Barron Associates, Inc.
Selected Current Research

SAE International
Aerospace Control & Guidance Systems Committee

Lake Tahoe, NV
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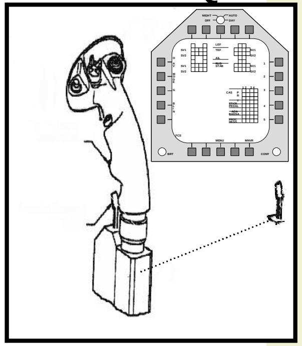
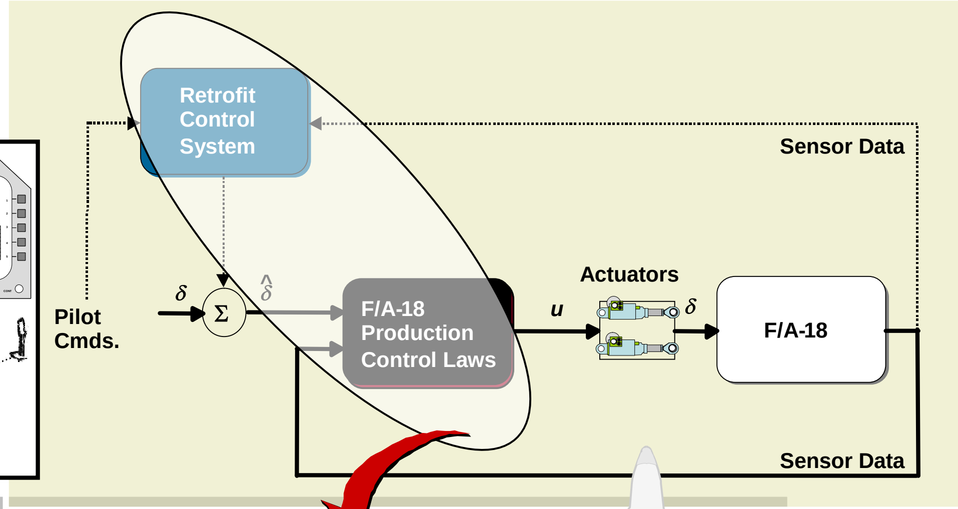
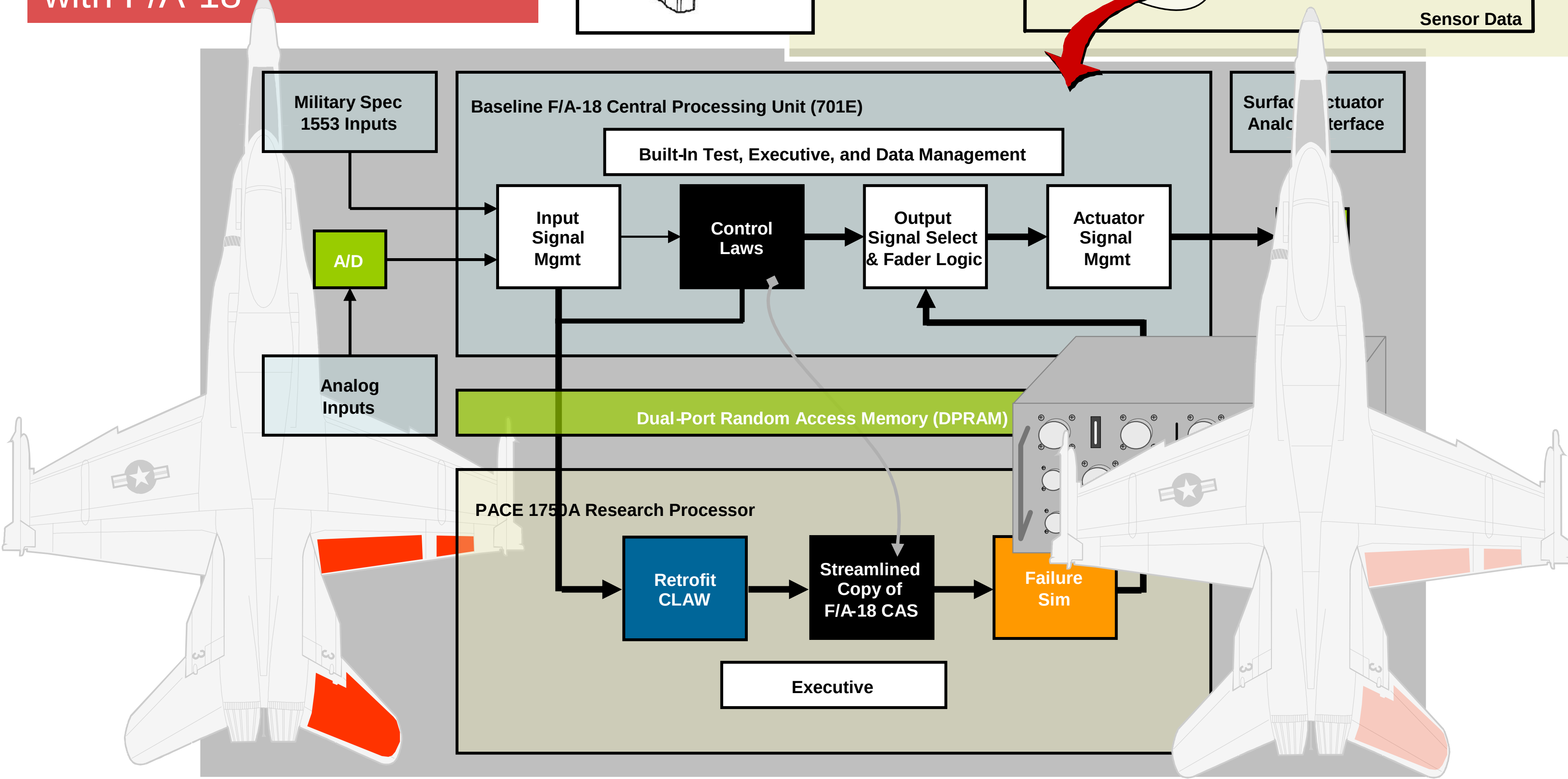
F/A-18 Flight Controls Retrofit

NAVAIR SBIR Phase II and Phase III IDIQ

Implemented in US Navy Fleet Support Flight Control Computer (FSFCC) for Seamless Integration with F/A-18







Initial F/A-18 Flight Test Program Completed

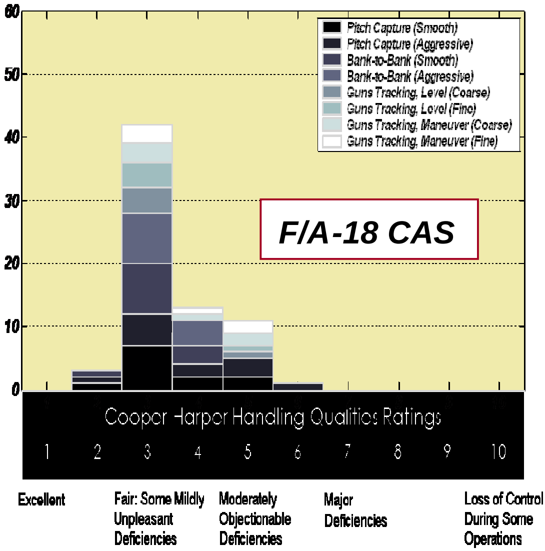
Retrofit Reconfigurable Control Systems

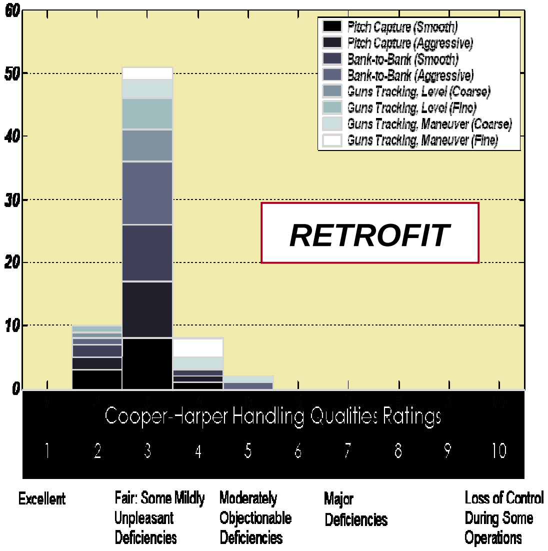
COTR: Dr. Anthony Page, NAVAIR 4.3.2.6

Scope: 4 flights including …

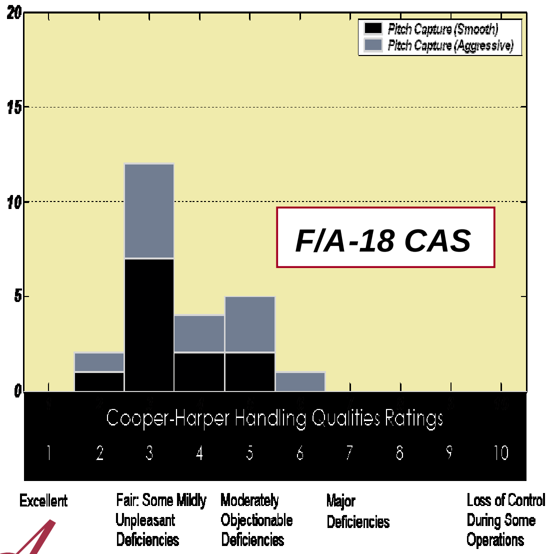
- FCs: Up-and Away / Powered Approach
- Failures: R/H Stabilator and R/H Aileron
- Maneuvers: Doublets, Captures, Target Tracking

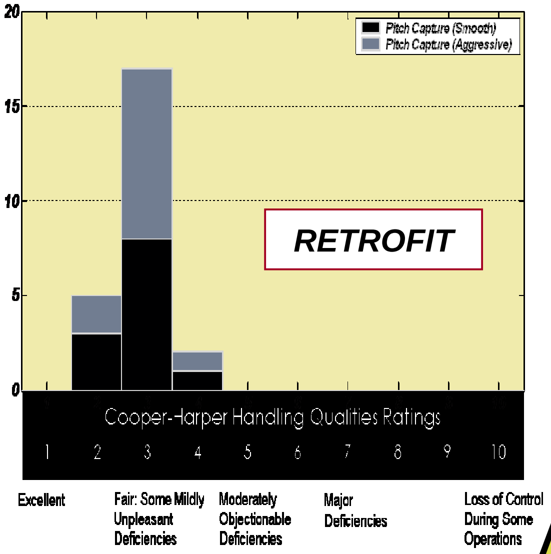
Benefits most pronounced for moderate (less-than-full) amplitude maneuvering with severe failures





Pilot A: Flights 1-3





Pilot B: Flight 4

Summary (UA Cases)

"Overall [airplane with retrofit] much more controllable …"

"For general flying qualities, 2 HQR points improvement overall"

"Being able to fly in general w/o retrofit: HQR 5 to 6"

"With retrofit – HQR 3 to 4"

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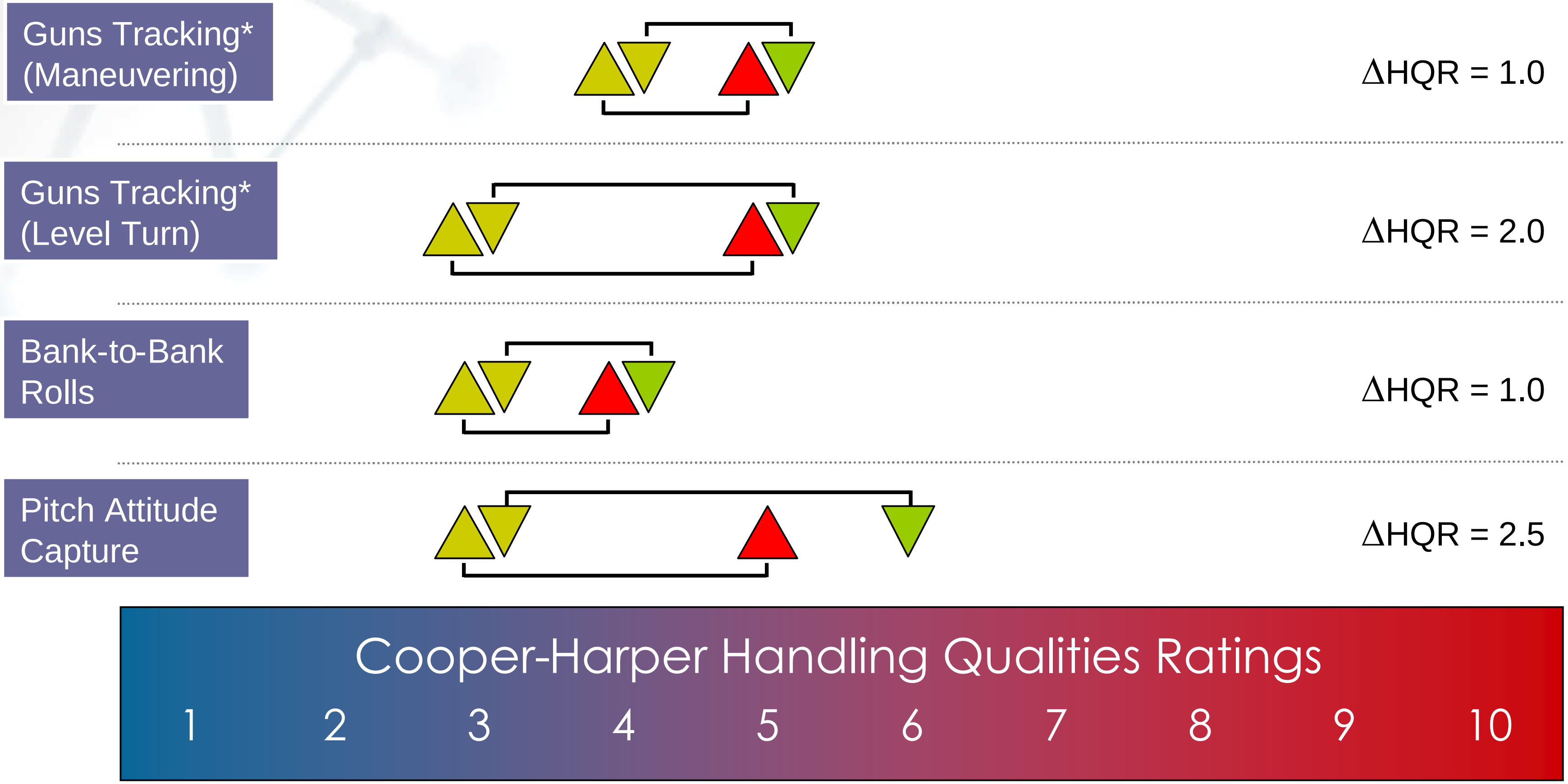
Average ΔHQR = 1.6

Flight Results: 30° Aileron Failure (UA)



Excellent

Fair: Some Mildly Unpleasant Deficiencies

Moderately Objectionable Deficiencies

Major Deficiencies

Loss of Control During Some Operations

Legend

- ▲ Retrofit – Smooth Mnvr. / Coarse Tracking
- ▼ Retrofit – Aggressive Mnvr. / Fine Tracking
- ▲ V10.1 CAS – Smooth Mnvr. / Coarse Tracking
- ▼ V10.1 CAS – Aggressive Mnvr. / Fine Tracking

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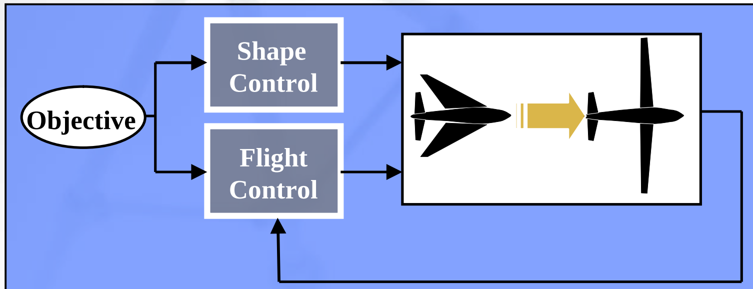
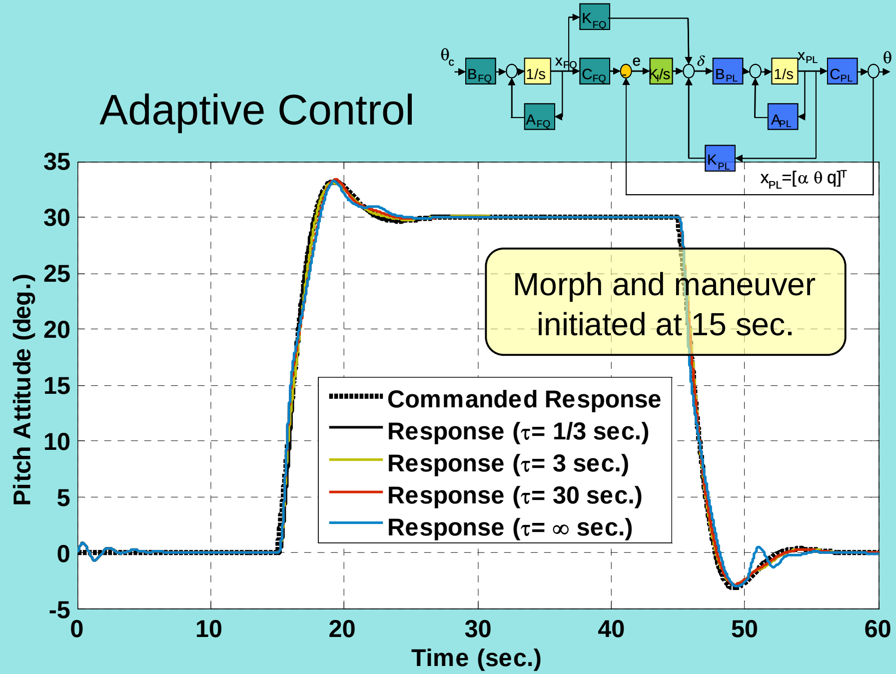
Adaptive Control of Morphing Aircraft



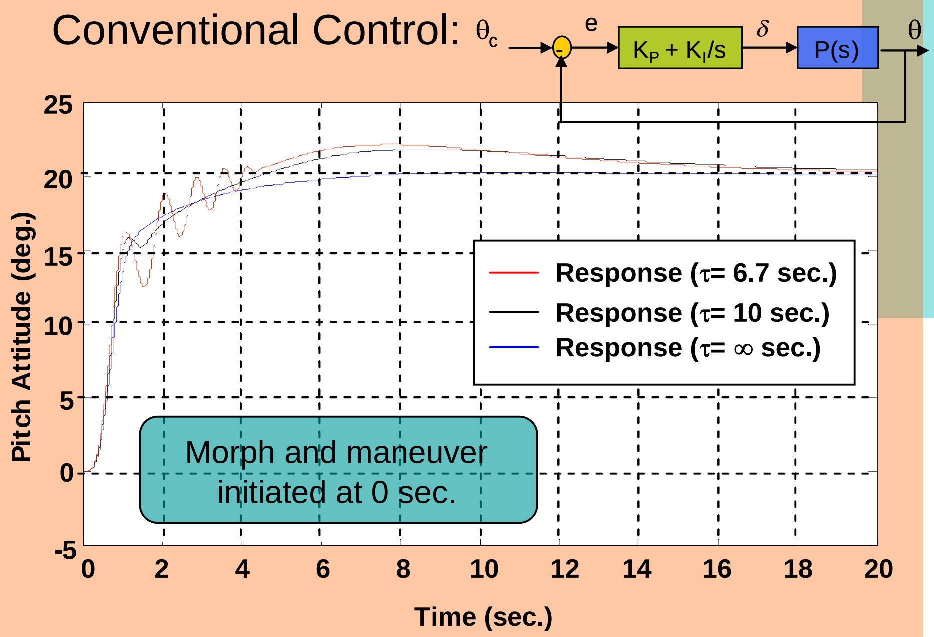
Goal: Stable flight control with limited model knowledge during wing-shape morphing

Adaptive Control



Result: Consistent stable response

Conventional Control:



Result: Inconsistent response and instability for faster morph times (τ>6 sec.)

AF SBIR Phase II

- *With*
  - NextGen / Northrop Grumman / VA Tech
- Bryan Cannon, COTR

Demonstration Goal

- Real-time wind-tunnel demonstration of stable morphing control using N-MAS wing

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High-Speed Supercavitating Torpedo

Challenges

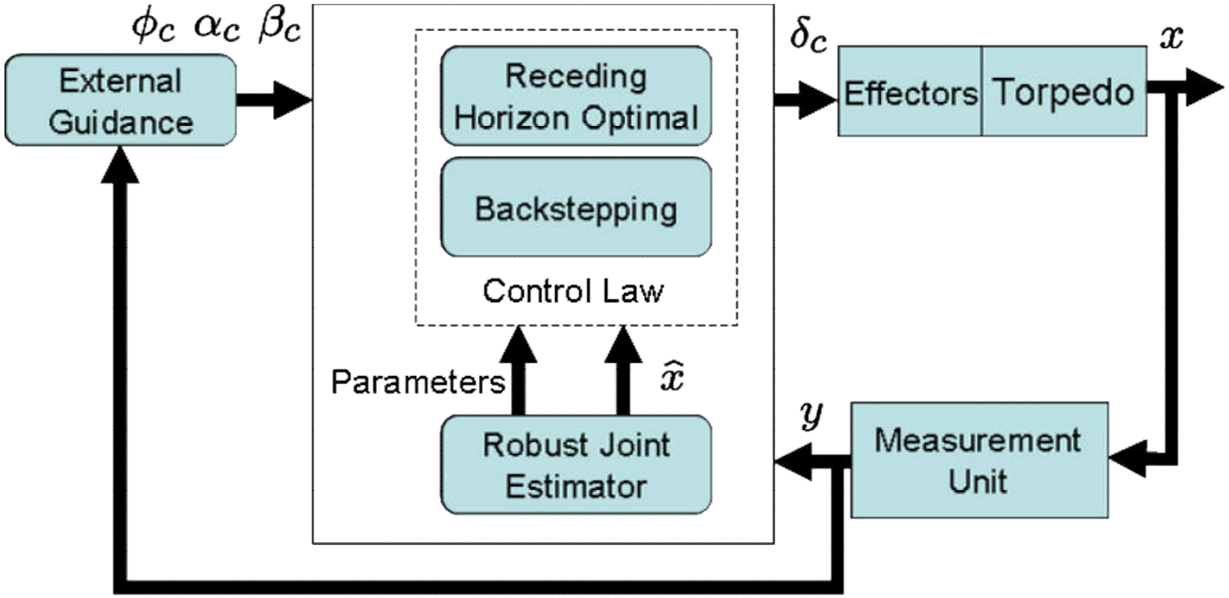
- **Memory Effects:** cavity shape and flow evolve as functions of current and prior motions
- **Output Feedback:** unknown states and uncertain parameters must be estimated
- **Other Important Considerations:** center of gravity aft of center of pressure, absence of lift, etc.

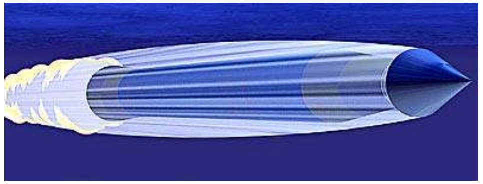
ONR Phase II SBIR

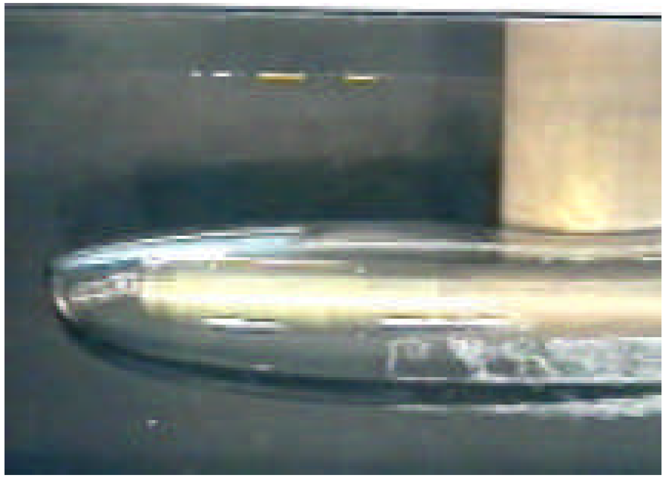
- With Anteon, U. Minn (Balas)
- Kam Ng, COTR

Demonstration Goal

- Real-time HIL water-tunnel demonstration







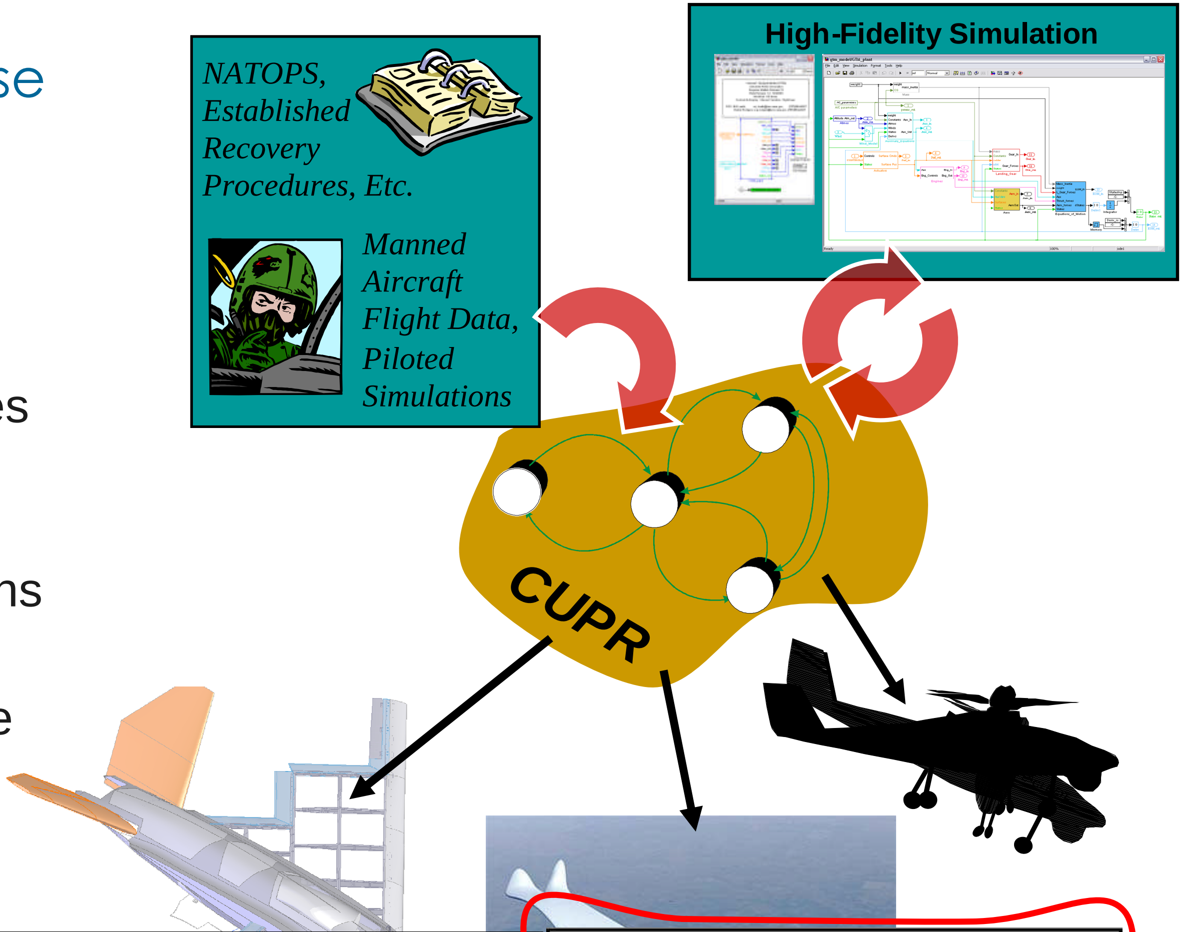
Collaboration w NASA LaRC
(Drs. Christine and Celeste Belcastro)

UAV Upset Recovery Control Systems

COTR: Mr. Jim Busey, NAVAIR

Develop a general-purpose automated-recovery system approach that

- learns appropriate recovery strategies
- adopts/encodes best-practices from the manned aircraft community
- avoids out-of-control conditions to the extent possible
- takes advantage of innovative actuation concepts



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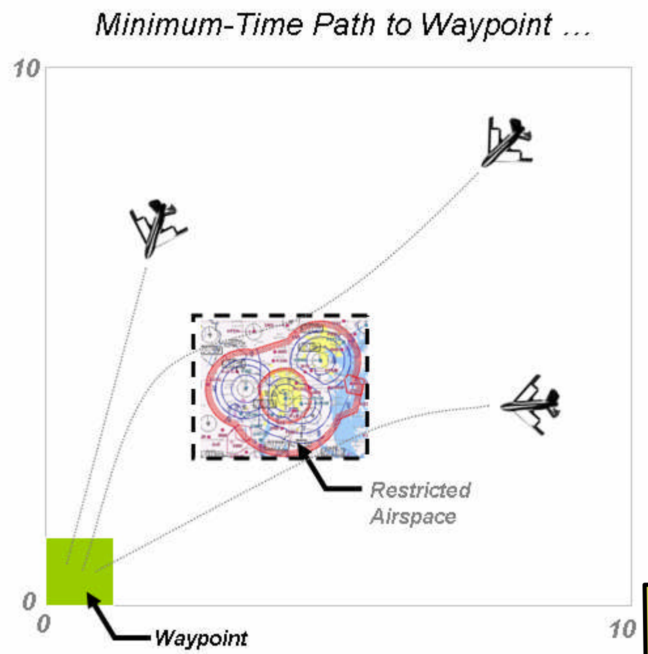
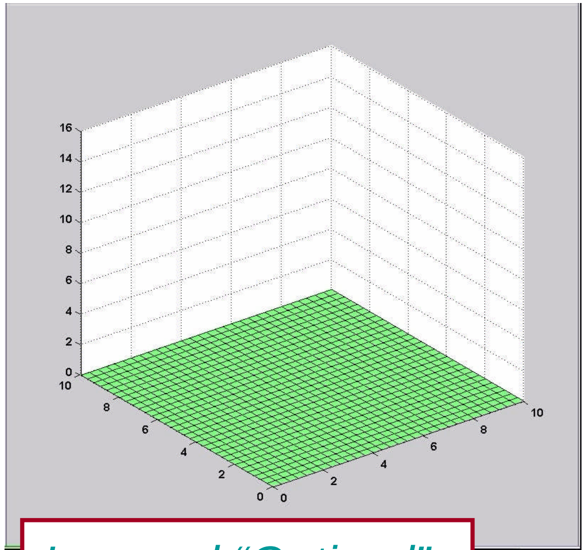
UAV Upset Recovery Control Systems

COTR: Mr. Jim Busey, NAVAIR

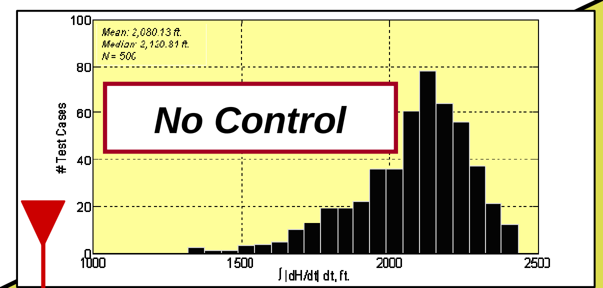
A First Example, Pulling Core Technologies Together:

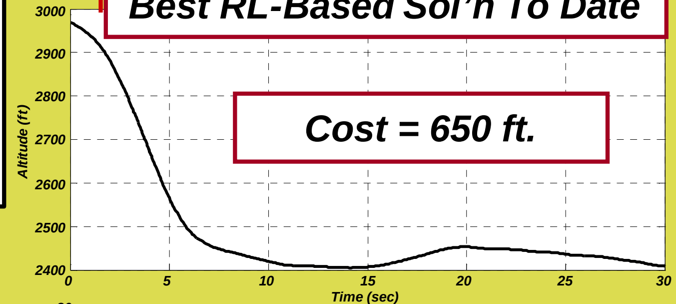
Structure-Learning Value Function Approximation & RL

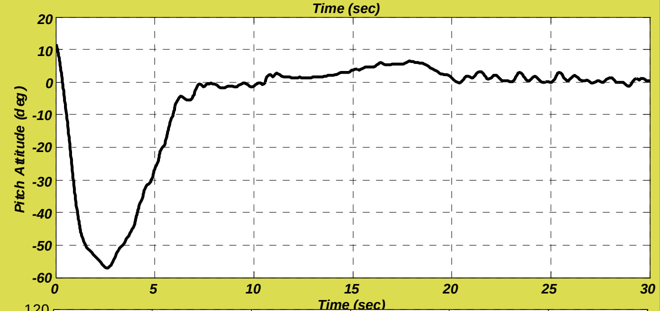


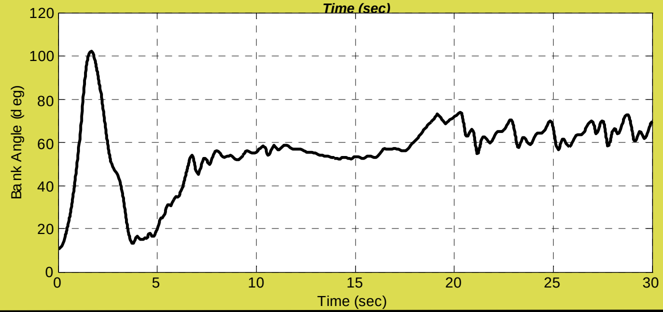


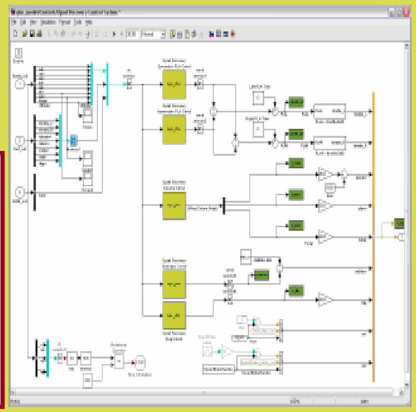
Learned "Optimal" Value Function











Upset Recovery Example

NASA GTM UAV

$$\min\left(\int |dH/dt|\,dt\right)$$

RL-Based Control of GTM Elevators/Ailerons viaRemote Pilot Command Paths

Application Testbeds

Two UAV platforms to develop upset recovery & prevention control designs …

National Aeronautics and Space Administration

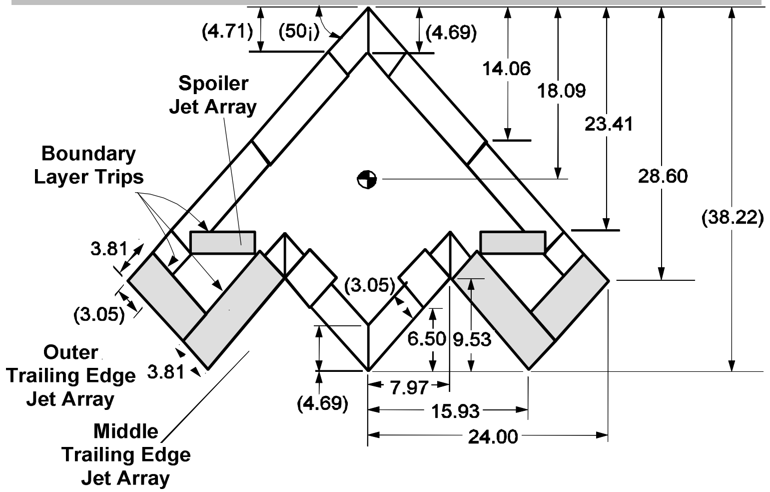
NASA Langley 757 Research Aircraft and 5.5% Remotely Piloted Research Aircraft

Control Algorithms Only (A) … *Algorithms + Add-On Aero Control Surfaces* (B)

Increased Departure Resistance, Performance, Etc.

BANTAM UCAV

Barron Assoc. Nonlinear Tailless Aircraft Model



Control Algorithms Only (A) … *Integrated Control Algorithms and Novel Devices* (C)

Increased Departure Resistance, Performance, Etc.

… Scalable control system architecture

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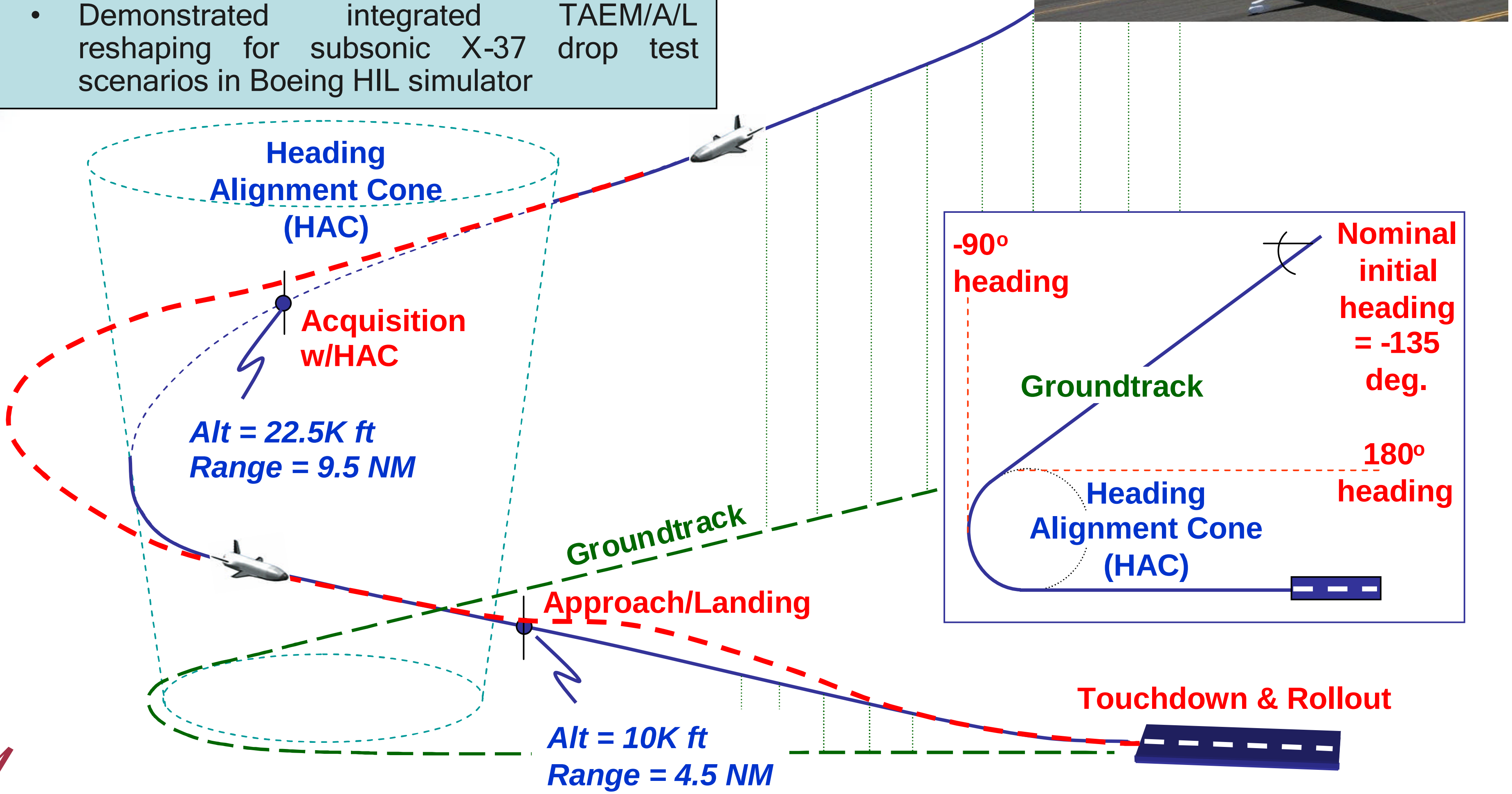
Adaptive RLV Guidance, Control, and Trajectory Generation

AF SBIR Phase III Enhancement

- With Boeing
- David Doman, COTR

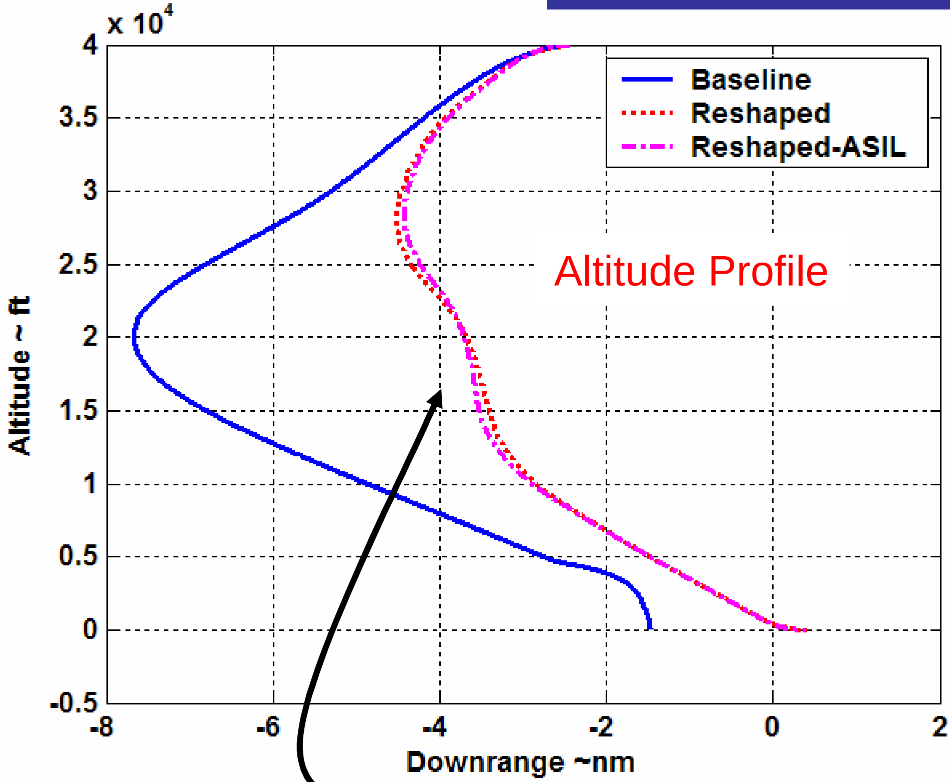
Demonstration Goal

- Demonstrated integrated TAEM/A/L reshaping for subsonic X-37 drop test scenarios in Boeing HIL simulator

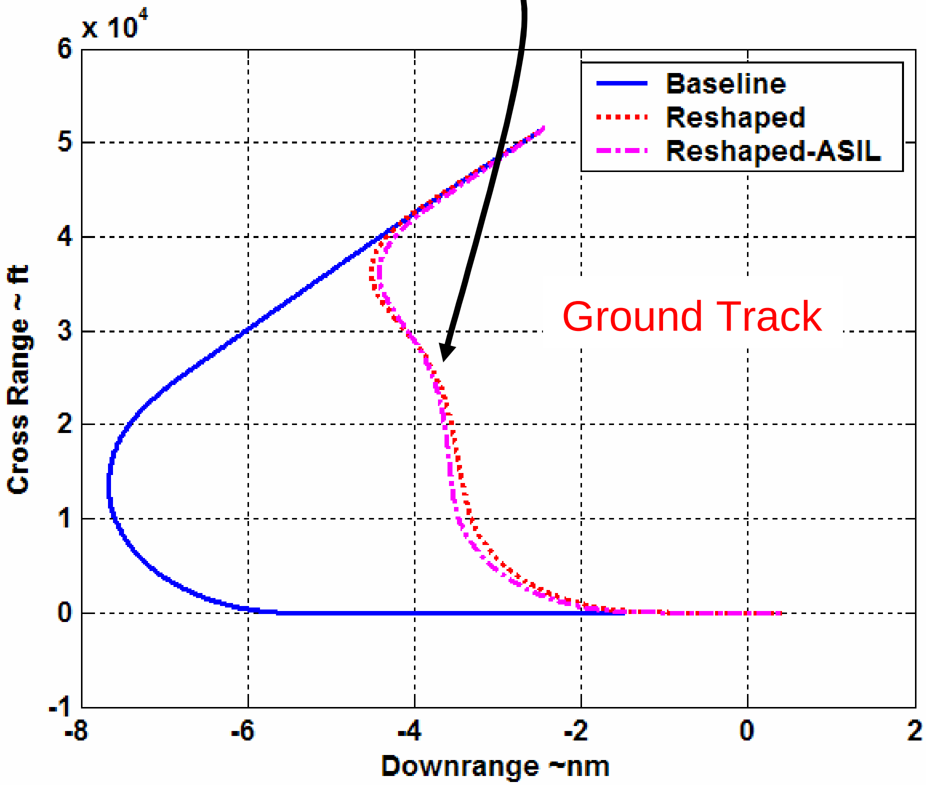


Case Study Results

Real-time, Hardware-In-the-Loop



- Simulink and ASIL results very close
- Adaptive system commands a "HAC turn" soon into the mission – "cuts the corner" to reduce downrange distance to runway – *conserves energy*



- Adaptive system commands much steeper descent – increases kinetic energy at touchdown – allows for greater control authority to execute final flare

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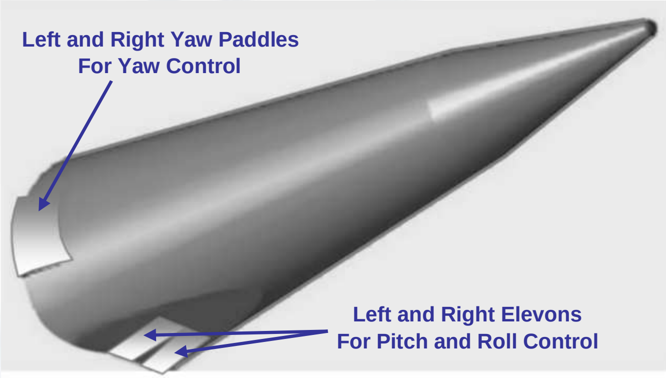
Case Study Results (cont.)

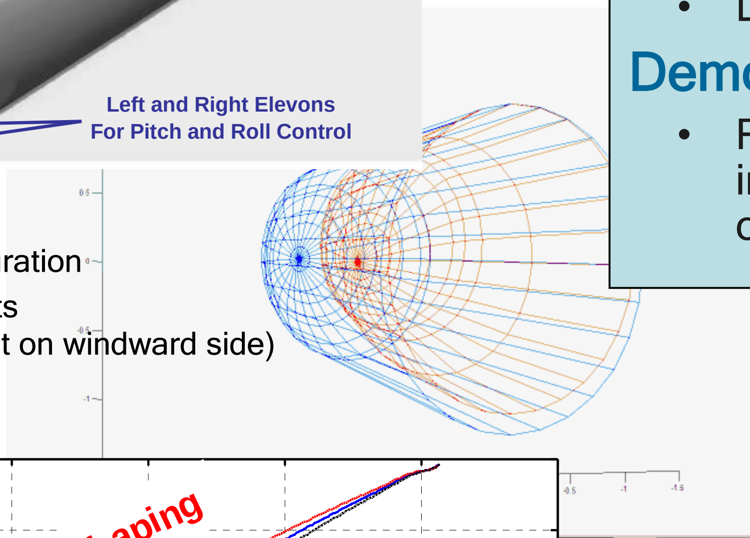
- w/o adaptation and in-flight energy management through trajectory reshaping, system cannot complete the mission
- With adaptation and trajectory reshaping, energy is properly managed under severe drag penalties – all required touchdown specifications achieved
- 51 cases run for final set of ASIL experiments
  - Variations included: initial heading (HAC) angle, wind direction, ablation effects, navigation errors, random turbulence, failure condition, and failure onset time

	Sink Rate (fps)	*Pitch Angle (deg)*	*Groundspeed (fps)*	*Downrange (ft)*	*Crossrange (ft)*
Specification	≥ -7.5	≤ 15	≤ 389	≥ 0	≤ +/- 50
Baseline-Matlab/Simulink	-357.2	22.8	370.2	-8942.7	-133.0
Reshaped-Matlab/Simulink	-4.9	14.8	271.8	2540.3	-24.4
Reshaped-ASIL	-2.9	14.3	271.7	2467.7	-25.3

Real-time, Hardware-In-the-Loop

CAV Trajectory Reshaping (DARPA FALCON Program)





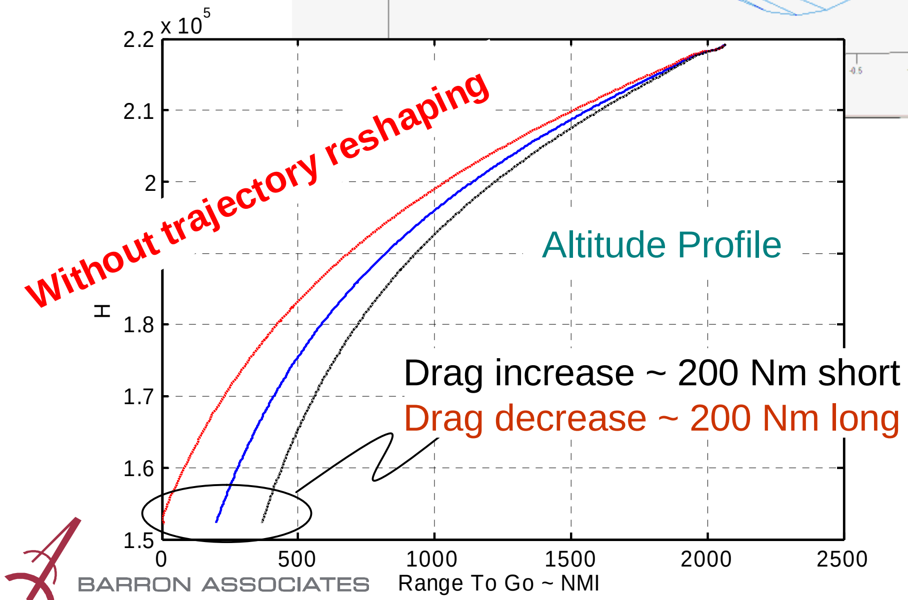
Bi-conic configuration
+ ablation effects
(more prominent on windward side)

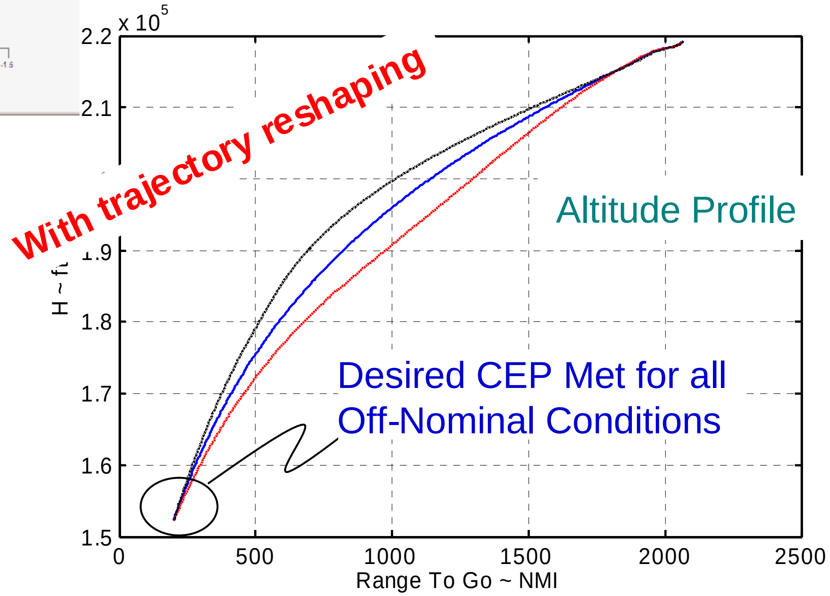
AFRL Phase III Enhancement

- With AFRL / Ping Lu (Iowa State)
- Dave Doman, COTR

Demonstration Goal

- Real-time HIL demonstration of V&V of intelligent UAV mission planning and control software





High-Speed Vertical Lift Simulation Development

High-speed vertical lift aircraft operated from ships

Support Controls Researchers

Simulation Development Goals

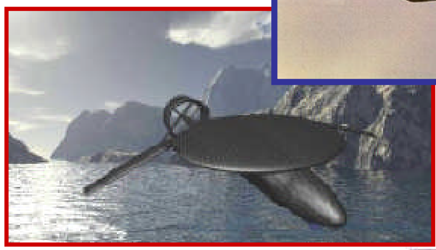
- Matlab / Simulink
- Modular -
  - Multiple vehicles with same/similar interface
- Complexity vs. fidelity
  - Dial-in Fidelity Options
- Publicly Releasable
- Integrate Related Navy Sim/Data
  - Ship airwake
  - Ship motion

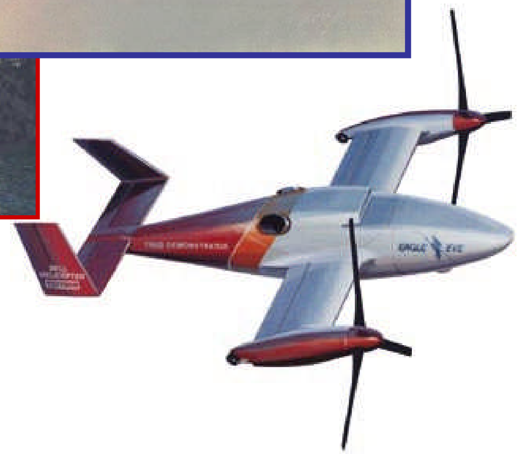
NAVAIR

- With U. of Liverpool
- Tony Page, COTR

Project Goal

- Publicly-Releasable Controls-Oriented Shipboard Operations Simulation





Adaptive Control of Synthetic Jet Arrays with Unknown Nonlinearities

Phase I Results

- Design for the arrangement of synthetic jet arrays that facilitates virtual shaping of an airfoil at low angles of attack
- Parametric model of synthetic jet actuators
- Practical, implementable adaptive control algorithm based on an adaptive nonlinearity inverse technique
- Successful simulation results using synthetic jets for virtual shaping of a tailless aircraft

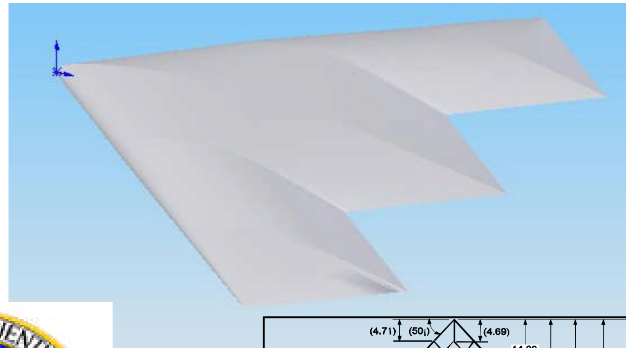
Phase II Plan

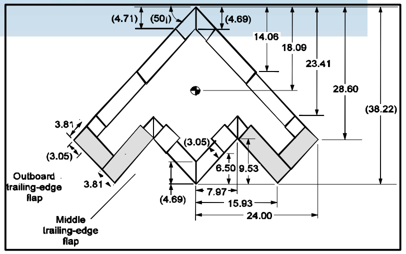
- Design and fabricate an innovative wind tunnel model with integrated synthetic jet actuators
- Demonstrate adaptive control of synthetic jet arrays for separation control at high angles of attack
- Demonstrate adaptive control of synthetic jet arrays for virtual shaping of airfoils at low angles of attack

ONR Phase II STTR

- With UVA and U. Wyoming
- Lt. Col Sharon Heisi, COTR, COTR

Phase II Wind Tunnel Model Design





Collaborators:

University of Virginia
PI: Dr. Gang Tao
Adaptive Control Development

University of Wyoming
PI: Dr. Douglas R. Smith
Modeling and Experiment Design

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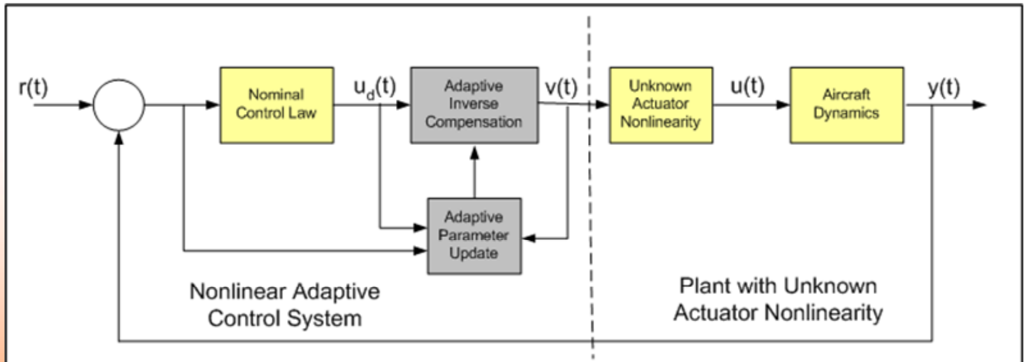
Adaptive Control for Active Flow Control

Identification and Significance of Innovation

- **Develop *active flow control techniques* that will enhance performance and improve safety for aircraft**
- **Phase I Focus: *Adaptive Control of Synthetic Jets for Flow Separation Delay***
- **Adaptive flow control will result in:**
  - ***Improved aircraft safety* in adverse flight conditions, such as those caused by failures**
  - ***Improved aircraft efficiency* using synthetic jets for virtual airfoil shaping**
- **Computational simplicity of approach allows for *onboard, real-time implementations***



$u_d(t)$: Commanded Control Surface Deflection
$v(t)$: Synthetic Jet Array Input Signal
$u(t)$: Effective Virtual Surface Deflection
Adaptive Compensation Objective:
$u(t) \rightarrow u_d(t)$ which implies $y(t) \rightarrow r(t)$

Technical Objectives and Work Plan

- **Main Objectives:**
  - **Develop flow control models**
  - **Develop adaptive control algorithms**
- **Main Work Tasks:**
  - **Implement synthetic jet actuators in a transport aircraft simulation**
  - **Implement adaptive control algorithms for the synthetic jet actuators**
  - **Perform aircraft safety analysis at high α**
  - **Perform closed-loop simulations**
  - **Design Phase II wind tunnel experiment**

NASA and Non-NASA Applications

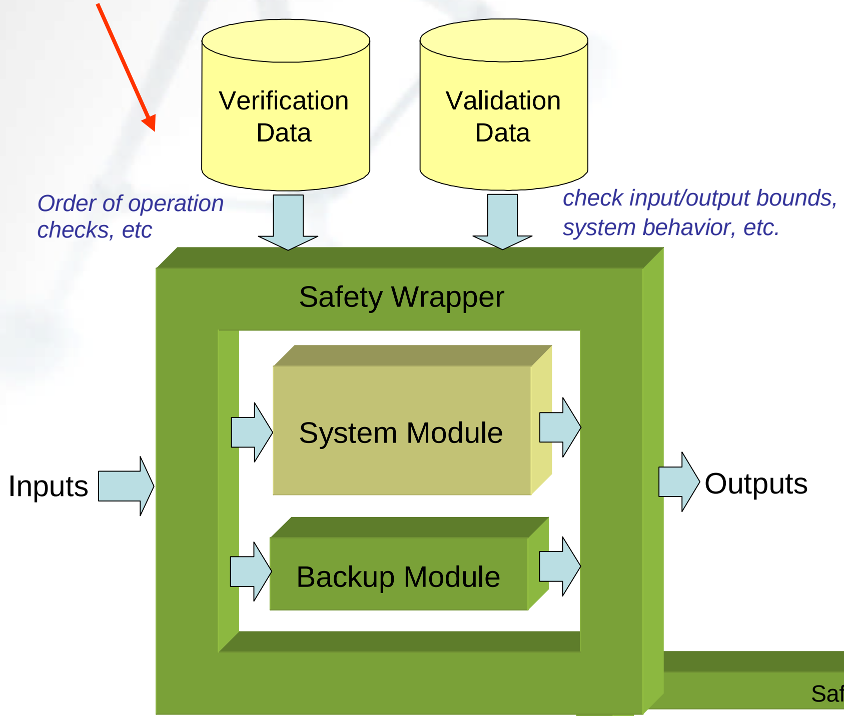
- **NASA Applications: *Capabilities for active flow control have clear applications to many NASA programs targeting improved dynamic performance and safety:* Intelligent Flight Control System (IFCS), Aviation Safety Program – Single Aircraft Accident Prevention**
- **Non-NASA Applications: "smart" munitions & guided missiles, UAVs, control surface boundary layer management for both commercial transport aircraft and high-performance military aircraft**

University of Virginia
University of Wyoming
Barron Associates

NON-PROPRIETARY DATA

Generic Run-Time V&V Safety Wrappers

Generic individual safety wrapper for one system module



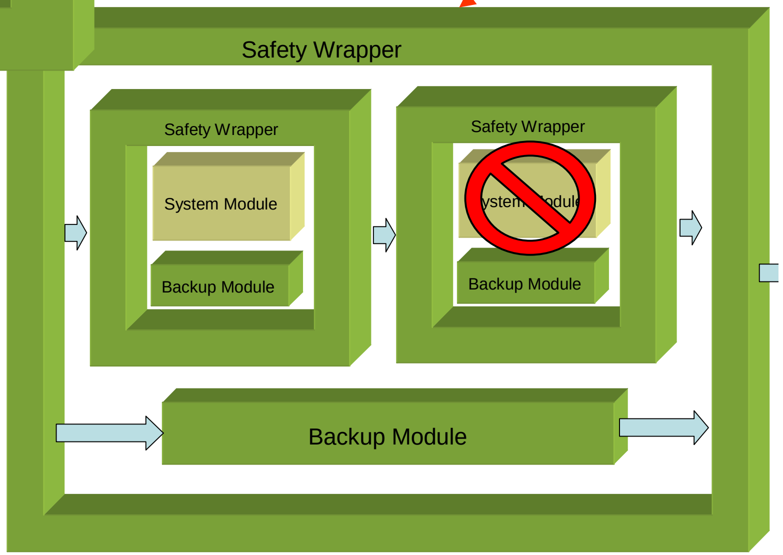
AF SBIR Phase II

- With Lockheed Martin
- Wendy Chou, COTR

Demonstration Goal

- Real-time HIL demonstration of V&V of intelligent UAV mission planning and control software

Safety wrapper for *overall* system comprised of a multitude of *subcomponent* safety wrappers



<u>Incremental degradation</u>: shut down only those sub-components not working, allowing other advanced components to continue operation

Failure Classes that can be Accommodated

- **System (Aircraft)**
- **SW Implementation**
- **SW Design**

An Autonomous Health Monitoring System for Hybrid Propulsion Vehicles

Significance of the Research

- Hybrid propulsion vehicles can potentially provide tactical and economic advantages for the U.S. Army
- The overall objective of this research is to develop and demonstrate an autonomous health monitoring system that detects and isolates component failures and predicts the remaining useful life of the hybrid energy sources

Phase I Plan

- Design and construct hybrid military vehicle simulations using SwRI's RAPTOR™ tool
- Identify sensors that will be used to monitor the health of the hybrid vehicles and collect sensor and actuator data from the unfaulted system
- Conduct a series of simulations to quantify the diagnostic and prognostic performance of the health monitoring system
- Begin development of the system "control rules" and the vehicle communication network and operator interface.

Collaborator:

Southwest Research Institute

Advanced Vehicle Technology Division

Investigators:
Scott McBroom
Ashok Nedungadi, Ph.D.

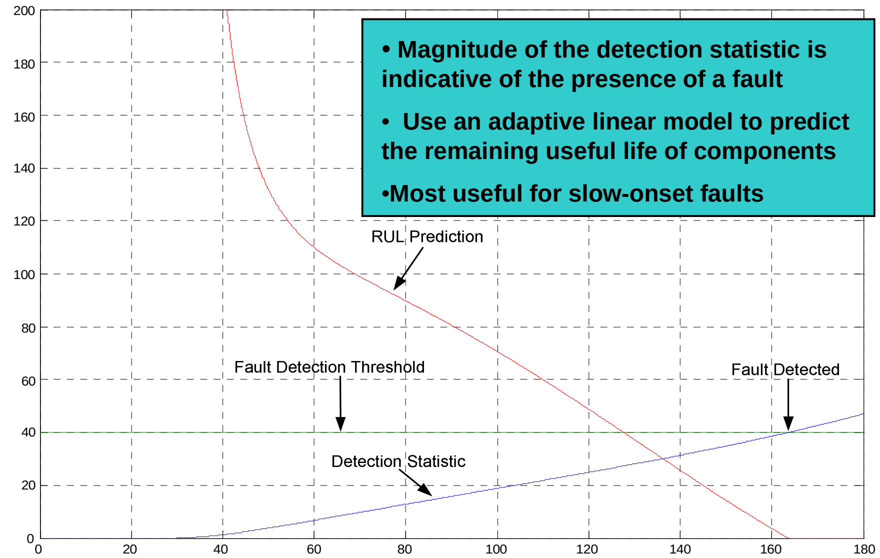
Southwest Research INSTITUTE

Phase I Results

- Constructed a marine diesel engine model in Matlab/Simulink that includes a diverse set of failure modes
- Applied generic algorithms that use statistical change detection to detect and isolate failures
- Achieved perfect fault detection and isolation performance for a variety of sensor and actuator failures

Phase II Plan

- Install a diesel engine in SwRI's engine test facility and instrument the engine with additional sensors, including accelerometers
- Operate the engine in a series of faulted and unfaulted conditions and record the data using a ruggedized ECU and data logger
- Optimize diagnostic and prognostic algorithms and demonstrate the algorithms in real-time
- Instrument a diesel engine aboard a research vessel and conduct a sea trial



Collaborator:

Southwest Research Institute

Dept. of Engine & Emissions Research

Investigators:
Jayant Sarlashkar, Ph.D.
Ryan Roecker

Sponsor:

Robert Brizzolara, Ph.D.
Ship Science & Technology Division
Office of Naval Research
Tel: (703) 696-2597

Office of Naval Research

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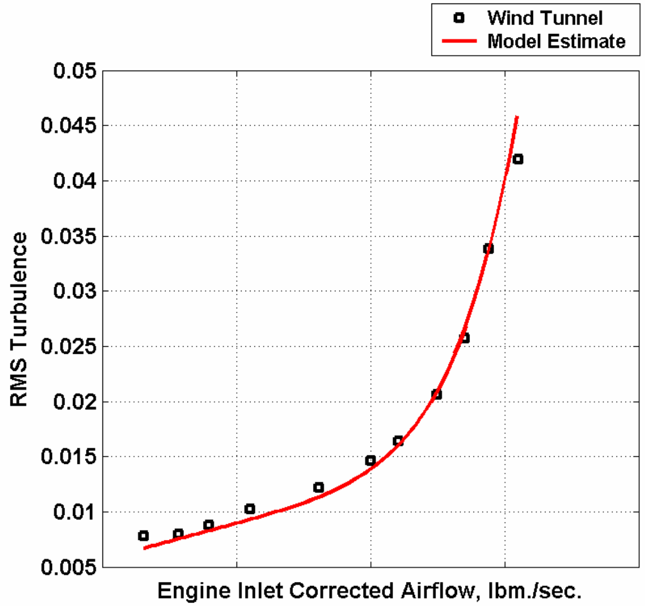
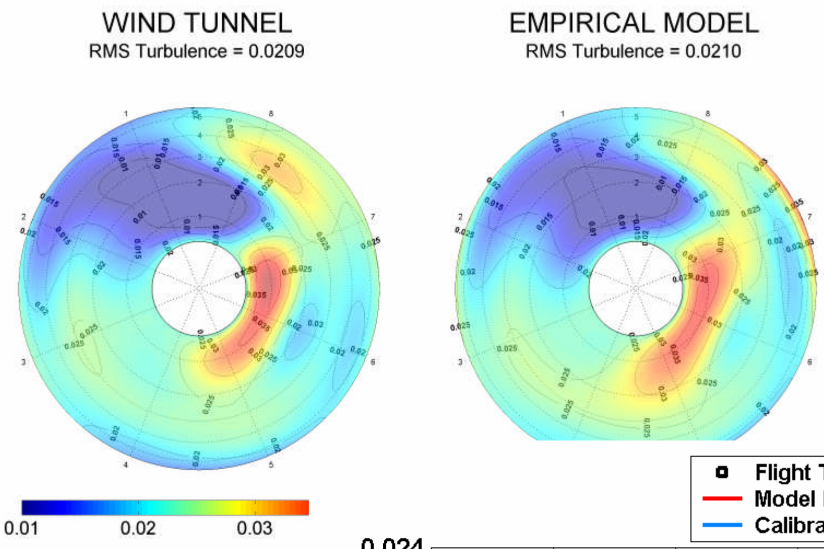
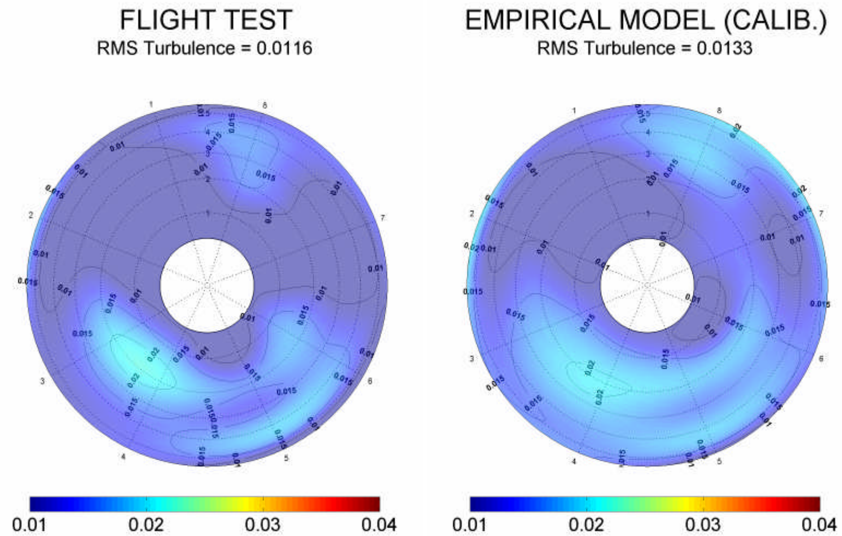
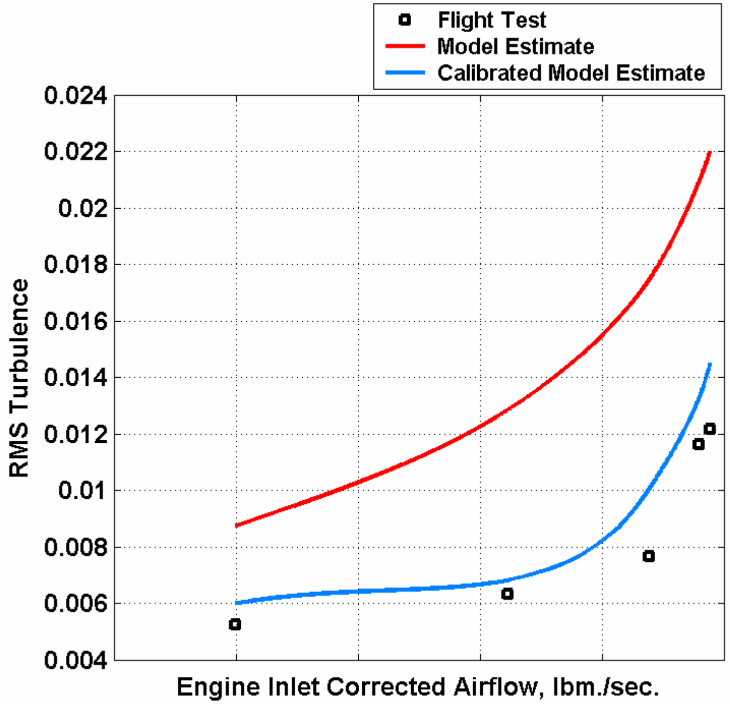
M&S
Automated Simulation Updating







RMS Turbulence Contours



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Analysis Methods, Software Tools, and Novel System Designs

V&V Through the Control Law Life Cycle