Enhanced Engine Control for Emergency Operation

Jonathan Litt
NASA Glenn Research Center

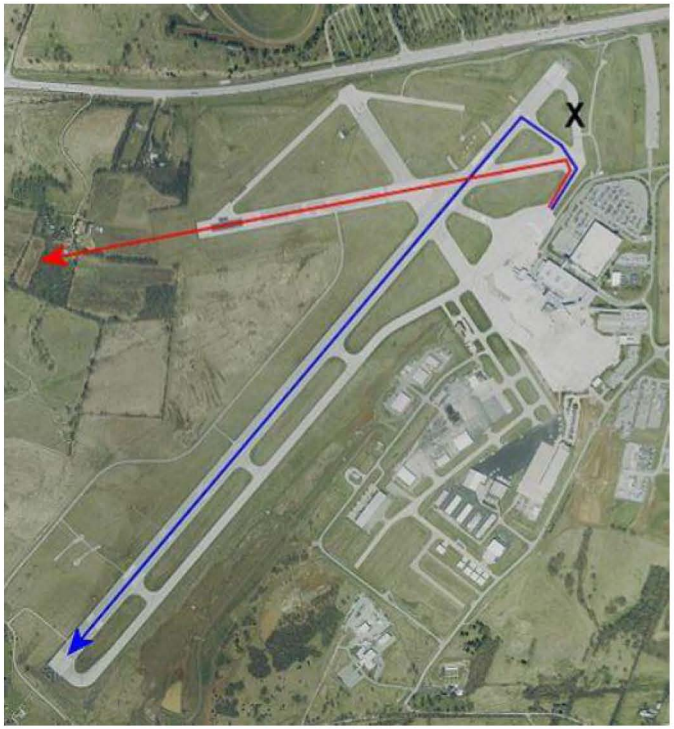
MEETING No. 110
AEROSPACE CONTROL AND GUIDANCE SYSTEMS COMMITTEE
October 11, 2012

Overview

- Motivation
- Approach
- Testing Results
- Conclusions and Future Work

Motivation

2003, DHL cargo plane
Missile strike caused hydraulics loss and wing damage



2006, Comair Flight 5191, Accidentally attempted takeoff on runway that was too short

2001, AA587
Airbus A300 vertical stabilizer and rudder separated in flight due to excessive rudder input in response to wake turbulence

Motivation

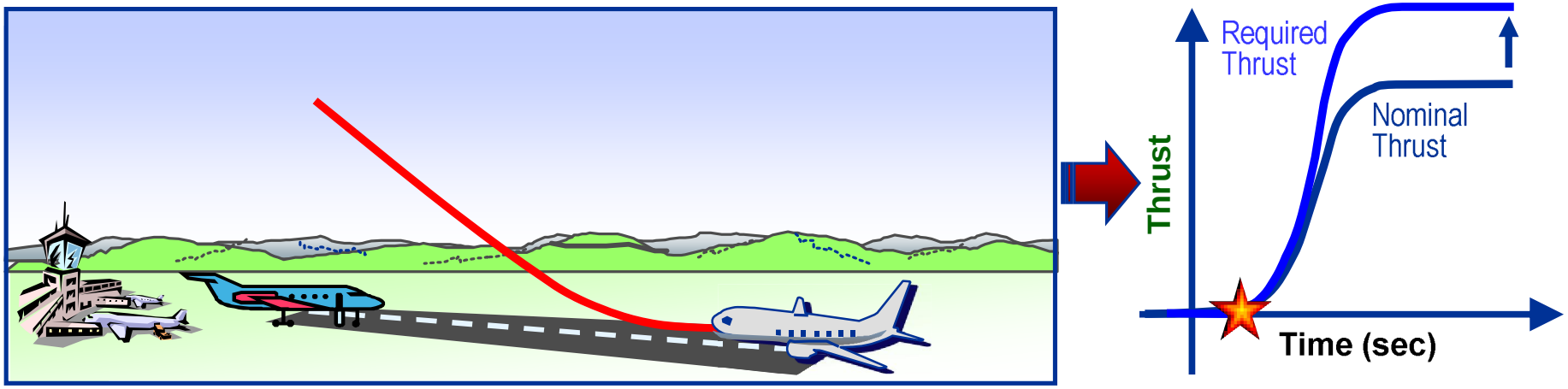
- UA232, DC-10, Sioux City, Iowa, July 1989
  - Uncontained tail engine failure
  - Lost all hydraulic systems
  - Used two good engines to maneuver and crash land

Previous Research

- The Sioux City Accident inspired a NASA flight test program to investigate the use of the engines for flight control
- This testing identified several problems with using only throttles for flight control
  - weak control moments
  - difficulty in damping phugoid and Dutch-roll oscillations
  - coupling between pitch and roll
  - sluggish engine response

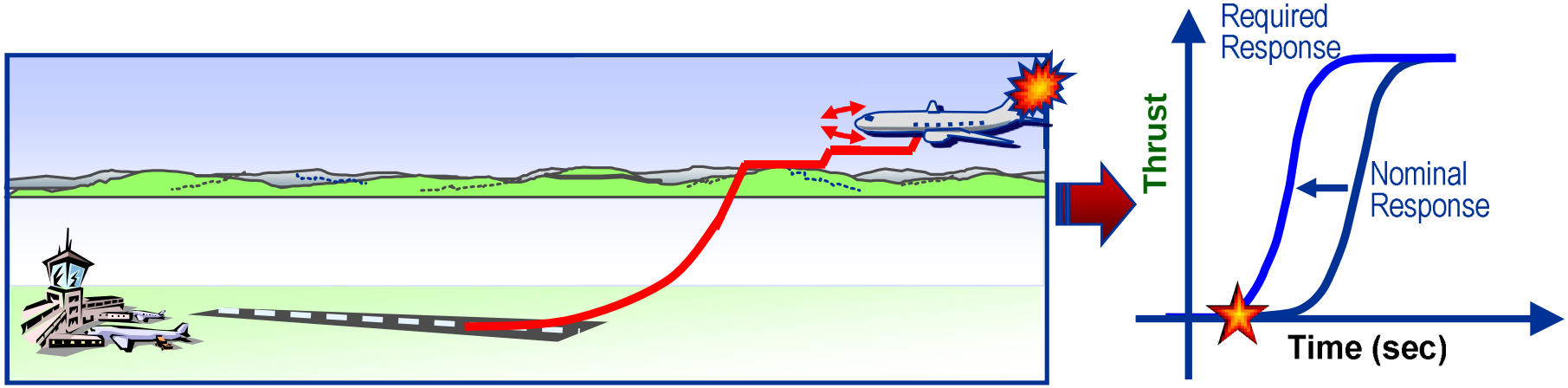
CAN ENHANCED PROPULSION CONTROL MODES HELP IN THESE SITUATIONS?

Scenario 1: Overthrust for Runway Incursion



- Need to takeoff in a shortened distance
- More thrust than is typically allowed is needed to safely takeoff
- Develop enhanced propulsion control algorithms for emergency situations

Scenario 2: Fast Response for Vertical Tail Damage



- Vertical tail damage decreases lateral directional stability
- Propulsion system can be used for flight controls
- Engine response is much slower than conventional flight control surfaces
- Develop enhanced propulsion control algorithms for emergency situations

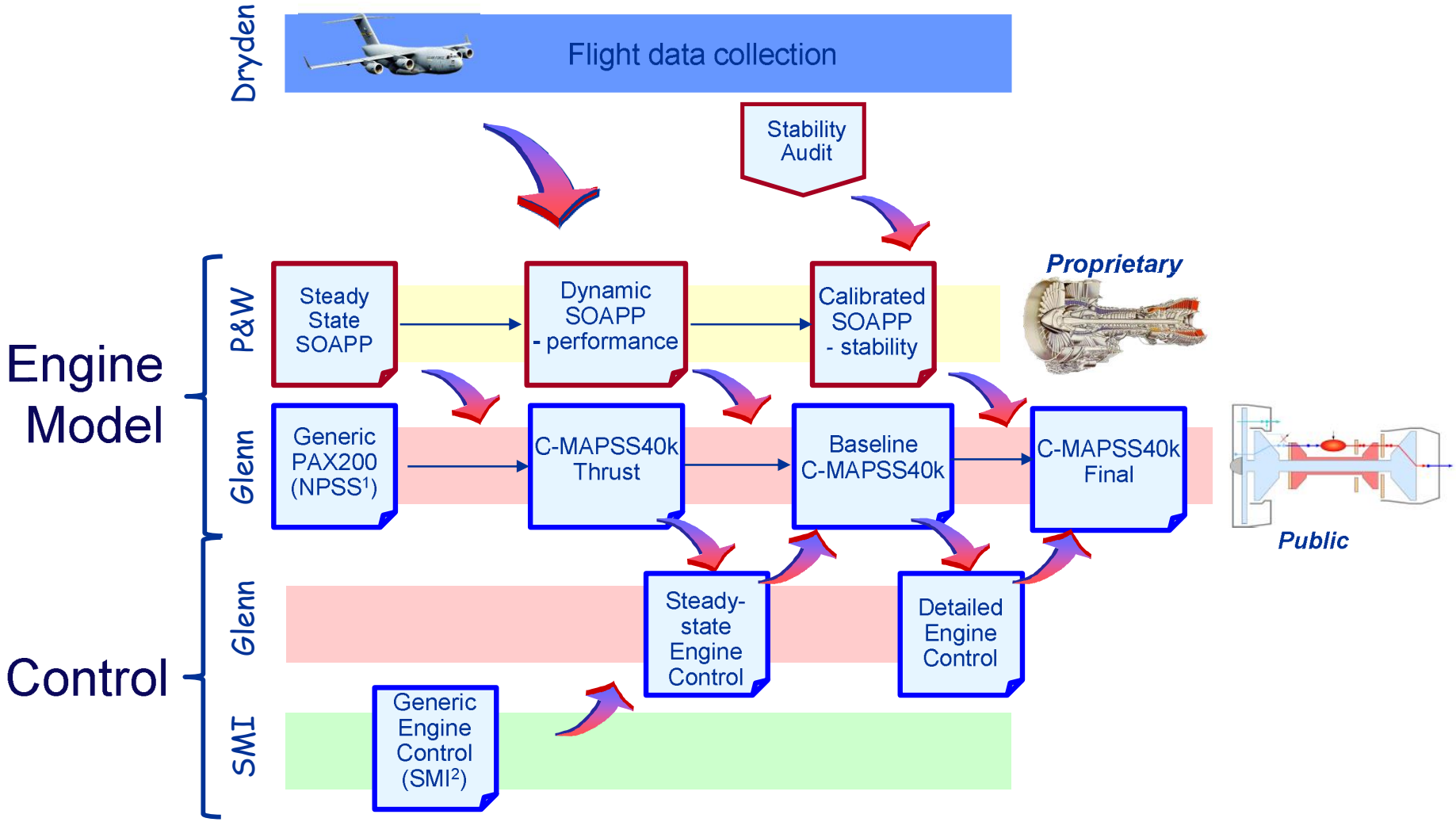
Engine dynamic simulation development

- Need an engine simulation that is capable of predicting the engine dynamics and controller reactions/limits

In 2006:

- No engine dynamic simulation available (government or industry)
- Information on stall/surge margin over the flight and operation was not available
- No realistic engine controller that was comparable to the FADEC

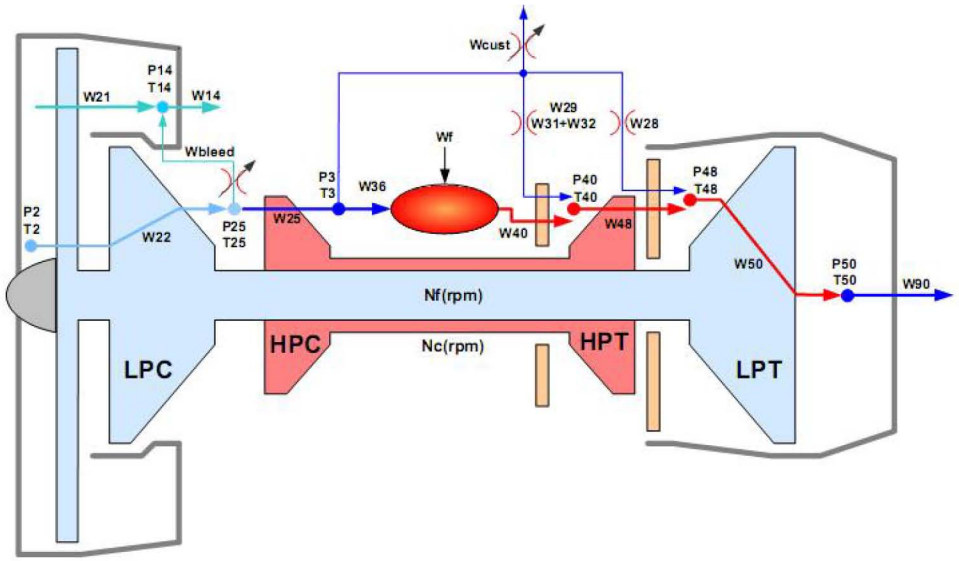
Creating A New High Fidelity Engine / Control Simulation



[1]Numerical Propulsion System Simulation, co-winner of the NASA Software of the Year Award for 2001
[2]Scientific Monitoring, Inc.

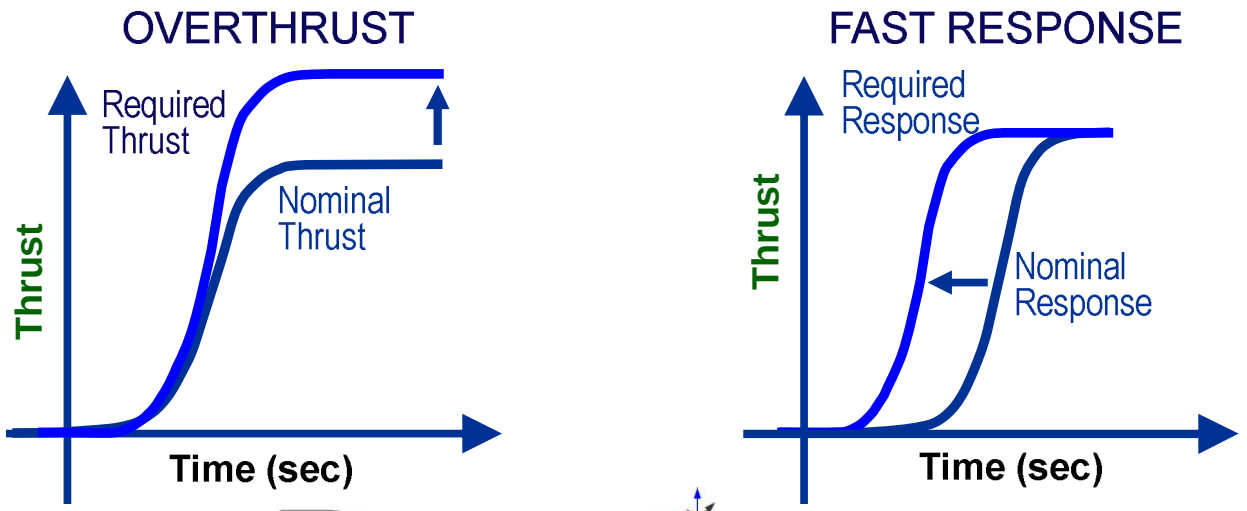
Commercial Modular Aero Propulsion System Simulation 40,000 (C-MAPSS40k)

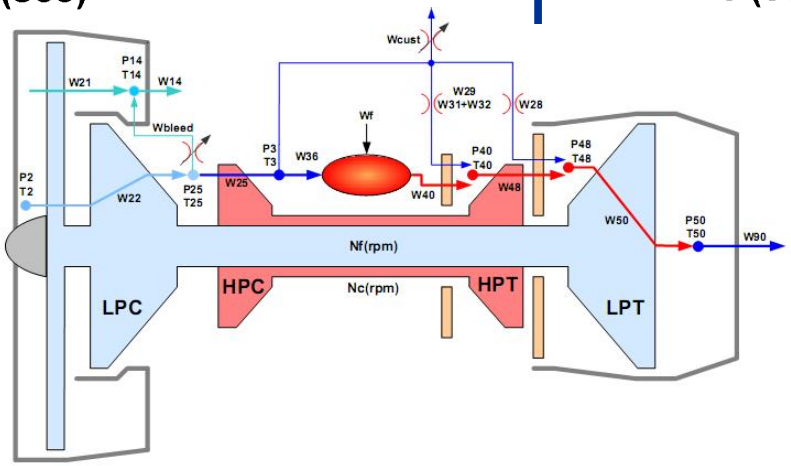
- 40,000 Lb Thrust Class High Bypass Turbofan Engine Simulation
- MATLAB/Simulink Environment
- Publicly available (restricted to US citizens)
- Representative dynamic performance
- Realistic controller
- Realistic surge margin calculations



2011 GRC Software of the Year Award nomination, Exceptional ICB Award, and NASA Group Achievement Award

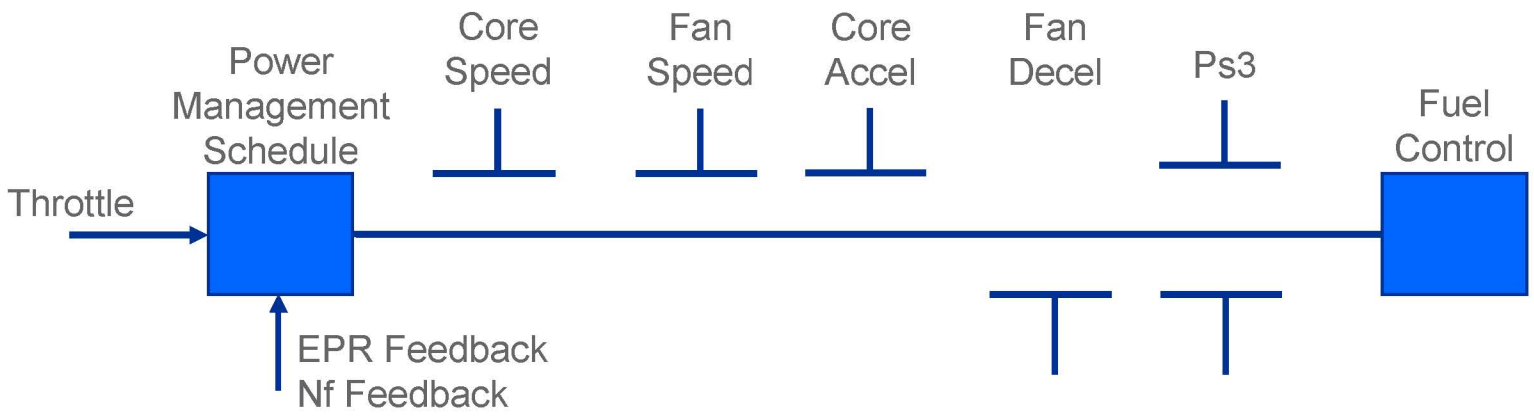
Realistic Enhanced Control Modes Implemented in C-MAPSS40k





Engine Control System

- Power Management
  - Responsible for holding current power level
- Protection Logic
  - Responsible for ensuring safe operation
  - Adjusts Fuel Flow to ensure limits are observed



There is Risk Associated With Enhanced Control

- Control Mode:
  - Fast mode to decrease throttle to thrust response time (increased risk of surge)
  - Overthrust mode to increase maximum thrust level (increased risk of structural failure)

- Requirements:
  - Ensure continuous engine operation (the engine must not surge)
  - Maintain engine conditions within minimum survivability limits (i.e., maintain temperatures and speeds to ensure successful landing while still providing required thrust)

Modification to Controller

Overthrust

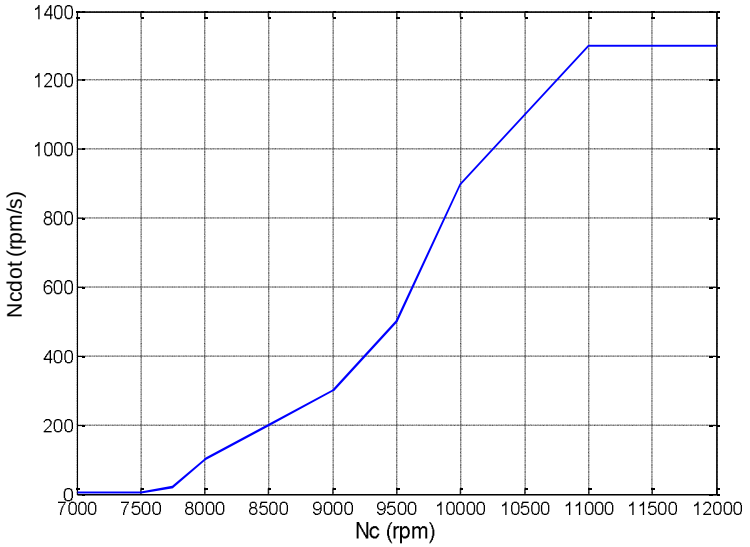
- Relaxed fan speed limit
- Relaxed core speed limit
- Added temperature limit

Fast Response

- Modified controlled gains
- Adjusted accel schedule

High Speed Idle in C-MAPSS40k

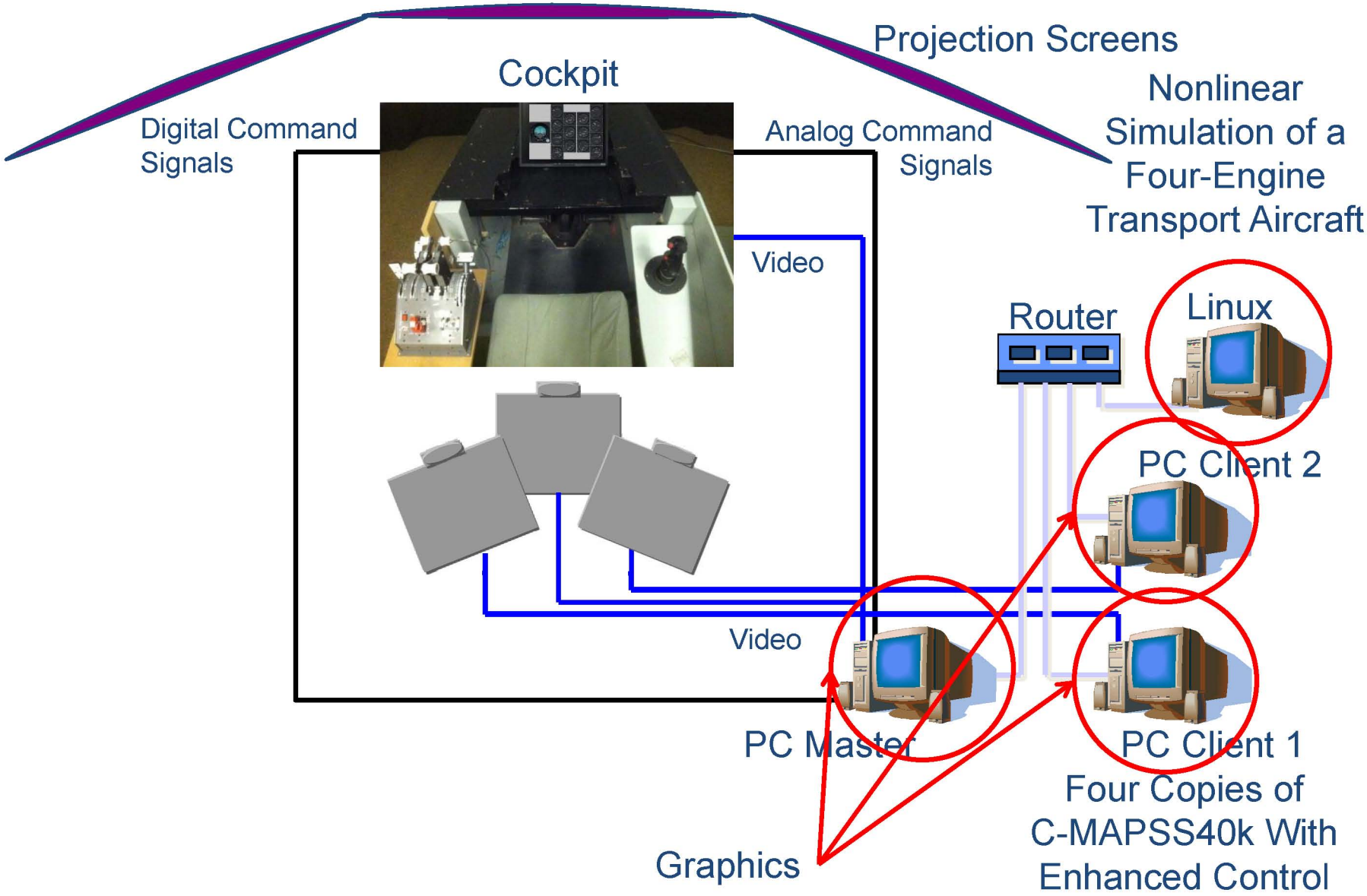
- In C-MAPSS40k, High Pressure Compressor surge is prevented by an acceleration limiter
  - Limits HPC acceleration based on HPC speed; low allowed HPC acceleration limit at low HPC speed



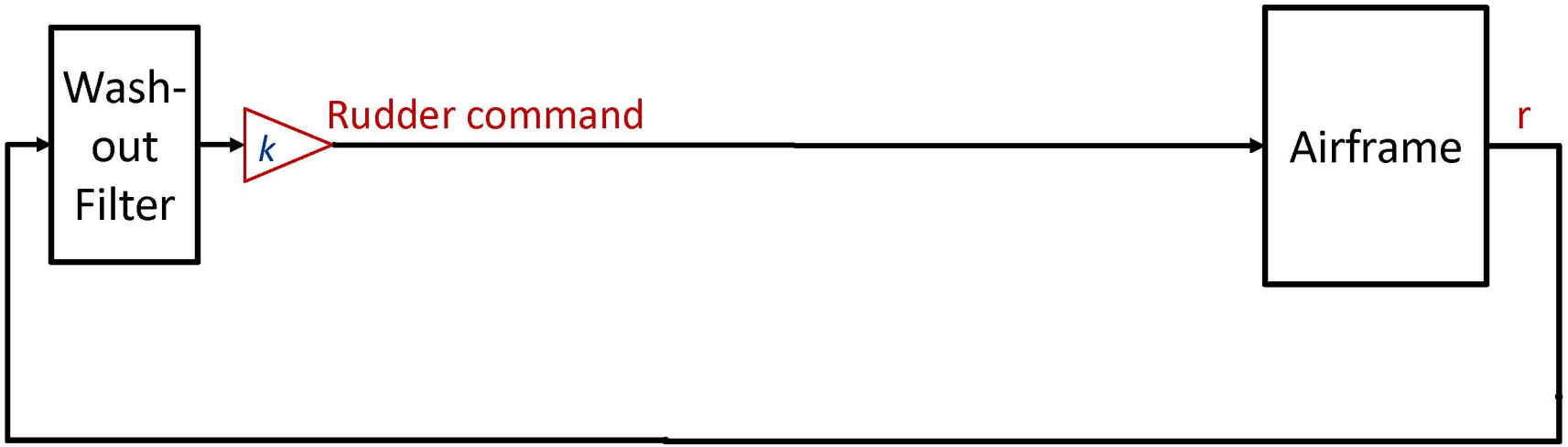
- Operate at higher shaft speeds
  - Increase engine idle setpoint
- Reduce excess thrust
  - Adjust variable stator vanes and bleed valves to operate “inefficiently”

We have a patent application for this technology

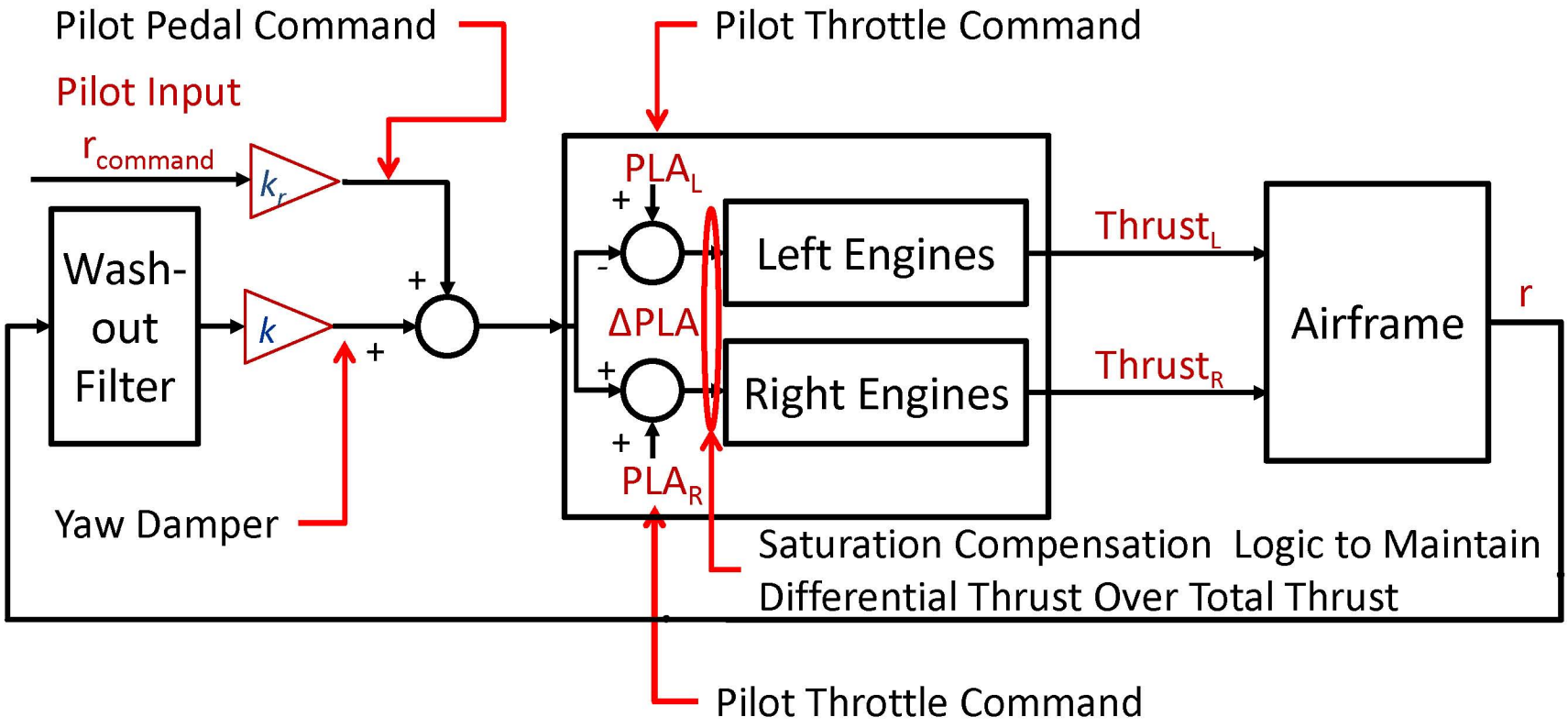
NASA GRC Piloted Control Evaluation Facility



Yaw Damper

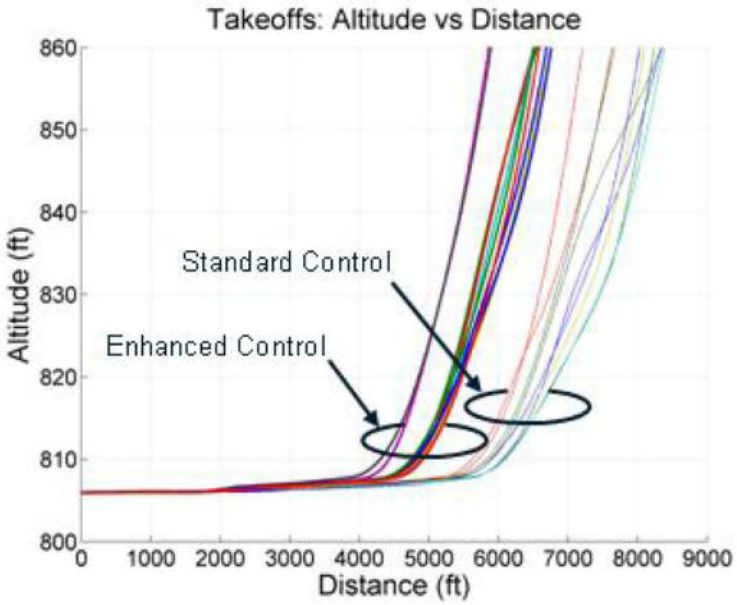


Engines Used for Yaw Damper



RESULTS:
Evaluation of Enhanced Propulsion Control on Takeoff Distance

Takeoff Distance Evaluation



- As expected, the use of Overthrust shortened takeoff distance significantly when compared to cases using standard takeoff thrust level
- The pilot also found Overthrust mode to be useful in flight

RESULTS:
Evaluation of Enhanced Propulsion Control on Aircraft Stability and Control

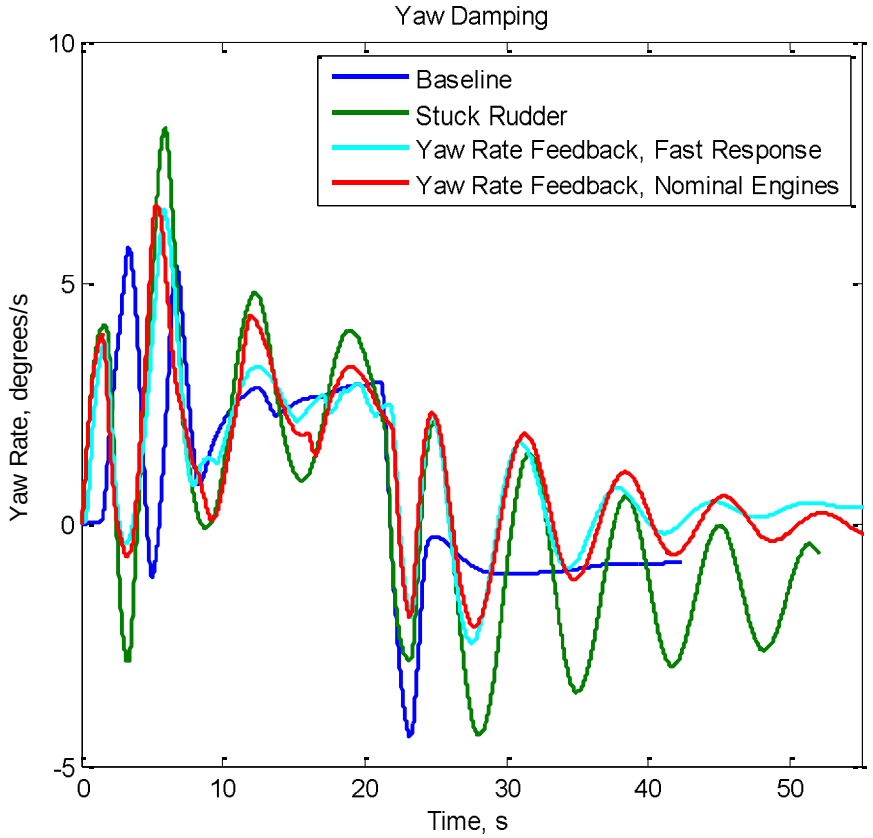
Multi-engine aircraft with rudder stuck in neutral position
Types of tests included…

- Yaw rate feedback to throttles to compare the fast responding engines' ability to damp Dutch roll compared to using nominal engines
- Manual manipulation of the throttles to determine reduction in pilot workload
- Landing in crosswind to demonstrate differential thrust performing rudder function

Evaluation of the Aircraft's Ability to Damp Dutch Roll

- For each trial, the pilot initiated the Dutch roll using the following procedure.
  - He trimmed the aircraft at the desired altitude and speed
  - moved the stick hard over to the right and banked to 40°, and turned right maintaining the roll angle
  - rolled out at a desired heading by moving the stick hard over to the left, releasing with wings near level, thus causing the Dutch roll.

Dutch Roll Damping



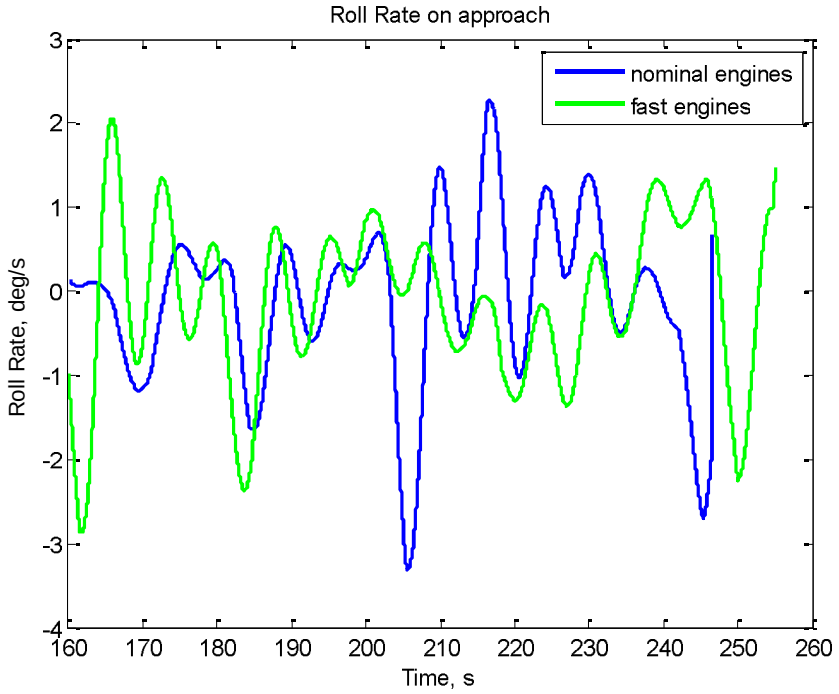
Yaw rate at 20,000 ft., 300 kts. demonstrating improved yaw damping with faster engine. The pilot initiated a Dutch roll by using the stick to bank and turn, then roll out rapidly.

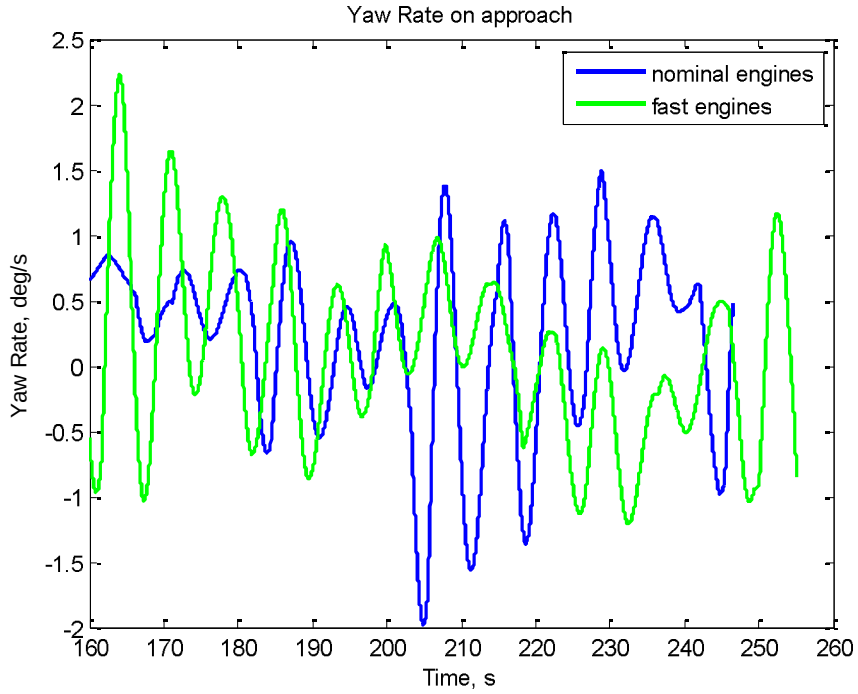
Final Approach

Ground track of impaired aircraft flying toward airport (CLE).

The pilot's view toward the airport (CLE) on approach.

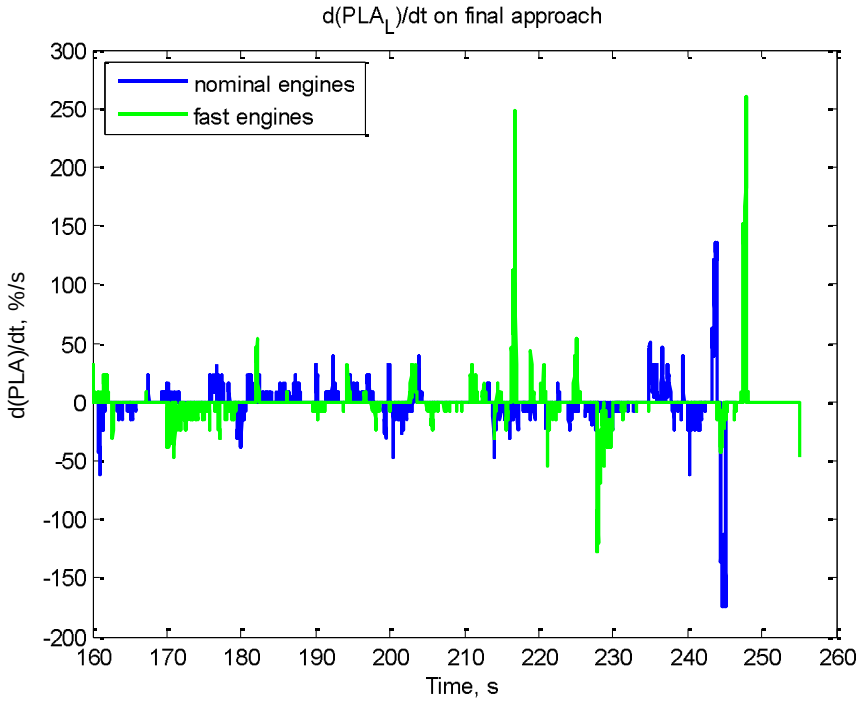
Throttles-Only Final Approach

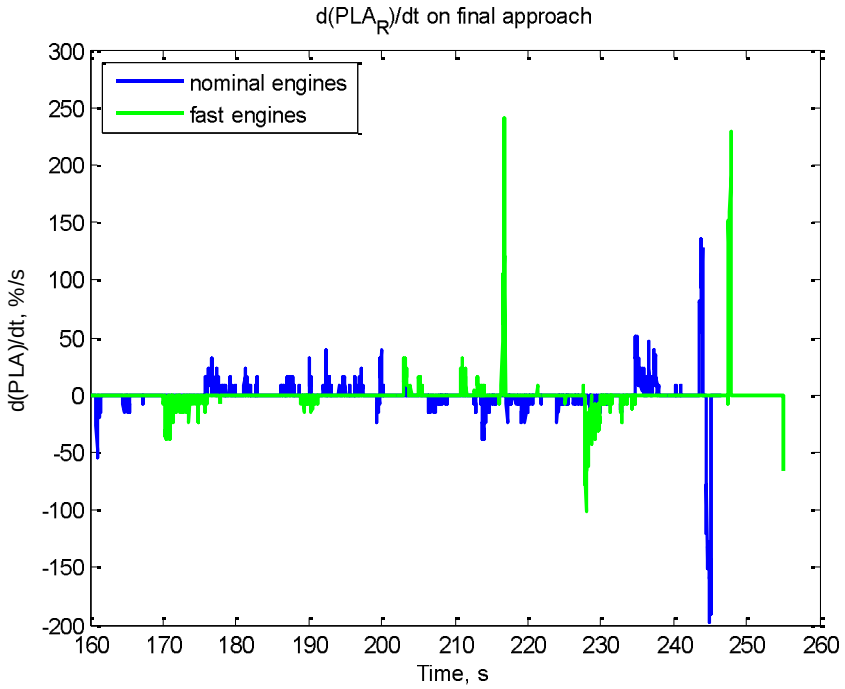




- No yaw rate feedback
- The pilot was careful not to overcompensate or accidentally initiate a large oscillation.
- He was able to achieve manageable roll and yaw rates, not much difference with faster engines.
- The pilot felt that the faster engine response provided an advantage for fine tuning

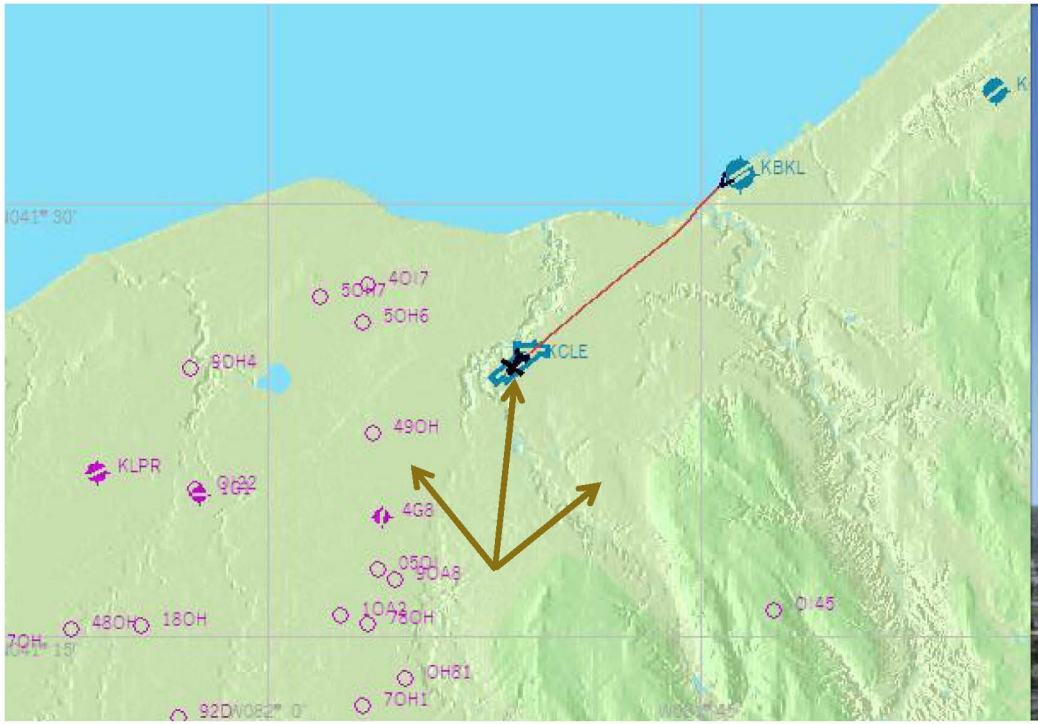
Derivative of Throttle Movement for Throttles-Only Final Approach





- The pilot made fewer, faster adjustments with the more responsive engines
- He made gentle adjustments more often with the nominal engines.
- The faster engines provided about the same level of flight control with lower pilot workload. This was especially important close to the ground.

Final Approach

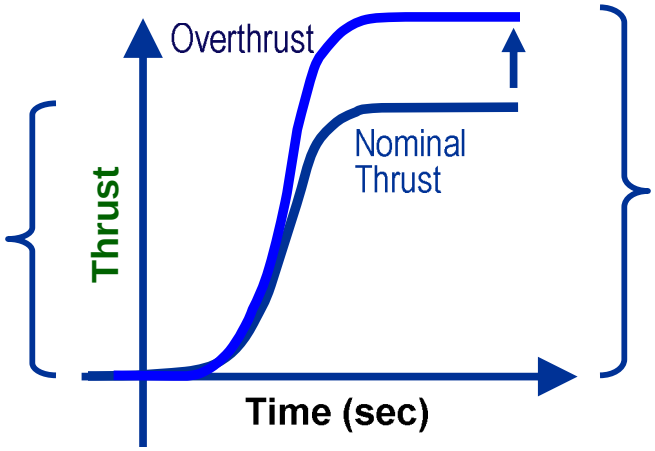


Ground track of impaired aircraft flying toward airport (CLE). Wind is shown decomposed in crosswind and headwind components.

The pilot's view toward the airport (CLE) on approach.

Overthrust

Nominal Throttle Range:
40°-80°



Enhanced Throttle Range:
40°-90°

The use of Overthrust mode allows the maximum throttle value to increase from 80° to 90°, providing additional thrust range capability

Final Approach

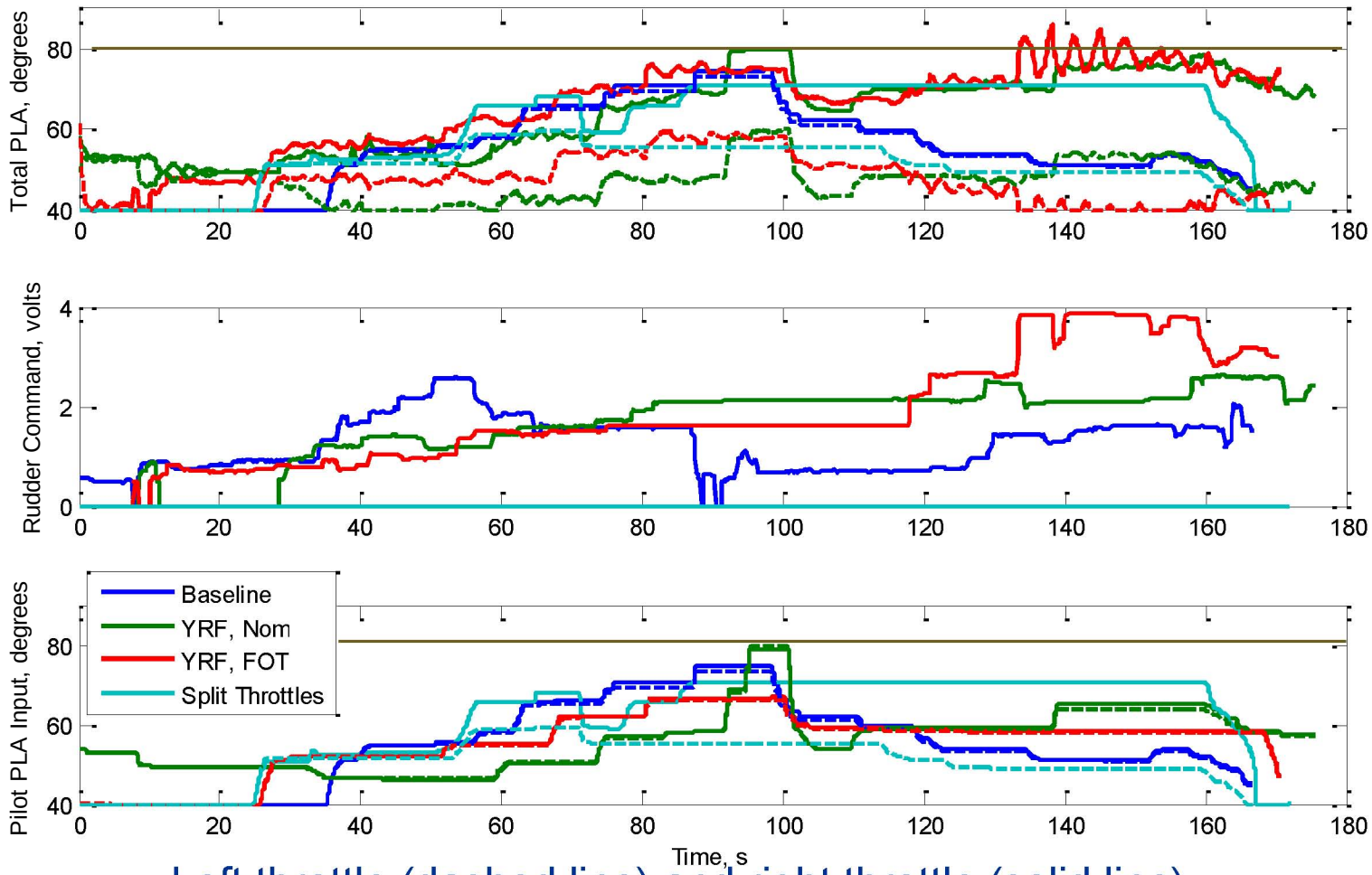
The tests included approaches with 10 kt crosswind with rudder stuck in neutral position.

- Yaw rate feedback with and without enhanced control was used
- Rudder pedals command throttle movement to generate differential thrust
- Saturation compensation system maintained differential thrust rather than total thrust

Things to Observe:

- Pilot's rudder input for the baseline case is not near its limit
- The crosswind could be accommodated by differential thrust
- Pilot's unwillingness to be aggressive enough at the beginning of the approach required extra thrust to compensate later.

Throttle Commands for Landing in 10 Kt Crosswind



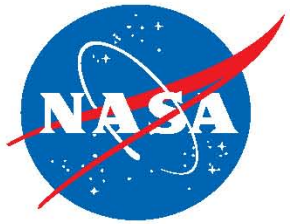
Left throttle (dashed line) and right throttle (solid line)

Conclusions

- C-MAPSS40k engine simulation has been developed and is available to the public
- The authenticity of the engine performance and controller enabled the development of realistic enhanced control modes through controller modification alone
- Use of enhanced control modes improved stability and control of an impaired aircraft
  - Fast Response is useful for manual manipulation of the throttles
  - Use of Fast Response improved stability as part of a yaw rate feedback system
  - Use of Overthrust shortened takeoff distance, but was generally useful in flight, too
- Initial lack of pilot familiarity resulted in discomfort, especially with yaw rate feedback, but that was the only drawback, overall the pilot found the enhanced modes very helpful

Future Work

- Loss of control prevention, mitigation, and recovery
  - Working on integrated flight/propulsion control with partners at NASA Langley and Pratt & Whitney
  - Modifying C-MAPSS40k to model high angle of attack operation realistically

Acknowledgments

- OA Guo
- Ryan May
- Jeff Csank
- Tom Lavelle
- Shane Sowers
- Amy Chicatelli
- Chris Fulton
- Karl Owen
- James Liu