F-15 IFCS

Intelligent Flight Control System

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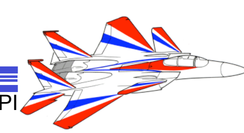
Project Chief Engineer

Project Participants

- **NASA Dryden Flight Research Center**
  - Responsible test organization for the flight experiment
    - Flight, range and ground safety
    - Mission success
- **NASA Ames Research Center**
  - Development of the concepts
- **Boeing STL Phantom Works**
  - Primary flight control system software (Conventional mode)
  - Research flight control system software (Enhanced mode)
- **Institute for Scientific Research**
  - Neural Network adaptive software
- **Academia**
  - West Virginia University
  - Georgia Tech
  - Texas A&M



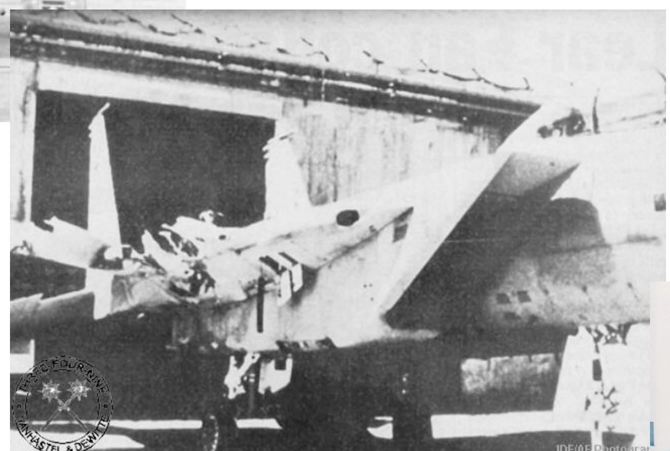
F-15 IFCS Project Goals

- **Demonstrate Revolutionary Control Approaches that can Efficiently Optimize Aircraft Performance in both Normal and Failure Conditions**

- **Advance Neural Network-Based Flight Control Technology for New Aerospace Systems Designs**

Motivation

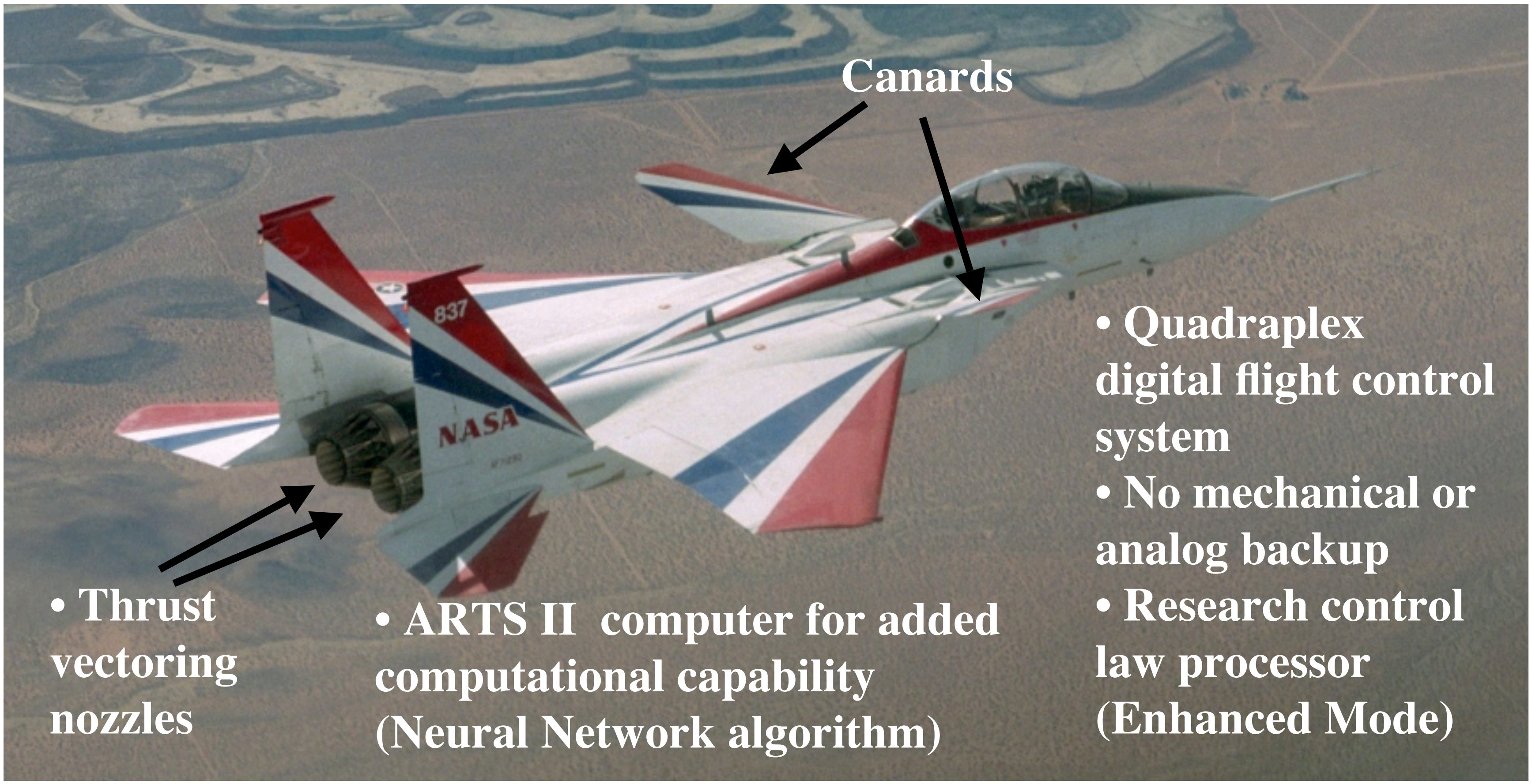
These are survivable accidents



IFCS has potential to reduce the amount of skill and luck required for survival

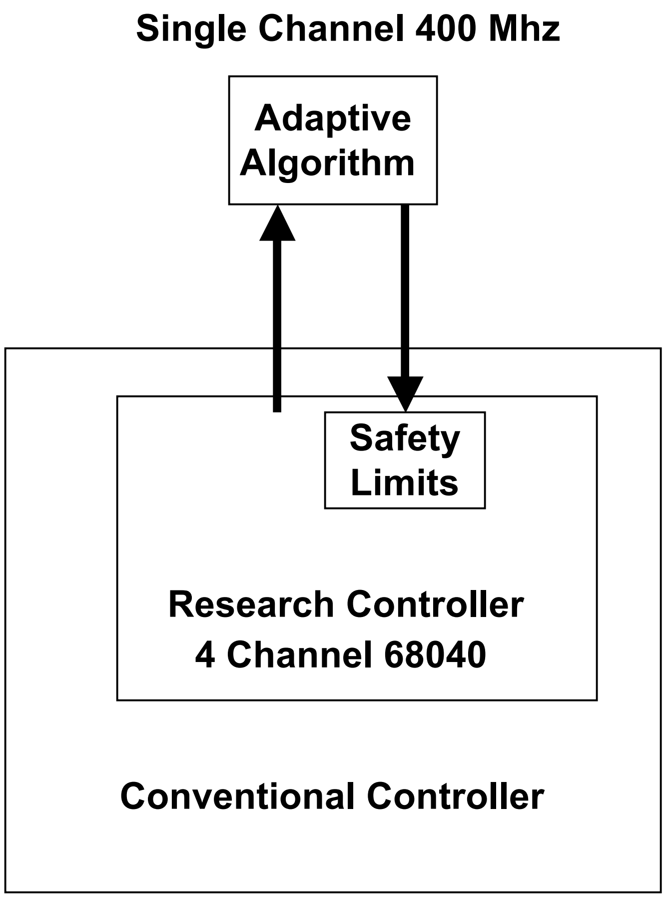
NASA NF-15B Tail Number 837

Extensively modified F-15 airframe

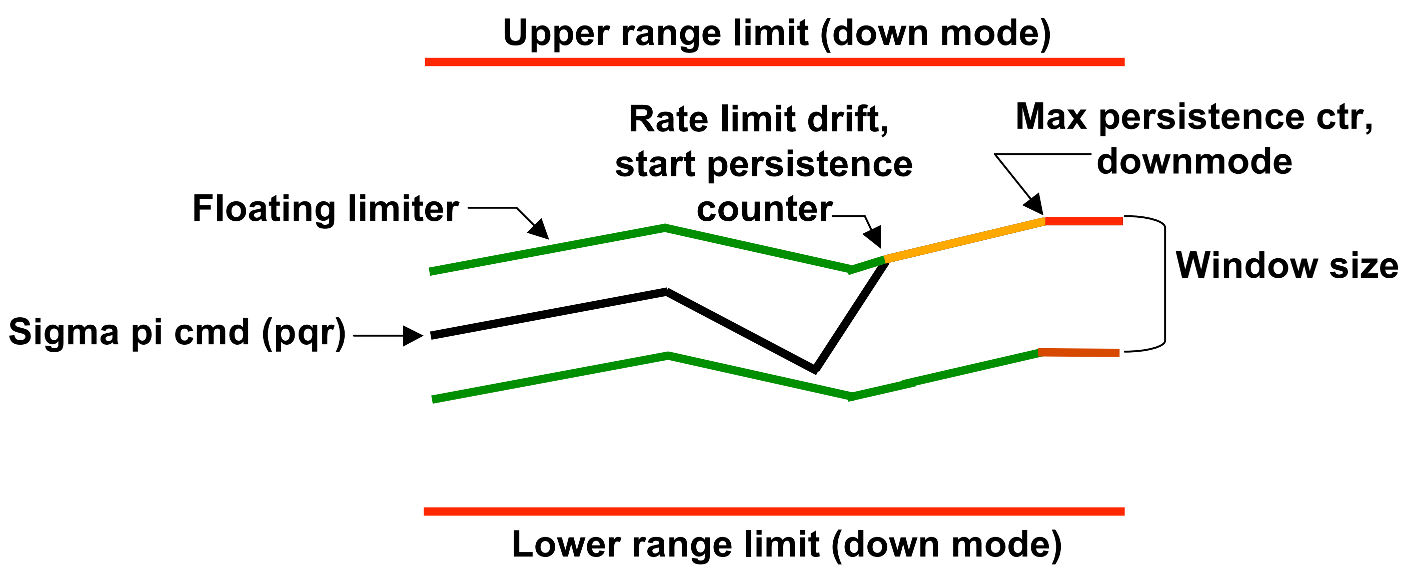


Limited Authority System

- 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



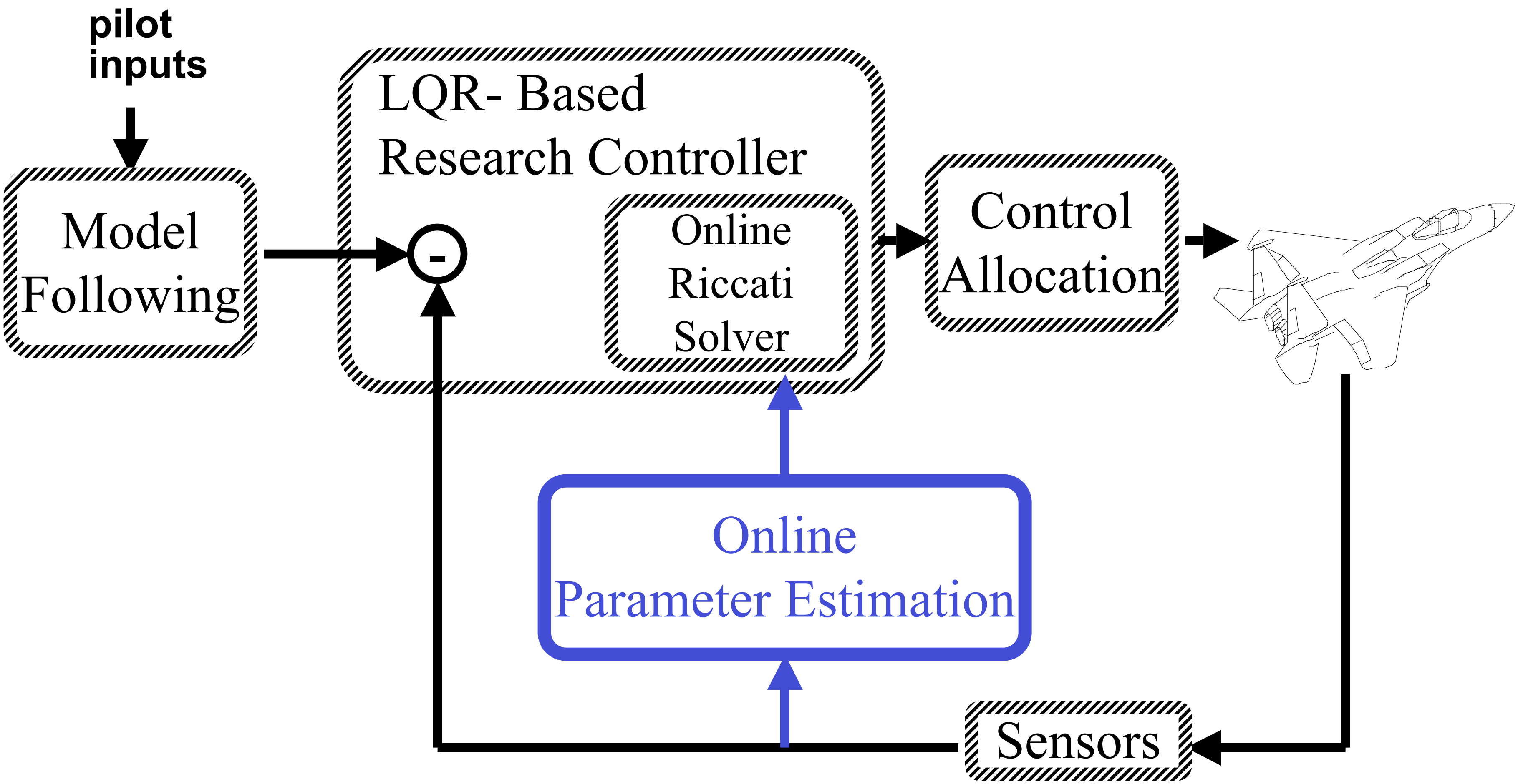
NN Floating Limiter



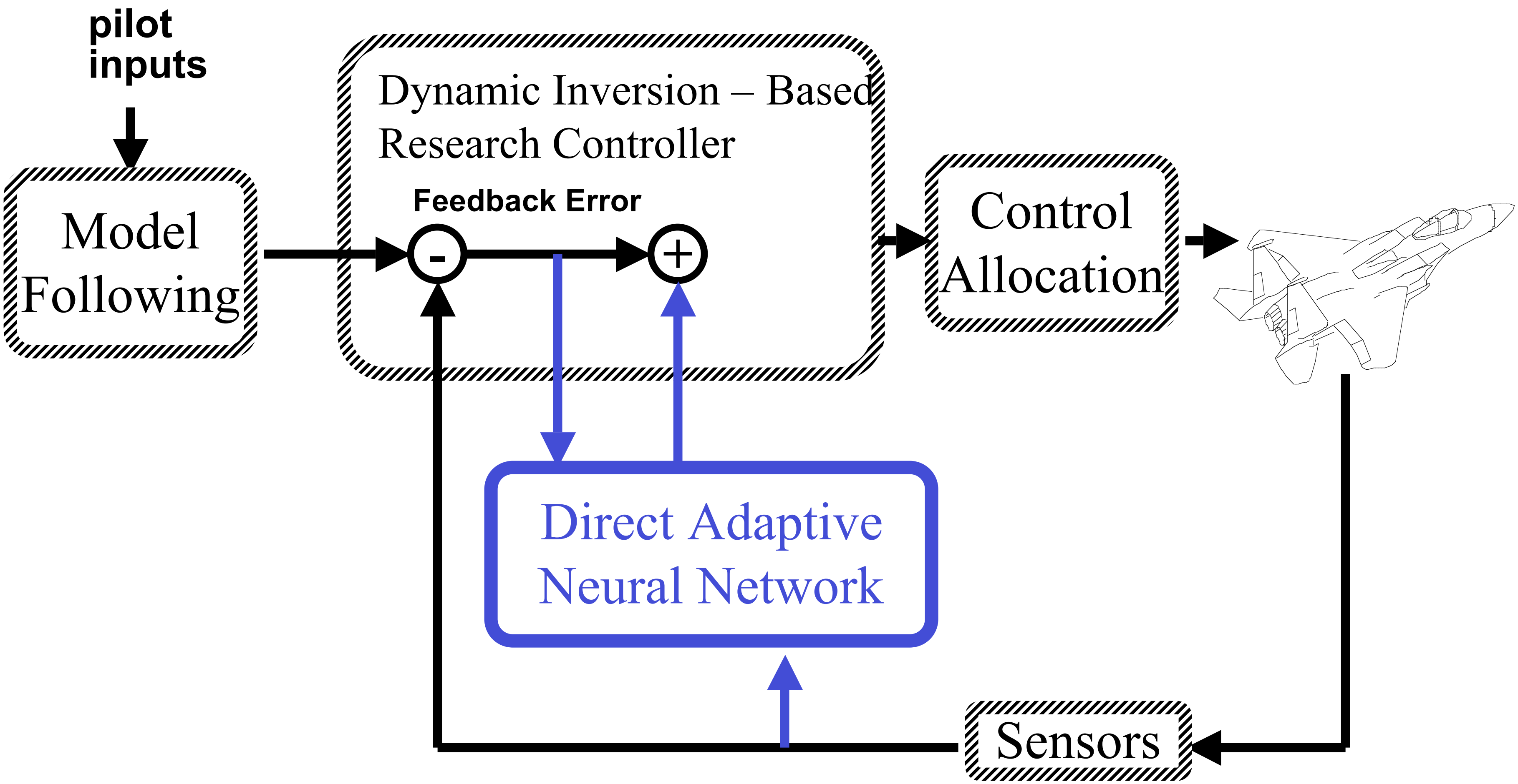
Black – sigma pi cmd
Green – floating limiter boundary
Orange – limited command (fl_drift_flag)
Red – down mode condition (fl_dmode_flag

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

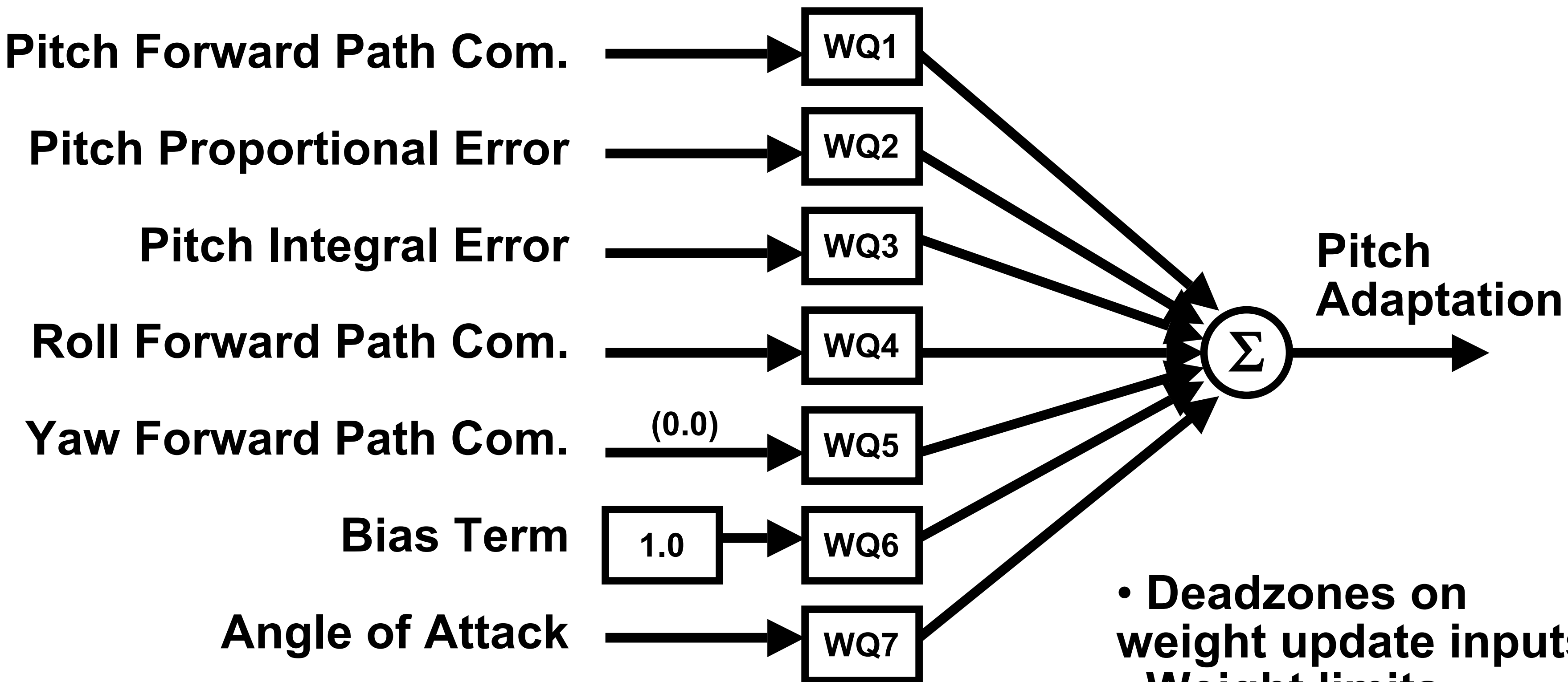
Gen I Indirect Adaptive
Control Architecture



Gen II Direct Adaptive
Control Architecture



Simplified Sigma-Pi Neural Network
Pitch Axis

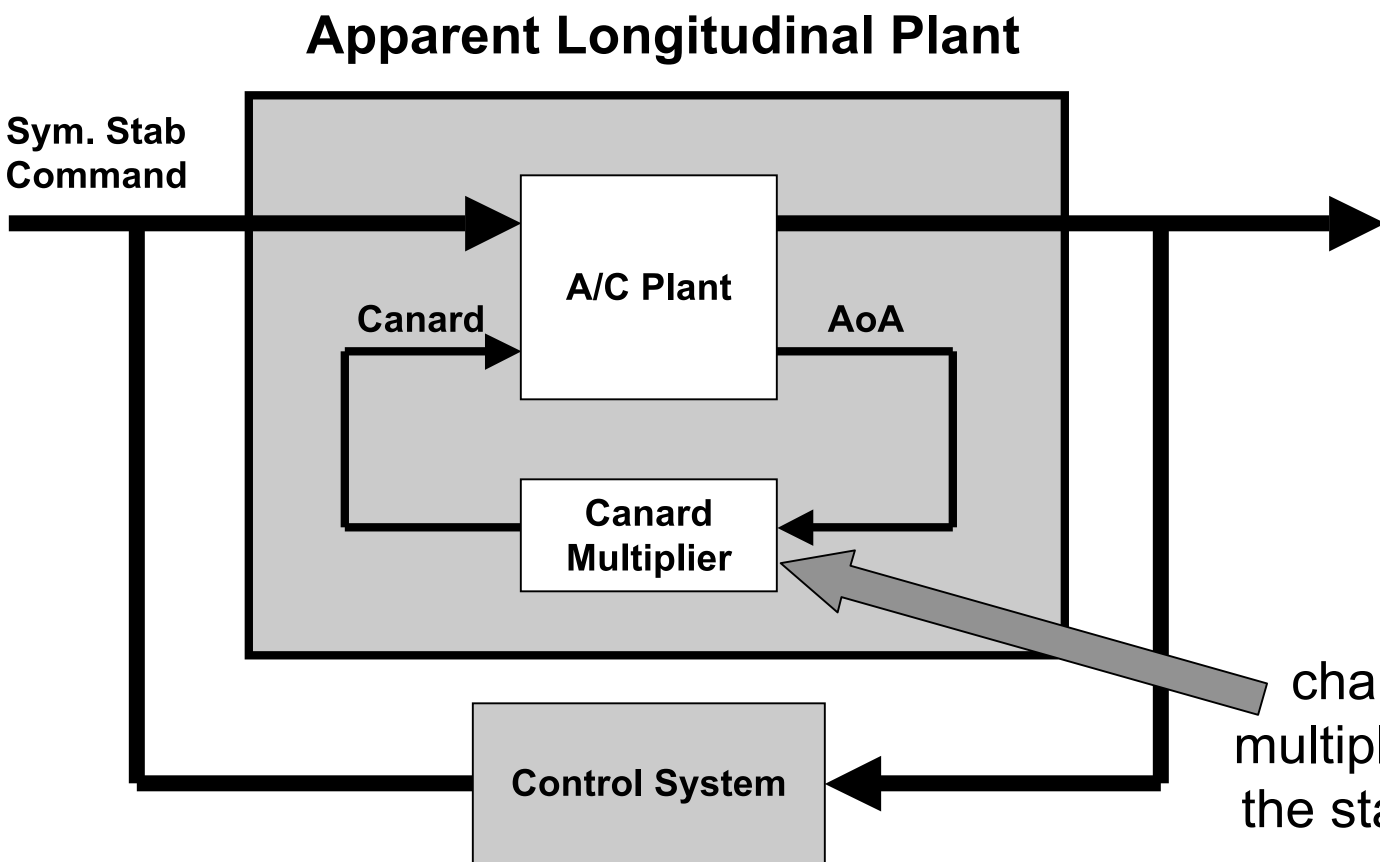


- Deadzones on weight update inputs
- Weight limits

Weight Update Law: $\dot{W} = -G(U_{err}B_a + LU_{err}W)dt$

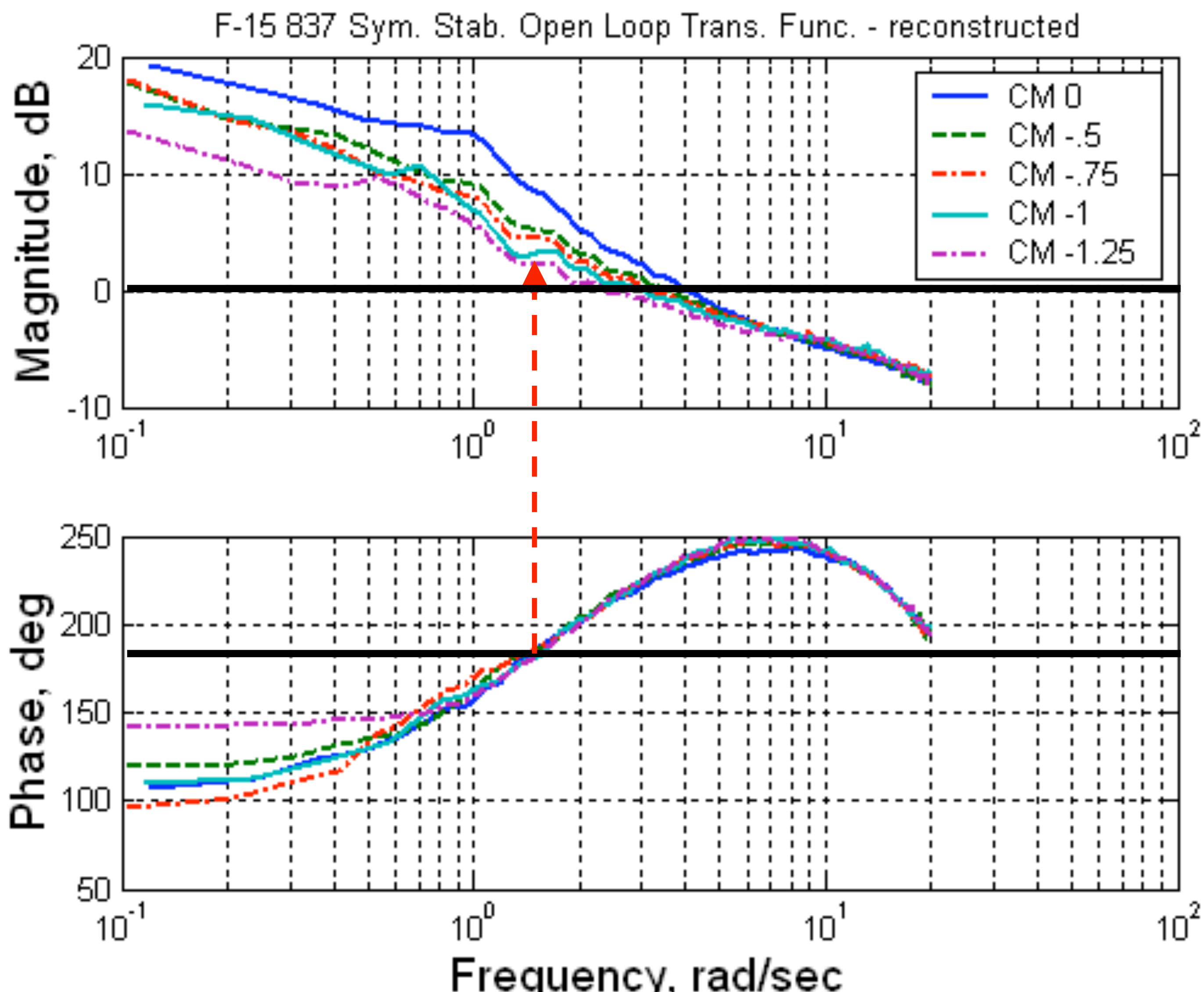
Simulated Destabilization
A-Matrix Failure

Canard Multiplier – "An A-Matrix Failure"



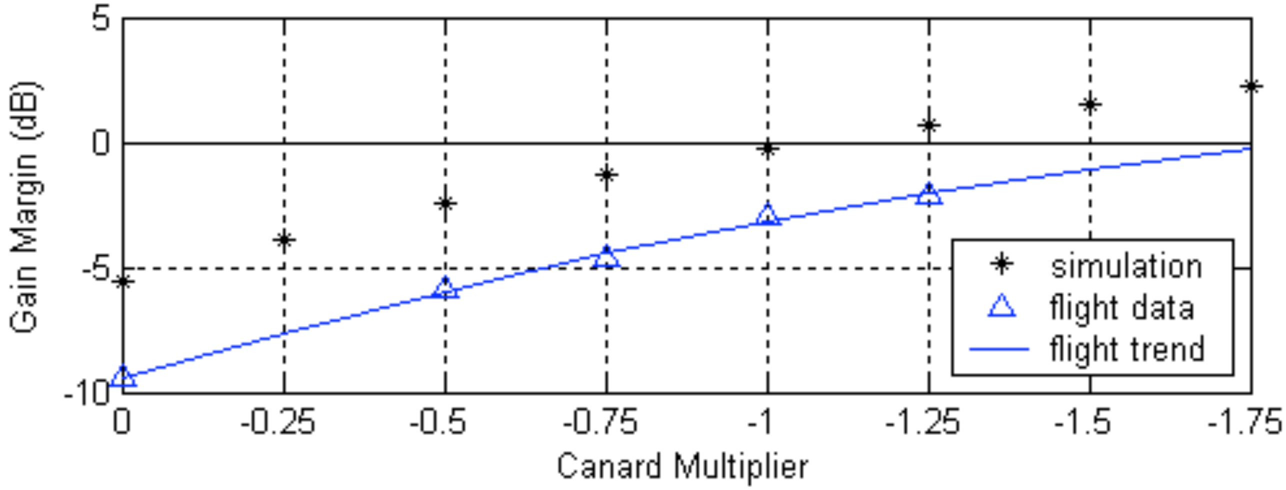
changing this multiplier changes the stability of the apparent plant

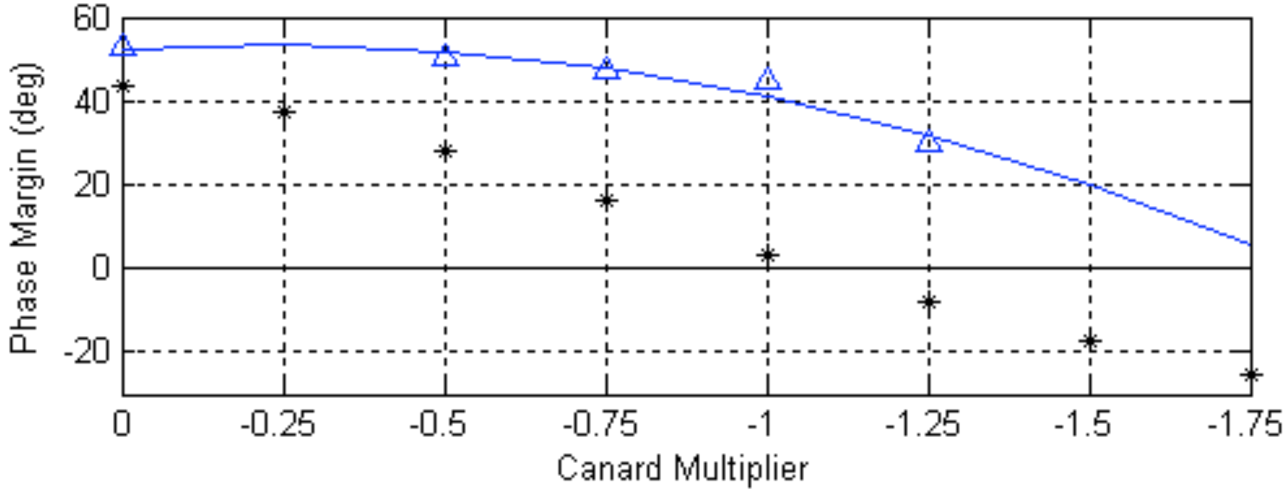
Flight Results – Failure with No Adaptation



Stability Margin Trends

Symmetric Stab Loop, NN Off





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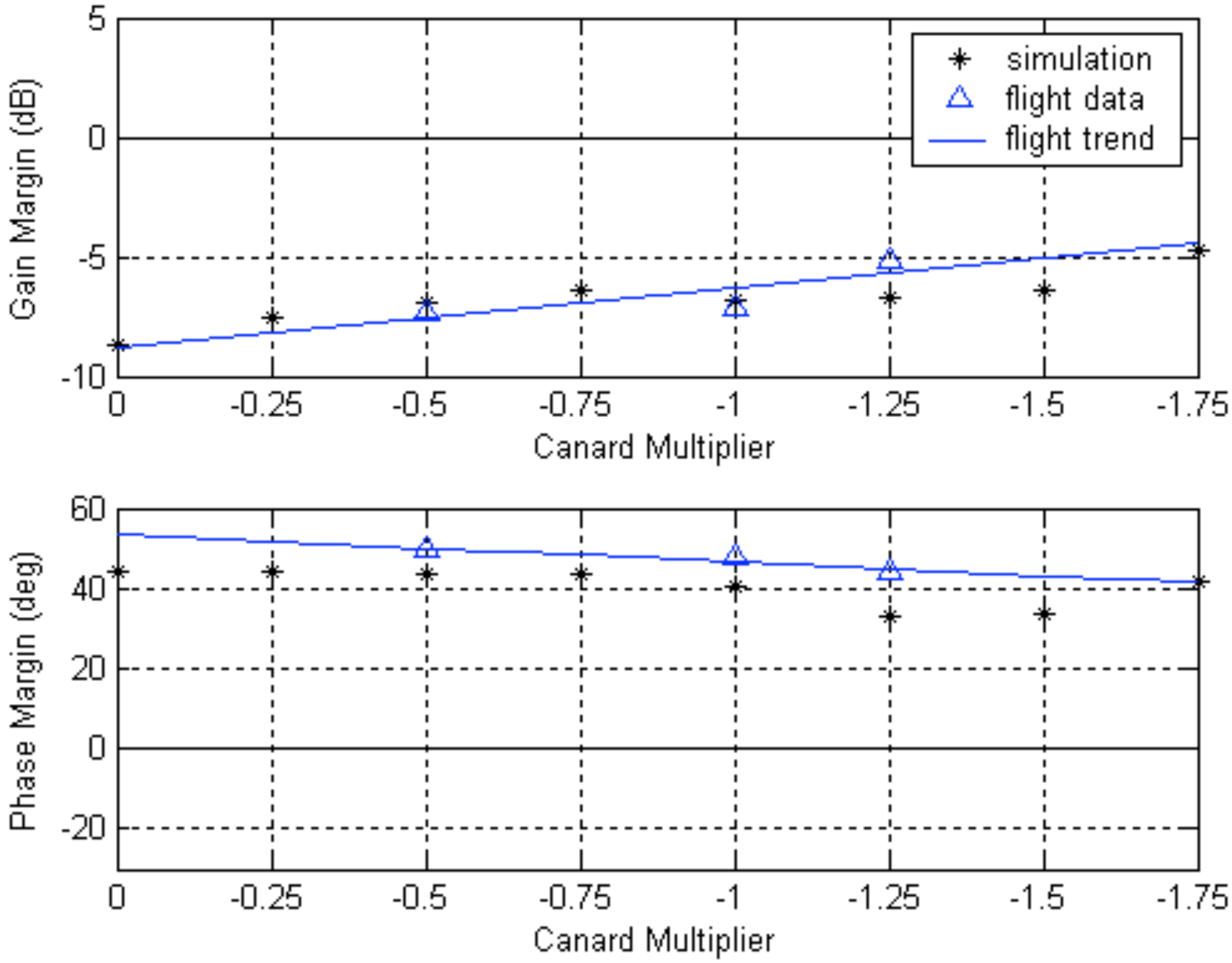
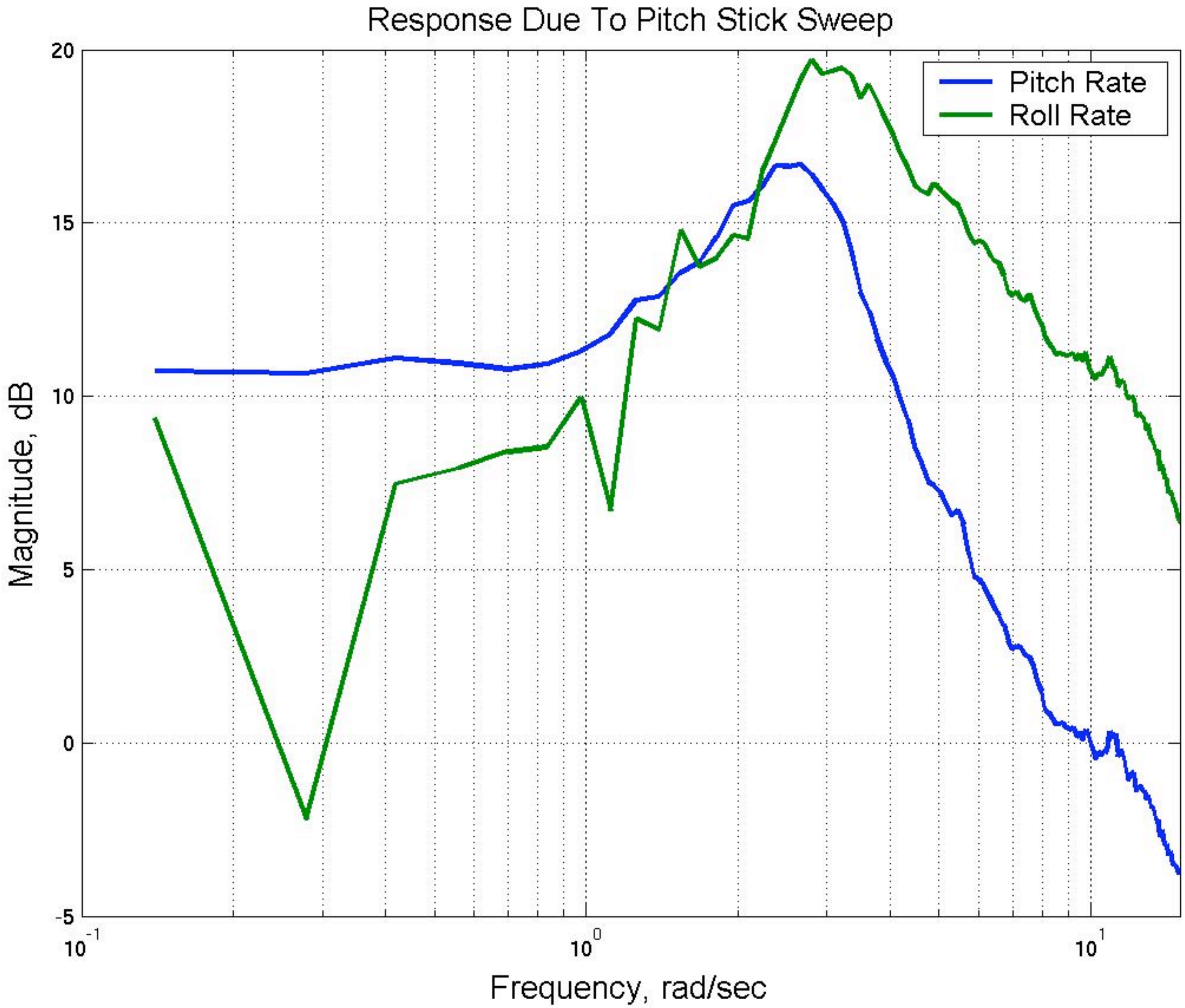


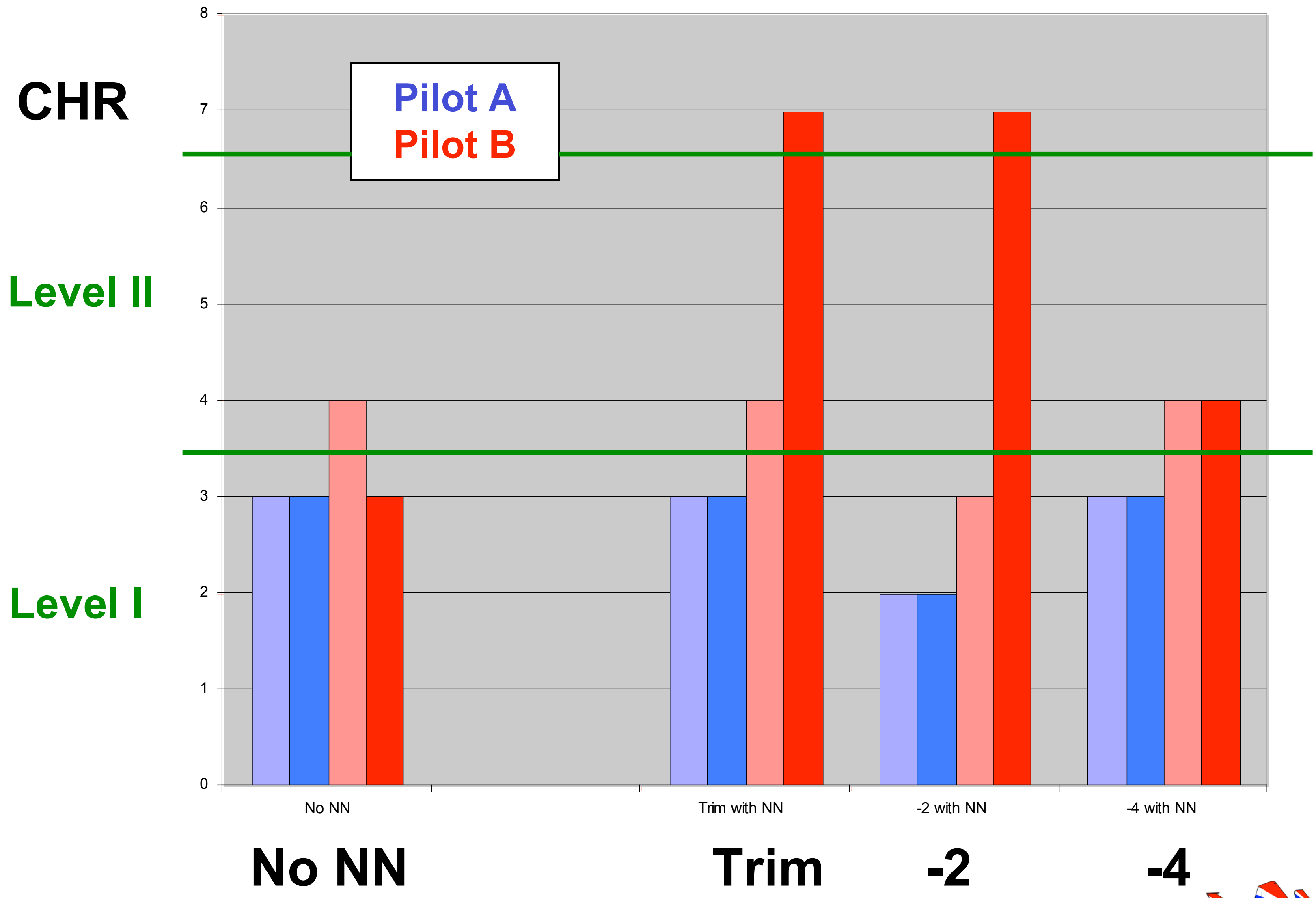
Frozen Stabilator
B-Matrix Failure

Simulated Stabilator Failure

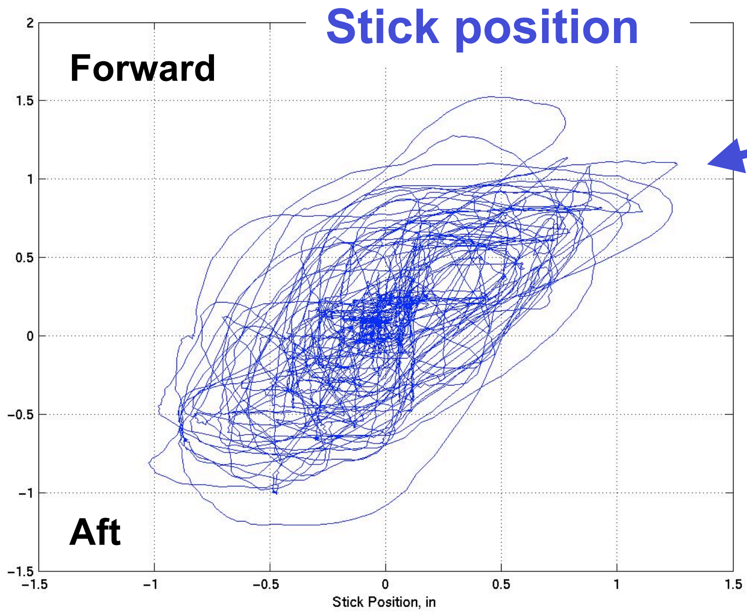
Flight Results
Simulated Frozen Stabilator



Pilot Ratings with Adaptation
Formation Flight Task

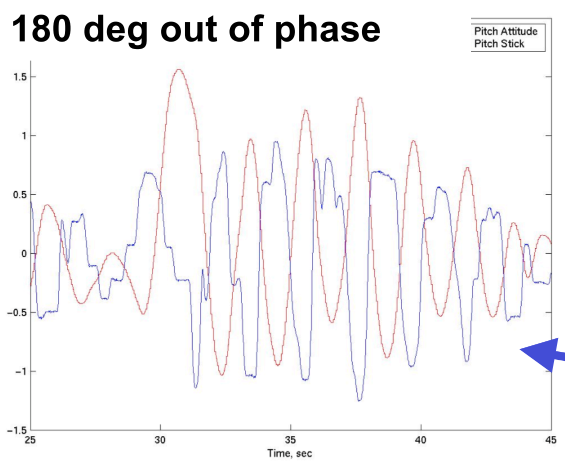


Simulated Frozen Stabilator



- Pilot unconsciously compensates for asymmetry

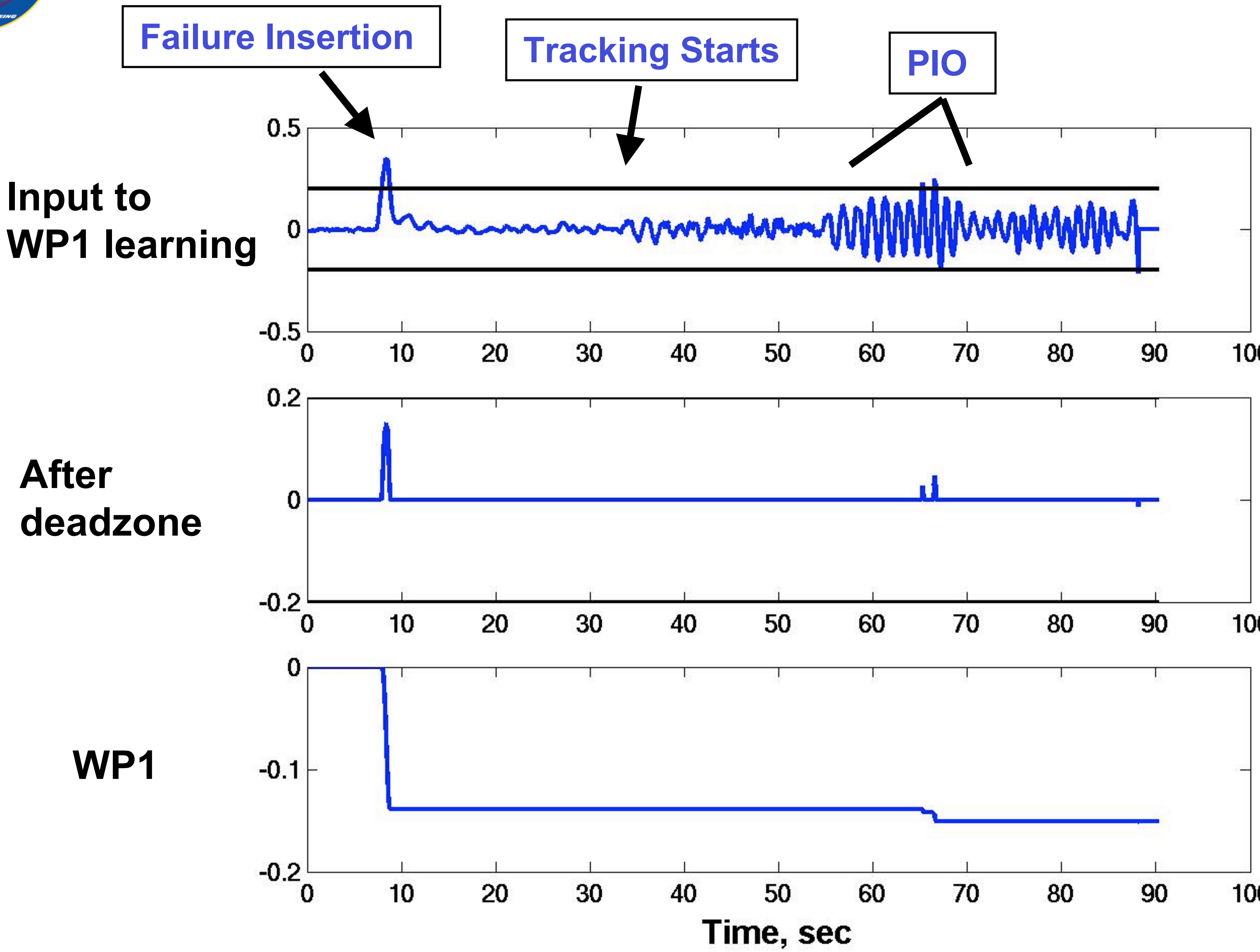
- Correlated pilot input presents greater challenge for adaptive system



+ 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

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

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?