Integrated Resilient Aircraft Control

Validation Through Full-Scale Flight Exploration

Objectives

Content goes here.

Technical Challenges

Content goes here.

Technical Approach

Content goes here.

Analysis

Content goes here.

Solution

Content goes here.

Results

Content goes here.

Conclusions

Content goes here.

Large photo in middle
EC04-0361-16

NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/Gallery/Photo/index.html
NASA Photo: EC04–0361–16 Date: December 15, 2004 Photo By: Carla Thomas

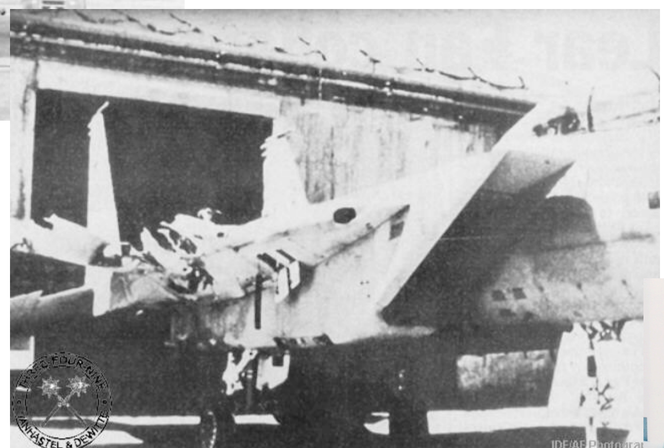
NASA's flexible–wing F/A–18 maneuvers through a test point during the second phase of the NASA/Air Force Active Aeroelastic Wing flight research program.

Full-scale Advanced Systems
(FAST) Airframe

Left Side

Objectives

These are survivable accidents



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

Objectives

- Regain Stable Platform
  - Metrics analogous to stability margins needed for adaptive control systems
  - Avoid adverse structural interactions
- Maneuverability
  - Control vehicle within new constraints
  - Respect structural limitations
  - Inform pilot of new performance limitations
- Provide ability to safely land airplane
  - Develop safest recovery trajectory

Focus Areas

- Simplified adaptive system
  - Goal: system that is more acceptable to the aerospace community in terms of complexity and testability
  - Benefit:
    - Gain experience in verification & validation of adaptive systems
    - Prove system stability.
- Pilot – adaptive controller interaction
  - Goal: provide mechanisms for feedback both to and from the pilot to allow for better understanding of what the adaptive system is doing and also some control over how much or little the system adapts
  - Goal: provide the capability to predict and prevent adverse interactions between the pilot and the adaptive system
  - Benefit:
    - Reduce potential Pilot Induced Oscillations tendencies due to aircraft damage
    - Reduce cross-axis coupling due to a failure.
- Integration with vehicle structure
  - Goal: alleviate a major roadblock to adaptive system implementation by providing information that allows the adaptive system to impose constraints that keep the aircraft within structural limits and provide methods that reduce the potential for adverse aeroservoelastic interactions
  - Benefit:
    - Prevention of static and dynamic structural over-load.

Technical Approach

Simulated Failures

- Surface command frozen
- Rudder toe-in
- Asymmetric flap
- Changes to onboard aero model
- Air data failures
- Others?

FAST Research Avionics Capabilities

- Dedicated Ghz processor for experiment
- Shell & process for Simulink autocode (or c-code)
- Can control commands to:

All aero surfaces (except speed brake)

All pilot inputs

Both engine throttles independently

- Limit checks done by Class A software in RFCS
- Potential for Class A experiment (dual ARTS IV or in quad RFCS) – take to landing?
- Tons of research instrumentation parameters (mostly related to structures)
- Simulated failure of multiple control surfaces

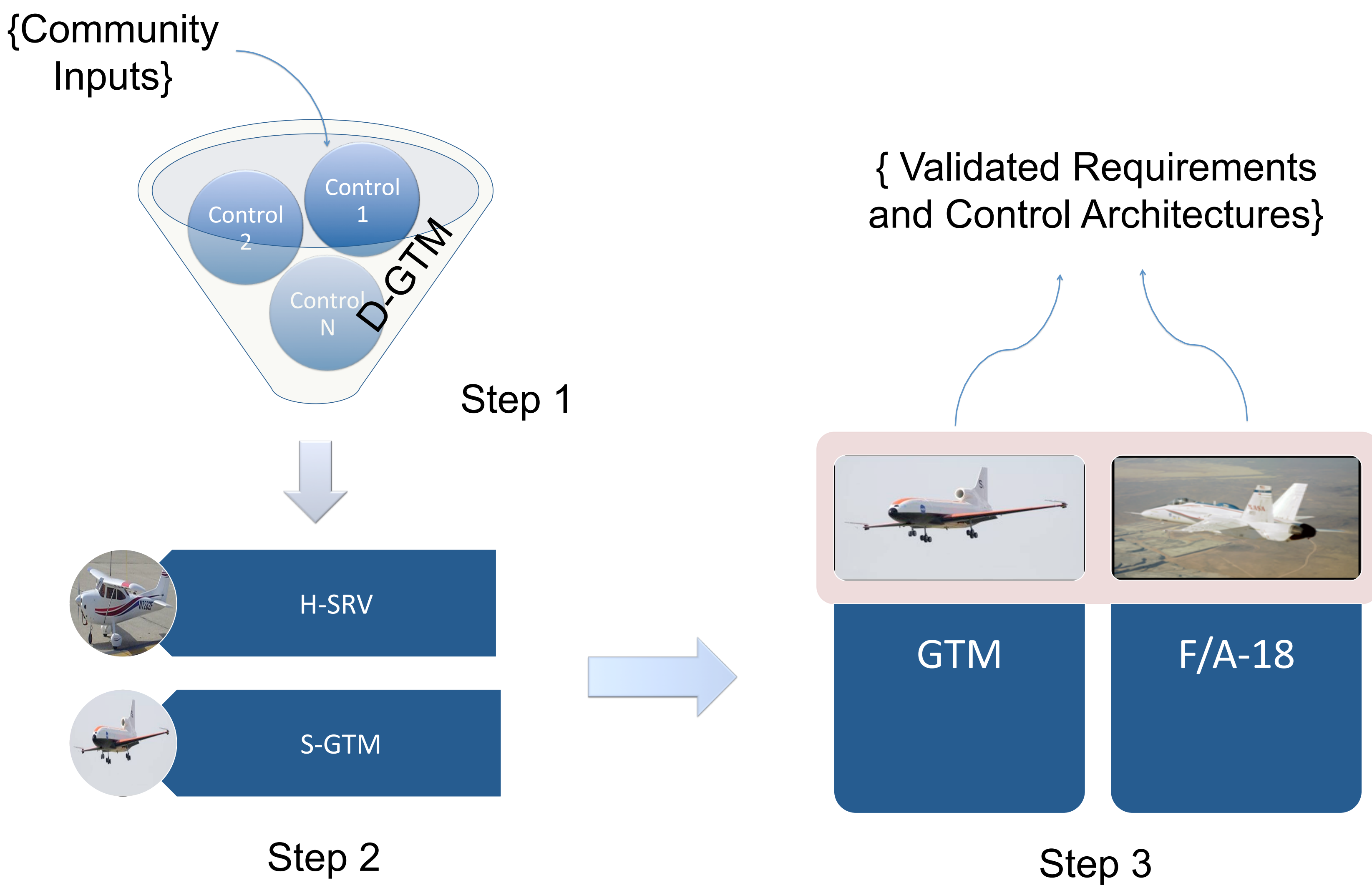
Flight Experiment

- Assess handling qualities of adaptive controller without failure
- Introduce simulated failures
- Assess handling qualities of adaptive controller with failures
- Re-assess handling qualities with simulated failures and adaptation.

- Report on “Real World” experience with adaptive flight control system

Middle

Adaptive Control Maturation Plan



IRAC Full Scale Flight Experiment Peer Review Selection Process

- Completed workshop at AIAA GNC in Chicago
  - Very good feedback and discussion
- Decision to emphasize three adaptive system Focus Areas:

  1 - Simplified Adaptive System
    - Analyzable
    - V&V able

  2 – Pilot Interaction

  3 - Structural Interaction
    - Static structures – fiber optic deflection measurement system
    - Aero-servo-elasticity – adaptive feedback to eliminate structural modes from sensed motion

Simplified Adaptive System

- Reduced complexity
- Compatible with global stability and performance proofs
- Restricted authority system with verifiable limits on the adaptation
- Conventional verification and validation methods apply
- Implementation in a multi-processor redundant system

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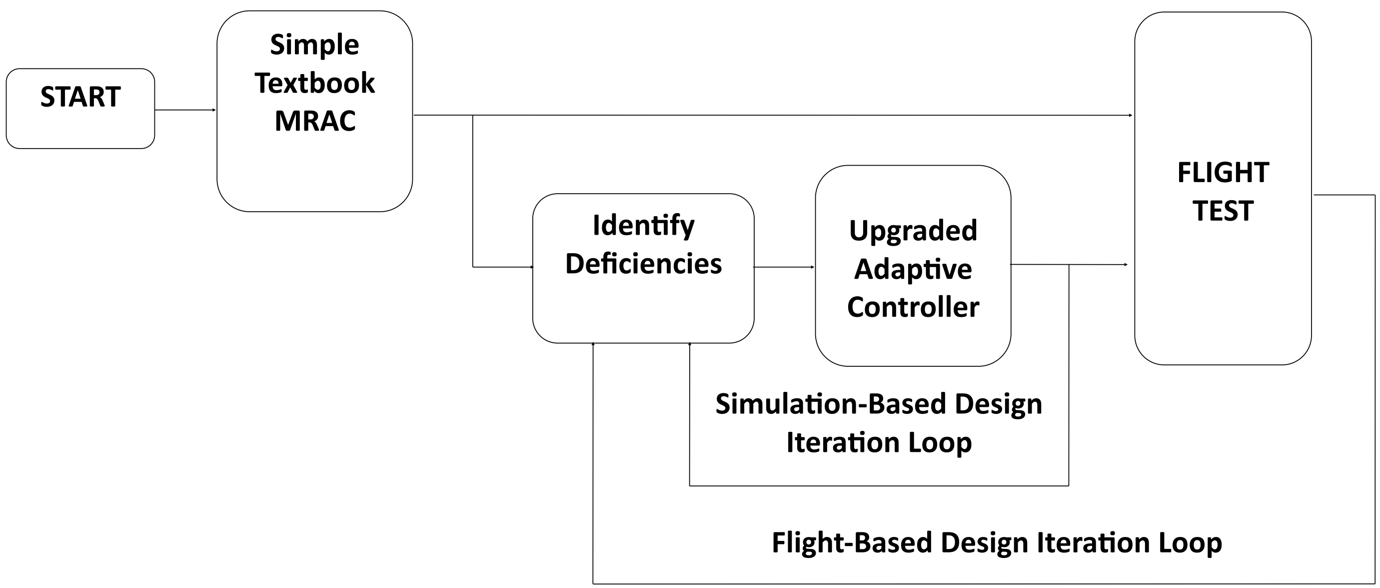
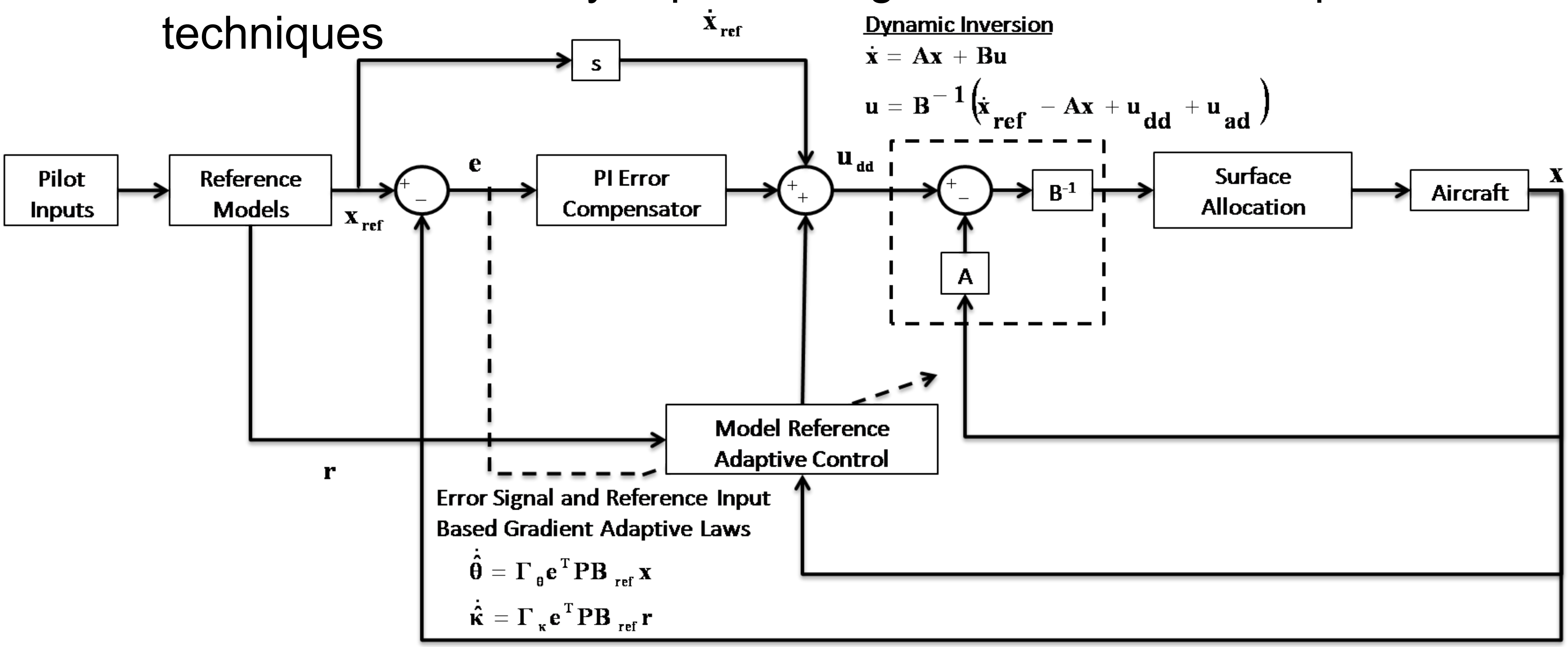


- Uncover limitations of adaptive control
  - ➢ Compensating state matrix failures with input (and/or parametric) adaptation
  - ➢ Compensating input matrix failures with parametric (and/or input) adaptation
  - ➢ Investigating adaptation due to cross axis effects
- Validate metrics for characteristics of adaptation and implementation
- Address limitations by implementing more advanced adaptive techniques

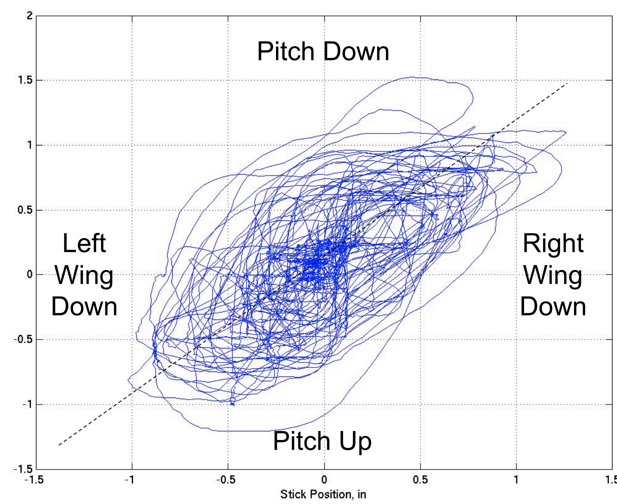


Right Side

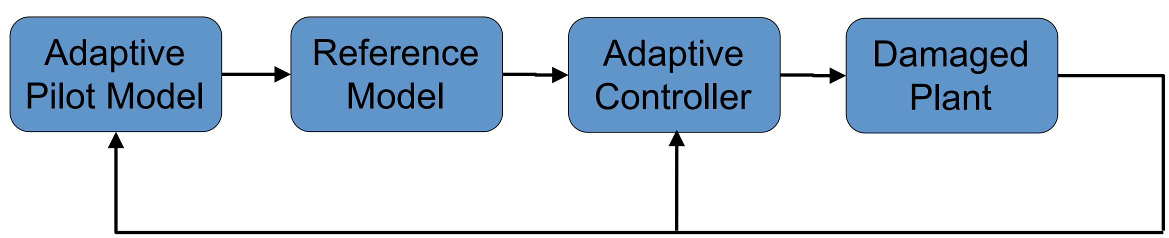
Pilot / Adaptive Controller Interaction

- Pilot control of adaptive algorithms
  - Initiate as an emergency system
  - Freeze learning upon suitable recovery
  - Adjust learning rates, dead-zones, etc.
- Adaptive system feedback to pilot
  - Stick and rudder command restrictions
  - Measure of current persistence of excitation
- Potential for adverse interactions
  - Excessive adaptation leading to actuator rate limitin
  - Improper adaptation leading to poor handling qualities / PIO characteristics

Example of Adverse Pilot-Controller Interaction



Pilot Cross-Axis Input for Pitch Task with an Asymmetric Failure (IFCS Flight 190)



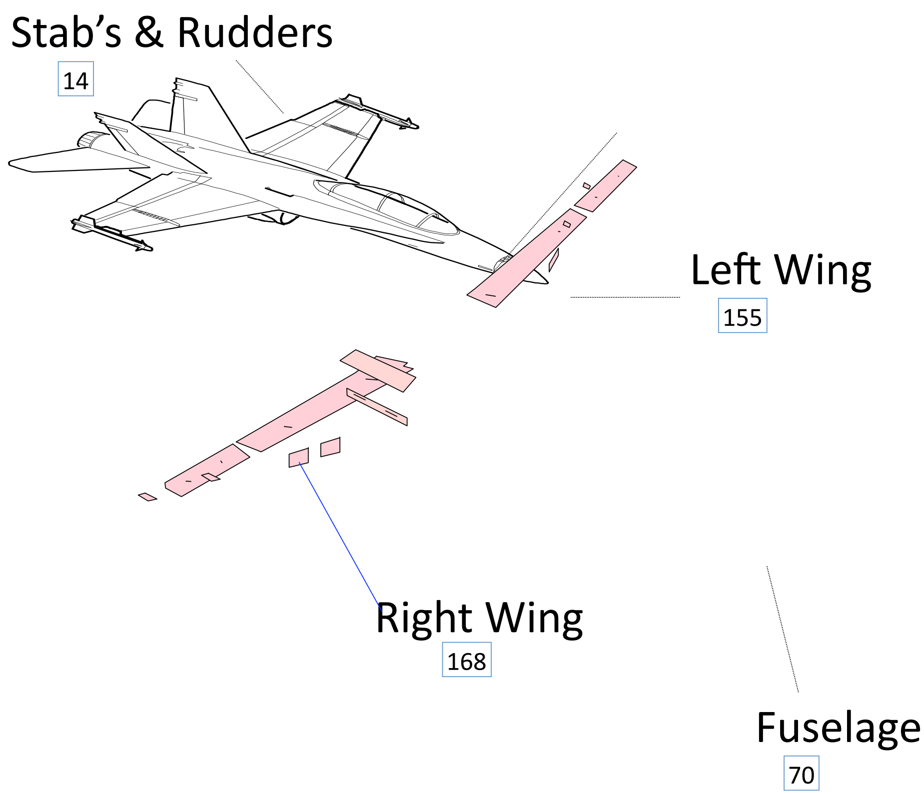
Architecture for the Analysis of Adverse Pilot-Controller Interactions

Integration with Vehicle Structure

- Existing Instrumentation
- Fiber optic shape sensing system
- Aero-servo elastic interactions
  - Active control of structural modes
  - Smart sensing (extract rigid body information)
  - Adaptive filters

Existing Instrumentation

TOTAL PARAMETERS - 1669



RH WING PARAMETERS-168

107 - FULL BRIDGE STRAIN GAGES
18 – ACCELEROMETERS
8 – POSITION SENSORS
10 – VOLTAGE SENSORS
3 – TEMPERATURE SENSORS
22 – PRESSURE SENSORS

LH WING PARAMETERS-155

77 - FULL BRIDGE STRAIN GAGES
18 – ACCELEROMETERS
8 – POSITION SENSORS
10 – VOLTAGE SENSORS
4 – TEMPERATURE SENSORS
22 – PRESSURE SENSORS
16 – FDMS TARGETS

FUSELAGE PARAMETERS-70

6 - MOTION PAK
7 – ACCELEROMETERS
7 – TEMPERATURES
8 – FUEL QUANITY
27 – MISC. A/C PARAMETER
15 – TCG PARAMETERS

EMPANNAGE PARAMETERS-14

4 – POSITIONS SENSORS
10 – ACCELEROMETERS

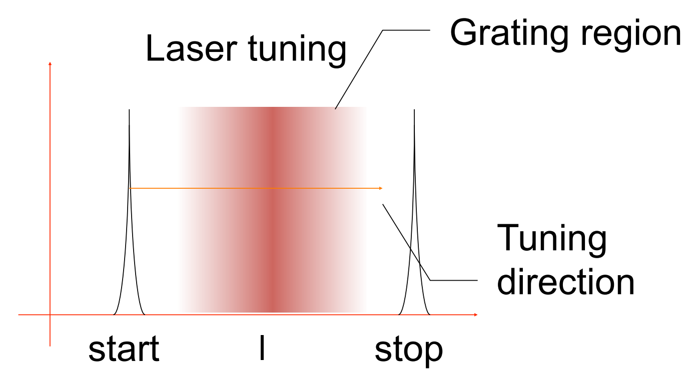
A/C 1553 DATA BUS – 1092

GPS/INS 1553 DATA BUS – 170

Fiber Optic System Overview

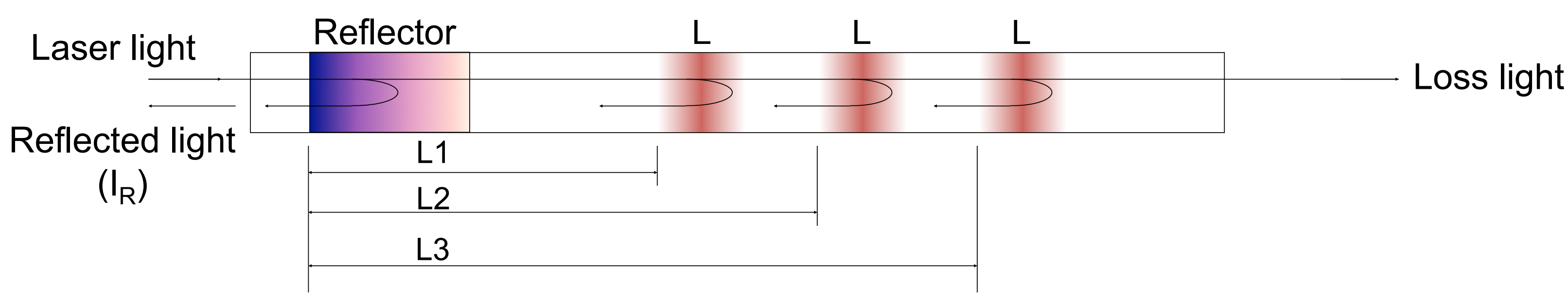
Fiber Optic Sensing with Fiber Bragg Gratings

- Immune to electromagnetic / radio-frequency interference and radiation
- Lightweight fiber-optic sensing approach having the potential of embedment into structures
- Multiplex 100s of sensors onto one optical fiber
- Fiber gratings are written at the same wavelength
- Typical gage lengths from 0.1mm to 100mm
- Uses a narrowband wavelength tunable laser source to interrogate sensors
- Typically easier to install than conventional strain sensors



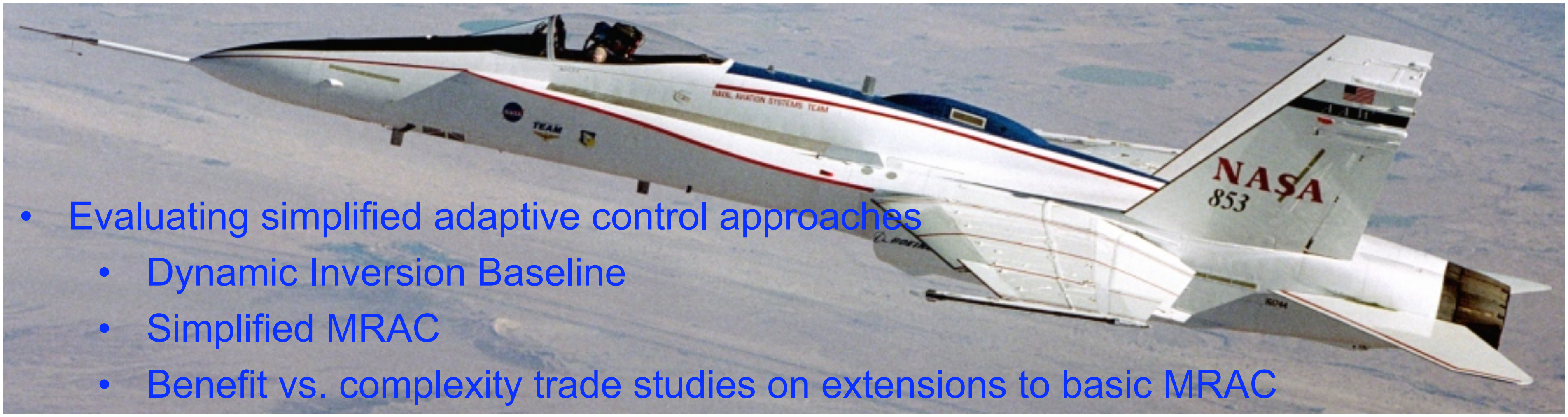
$$I_R = \sum_i R_i Cos(k2nL_i) \qquad k = \frac{2\pi}{\lambda}$$

R_i – spectrum of i^{th} grating
n – effective index
L – path difference
k – wavenumber



FAST Current Status

- Completed Hardware-in-the-loop testing (August)
    - Aircraft is currently flying non-research flights
        - First flight of new hardware March 2010
        - Peer reviewed experiment to fly in March 2011



- Evaluating simplified adaptive control approaches
    - Dynamic Inversion Baseline
    - Simplified MRAC
    - Benefit vs. complexity trade studies on extensions to basic MRAC

- Investigating ways for pilot to control learning rates
- Planning to fly cross-coupling handling qualities metric development test with AFFTC test pilot school
- Future planned work
    - Interaction between adaptive pilot model and adaptive system
    - Adaptive controller implemented in redundant system

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”