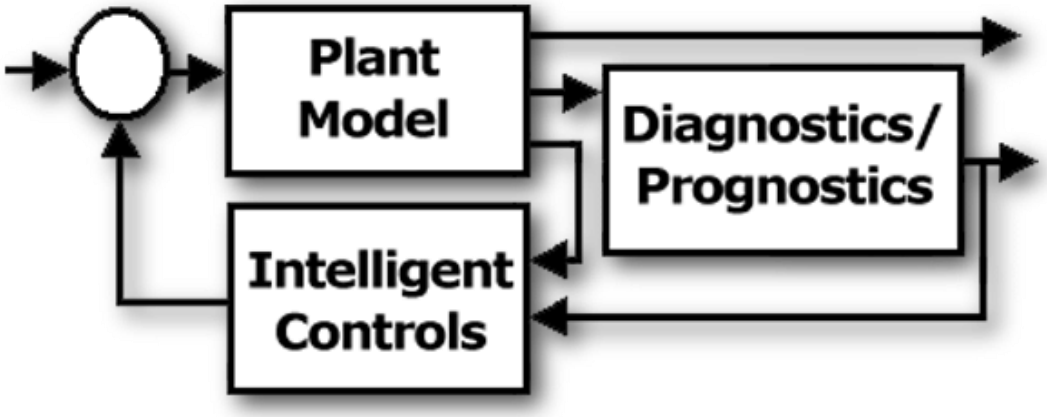
Integrated Propulsion Control and Dynamics (IPCD) Research for the NASA Integrated Resilient Aircraft Control (IRAC)



Propulsion Controls and Diagnostics Workshop
Dec. 8-10, 2009

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IPCD Team Members

GRC In-House Researchers

- OA Guo
- Jonathan S. Litt
- Shane Sowers, Qinetiq Corporation
- Ryan May, ASRC Aerospace Corporation
- Jeff Csank, N&R Engineering
- Thomas M. Lavelle
- NPSS modeling and simulation group (GRC/RTM)

NRA Partners

- Pratt & Whitney
- Scientific Monitoring, Inc.
- Boeing
- Univ. of Connecticut

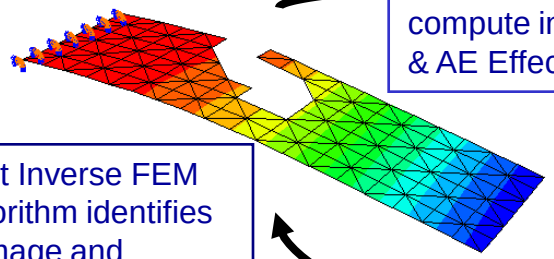
IRAC/IPCD Research Overview

- 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

IRAC System Concept

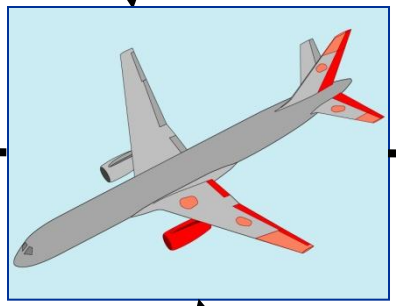
Integrated Adaptive Flight/Structural/Propulsion Control

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



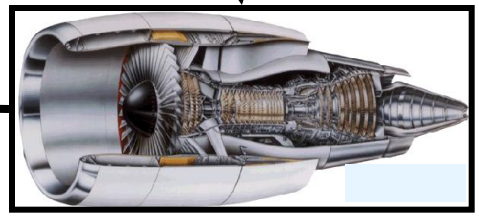
Fast Inverse FEM algorithm identifies damage and predicts deformations in real time

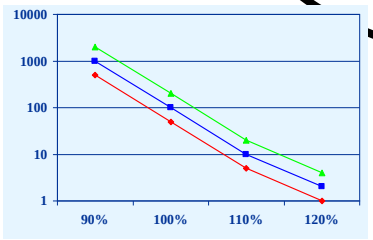
Adaptive Flight Control
- Decisions Based on Failures/Impairment/Damage, Remaining Control/Engine Capabilities, Risks Associated with Accommodation/Recovery, Flight Safety Margins
- Combinations of Internal & External Loss-of-Control Factors
- Includes Upset Recovery under Failures/Damage/Disturbance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



Strain sensors provide discrete measurements in real time

Flight Control Commands
- Engine Operation Mode
- Engine Performance Requirements



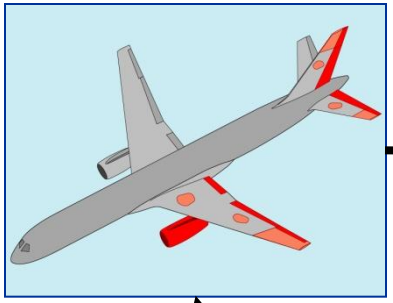


Engine Status Report
- Engine Failure/Damage Condition
- Engine Performance Limits
- Performance/Life Trade-off Curve

- Engine Failure/Damage Assessment
- Survival Operation Mode for Damaged Engine
- Optional Operation Beyond Designed Envelope

IRAC System Concept

IRAC Propulsion



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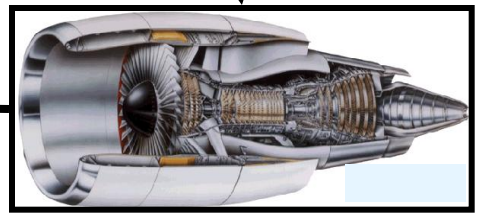

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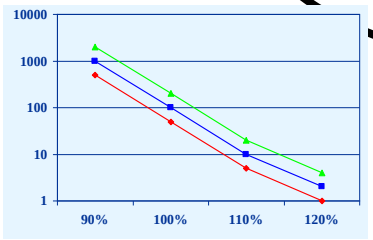

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Enhanced Propulsion Research Concept

- 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

Enhanced Engine Operation

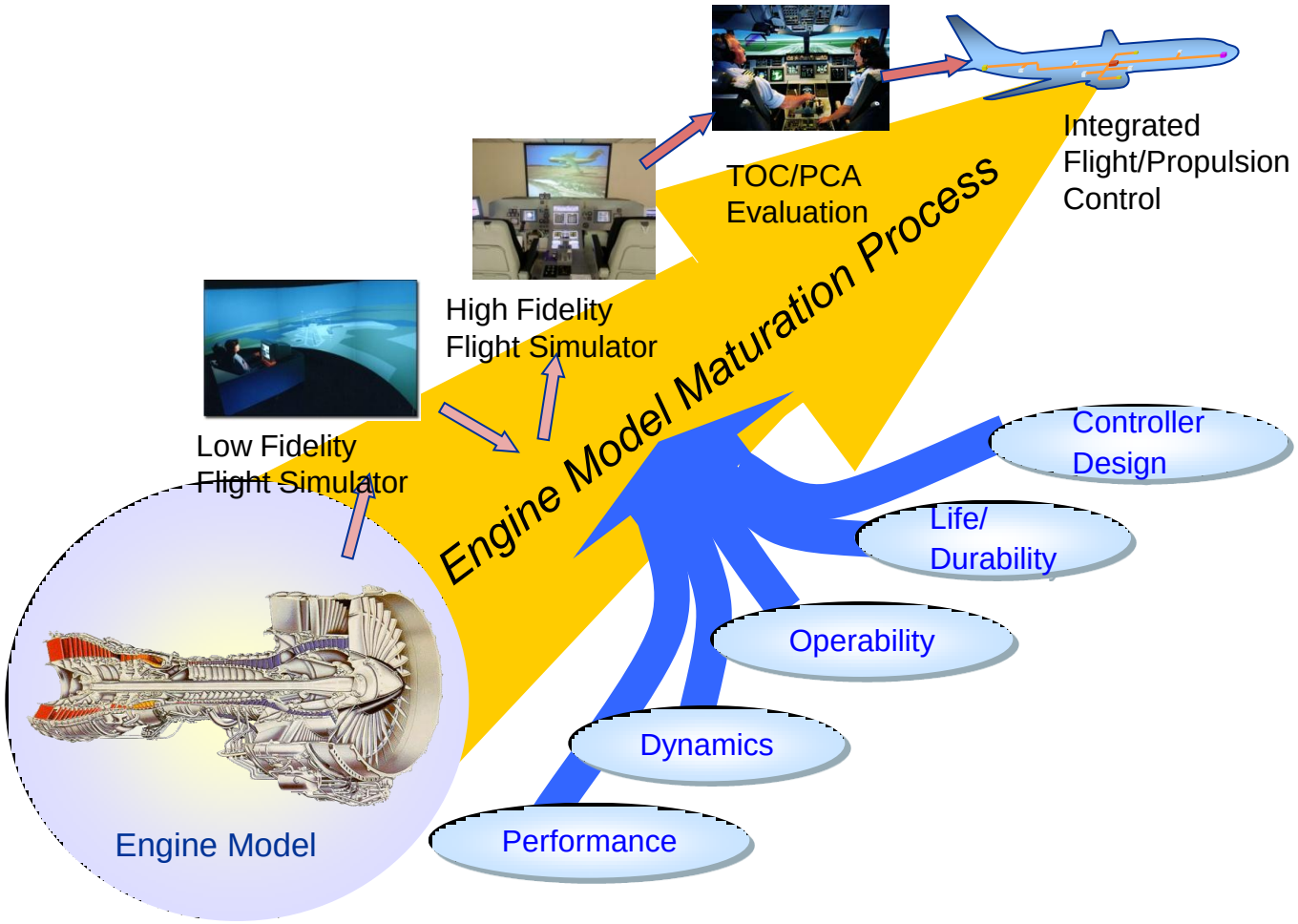
IPCD Research Areas

- 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

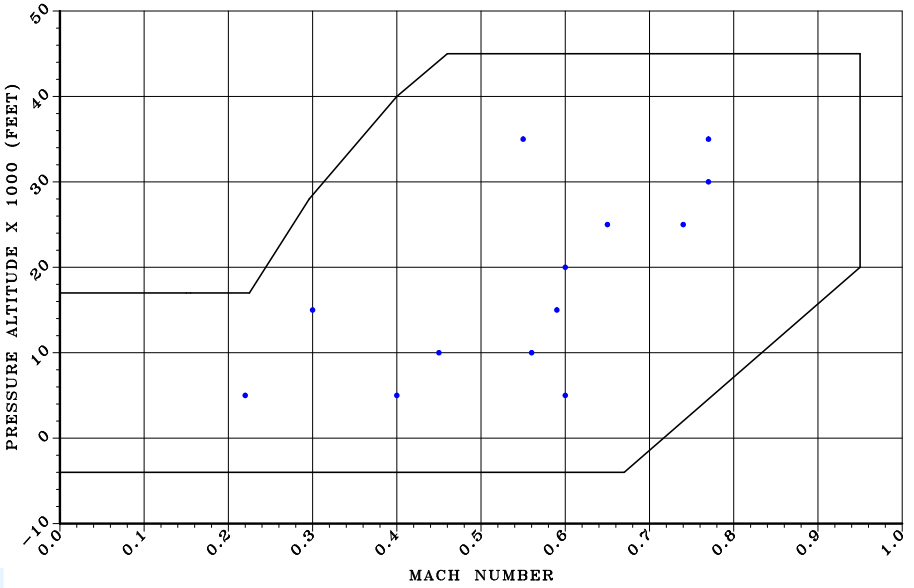
Engine Simulation and Controller Development

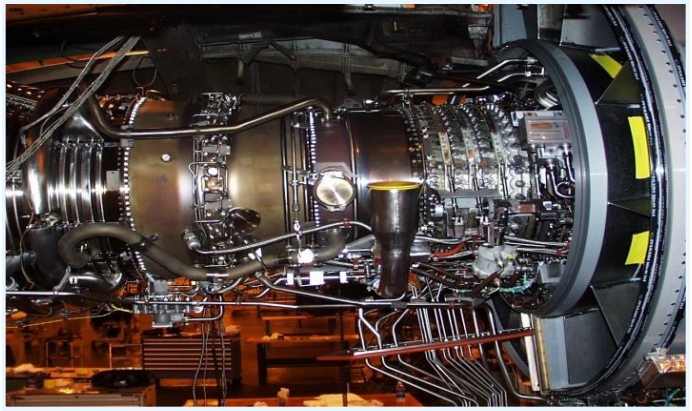


Flight Test Data Collection

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

Fast engine response control research

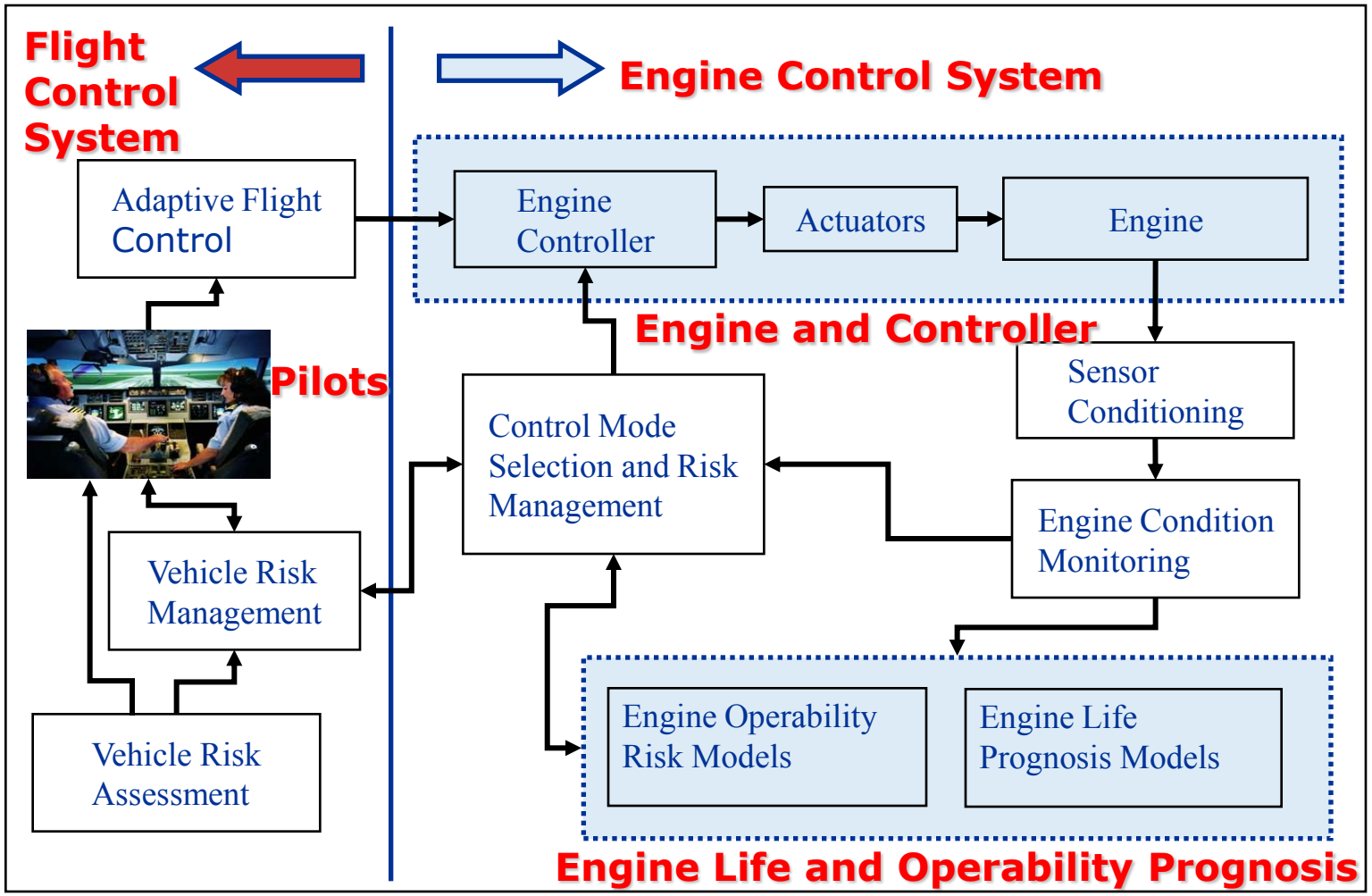
Approaches:

- 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



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