Integrated Propulsion Control and Dynamics (IPCD) Research for the NASA Integrated Resilient Aircraft Control (IRAC)

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IPCD Team Members

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**NRA Partners**
- Pratt & Whitney
- Scientific Monitoring, Inc.
- Boeing
- Univ. of Connecticut
IRAC/IPCD Research Overview

- High Level IRAC Concept revisited
- Vision for Enhanced Engine Operation
- Integrated Propulsion Control and Dynamics (IPCD) Research Areas
  - Engine Performance Requirements
  - Engine Simulation and Controller Development
  - Fast Engine Response Research
  - Risk Assessment Tool Development
  - Integration with Flight Control/Simulation
  - Engine Icing Modeling and Control
- Summary
**Integrated Adaptive Flight/Structural/Propulsion Control**

**Adaptive Flight Control**
- Decisions Based on Failures/Impairment/Damage,
  Remaining Control/Engine Capabilities, Risks Associated
  with Accommodation/Recovery, Flight Safety Margins
- Combinations of Internal & External Loss-of-Control Factors
- Includes Upset Recovery under Failures/Damage/Disturbance
  Conditions and Adaptive Guidance

**Flight Control Commands**
- Engine Operation Mode
- Engine Performance Requirements

**Engine Status Report**
- Engine Failure/Damage Condition
- Engine Performance Limits
- Performance/Life Trade-off Curve

**Fast Inverse FEM**
algorithm identifies damage and predicts deformations in real time

**Direct FEM models**
compute internal loads & AE Effects in real time

**Strain sensors**
provide discrete measurements in real time

**Engine Failure/Damage Assessment**
- Survival Operation Mode for Damaged Engine
- Optional Operation Beyond Designed Envelope
IRAC System Concept

IRAC Propulsion

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Enhanced Propulsion Research Concept

Past research and experience have shown that propulsion systems can be very effective in helping airplanes recover from adverse conditions:
  – TOC (Throttle-Only-Control) research experience
  – PCA (Propulsion Controlled Aircraft)

However, preliminary studies show that there are many other potentially catastrophic scenarios in which airplanes could be saved if the engines could:
  – Respond faster
  – Generate more thrust for a short period of time
  – Better integrate with the flight control system
IPCD Research Areas

- Engine performance requirements study
  - NASA/ARC Study
  - Boeing Study
- Engine simulation and controller development
  - Past simulation MAPSS, C-MAPSS,
  - Flight data collection for engine dynamics
  - Baseline controller design and stability margins
  - New C-MAPSS40K (was C-MAPSS2)
- Fast engine response control research
  - Engine control limits
  - Innovative configurations and control
  - NRA partners
    - P&W
    - SMI
- Risk assessment tool development
  - Engine health condition
  - Risk of enhanced engine operation
  - Risk Management/trade-off
- Integration with Flight Control
  - Simulation Platform
  - Integration Issues
- Engine icing modeling and control research
Engine Requirements Study

• **Two studies were performed**
  – Scenarios selected
  – P&W/Boeing
  – NASA/ARC

• **Preliminary studies show:**
  – Faster responding engine is critical in many known scenarios
  – The requirements are highly aircraft configuration dependent
Flight Test Data Collection

Flight Test Summary

• 1 data flight
• ~4 flight hours
• 2 performance calibrations
• ~20 throttle transients

Test flight Completed on 12/12/07
Engine Simulation Development History

- **MAPSS (Modular Aero-Propulsion System Simulation)**
  - Military-type turbofan engine
  - Multi-variable Controller
- **C-MAPSS**
  - Very Large (90K class) commercial turbofan engine
  - Includes realistic FADEC-like controller
- **C-MAPSS40K (was C-MAPSS2)**
  - Large (40K class) commercial turbofan engine
  - Includes realistic FADEC-like controller
  - Include engine dynamic and operability margins

See our branch web site for update and download information: [http://www.grc.nasa.gov/WWW/cdtb/software/index.html](http://www.grc.nasa.gov/WWW/cdtb/software/index.html)
Fast engine response control research

Approaches:
• Engine Controller Limits Study and Relaxation
• Innovative Configuration/Operation Studies

Two NRA partners:
• Pratt & Whitney
  – Two subcontractors: Boeing and Univ. of Connecticut
  – Flight data analysis
  – Dynamic engine study
  – Engine requirement study
  – Fast response engine study

• Scientific Monitoring, Inc.
  – Fast response engine control
  – New actuator, configuration study
  – Flight simulator (GTM) implementation
High Level Risk Assessment Architecture

- Flight Control System
  - Adaptive Flight Control
  - Vehicle Risk Management
  - Vehicle Risk Assessment
- Engine Control System
  - Engine Controller
  - Actuators
  - Engine
  - Control Mode Selection and Risk Management
- Engine and Controller
  - Sensor Conditioning
  - Engine Condition Monitoring
  - Engine Operability Risk Models
  - Engine Life Prognosis Models
- Engine Life and Operability Prognosis
- Pilots
- Engine Control System
Risk Assessment Tool Development

Engine Life/Risk Study Involving:

– Failure Mode Analysis
  • Structural damage assessment

– Component Life Models
  • Component failure modes for various operating conditions

– Stochastic Life Models
  • Probabilistic distribution
  • Required confidence level
  • Risk trade-offs

– Remaining Life Prediction
  • Engine accumulated usage
  • Probabilistic life estimate for extended operation
Integrated Flight/Propulsion Control

Simulation Platforms:
- GTM
- GRC Flight Simulator
- Boeing Flight Simulator
- Other NASA Flight Simulators

Issues
- Use propulsion system as a redundant set of actuators
  - Direct access by flight controller
  - Engine controller integrity
- Trigger
  - When to invoke emergency control mode
  - FADEC vs. Flight Controller
- Risk management at system level
  - Perceived risk by pilot
  - Aircraft condition
  - Engine Condition
  - Engine enhancement operating risk
  - Decision/optimization methodology
Summary

- Completed C-MAPSS40K, a major engine simulation package for research

- Fast Engine Response team includes in-house researchers and NRA partners

- Risk assessment tool has been developed and the trade-offs of risk and performance are addressed.

- Fast engine response control algorithm to be demonstrated in a flight simulator at the end of 2010.
What is next

• The current IRAC project will be revised in FY11.

• New areas of research include:
  – Loss of Control Research
  – Flight Control Research
  – Verification & Validation
  – Flight Test for Advanced Concepts