Incorporating Active Flow Control technology into Aircraft Design for DARPA's CRANE Program

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23 Years Aerospace Experience

- Lockheed Martin
- Sikorsky Aircraft
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Overview

Program Objectives

CRANE Team

Problem Statement

Active Flow Control Aircraft Design

Wrap-up

CRANE Objectives

"CRANE will **design, build, and flight test an X-Plane that incorporates Active Flow Control (AFC)** as a primary design consideration."

"CRANE looks to **inject a disruptive technology** into the aircraft design process, shifting aircraft design methodology moving forward. This effort will **explore maturation of flow control technologies and design tools** to a level that allows them to be incorporated early in the design process with a confidence level that optimizes the full utilization of their benefits."

Problem Statement

Aircraft Conceptual Design +
Technology & Trade Space Exploration

Low Order Physics Models & Simulation
Multidisciplinary Design Analysis & Optimization

Modest Computing Resources
Rapid results

Active Flow Control

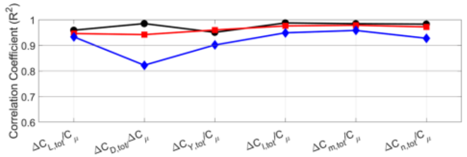
High Fidelity Physics Models
Computational Fluid Dynamics

Significant Computing Resources
Slow results

How do we integrate high fidelity physics models in rapid conceptual design studies?

Lockheed Martin Approach

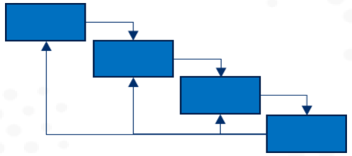
Develop an AFC-enabled **design library**



Response Surface Models

Integrate AFC Into CD Process

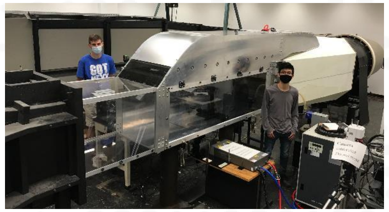
Develop AFC **design analysis methods**



MDO, S&C, FC, OA models

Deliver Trade Study Results

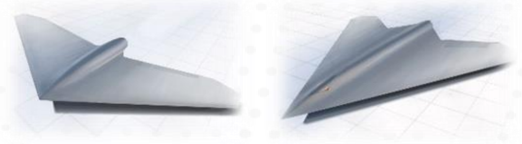
Perform **test activities** for **verification** and risk reduction



Wind Tunnel Testing

Verify, Calibrate CRANE Analytical Methods

Design, Build, Fly an AFC-enabled X-plane to verify methodology and demonstrate novel mission capabilities



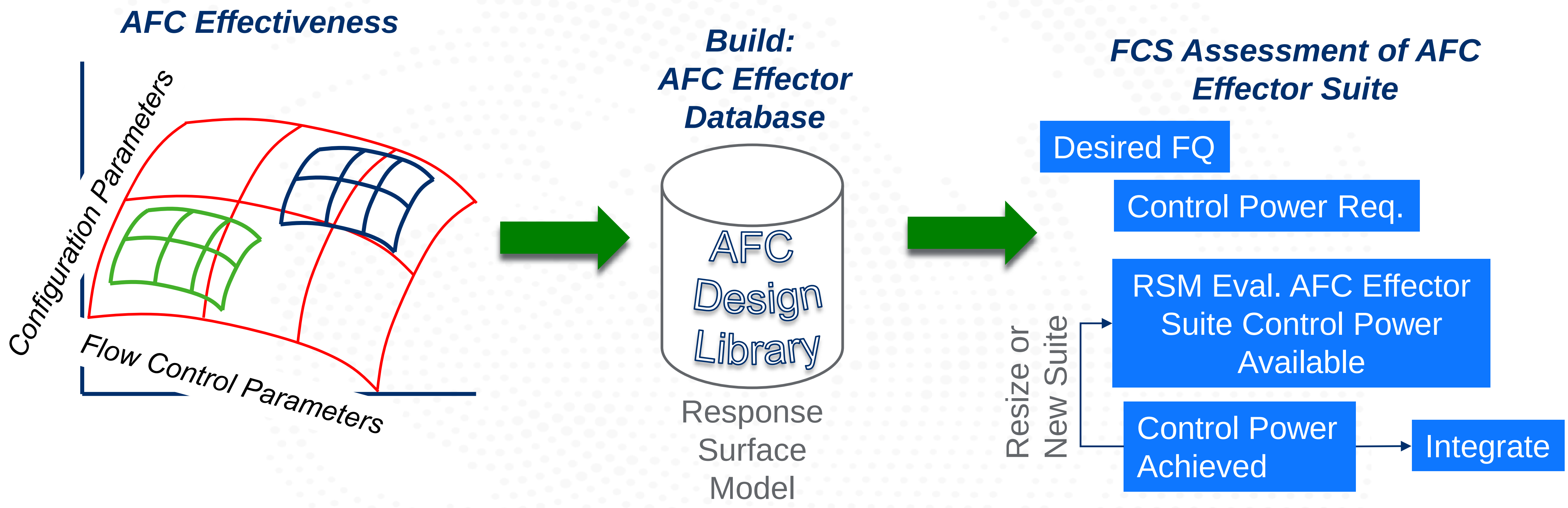
X-Plane Development

Demo CRANE Capabilities

Advancing Methods for AFC-Enabled Aircraft Design and Analysis

AFC Aerodynamic Design Library Development

Develop Parameterized AFC Aerodynamic Databases for Control Effector Suite Integration and Sizing

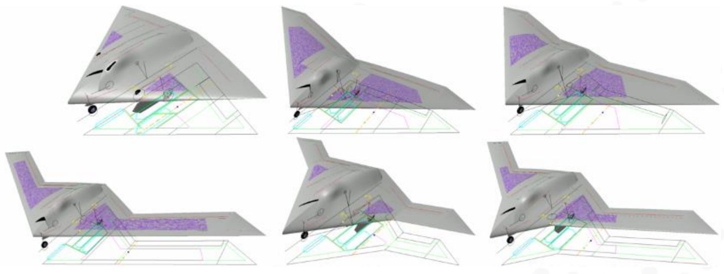


DOE Yields Aerodynamic Database Vital to Flight Control Simulations and Control Effector Suite Sizing

AFC Aero Design Library – Large Design Trade Space

Configurations

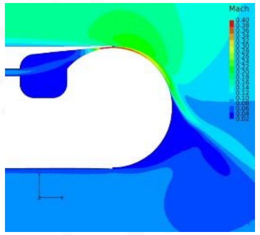
- Various Planforms
- Various Wing geometries



Flow Control Techniques

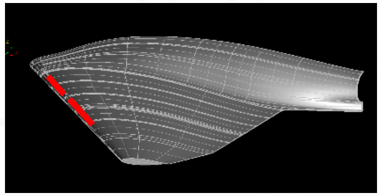
TE Coanda Blowing

- High Lift
- Control Power
- *Only Select Cases to date*



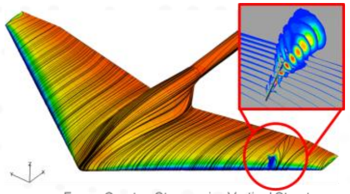
LE Tangential Blowing

- High Lift
- Control Power



Fluidic Fences/Spoilers

- Decoupled Control Power
- High AOA stability


Fence Creates Streamwise Vortical Structure

Design Variables

Design Variables	Type
LE Sweep (deg)	Wing
TE Sweep (deg)	
Span	
Taper	
Twist (deg)	
Dihedral (deg)	
….	
T/C (%)	Airfoil
X_t/c Max Location	
LE Radius	
Camber	
…	
Type(s)	Flow Control
Exit Geometry (slot …)	
Exit Area (in2)	
X,Y, Z Location	
Injection Angle - Pitch (deg)	
Injection Angle - Yaw (deg)	
Sweep (deg)	
Effector Span Fraction	
Amplitude/Span (lbs/sec)	
Frequency (Hz)	
…	
Angle of Attack (deg)	Flight Condition
Sideslip (deg)	
Ground Effect (H/b)	
Mach	
…	

Central Composite Design DOE Matrices

- 3 factor / 3 level
- 4 factor / 3 level

Response Surface Models Derived from 50+ DOE Studies – Large Multivariate Trade Space

Computational Methods for AFC Aero Data

AFC Utilizes time-accurate CFD simulations to Capture Unsteady Effects

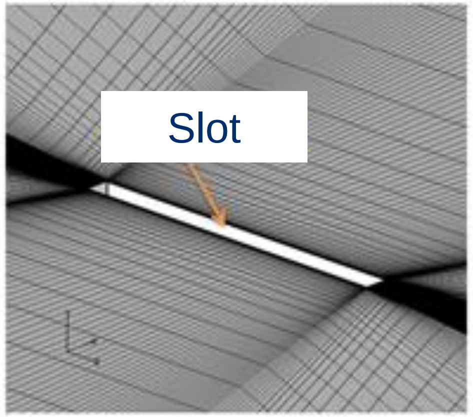
- In-loop Time Accurate CFD Does Not Meet MDAO Conceptual Design Cycle Time Scales

Calibrated Time-averaged Source Models suitable for Conceptual Design environments

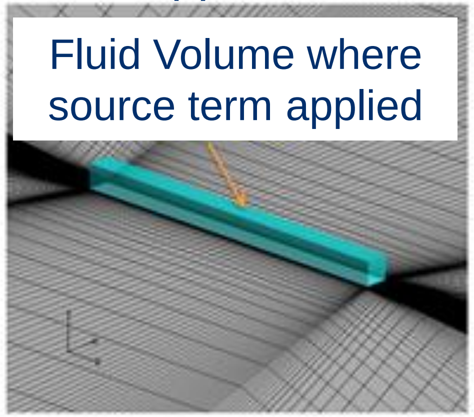
- Use steady-state CFD to facilitate optimization and reduce reliance on time accurate simulations during conceptual design
- Source term approach imparts time averaged body forces to the flow field
- Examples include: Steady Jets Pulsed Jets Vortex Generators

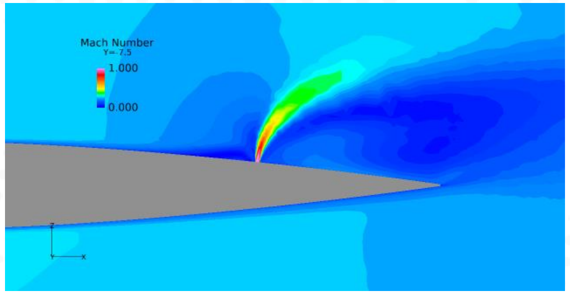
AFC RSMs useful for control effector suite selection and sizing to meet flying quality requirements

Gridded Slot

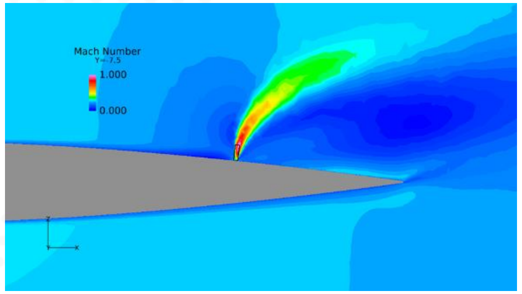


Source Volume Approach





Gridded Jet



Body Force Model

Calibrated AFC Effector Models Accelerate Development of AFC Aero Database

ERDC HPC Partnership

ERDC ITL
INFORMATION TECHNOLOGY LABORATORY

Use of USG-provided HPC resources

- Augmented LM HPC resources

Using LM & Commercial Codes

- Falcon, Splitflow, Pointwise, Fieldview

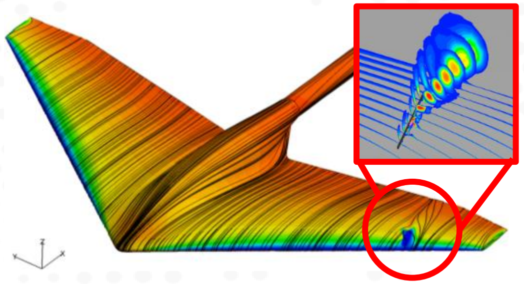
Mix of RANS and time accurate solutions

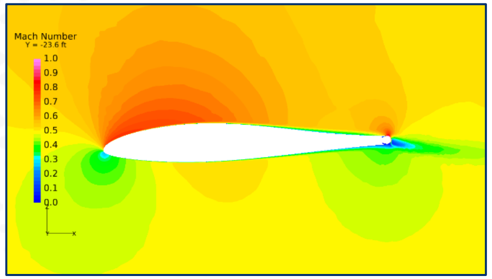
Focus areas:

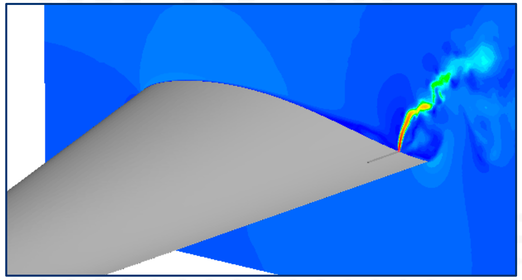
- AFC Effector Suite Design
- Aerodynamic database for X-plane
- AFC Modelling and Verification

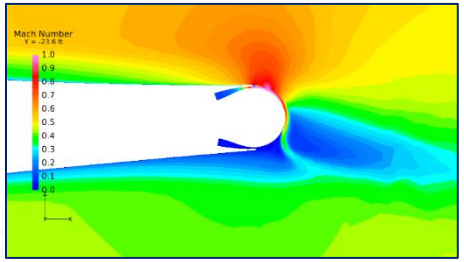
ERDC team helpful and responsive

> ½ of 6000+ CFD jobs run on "Jim"









ERDC Cluster ("Jim") enabled rapid CFD analyses & RSM development

USG-Provided HPC Resources is a Useful Model for Future Development Efforts

Conceptual Design & Analysis Methods for AFC-Enabled Aircraft

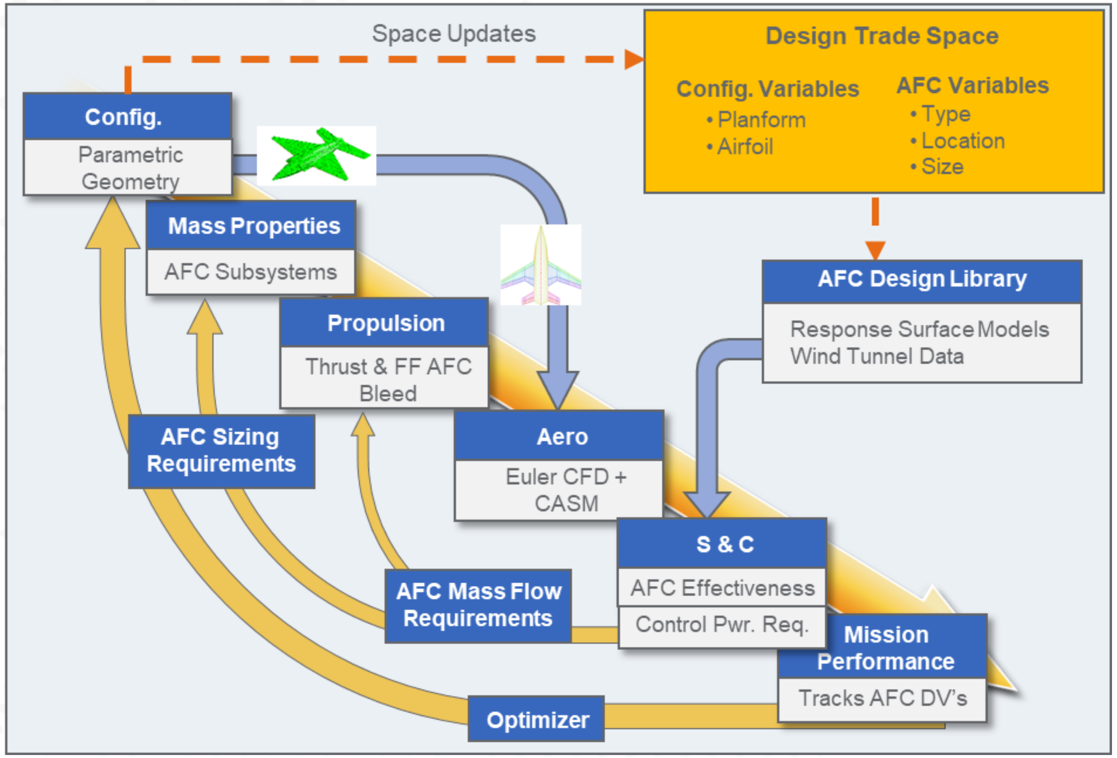
LM Approach to AFC-Enabled Conceptual Design

Run high fidelity Aero analysis offline

Utilize RSM to integrate AFC aero into design loop

Explore Design Space, Conduct Trade Studies

Assess Vehicle level impact, Mission Effectiveness



Key Considerations:

- AFC Aerodynamic effects in sizing
- Engine bleed effects
- Air supply architecture
- Control Power & Maneuverability
- AFC Effector S&C Metrics
- Operational Utility

AFC Effects Need to be Implemented in the Conceptual Design Sizing Loop

Key Physics Models modified for AFC

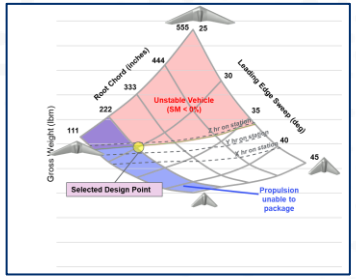
Conceptual Design Tools
- Incorporating AFC forces and moments into aero, S&C models
- AFC sizing, weight estimation, layouts, trades
- Propulsion impacts with AFC

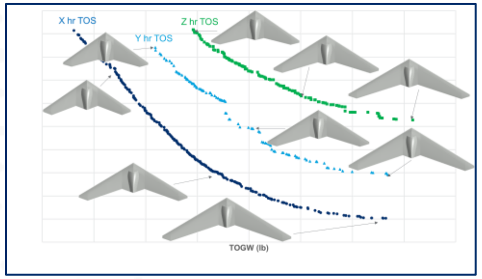
Stability and Control Models
- Control Power Required and Control Power Available with AFC

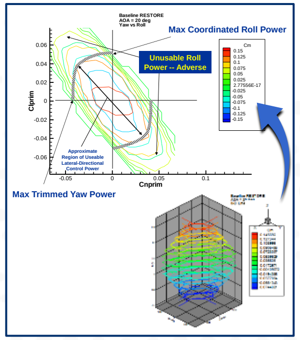
Propulsion System Modeling
- Engine Bleed studies

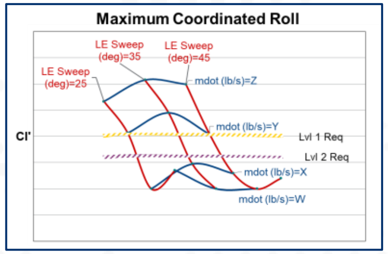
AFC Subsystem Modeling
- Air Source trades
- Turbo Machinery modeling and simulation
- Duct losses, Valves, Dynamic Simulations

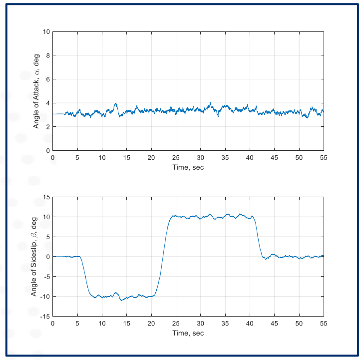
Flight Control Modeling and Simulation
- Matlab Simulink models tailored to use aero data and coefficients due to AFC effectors

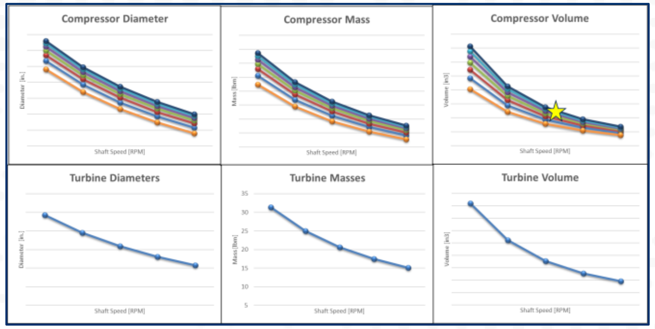


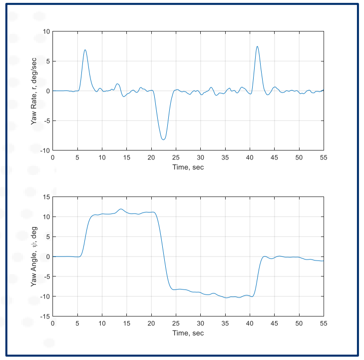












Modification of AC Design Physics Models is Key to Advancing AFC-enabled Aircraft Design

AFC Test & Verification

LM CRANE Test & Verification Approach

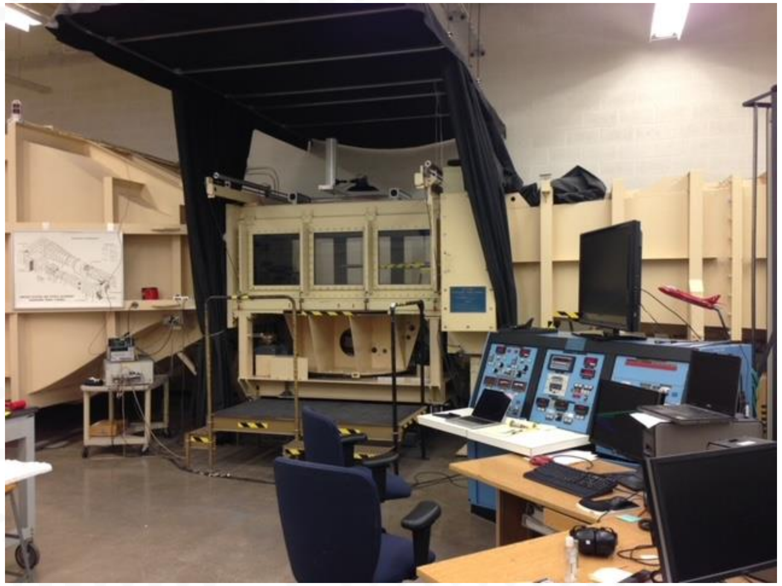
Test activities critical to:

- Validate modeling and simulation
- Burn down technical and programmatic risk

Utilize affordable and agile partners where possible

Address unique challenges:

- AFC Aerodynamics
- AFC Scaling (tactically relevant size & performance)
- AFC Airworthiness
- AFC Flight Controls/CLAW



USAFA Subsonic WT

Small & Med Wind Tunnel Testing
AFC Aero Database

→ **Foam Model Flight Testing**
RPV Risk Reduction

→ **RPV Design, Flight Testing**
AFC Flight Controls

→ **Large Scale Aircraft Wind Tunnel Testing**
AFC Scaling, Aero data, Flight Controls

LM approach focuses on critical AFC challenges and path to airworthiness

Wind Tunnel Testing

Several Vehicle and AFC configurations tested

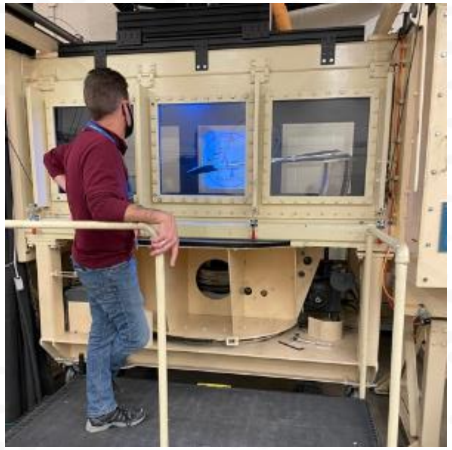
Experimental database to verify numerical simulations

Document control power available (multiple configs)

Quantify aerodynamic, actuator momentum, and internal pressurization effects

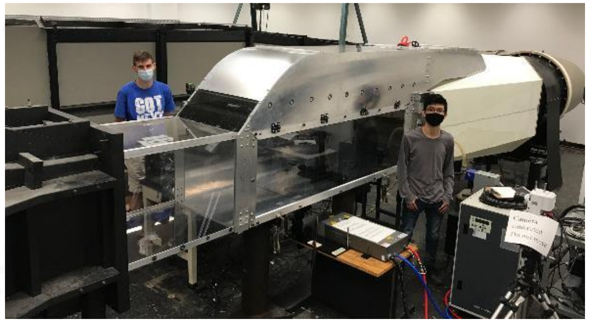
Use variable-fidelity wind tunnels to explore broad parameter space while focusing resources onto most effective control effectors

Develop aerodynamic database for flight controls



USAFA Subsonic WT
Med scale, med fidelity

Beech Memorial WT
Large scale, high fidelity



Fejer Unsteady Flow WT
Small scale, low fidelity

Wind Tunnel Testing serves a critical role in AFC development

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Wrap Up

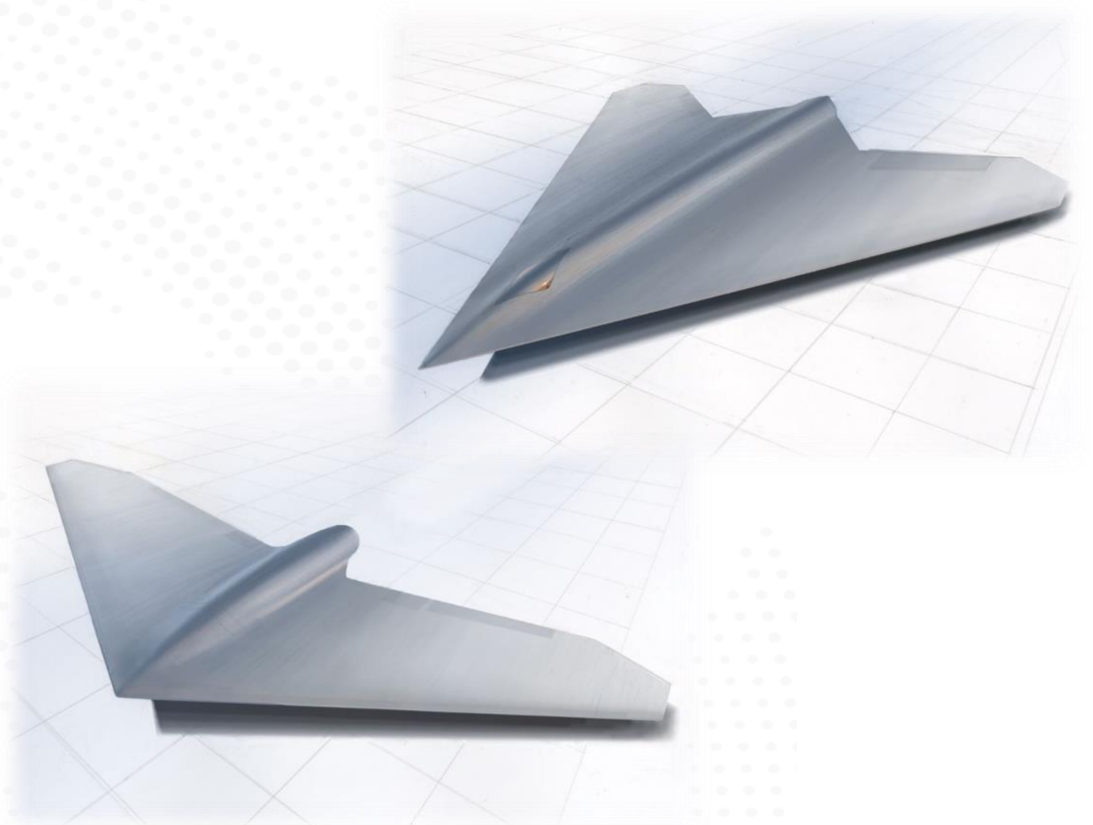
Challenges exist to merge low and high fidelity methods to properly study AFC

AFC aerodynamic database is essential

New Design Engineering methods required for AFC-enabled aircraft design

Test activities are critical for verification, risk reduction

AFC X-Plane will be first demonstration at relevant scale



Active Flow Control offers potential to revolutionize next generation aircraft design

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