




UWAL Wind Tunnel Demonstration

University of Washington test team

- SSCI, University of Washington, Boeing, NASA Ames ACES Group



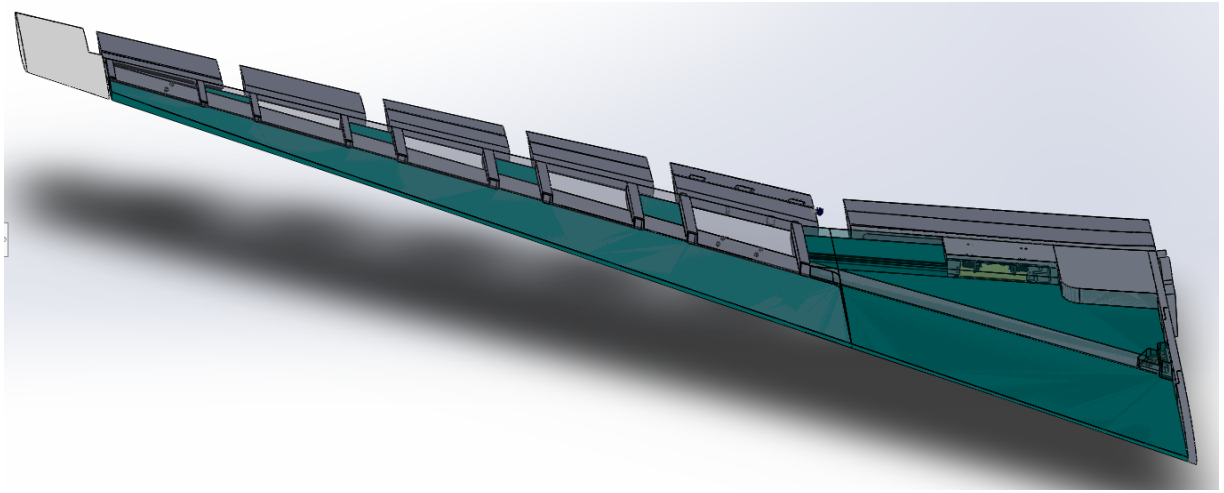
West Side View of Kirsten Wind Tunnel

Experimental description

- Objective is to demonstrate multi-objective GLA control for flexible wing
- Low speed tunnel test
- Low cost wing development and design
  - VCCTEF actuation
  - Traditional sensors only
- Gust generator development necessary

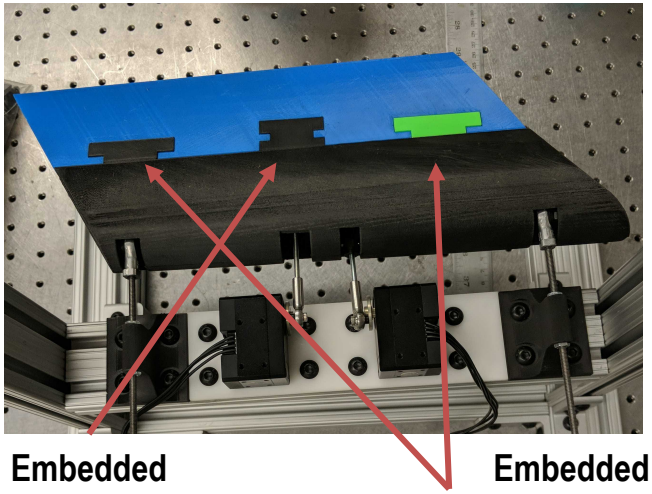
Serves as risk reduction measure for subsequent transonic IAWTM test

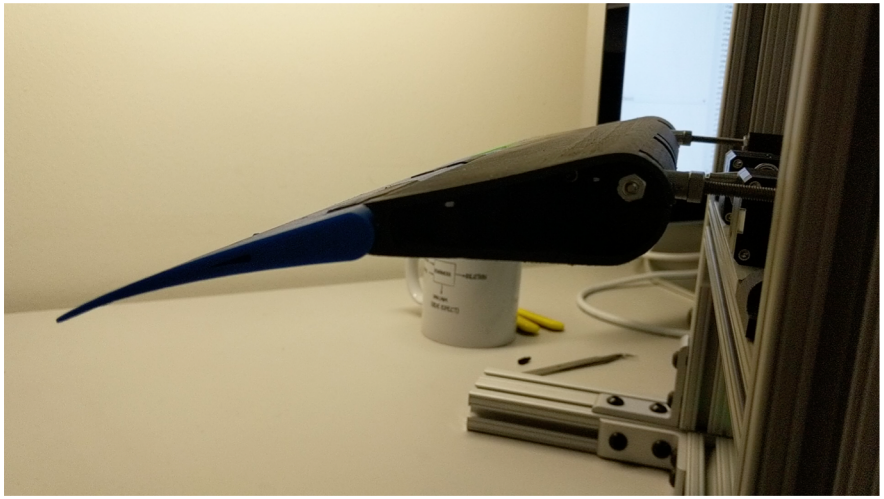
UWAL ASE Wind Tunnel Model



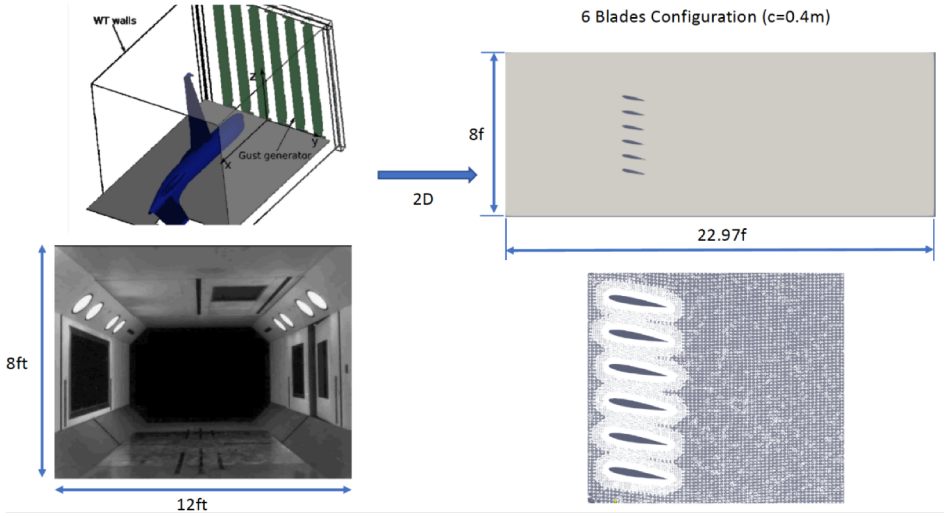
Foam base with central spar—allows for flexible structure with functional ultimate strength

VCCTEF Flap Prototype





UWAL Gust Modeling

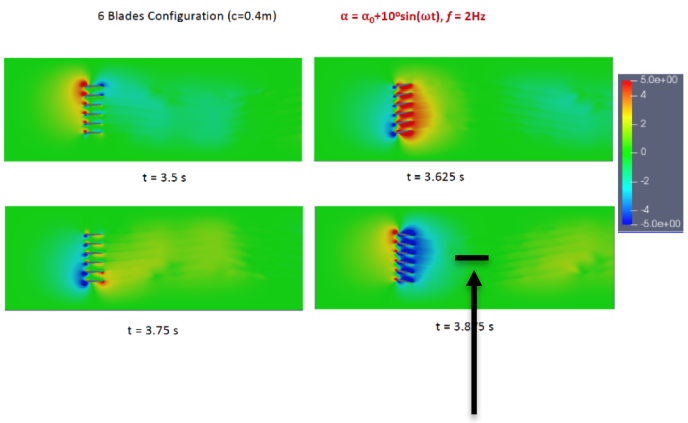


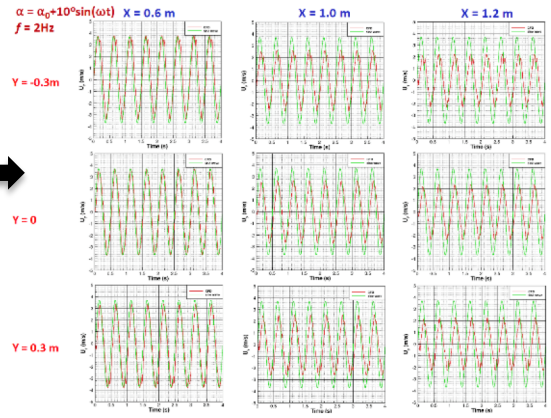
Gust model identified from CFD simulation

- Predict gust at wing from look-ahead point
- Stand in for LIDAR readings
- Facilitates accurate GLA

Translated to temporal waveform

Gust propagation model identified





$$\hat{w}_{\text{wing}} = G(s)w_{\text{ahead}}$$