Future of Aircraft Engine Control and Challenges in Getting There

Panel Session at 2013 GTI Turbo Expo
June 5, 2013, San Antonio, TX

Panel Members

Dr. Sanjay Garg, NASA Glenn Research Center, Cleveland, OH – (Chair)
William E. Rhoden, UTC Aerospace Systems, Windsor Locks, CT
Dr. Wolfgang Horn, MTU Aero Engines AG, Munich, Germany
James Urnes, Sr., Boeing Research and Technology, St. Louis, MO
Dennis E. Culley, NASA Glenn Research Center, Cleveland, OH

AGENDA

- Panel Member Introductions
- 15 Minute presentations by Panel Members:

Sanjay Garg: Overview and Propulsion Control Needs to meet NASA Aeronautics Research Program Goals

Bill Rhoden: An OEM Perspective on the Future of Engine Controls

Wolfgang Horn: A Systems Perspective on Future Aero Engine Control

James Urnes: Integrating Propulsion Control with Aircraft Systems to Provide Increased Performance

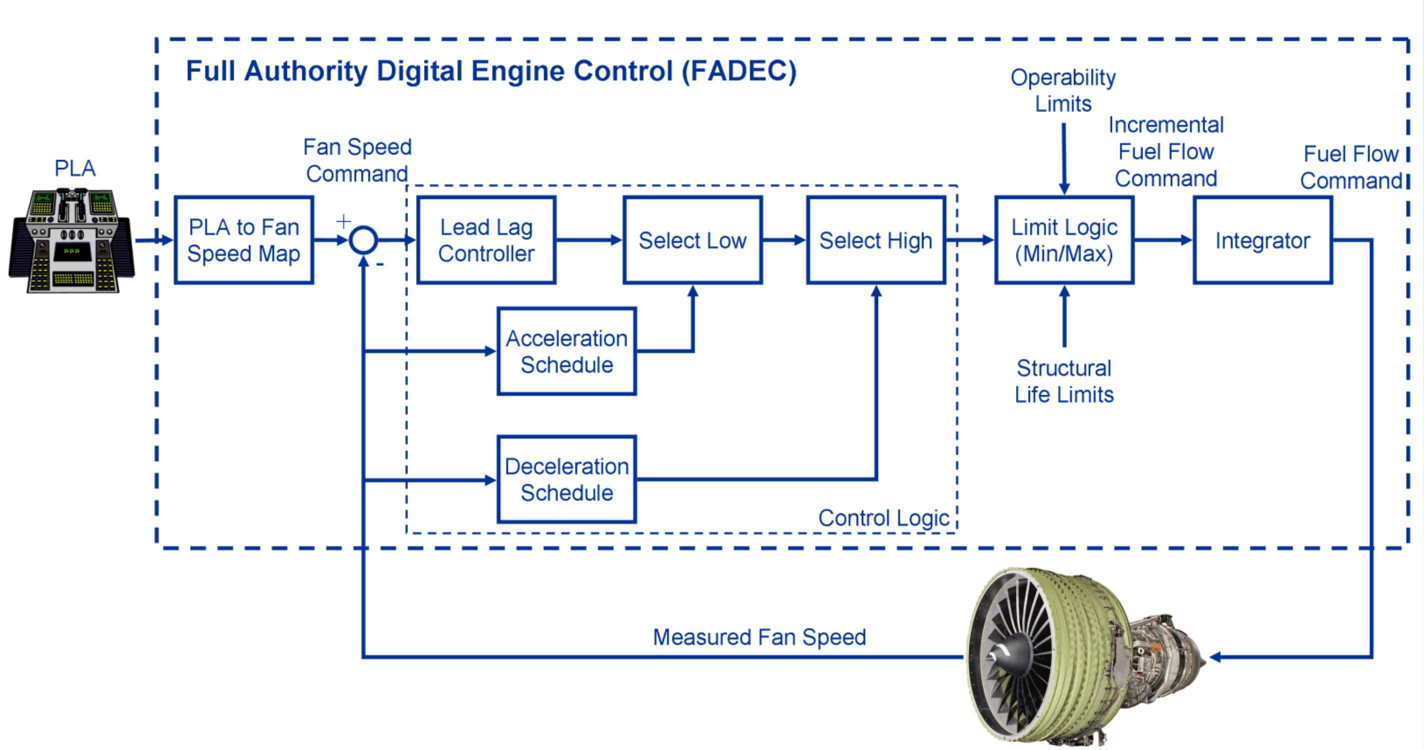
Dennis Culley: The Needs and Challenges for Distributed Engine Control

- Q&A / Discussion

Overview

Typical Current Engine Control

- Allows pilot to have full throttle movement throughout the flight envelope
  - There are many controlled variables – we will focus on fuel flow



- Engine control logic is developed using an engine model to provide guaranteed performance (minimum thrust for a throttle setting) throughout the life of the engine

  - FAA regulations provide a maximum rise time and maximum settling time for thrust from idle to max throttle command

Limitations of Current Engine Control

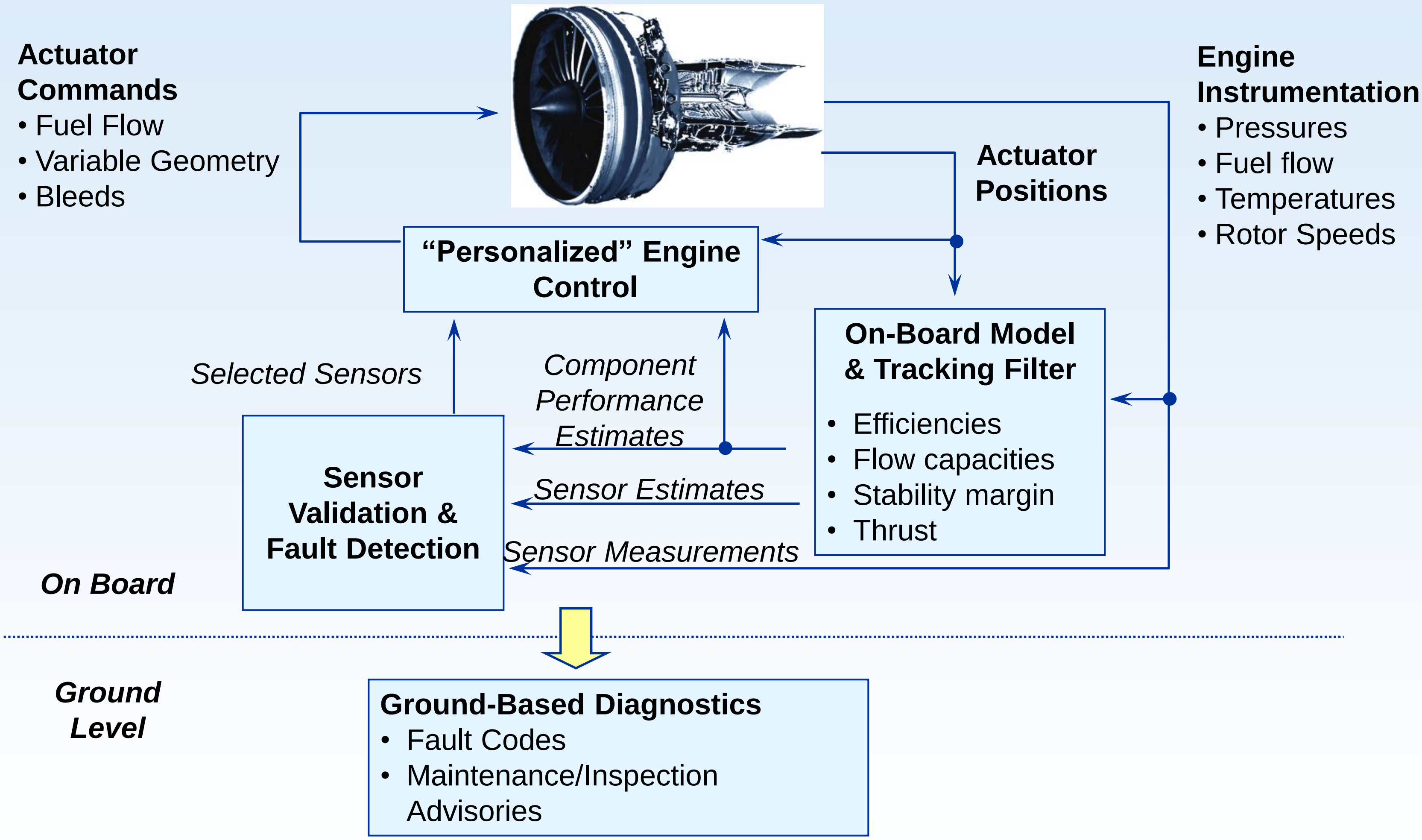
Control Logic

- Quantities that need to be controlled (Thrust) and limited (Stall Margin, Turbine Inlet Temperature etc.) are not directly measurable – round about approach leads to conservative design
- “Static” control logic - Operating line designed for safe operation with guaranteed minimum performance at end of life engine. Engine operates less efficiently through most of operational life
- Limits the use of engine as an effective flight actuator in emergencies

Control Hardware Architecture

- Dependence on off-the-shelf electronics limits to a “centralized” control - creates issues such as reliability, obsolescence management etc.
- Significantly limits capability to capitalize on information technology advancements – faster, more memory hardware, new sensors etc.
- Does not allow introduction of active component control technologies

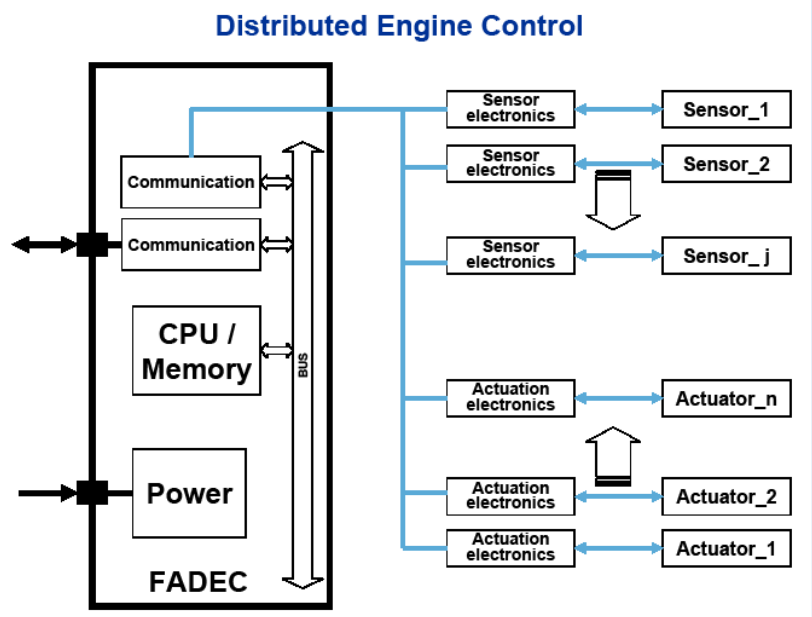
Model-Based Controls and Diagnostics

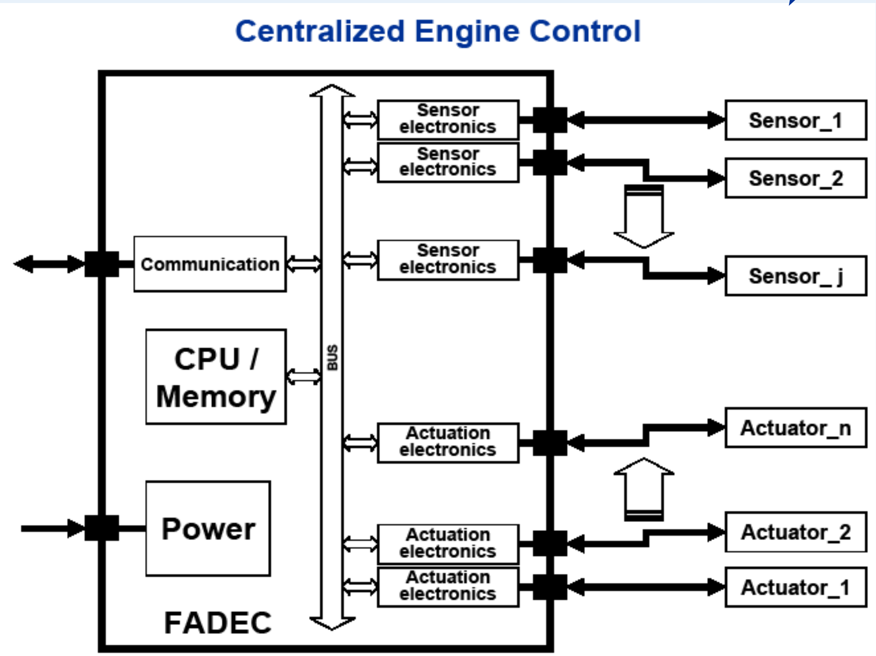


Distributed Engine Control

Objectives:

- Reduce control system weight
- Enable new engine performance enhancing technologies
- Improve reliability
- Reduce overall cost





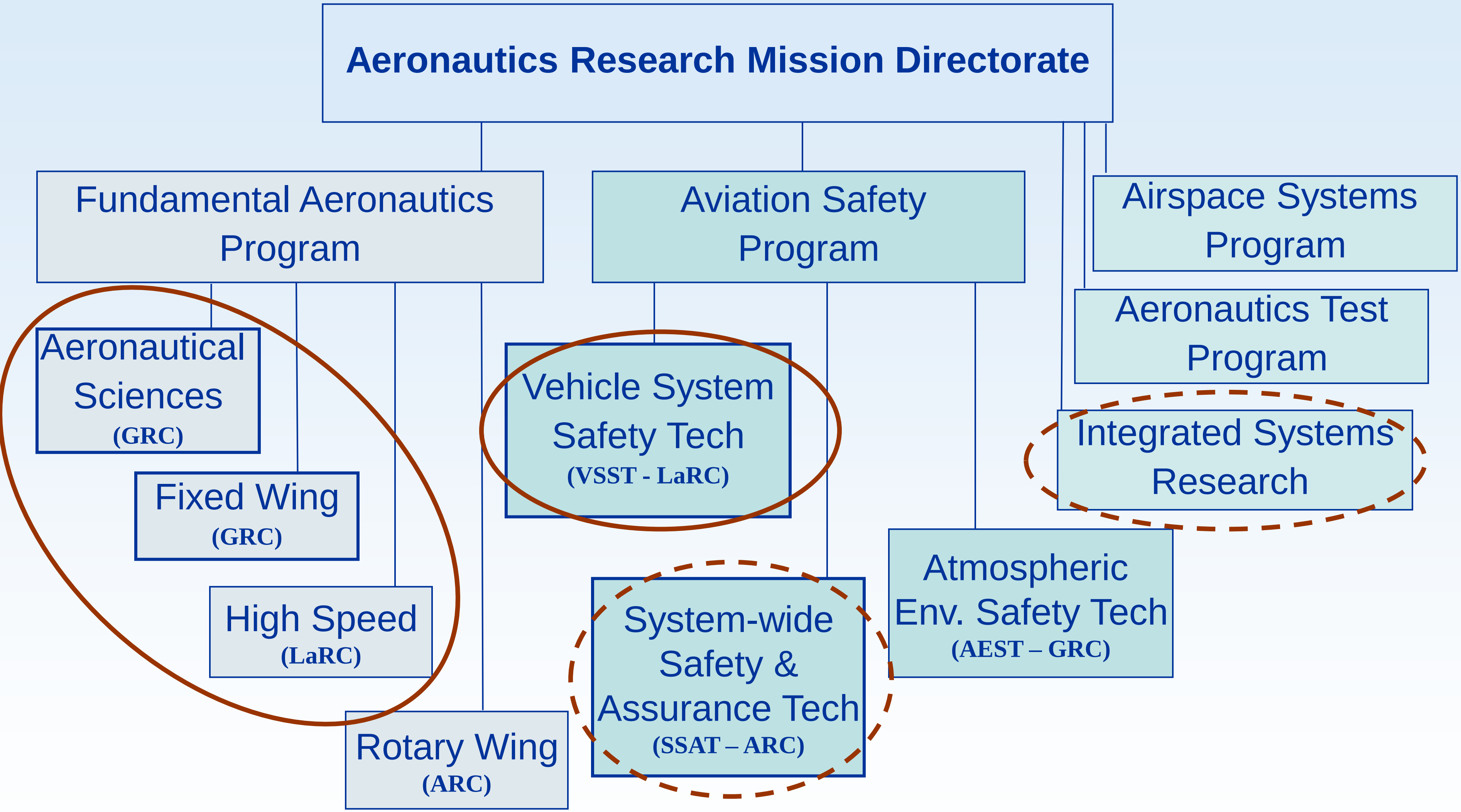
Challenges:

- High temperature electronics
- Communications based on open system standards
- Control function distribution

Government – Industry Partnership
Distributed Engine Control Working Group

Propulsion Control Research at NASA GRC to Meet NASA Aeronautics Program Goals

NASA Aeronautics Program Structure
Effective FY13



CDB Tasks Under NASA Aeronautics Research

Fundamental Aeronautics Program (FAP)

Aeronautical Sciences (AS):

- **Distributed Engine Control**
- **Model-Based Engine Control**
- Active Combustion Control
- Pressure Gain Combustion

Fixed Wing (FW):

- Dynamic Systems Analysis – new start

High Speed (HS):

- Aero-Propulso-Servo-Elasticity

Aviation Safety Program

Vehicle System Safety Technologies (VSST):

- **Gas Path Health Management**
- **Robust Propulsion Control**

Aviation System Safety Technologies (ASST):

- **Run-time Validation of Complex Systems**

(Bolded tasks contribute directly to vision of Future Aircraft Engine Control)

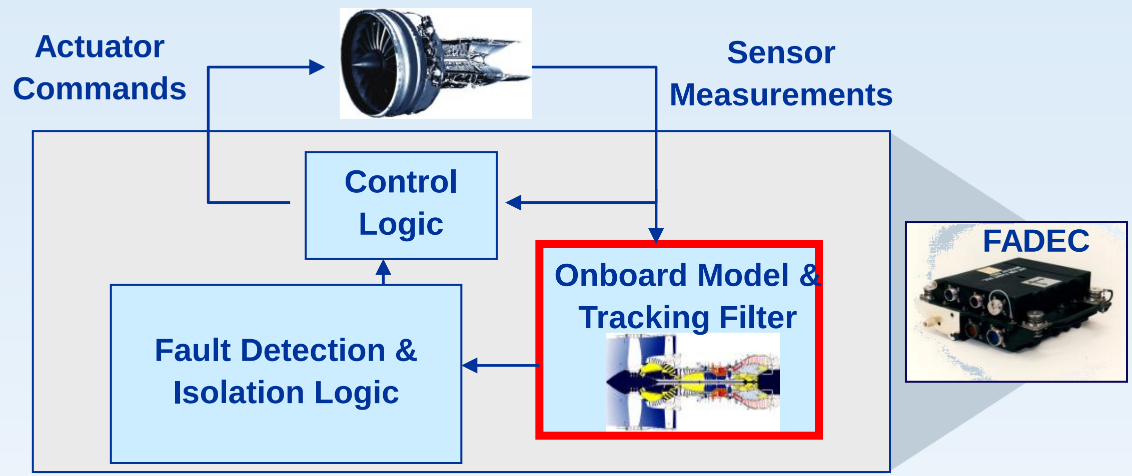
Optimal Tuner Selection for Kalman Filter-Based Performance Estimation

Background:
- Self-tuned on-board engine model
- Applies Kalman filter-based tracking filter

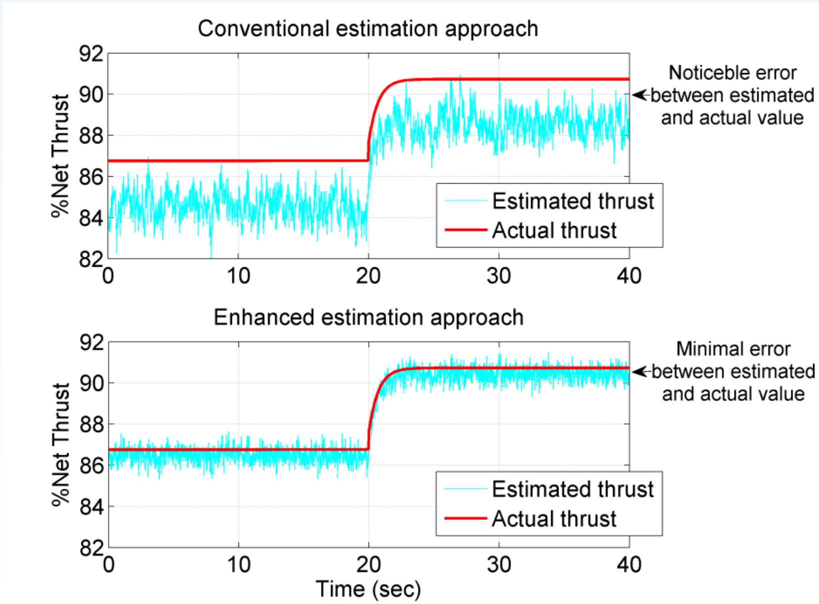
Challenge:
- Underdetermined estimation problem – more unknowns (health parameters) than available sensor measurements

Approach:
- Define tuner vector that is a linear combination of all health parameters and systematically selected to minimize KF mean squared estimation error in the parameters of interest

Results:
- Linear Monte Carlo simulation studies have shown a mean error reduction of approximately 33%



Model-based Performance Estimation Architecture



Thrust estimation accuracy comparison
(conventional vs. optimal model tuning parameters)

Model Based Engine Control

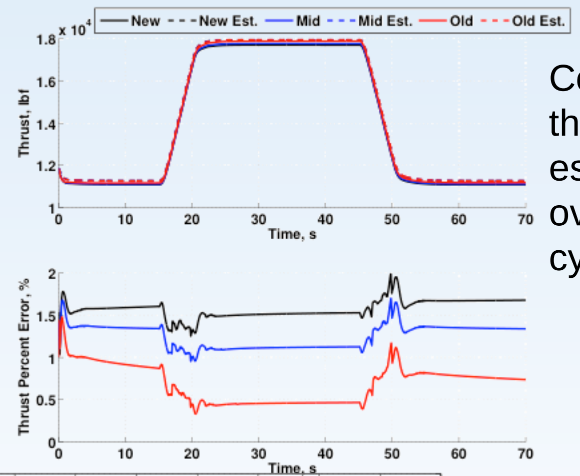
Objective

- Use an on-board "self-tuning" model of the engine to provide accurate estimates of unmeasured parameters for control design as the engine ages
- Allow for the engine to operate more efficiently and extend operating life

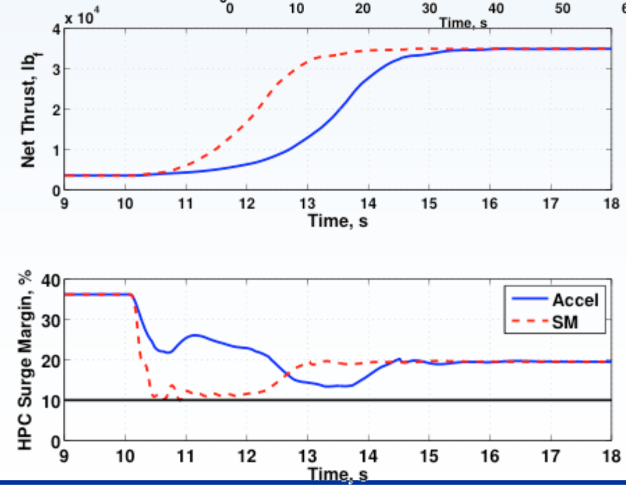
Approach

- CMAPSS40k simulation as baseline engine
- Integrate engine with Optimal Tuner Kalman Filter to get estimates of unmeasured parameters
- Replace current control architecture with a Thrust controller and Stall Margin limit protection

Results



Comparison of the true and estimated thrust over engine life cycle



Stall Margin limiter compared to traditional core acceleration limiter

Accomplishments

- Developed a nonlinear MBEC architecture with application to C-MAPSS40k demonstrating good thrust tracking response. Resolved issues with obtaining good estimates of Stall Margins.

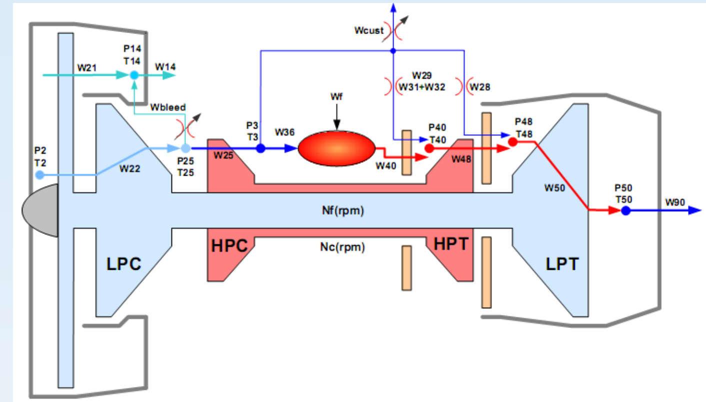
Future Plans

- Results using the MBEC architecture with a realistic nonlinear engine model to be presented at the 2013 AIAA JPC
- Investigate potential to improve efficiency by raising the compressor operating line

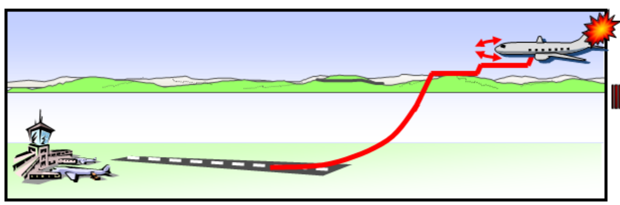
Enhanced Propulsion Control Modes for Emergency Operation

Enhanced Propulsion Control Modes for Emergency Operation

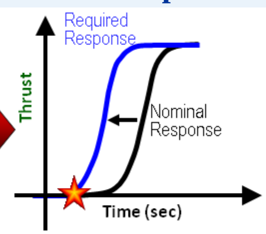
- Overthrust and Fast Response Control Modes have been developed using the Commercial Modular Aero-Propulsion System Simulation 40k (C-MAPSS40k), and evaluated in a piloted flight simulator
- Improved yaw damping has been demonstrated with Faster Response engines when differential thrust is used to compensate for a stuck rudder
- Required takeoff distance is reduced with Overthrust



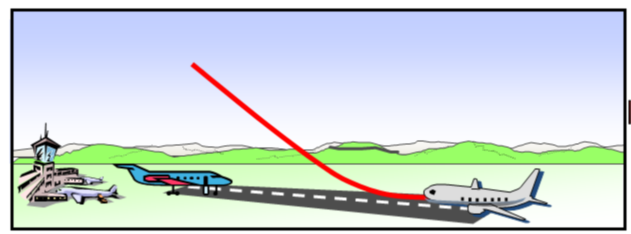
Rudder Damage in Flight



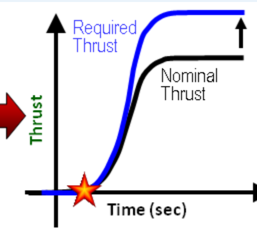
Fast Response

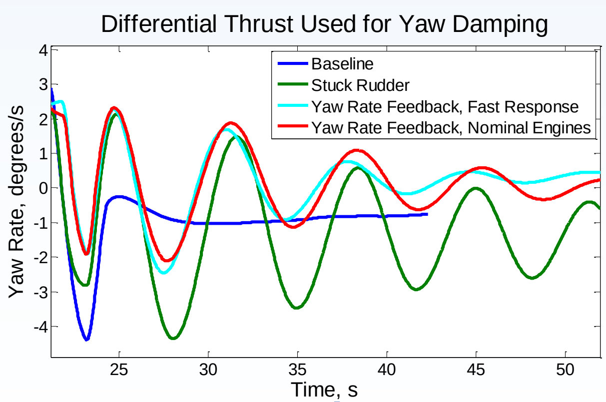


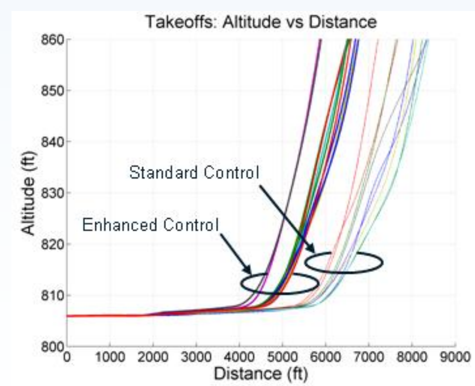
Runway Incursion



Overthrust







Glenn Research Center

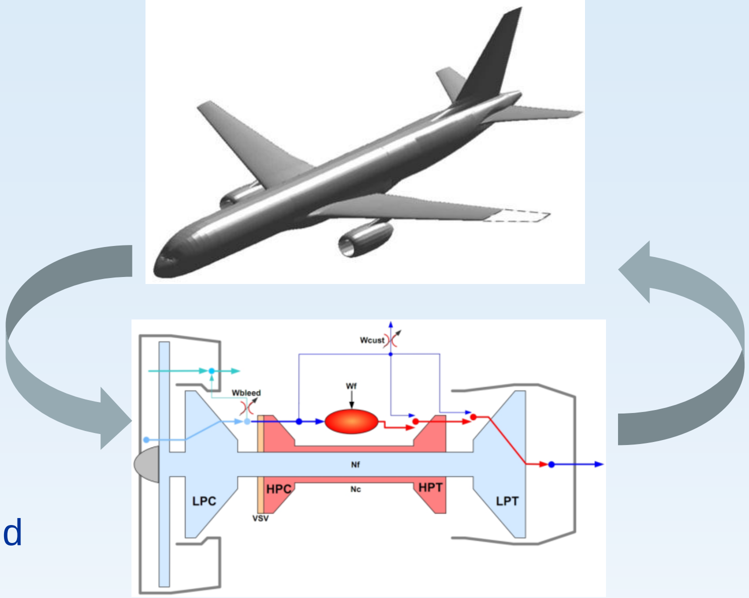
Controls and Dynamics Branch

at Lewis Field

Integrated Flight and Propulsion Control

Technical Challenge Problem

- Currently, flight control logic is designed separately from the propulsion control with the assumption that pilot integrates the propulsion system with flight control using the throttle
- An integrated approach to flight and propulsion control system design can provide enhanced performance capability which can potentially increase airplane safety dramatically by allowing the use of propulsion system as a flight control effector.

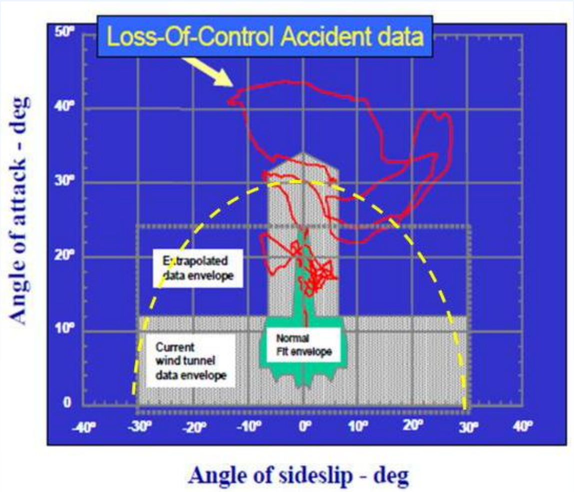


Research Objectives

- Specify and evaluate the full potential of integrated flight and propulsion control (IFPC) for enhanced flight safety

Research Approach

- Develop new integrated flight and propulsion controller architecture
- Develop control algorithms that can fully utilize the propulsion system as flight actuators with different response time
- Demonstrate the impact of new IFPC architecture on flight envelope protection and accommodation of simulated actuator failures – in simulation and in piloted evaluations of a flight simulator



Challenges in Getting There

- **Buy-in from Product / Technology Development managers on the need to invest in advancing controls technology**
  - Controls seen as a "mature" field – more of an engineering development area rather than research & technology development
- **Controls benefits are difficult to articulate at systems level – weight reduction, efficiency improvement, environment impact reduction etc.**
  - Systems analysis tools are based on steady-state performance – do not include assessment of technologies for challenges associated with ensuring safe transients and off-design operation.
- **Controls is a multi-disciplinary field. Most technology development programs are component/discipline focused**
  - Difficult to overcome inertia towards working in cross-disciplinary teams