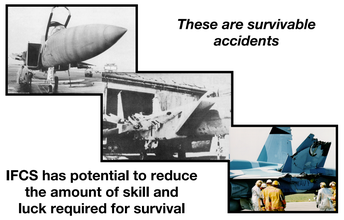
National Aeronautics and Space Administration

Validation Through Full-Scale Flight Exploration

Objectives



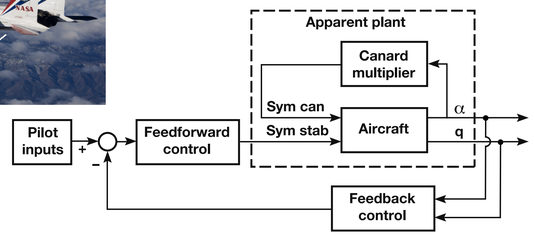
These are survivable accidents

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

- Regain stable platform
  - Typically measured in terms of stability margin
  - Stability margin not explicitly fed into adaptation
- Ability to re-establish good handling qualities
  - Measured in terms of model following
    - Response should fall within MUAD envelope
    - If successful should provide good handling qualities
- Provide ability to safely land airplane
  - Stay within maneuver constraints
  - Respect structural limitations

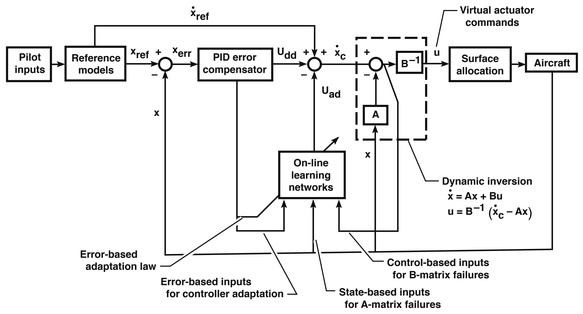
Simulated Failures

Longitudinally Destabilized Plant

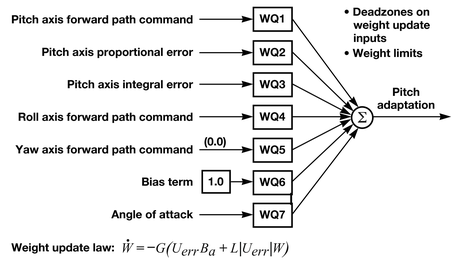


Flight Control Design

Direct Adaptive Control Architecture



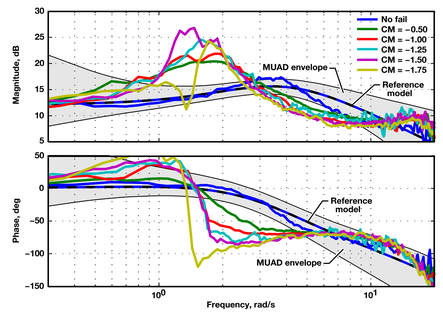
Simplified Sigma-Pi Neural Network Pitch Axis



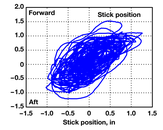
Weight update law: $\dot{W} = -G(U_{err} B_a + L|U_{err}|W)$

Flight Results

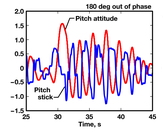
Closed Loop Frequency Response No Adaption



Simulated Frozen Stabilator



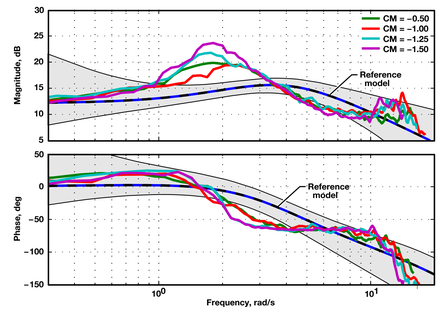
- Pilot unconsciously compensates for asymmetry
- Correlated pilot input presents greater challenge for adaptive system



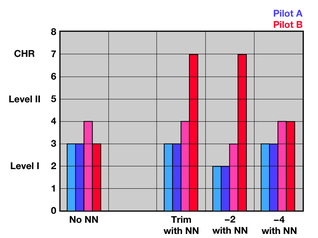
\+ Adaptive system reduced the amount of cross coupling

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

Closed Loop Frequency Response With Adaptation



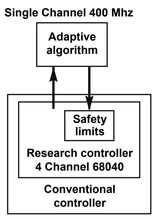
Pilot Ratings With Adaptation Formation Flight Task



Implememtation

Limited Authority System

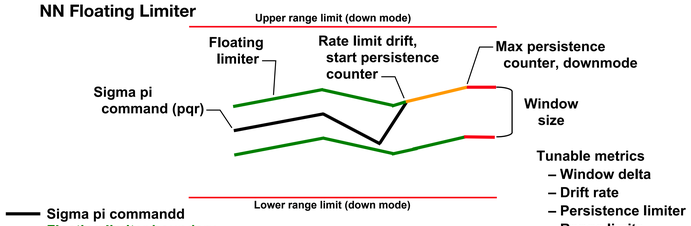
- Adaptation algorithm implemented in separate processor
  - Class B software
  - Autocoded directly from Simulink block diagram
  - Many configurable settings
    - Learning rates
    - Weight limits
    - Thresholds, etc.
- Control laws programmed in Class A, quad-redundant system
- Protection provided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



Flight Experiment

- Assess handling qualities of Gen II controller without failure
- Introduce simulated failures
  - Control surface locked ("B matrix failure")
  - Angle of attack to canard feedback gain change ("A matrix failure")
- Assess handling qualities of Gen II controller without failure
- Re-assess handling qualities with simulated failures and adaptation
- Report on "Real World" experience with adaptive flight control system

NN Floating Limiter

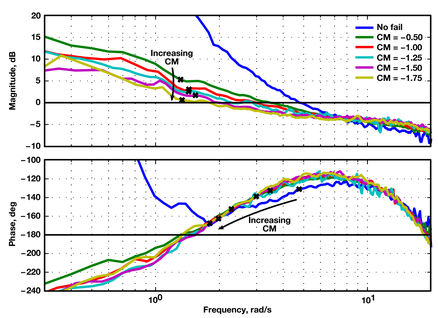


Tunable metrics
- Window delta
- Drift rate
- Persistence limiter
- Range limits

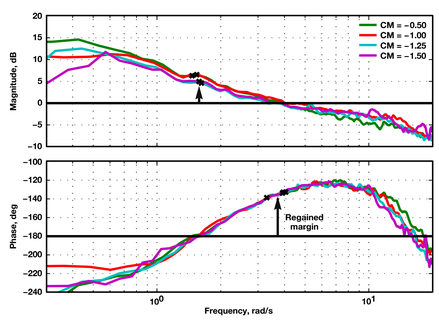
IRAC

Flight Results

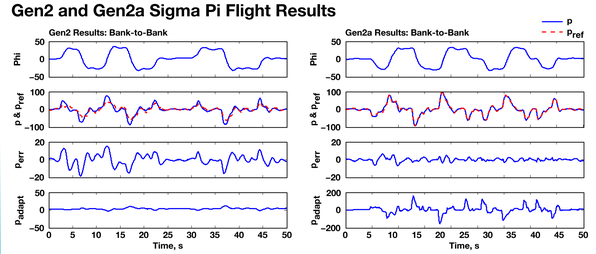
Open Loop Frequency Response



Open Loop Frequency Response With Adaption



Gen2 and Gen2a Sigma Pi Flight Results



Future Direction

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:
- Adaptively augmenting control by integrating propulsion control
- Assessing integrated adaptive flight management and planning
- Sensing and suppressing aero- servoelastic (ASE) interactions
- Integration of static structural load measurements with adaptive controller

Conclusion

- 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"

Integrated Resilient Aircraft Control

www.nasa.gov