IRAC Full-Scale Flight Test

John Bosworth
Co-API
IRAC V&V and Testbeds

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Why?

The NASA Dryden Flight Research Center was named after Dr. Hugh L. Dryden, the first Deputy Administrator of NASA. The following is his explanation as to why there is a need for flight research,

"... to separate the real from the imagined and to make known the overlooked and the unexpected...".

Current IRAC Flight Assets

NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/Gallery/Photo/index.html
NASA Photo: EC03–0039–1 Date: February 7, 2003 Photo By: Jim Ross

NASA Dryden's highly–modified Active Aeroelastic Wing F/A–18A shows off its form during a 360–degree aileron roll during a research flight.

F/A-18 853 (in development)

Flight validated sim

68040 RFCS

HIL test bench

NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/Gallery/Photo/index.html
NASA Photo: EC03–0311–05 Date: December 4, 2003 Photo By: Jim Ross

C–17 in flight over Rogers Dry lakebed

C-17 T1 (USAF asset)

Primarily engine instrumentation

Dryden Flight Research Center EC96-43780-1 Photographed 10/96
Striking Silhouette: F-15B Advanced Control Technology for Integrated Vehicles (ACTIVE) research program. NASA photo by Jim Ross

F-15 837

Flight validated sim

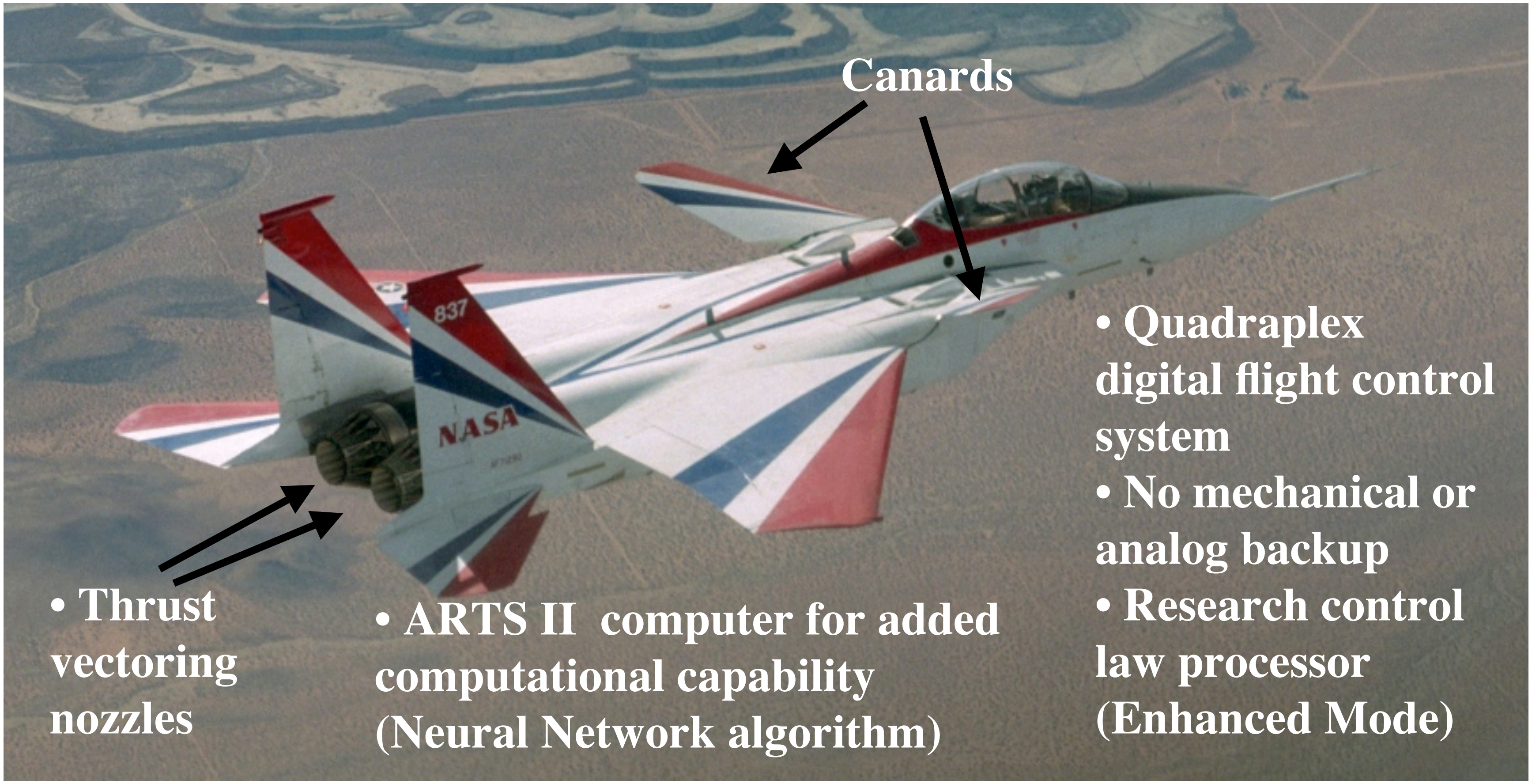
68040 enhanced mode

ARTS II

HIL at Boeing

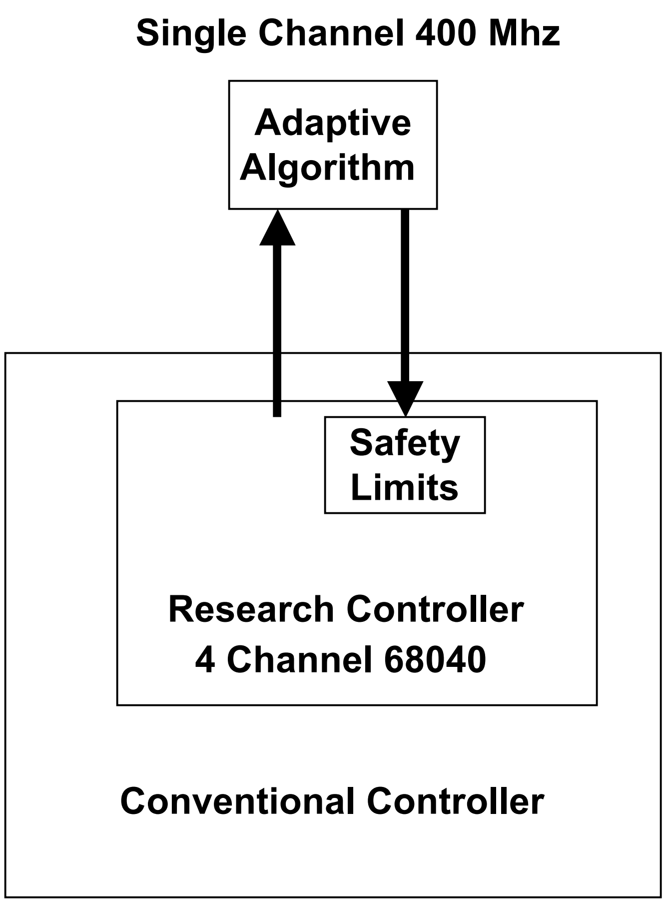
NASA NF-15B Tail Number 837

Extensively modified F-15 airframe

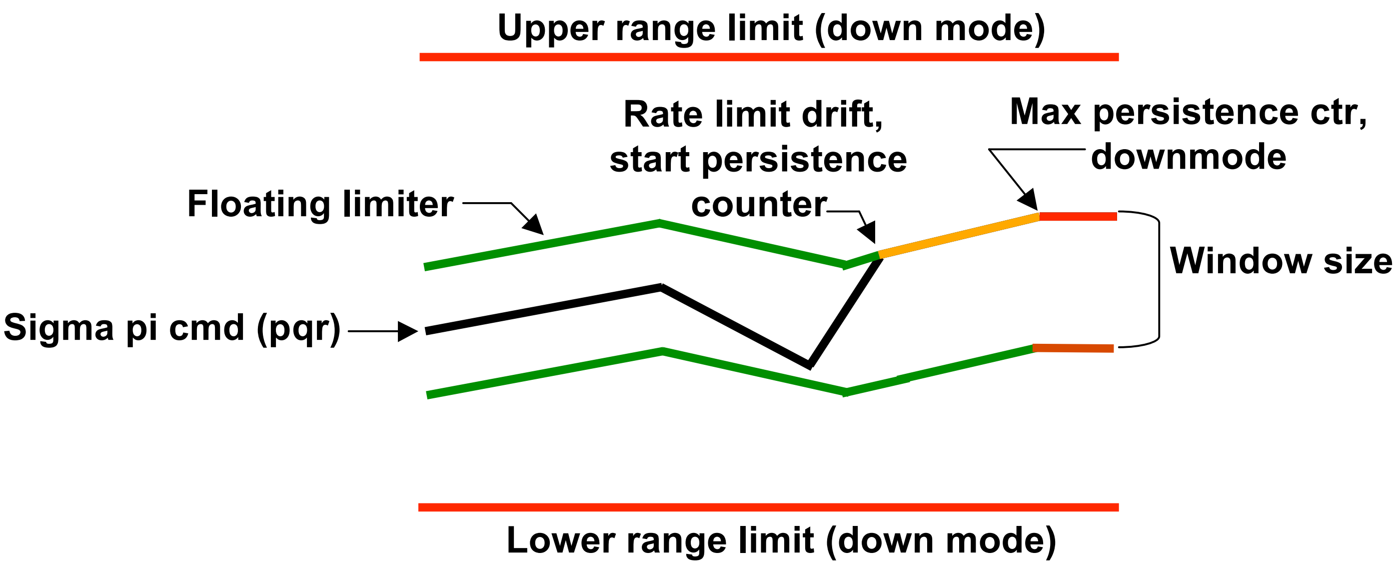


Limited Authority System

- Adaptation algorithm implemented in separate processor
  - Class B software
  - Autocoded directly from Simulink block diagram
  - Many configurable settings
    - Learning rates
    - Weight limits
    - Thresholds, etc.
- Control laws programmed in Class A, quad-redundant system
- Protection provided by floating limiter on adaptation signals



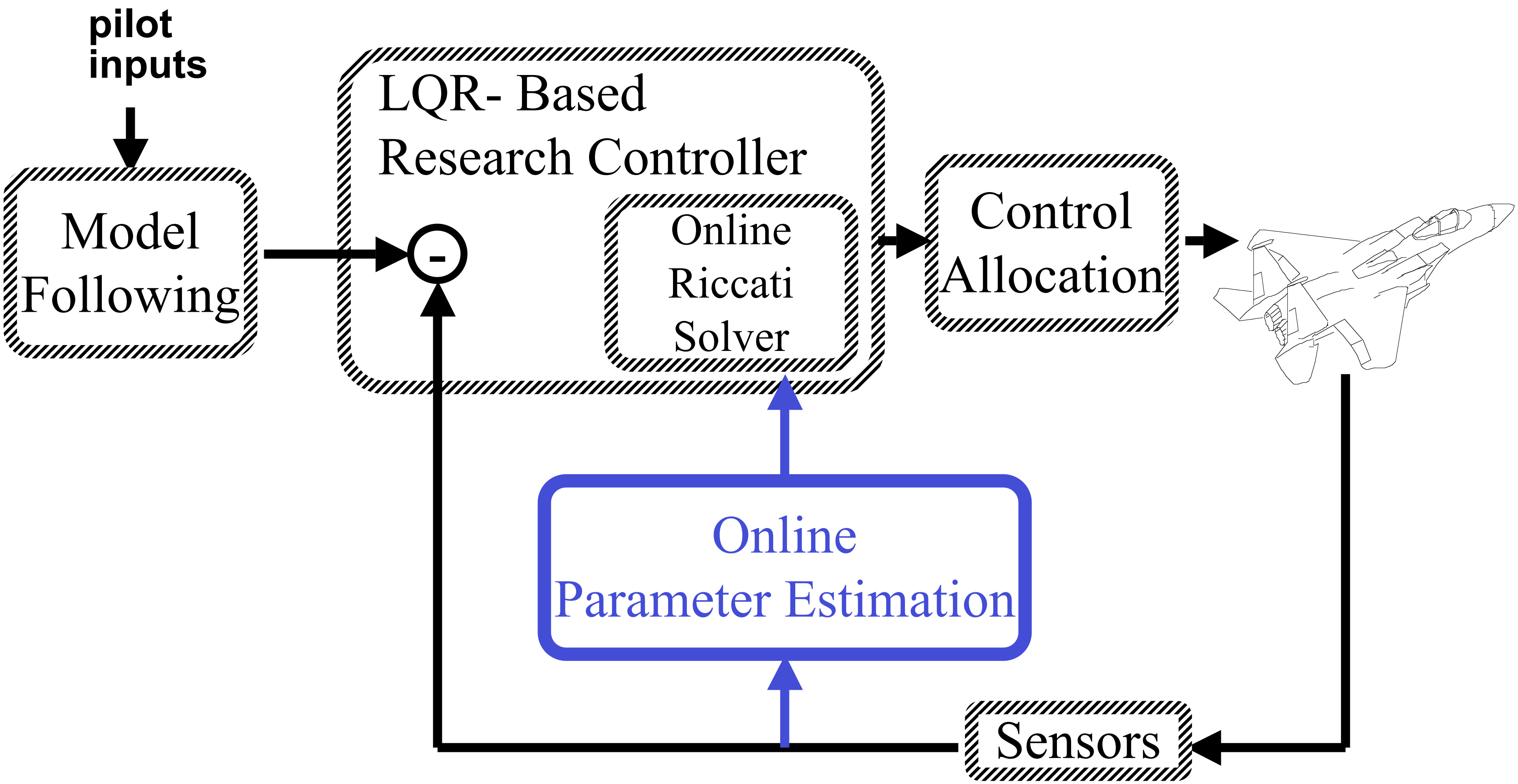
NN Floating Limiter



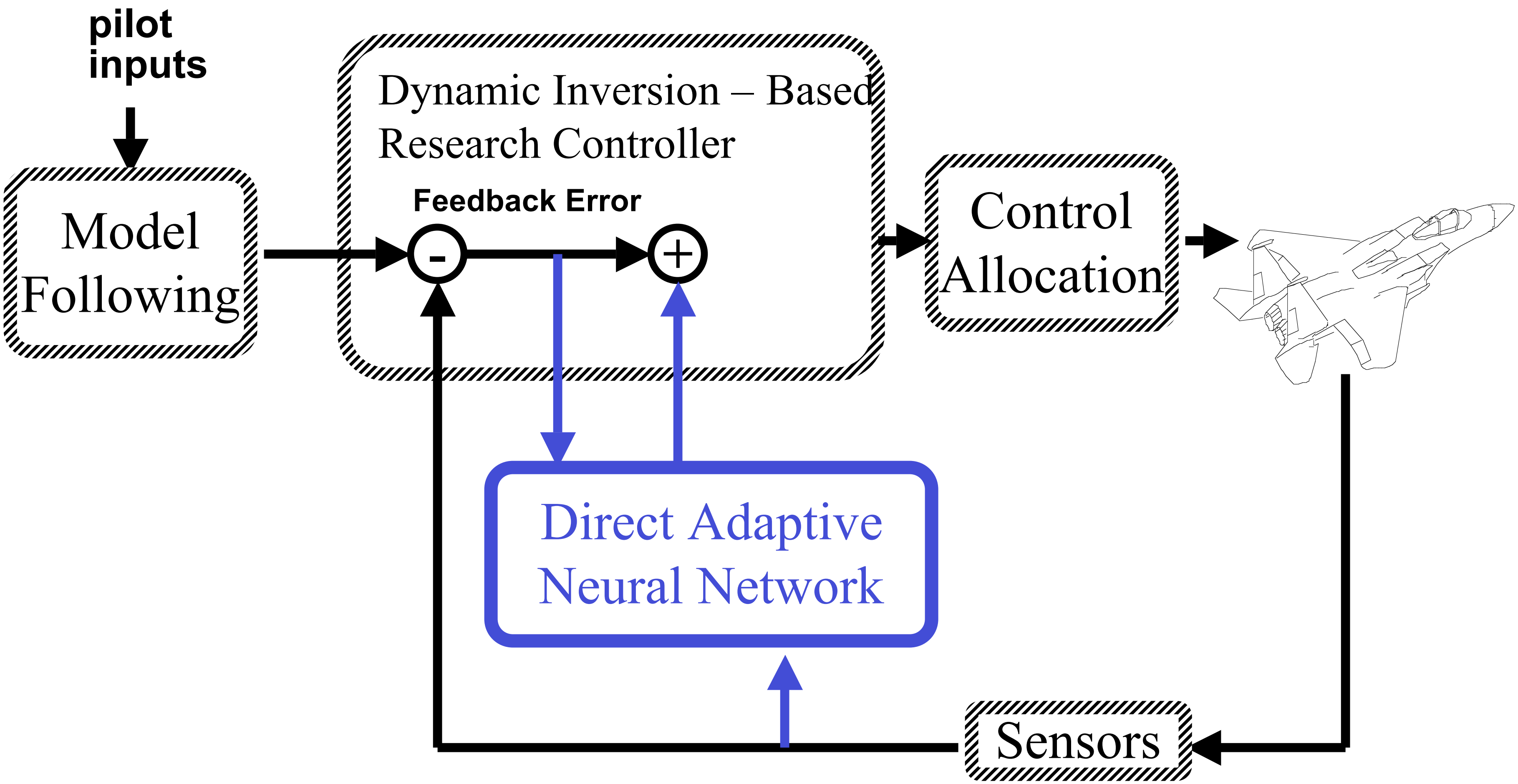
Black – sigma pi cmd
Green – floating limiter boundary
Orange – limited command (fl_drift_flag)
Red – down mode condition (fl_dmode_flag

Tunable metrics
- **Window delta**
- **Drift rate**
- **Persistence limiter**
- **Range limits**

Gen I Indirect Adaptive
Control Architecture

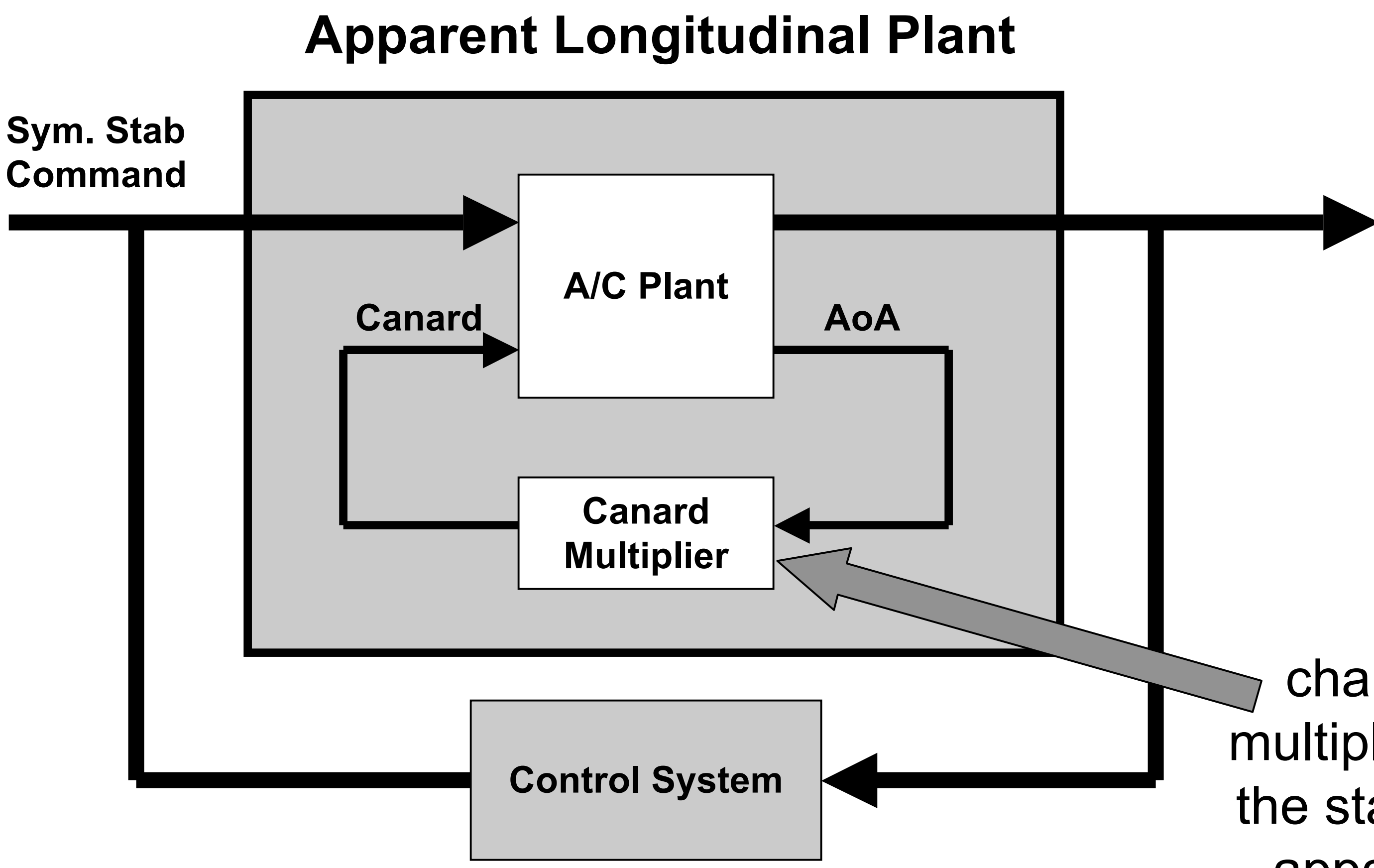


Gen II Direct Adaptive
Control Architecture



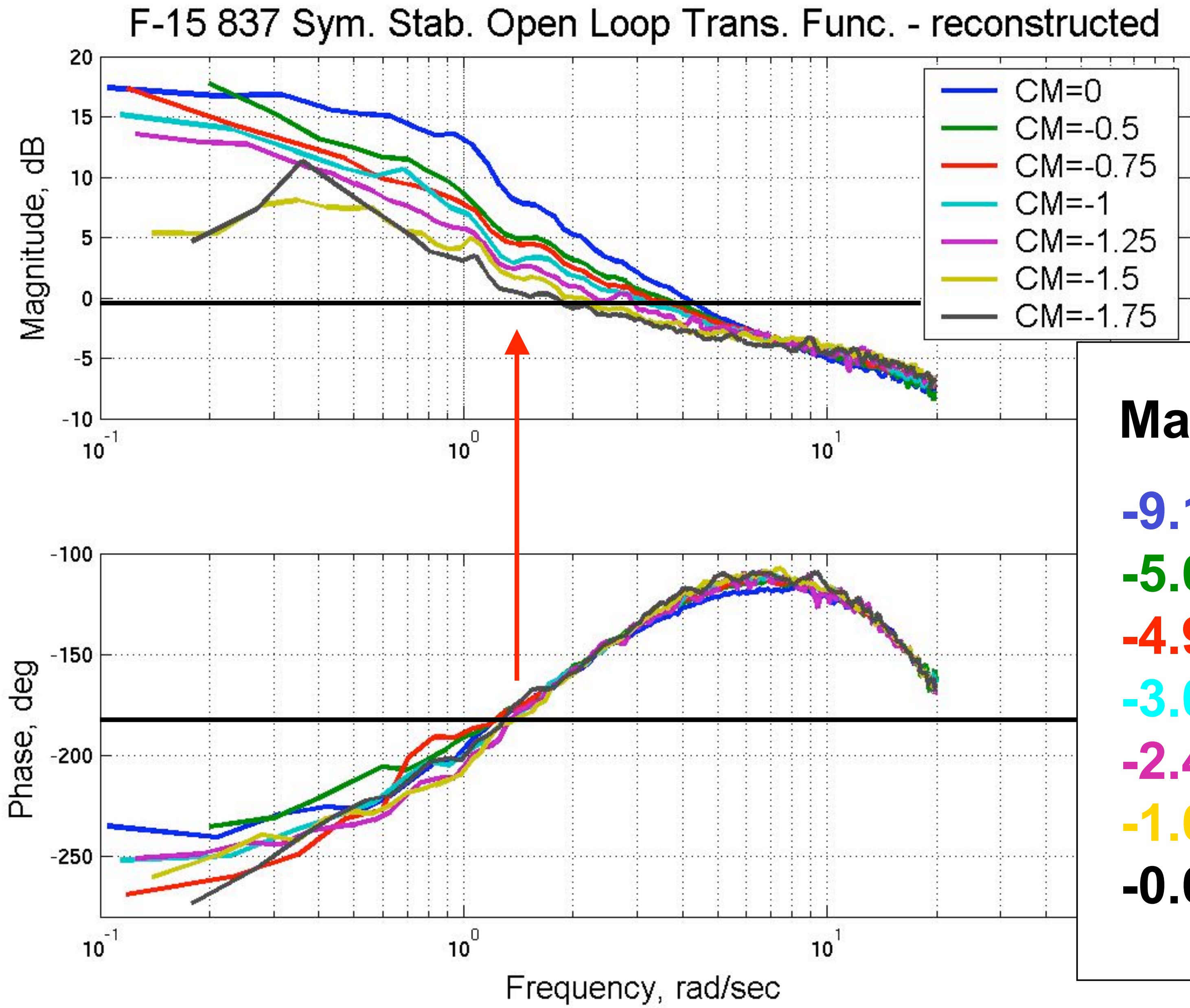
Simulated Destabilization
A-Matrix Failure

Canard Multiplier – "An A-Matrix Failure"



changing this multiplier changes the stability of the apparent plant

Flight Results – Failure no Adaptation

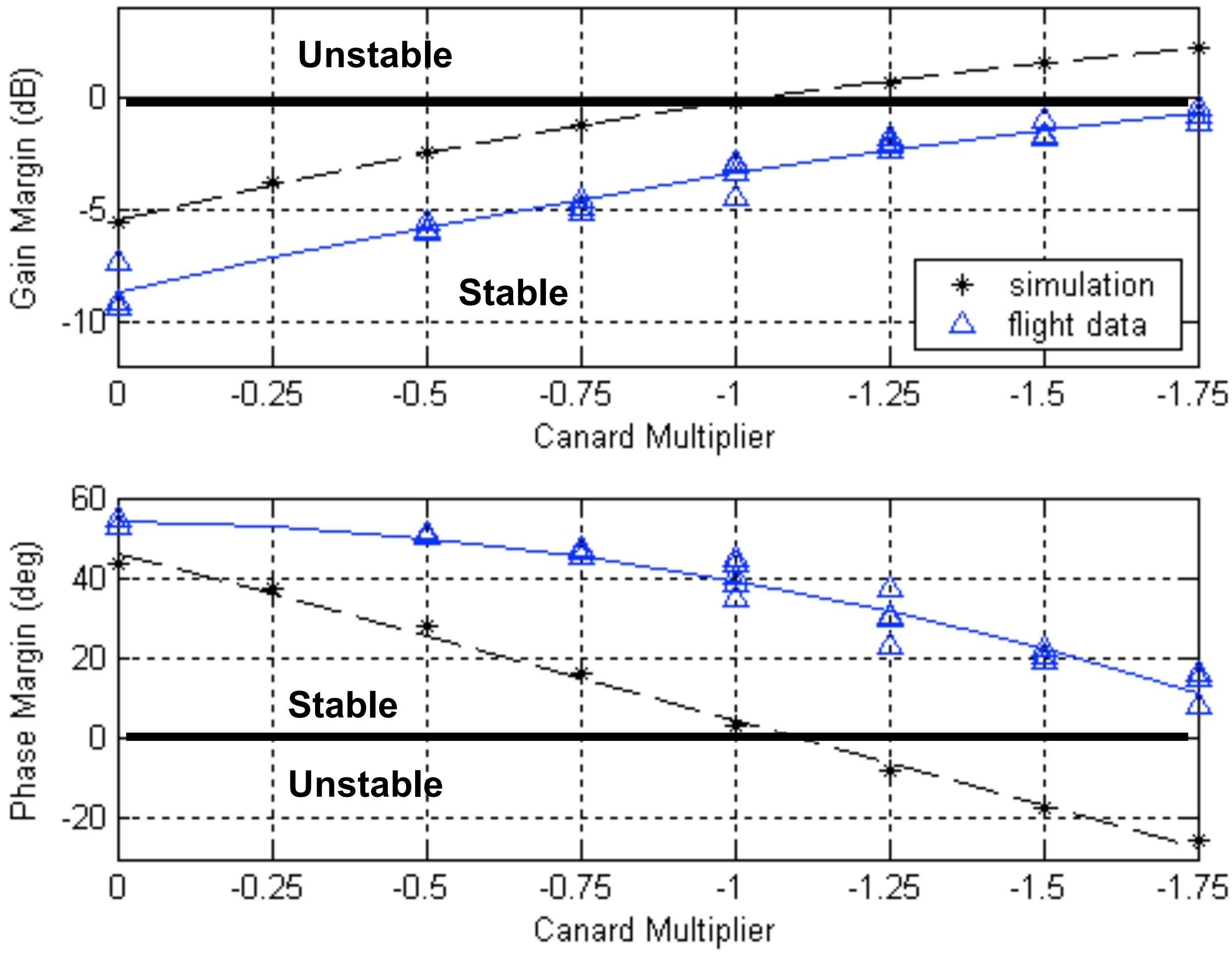


Margins

-9.1 dB
-5.6 dB
-4.9 dB
-3.0 dB
-2.4 dB
-1.6 dB
-0.6 dB

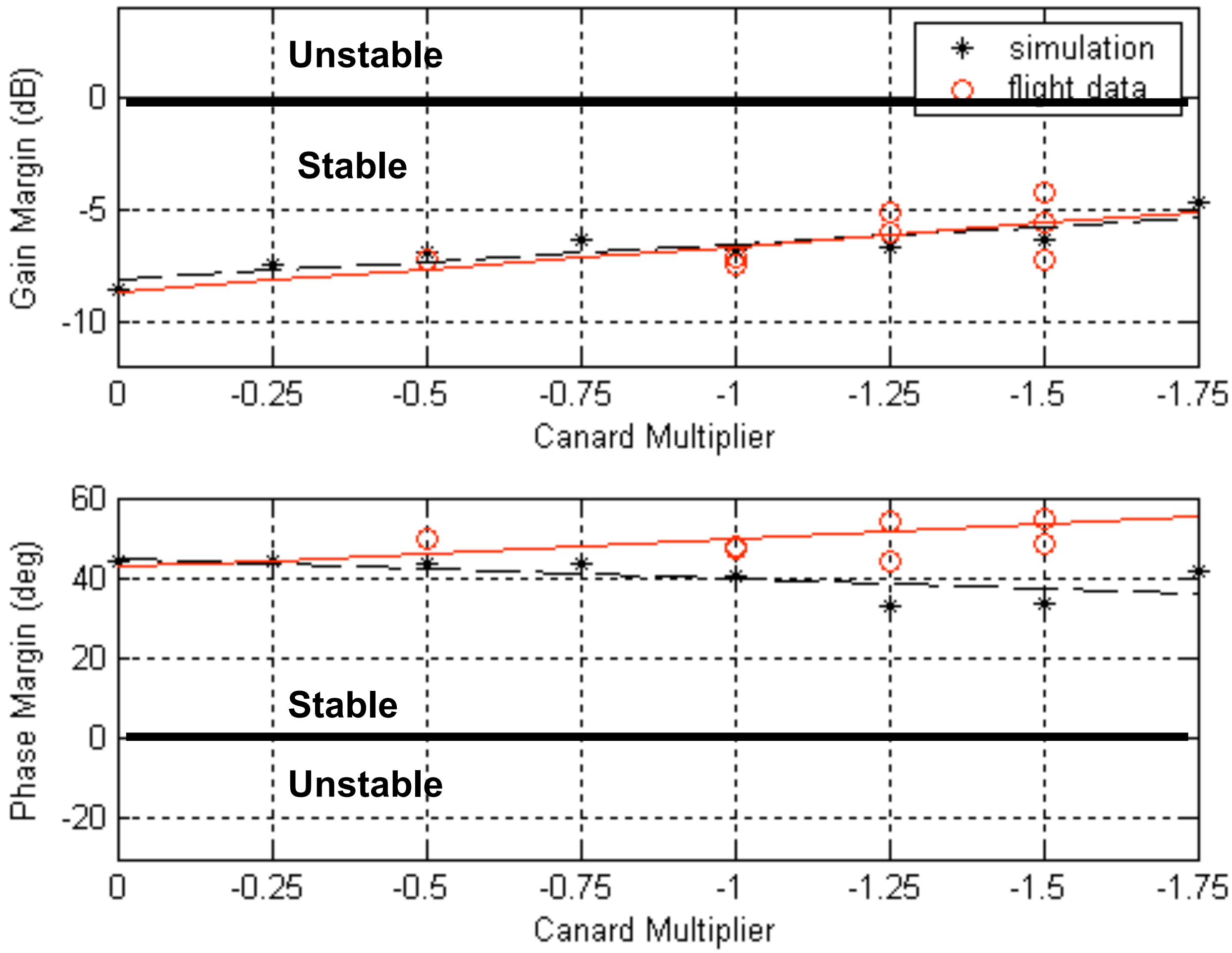
Stability Margin Trends

Symmetric Stab Loop, NN OFF



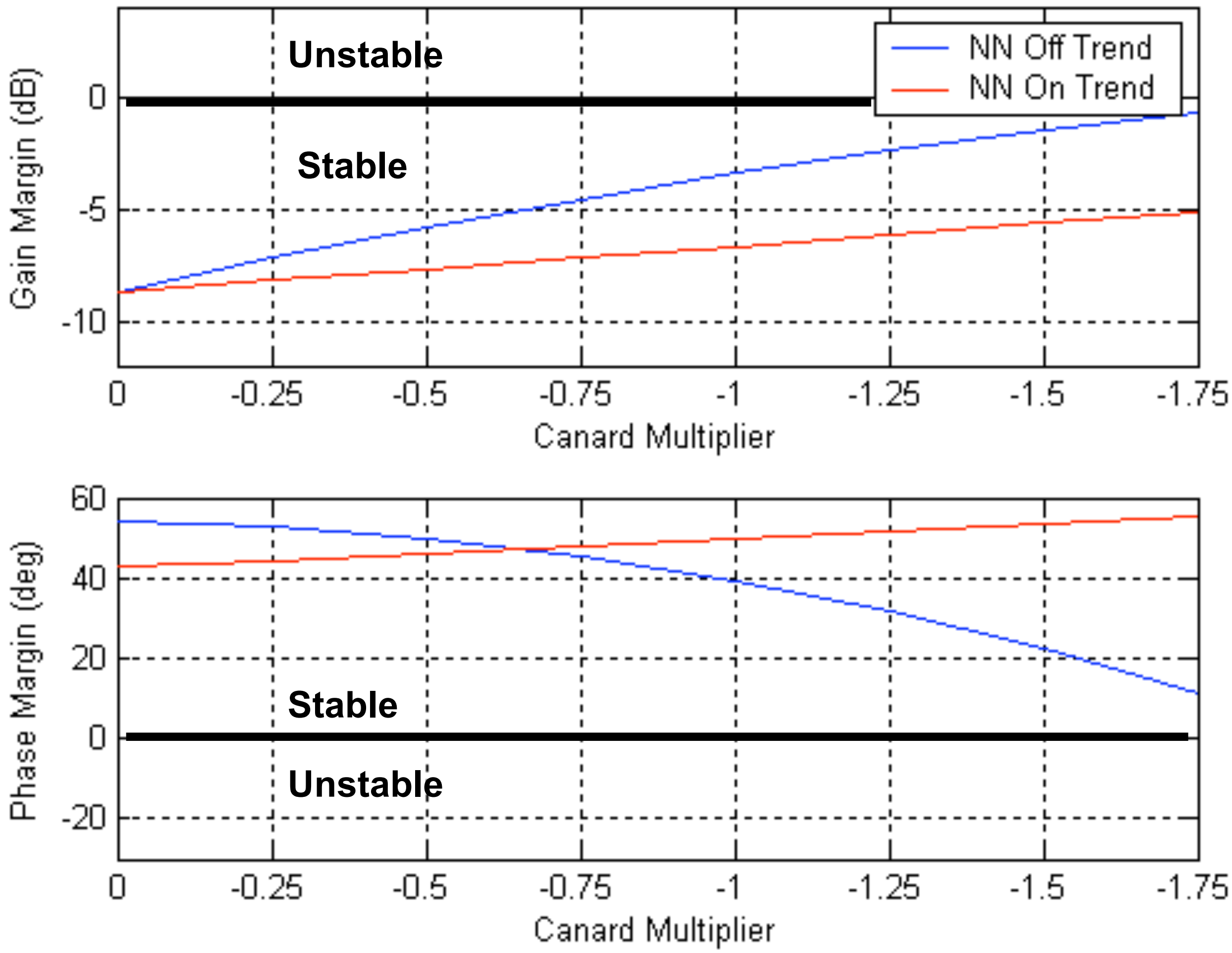
Stability Margin Trends

Symmetric Stab Loop, NN ON



Stability Margin Trends

Symmetric Stab Loop, NN Off vs. NN On

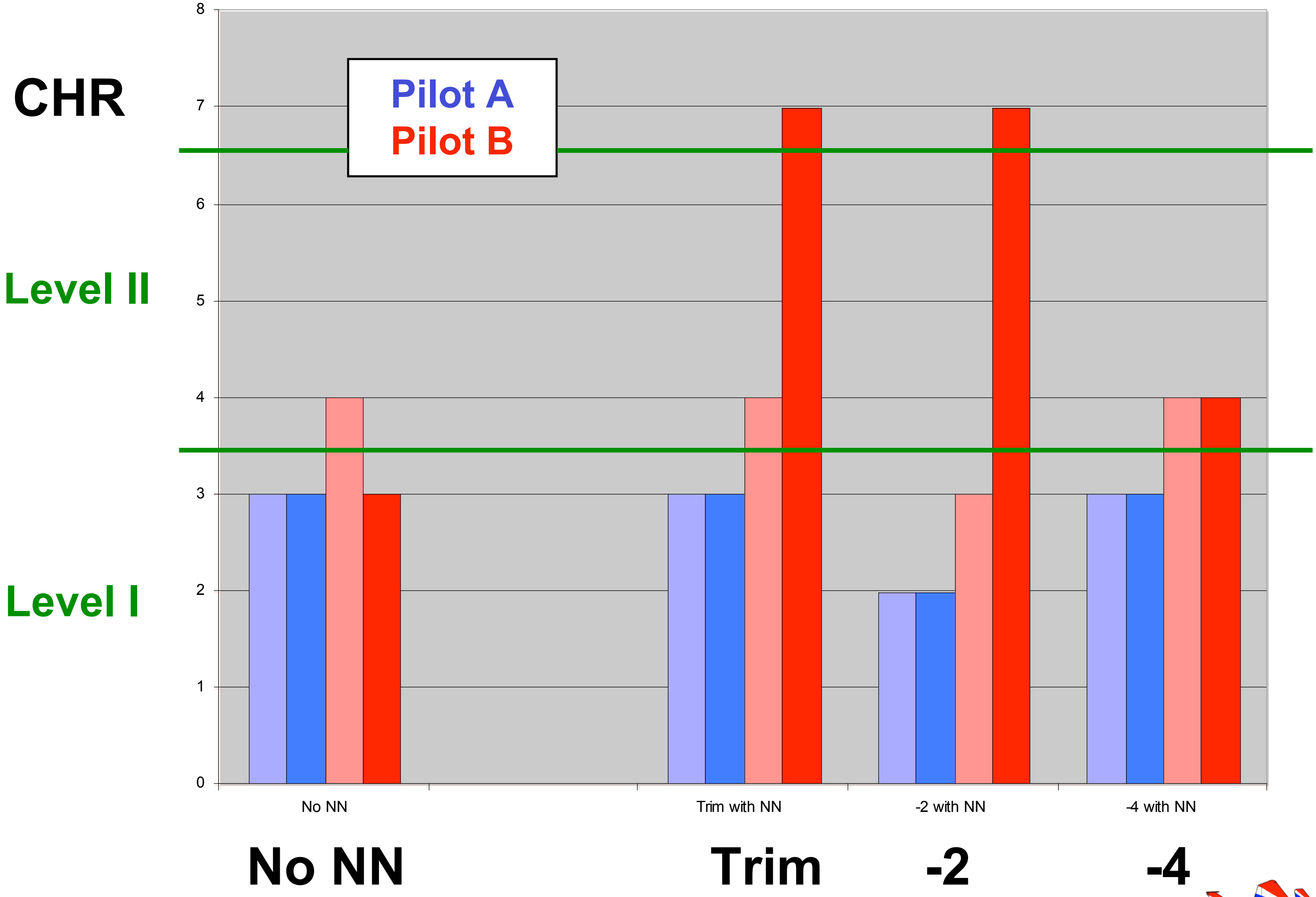


Frozen Stabilator
B-Matrix Failure

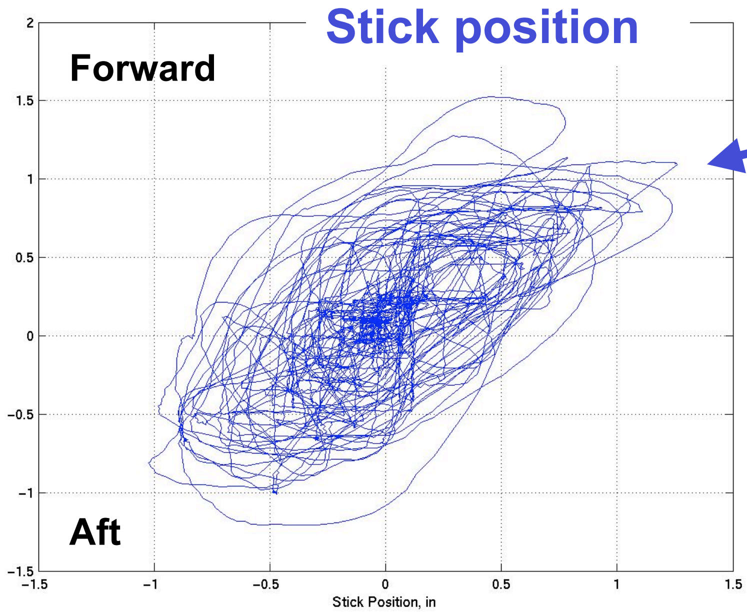
Simulated Stabilator Failure

Flight Results
Simulated Frozen Stabilator

Pilot Ratings with Adaptation
Formation Flight Task



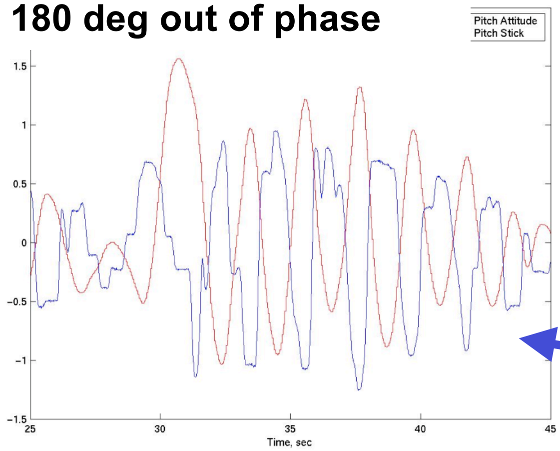
Simulated Frozen Stabilator



• Pilot unconsciously compensates for asymmetry

• Correlated pilot input presents greater challenge for adaptive system

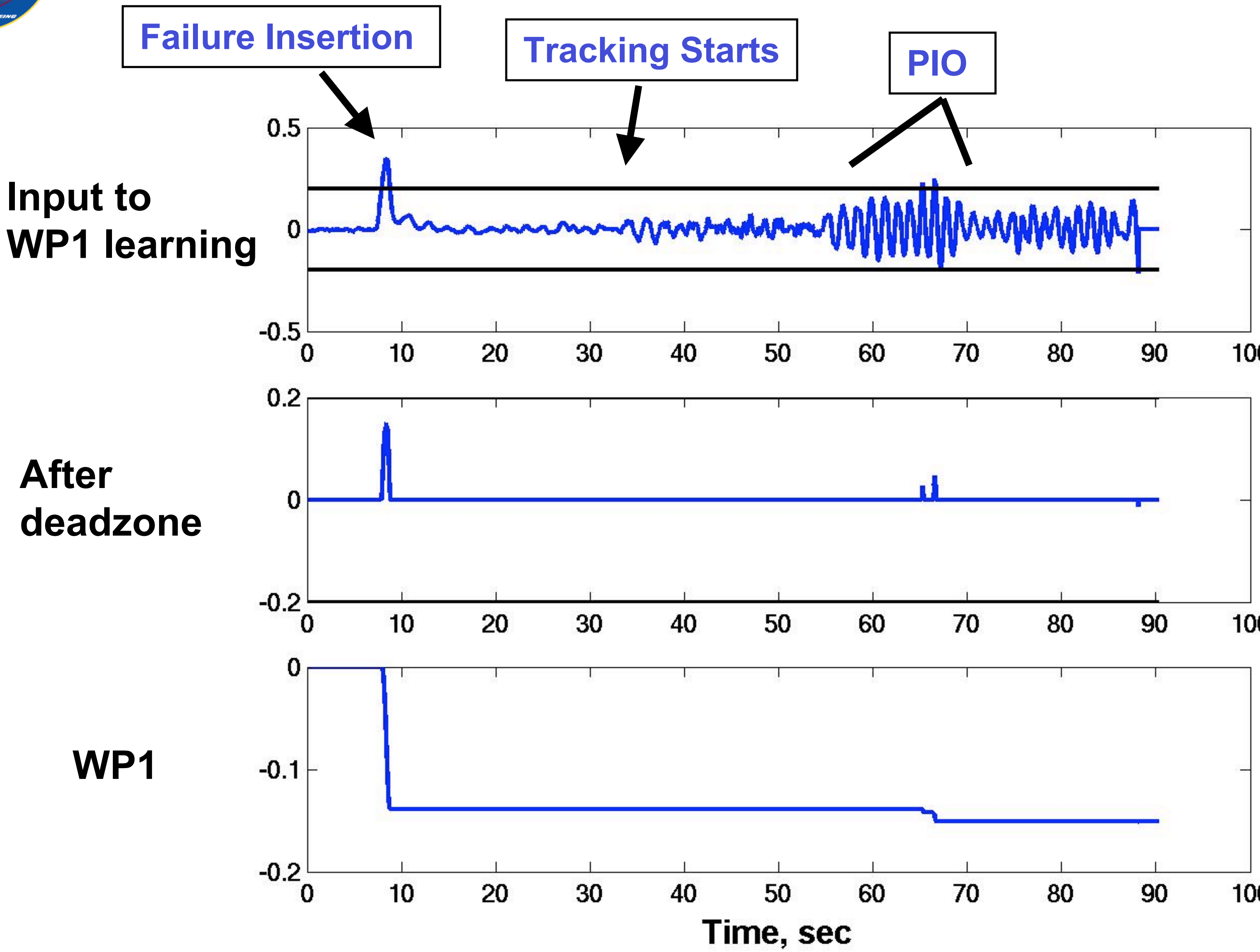
180 deg out of phase



+ Adaptive system reduced the amount of cross coupling

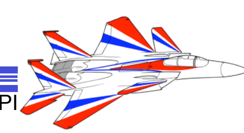
- Adaptive system also introduced tendency for pilot induced oscillations (PIO)

Deadzone Effect



F-15 837 Summary

- **Adaptive system generally behaved as predicted**
  - **Weights adjusted in correct direction**
  - **Real world turbulence and measurement noise did not adversely affect learning**
  - **Only safety disengagements observed were due to very aggressive pilot inputs**
- **Simulated destabilization less than predicted**
  - **Flight vehicle more stable than aero model predicts**
  - **Software change in work to increase destabilizing gain**
- **Adaptation to frozen stabilator introduced PIO tendency**
  - **Interesting interaction between pilot adaptation and system adaptation**
  - **Working on an improved neural network**



Upcoming

- **Larger canard multipliers**
  - Finish maneuver clearance with adaptation ON
  - Perform formation flight and air-to-air tracking evaluations
- **Improved neural network design**
  - Evaluate improvements with locked stabilator failure

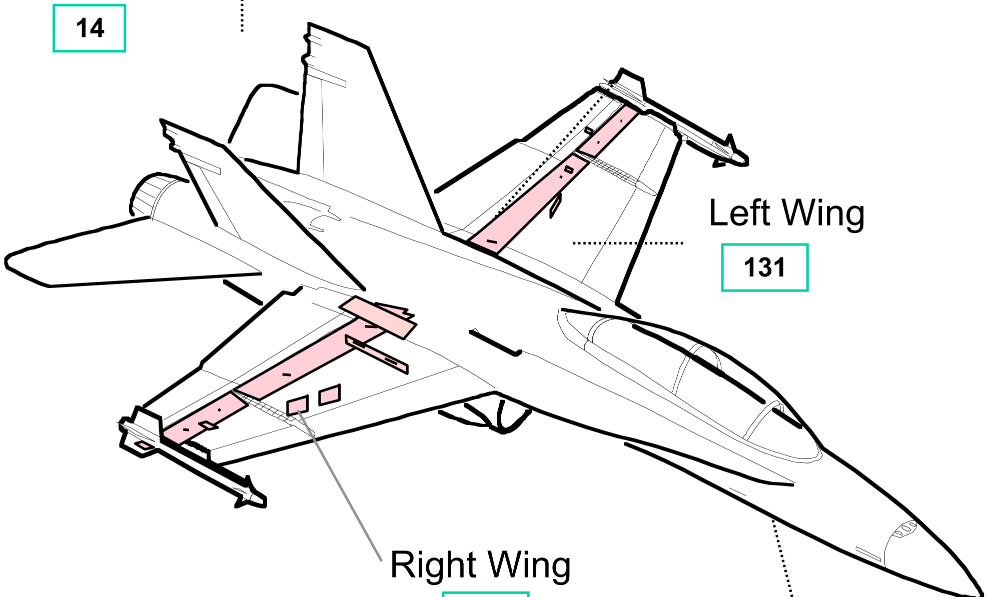
NASA F/A-18 Tail Number 853

- Quad 68040 Research Flight Control System with production control system as backup
- Extensively instrumented for flight loads
- Wing deflection measurement system
- Faster, more capable RFCS in work

Future adaptive research areas:
- Implementing adaptive control algorithms in a multi-processor redundant system
- Adaptively augmenting control by integrating propulsion control
- Assessing integrated adaptive flight management and planning
- Automatically sensing and suppressing aeroservoelastic (ASE) interactions
- Integration of static structural load measurements with adaptive controller

F/A-18 853 INSTRUMENTATION - SENSORS

- Sensor by location



RH WING PARAMETERS-144

- 106 - FULL BRIDGE STRAIN GAGES
- 18 – ACCELEROMETERS
- 8 – POSITION SENSORS
- 10 – VOLTAGE SENSORS
- 1 – TEMPERATURE SENSORS

LH WING PARAMETERS-131

- 76 - FULL BRIDGE STRAIN GAGES
- 18 – ACCELEROMETERS
- 8 – POSITION SENSORS
- 10 – VOLTAGE SENSORS
- 2 – TEMPERATURE SENSORS
- 16 – FDMS TARGETS

FUSELAGE PARAMETERS-55

- 6 - MOTION PAK
- 7 – ACCELEROMETERS
- 7 – TEMPERATURES
- 8 – FUEL QUANITY
- 27 – MISC. PARAMETERS

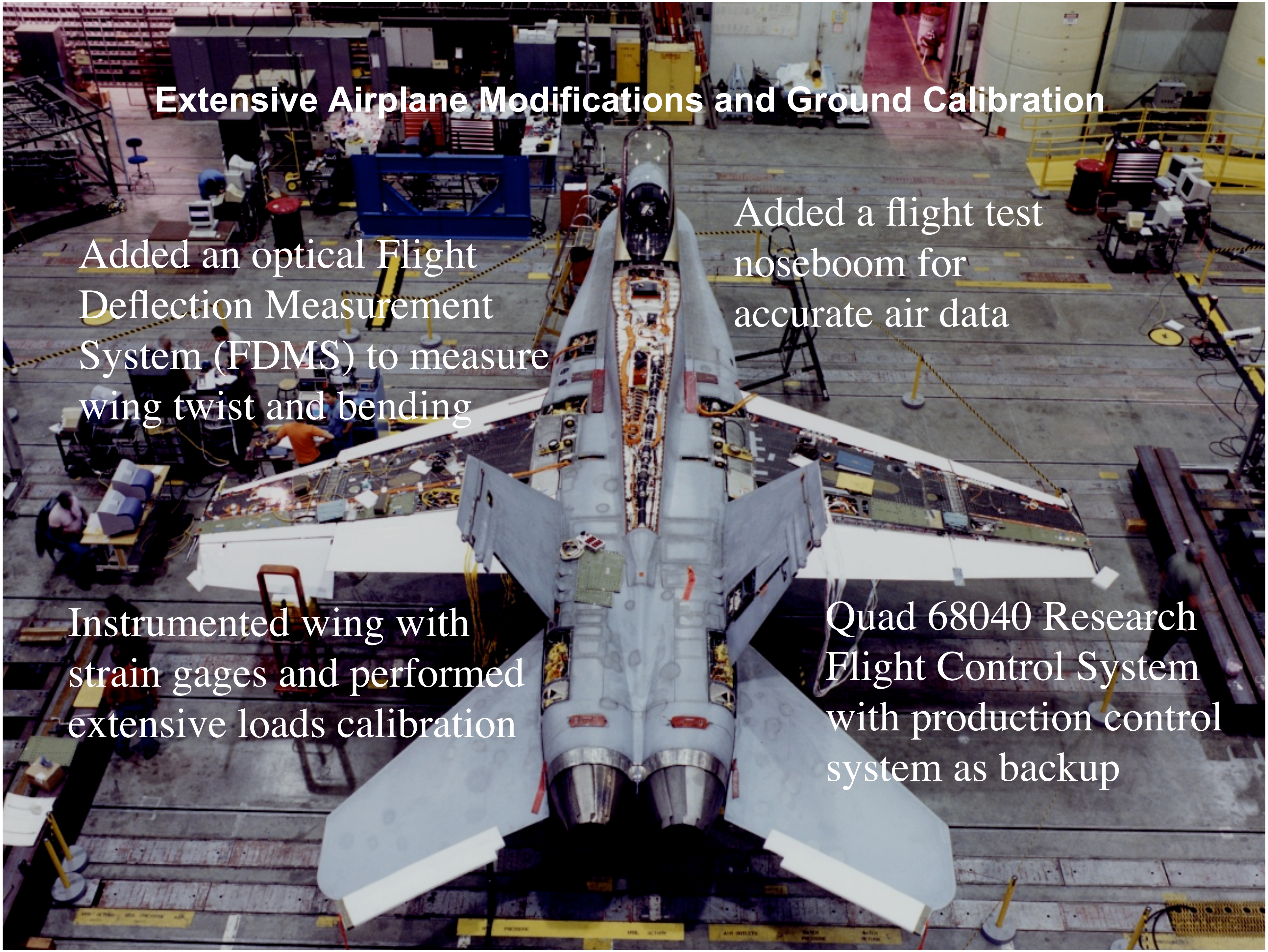
EMPENAGE PARAMETERS-14

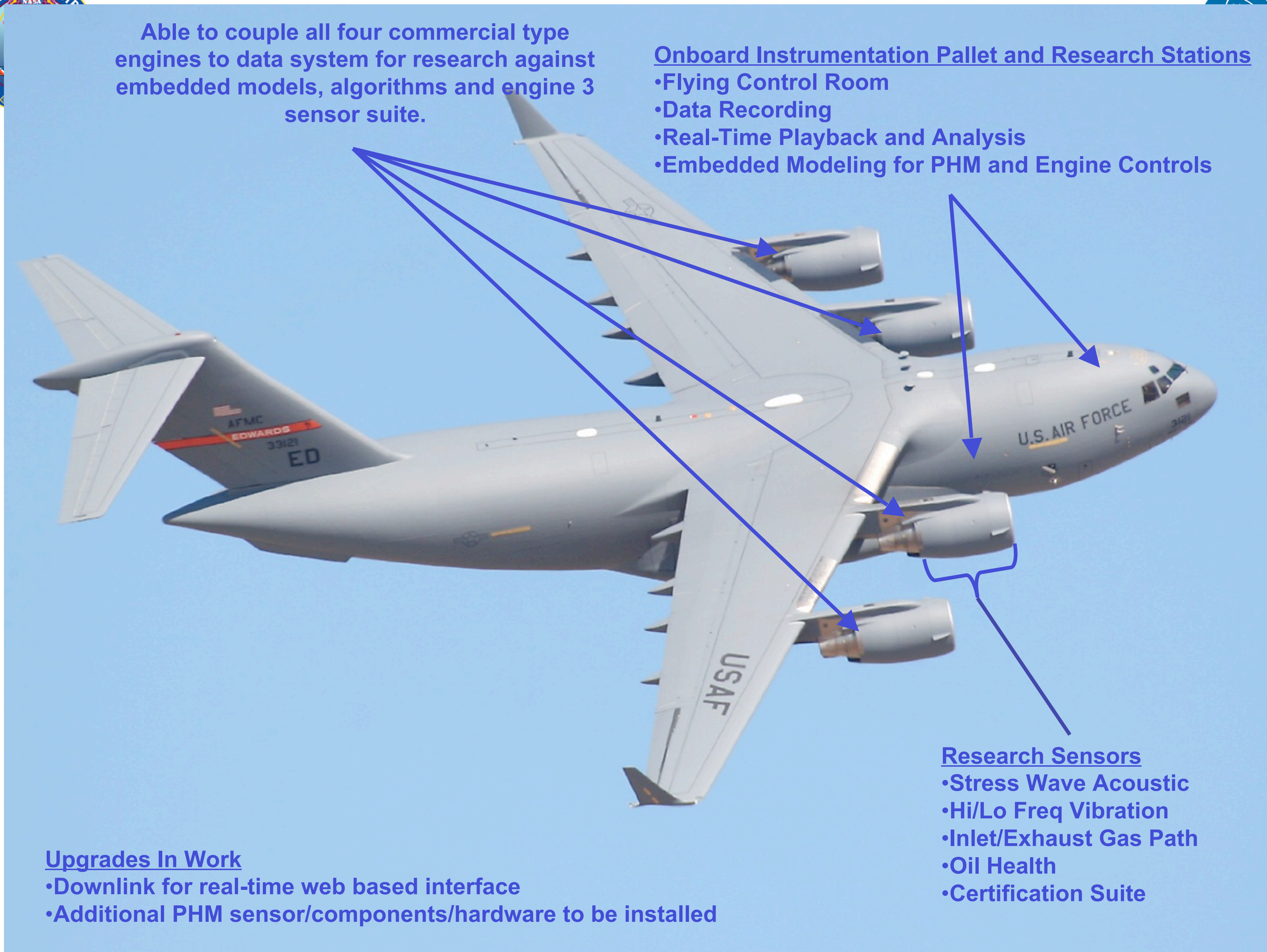
- 4 – POSITIONS SENSORS
- 10 – ACCELEROMETERS

A/C 1553 DATA BUS – 1092

GPS/INS 1553 DATA BUS – 170

T0TAL PARAMETERS - 1604


Extensive Airplane Modifications and Ground Calibration
Added an optical Flight Deflection Measurement System (FDMS) to measure wing twist and bending
Added a flight test noseboom for accurate air data
Instrumented wing with strain gages and performed extensive loads calibration
Quad 68040 Research Flight Control System with production control system as backup


Able to couple all four commercial type engines to data system for research against embedded models, algorithms and engine 3 sensor suite.
Onboard Instrumentation Pallet and Research Stations
•Flying Control Room
•Data Recording
•Real-Time Playback and Analysis
•Embedded Modeling for PHM and Engine Controls
AFMC
EDWARDS
33121
ED
U.S. AIR FORCE
USAF
Research Sensors
•Stress Wave Acoustic
•Hi/Lo Freq Vibration
•Inlet/Exhaust Gas Path
•Oil Health
•Certification Suite
Upgrades In Work
•Downlink for real-time web based interface
•Additional PHM sensor/components/hardware to be installed

Conclusions

- **Full scale flight test forces designers to address real-world issues**
- **Provides high-visibility demonstration**
- **Adds credibility that adaptation technology can be a viable design option**
- **Helps to "separate the real from the imagined"**

Potential Future Work

- **How to sense and incorporate structural limitations into the adaptive algorithm**
- **Develop better metrics – What is most important to ensure that a damaged vehicle can be safely landed?**
- **Investigate adaptive notch filters to avoid adverse aero-servo-elastic (ASE) interactions**
- **Develop and validate requirements for the use of propulsive control for failure / damage conditions**

- **Maintain long-term effort to advance adaptive control technology**

Questions?