Scenarios and Engine Response Requirements

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Presentation Summary

- Background/Objective
- TOC (Throttles Only Control) Methods & Concerns
- Overview of Past Flight Test and Simulation Results
- Compilation of Other Results
- Summary & Conclusion
- Acknowledgment

Motivation

- UA232, DC-10, Sioux City, Iowa, July 1989
  - Uncontained tail engine failure
  - Lost all hydraulic systems
  - Used two good engines to land airplane
  - Fatalities: Crew (1/11), Passengers (110/285)
- DHL, A-300,Baghdad, Iraq, November, 2003
  - Attacked by Surface-to-Air Missile (SAM)
  - Lost all hydraulic systems
  - Used two good engines to land airplane
  - No Fatalities

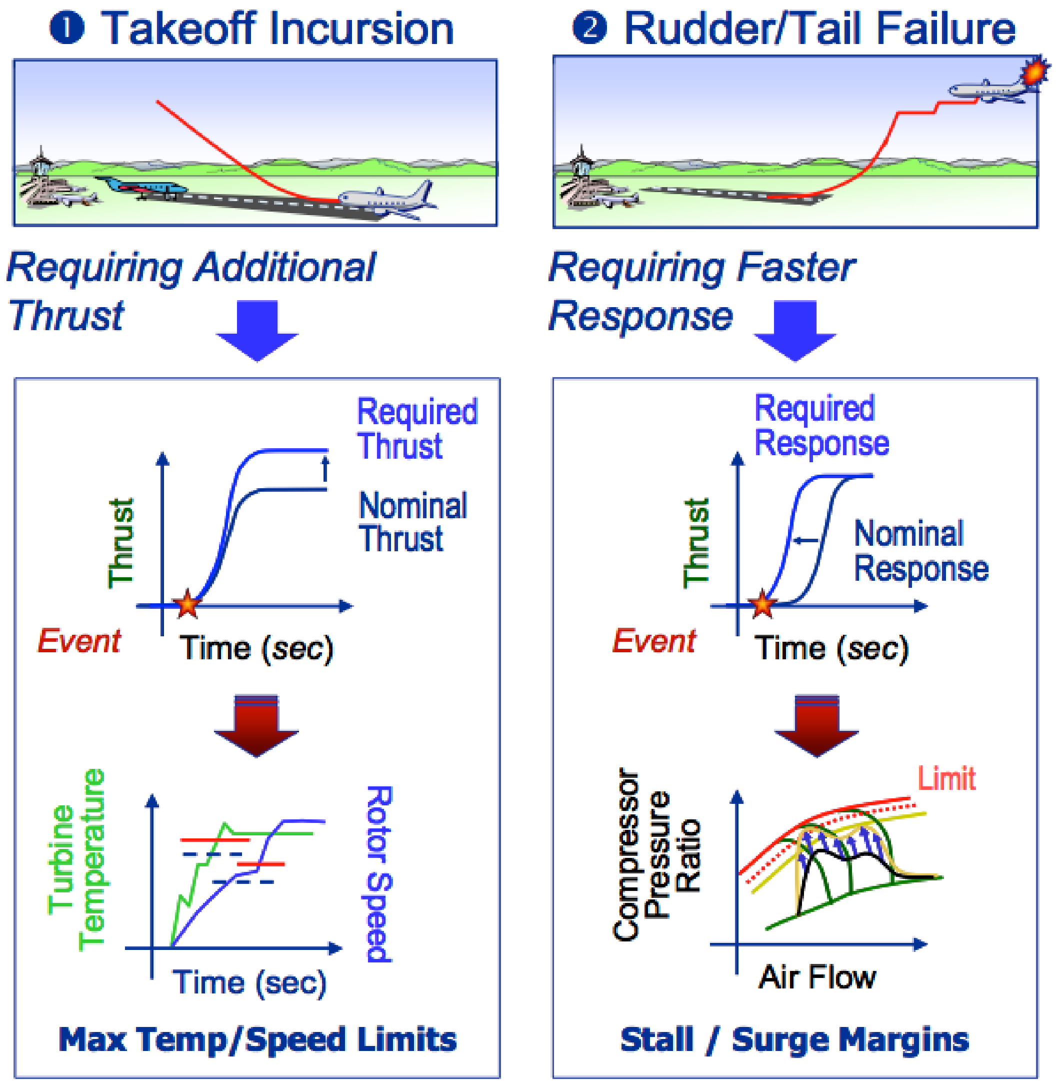
Objective

Two types of engine responses to be analyzed: overthrust and fast response

Considerations:
Structural limits
Stall Margins
Engine Condition

Requirements via Scenario Analysis

Using Aircraft Flight Simulator



TOC Methods

- Roll/Yaw/Bank Angle – Differential Thrust
- Pitch – Collective Thrust
- Speed – Collective Thrust, Creating Drag

TOC Concerns

- Slow Engine Response
- Weak Control Moments
- Coupling Between Pitch and Roll
- Difficulty in Damping Phugoid and Dutch-Roll Oscillations
- Landing
- Pilot Unfamiliarity – Steep Learning Curve
- Sink Rates

Summary of Past Flight Tests and Simulations of Throttles Only Control

B-757

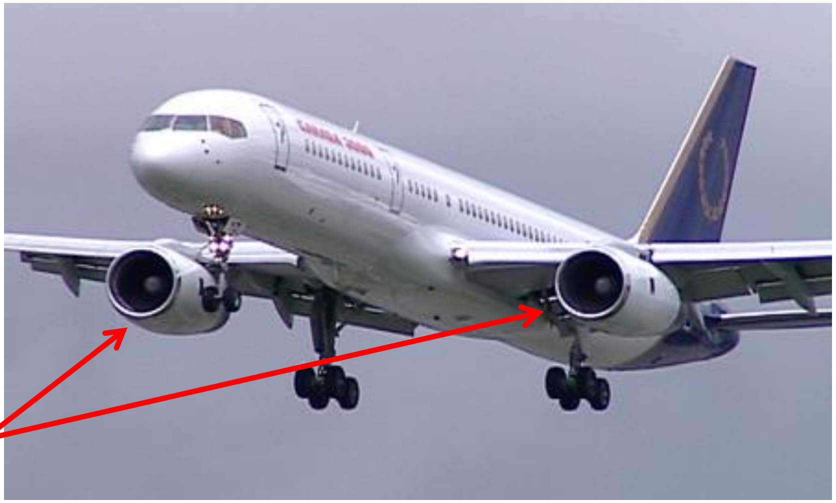
- Plenty of pitch and roll authority

Longitudinal Time Responses	
Alititude (ft)	Time Constant (s)
2,000	4
15,000	8
35,000	15

Bank Command Step Responses	
Alititude (ft)	Time Constant (s)
2,000	3
15,000	6
35,000	10

Ref: Bull, J., Mah, R., Hardy, G., Davis, G., Conley, J., Williams, D., Blake, M., Gibson, J., Bryant, D., "*Piloted Simulation Tests of Propulsion Control as Backup to Loss of Primary Flight Controls for a Mid-Size Jet Transport";* December 1995.

- Max Roll Rate=15deg/s
- Roll Rate @
  0.1EPR diff thrust=3deg/s
- Sink Rate=11.7ft/s



Engines widely spaced below wings

Ref: Burcham, Frank W.: "*Manual Manipulation of Engine Throttles For Emergency Flight Control*"; January 2004.

B-720

- Most pilots were unable to make successful landings
  - 1s lag in pitch and roll
  - Lightly damped dutch roll
- Good roll rates: approx 20 deg/s
- Max Pitch Rates:
  - 1.8 deg/s @ 160kn
  - 1.1 deg/s @ 200 kn

Engines very widely spaced below wings

Ref: Burcham, Frank W.: “*Manual Manipulation of Engine Throttles For Emergency Flight Control*”; January 2004.

B-727

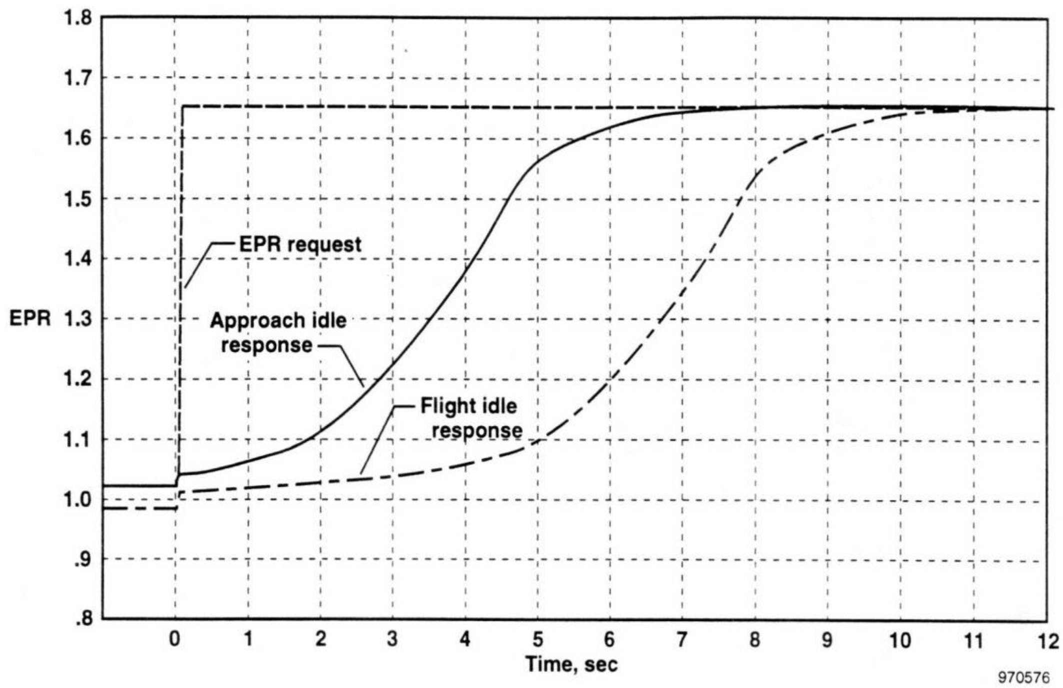
- Roll Rates: approx 3-4 deg/s
- Slowing down for landing requires the development of nose-up pitching moments; 5° pitch increase=21s
- Nose up pitch rates at full throttle were about 0.75deg/s
- Neither Pilot could make a successful landing

Ref: Burcham, Frank W.: "*Manual Manipulation of Engine Throttles For Emergency Flight Control*"; January 2004.

Rudder/Tail Failure

B-727 Simulation Results

- 3s from idle to 30% throttle, 3 sec. from 30%-100% full throttle
- Takes about 7.5s from approach idle (higher power) and 10.5s from flight idle (slightly lower initial power setting).

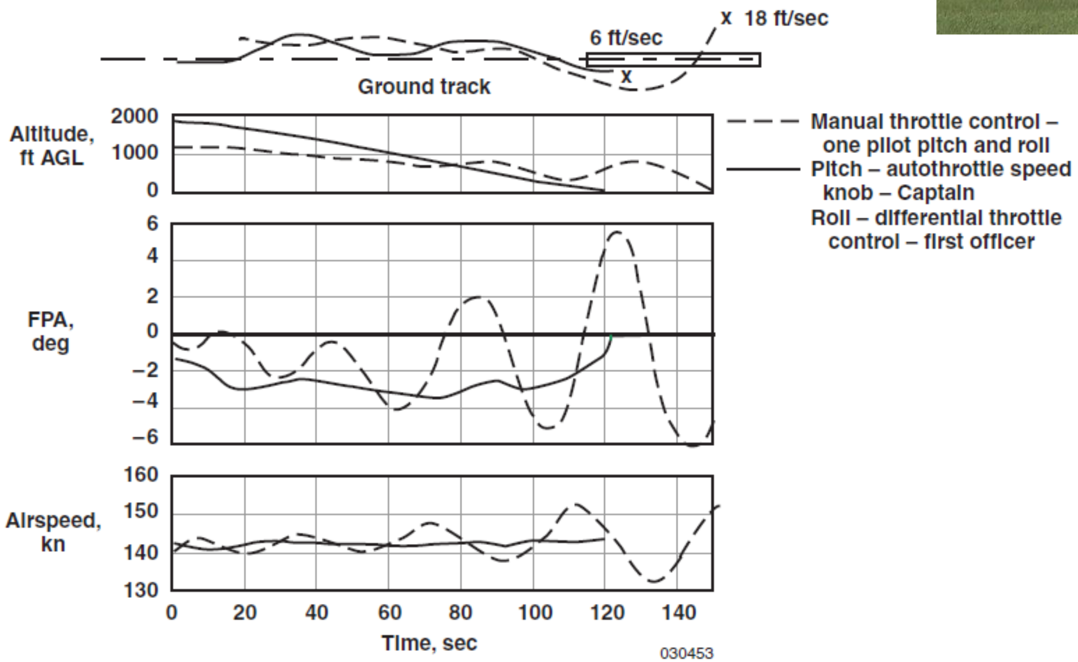


Ref: Burcham, Frank W.: "*Controlling Crippled Aircraft – With Throttles*"; September,1991.

MD-90

- Pitch is very difficult to control
- Sluggish Roll Control
- No successful landings made
- Split-Task Technique

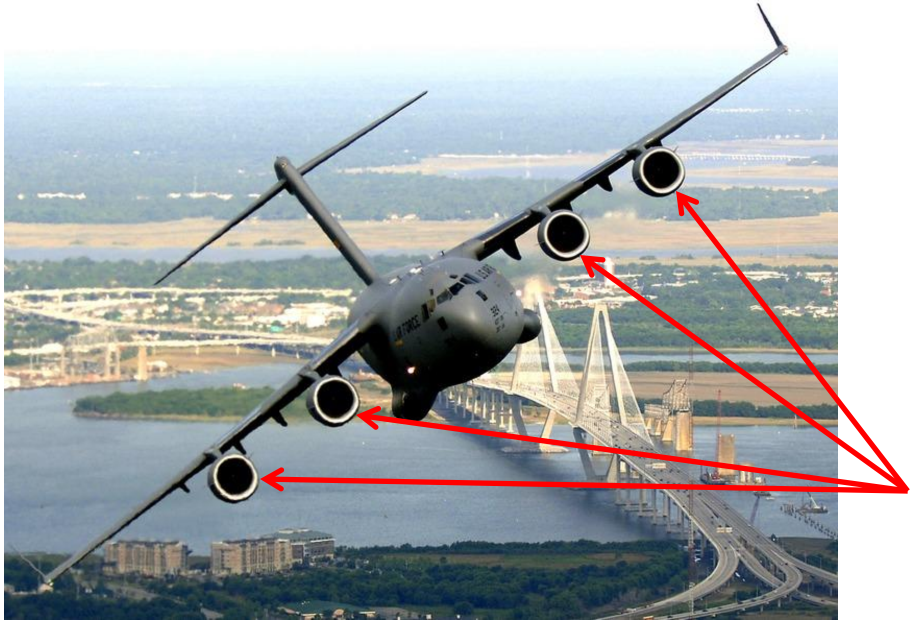
Engines rear-mounted, close to fuselage, and above wings



Ref: Burcham, Frank W.: "*Manual Manipulation of Engine Throttles For Emergency Flight Control*"; January 2004.

C-17

- Significant positive pitching moment with thrust
- Precise heading control difficult
- Slow engine response times
- High sink rates – around 15ft/s
- Split-Task piloting enabled 3 consecutive safe landings



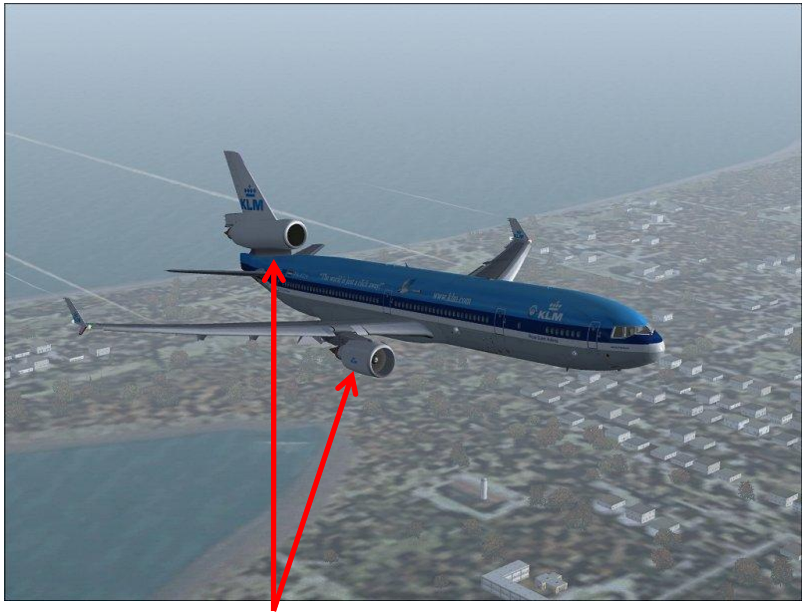
MD-11

- Max roll rate of 7-8deg/s was achieved, while 10deg/s or more are required for successful landings
- A -2° pitch command was reached in about 7s
- Takes as long as 12s from idle to full power
- 204kn tire landing speed limit
- Requires a 2.3° glide slope

(or shallower)

- A 5° track command took 15s

Ames Approach Simulator	
Motion:	Max Velocity:
Roll	20°/s
Pitch	30°/s
Yaw	9.7°/s



Two engines widely spaced below wings and one rear-mounted

Ref: Burcham, Frank W.: "*Manual Manipulation of Engine Throttles For Emergency Flight Control*"; January 2004.

Ref: Burcham, F. W., Burken, J. J., Maine, T. A.; and Fullerton, C. G., "*Development and Flight Test of an Emergency Flight Control System Using Only Engine Thrust on an MD-11 Transport Airplane*", NASA/TP-97-206017, October 1997.

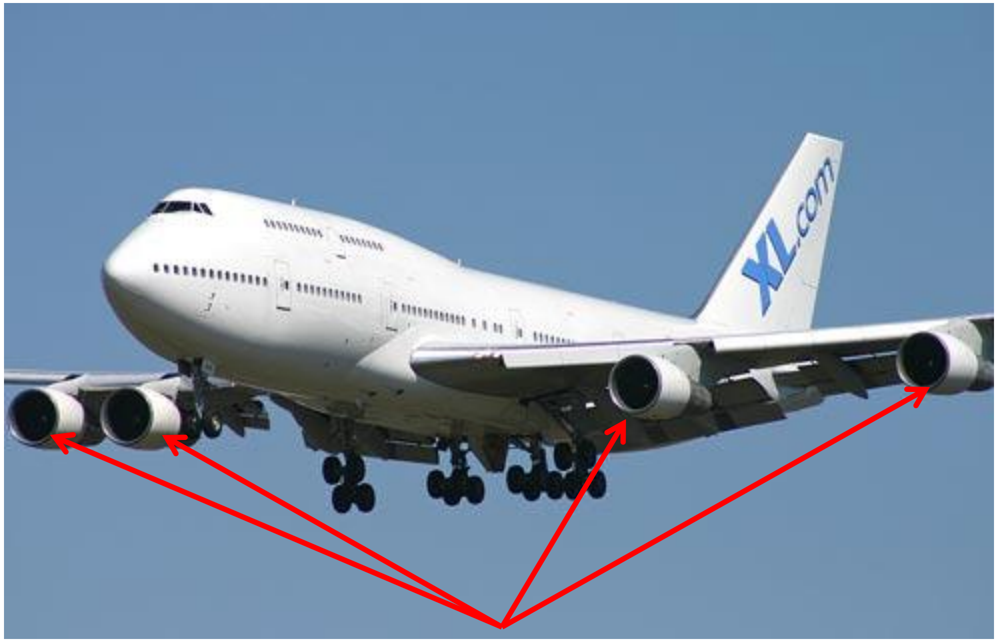
Ref: Burken, J. J., Burcham, F. W., Maine, T. A., Feather, J., Goldthorpe, S., Kahler, J. A., "*Flight Test of a Propulsion-Based Emergency Control System on the MD-11 Airplane With Emphasis on the Lateral Axis,*" AIAA Paper 96-3919, July 1996.

B-747

- Large inertia creates a sluggish roll response
- Large pitch control lags
- High sink rates (and approach speeds)

Touchdown:	
From TD Point:	780', ±660'
From Centerline:	Left 7', ±23'
Sink Rate:	8ft/s, ±3ft/s

- EPR response time constant≈1.1s @ low altitude, and ≈2.5s @ 35,000'
- Roll rates of 4-5deg/s were obtained in simulation using full differential thrust



Engines very widely spaced below wings

Requirements Developed Using GTM

- For "benign" case of control surfaces locked at trim:
  - Engine Response Requirements driven by Phugoid Mode
  - Engine speeds that are at least 3 times the Phugoid natural frequency at 2,000', and damping ratios between 0.7 and 1.0 result in satisfactory control for both flight path and track angle throughout the flight envelope studied:

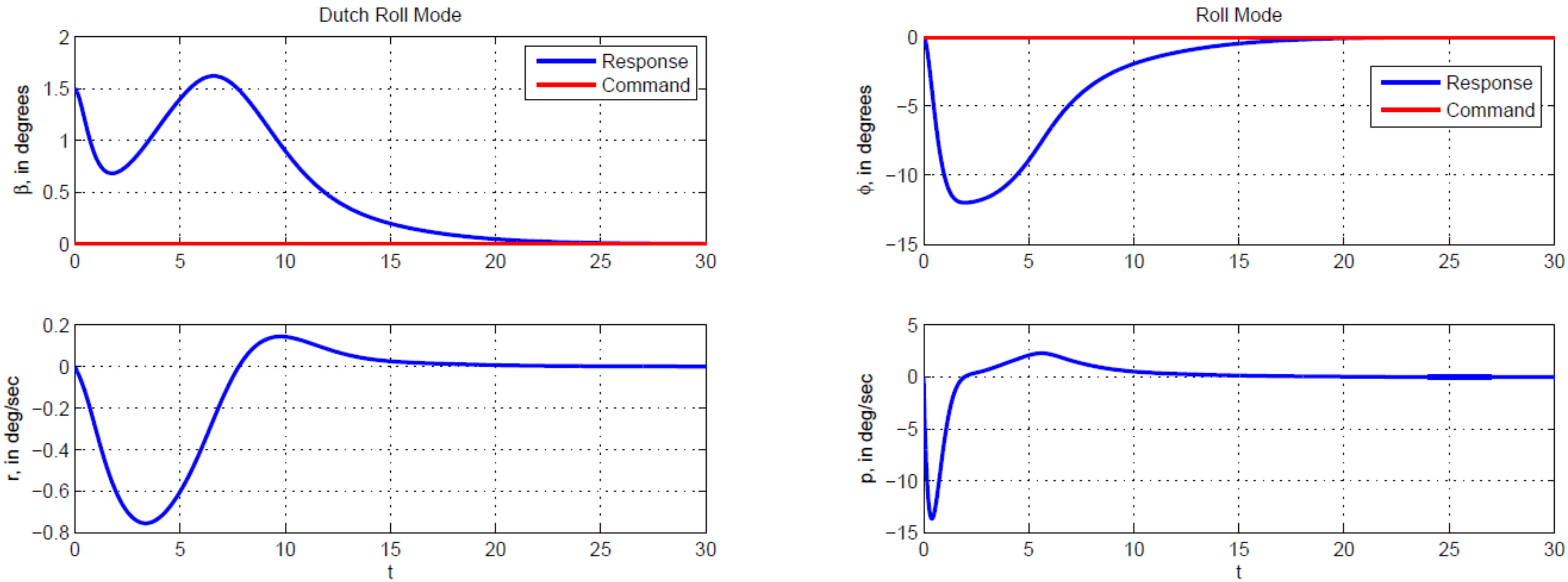
Phugoid Mode Characteristics	**Engine Requirements**
Natural Frequency=0.12 rad/sec	Natural Frequency>0.36 rad/sec
Natural Period=53 sec	Natural Period<16.8 sec
ζ=0.05	ζ=0.8

Ref: Perot Systems Task 217 Report*: "Engine Response Requirements Study for Satisfactory Propulsion Control Under Adverse Conditions",* September 16, 2008

- For loss of vertical tail:
  - Only linearized lateral-directional dynamics were considered, since *the longitudinal dynamics do not change much* and the model is still symmetric about the vertical plane.

Ref: Stepanyan, V., Krishnakumar, K., Nguyen, N., "Adaptive Control of a Transport Aircraft Using Differential Thrust," AIAA 2009-5741, AIAA Guidance, Navigation, and Control Conference, 10 - 13 August 2009, Chicago, Illinois

Adaptive Integrated Flight/Propulsion Control



(a) Sideslip angle and yaw rate

(b) Roll angle and roll rate

Lateral directional performance of the airplane (linear models used)

Damage case is vertical tail loss with no rudder authority. Results use differential thrust and ailerons to stabilize the airplane.

Ref: Stepanyan, V., Krishnakumar, K., Nguyen, N., “Adaptive Control of a Transport Aircraft Using Differential Thrust,” AIAA 2009-5741, AIAA Guidance, Navigation, and Control Conference, 10 - 13 August 2009, Chicago, Illinois

Summary & Conclusion

- A lot of information is available but no specific requirements can be developed
- Surveying past work and the listing of shortcomings from simulations and historical accidents can provide a starting point for requirements
- The control solution depends completely upon the situation—this is defined by the airplane’s configuration, the type of damage or danger, and the performance requirements
- Because it is ultimately a flight control problem, the requirements must come from the flight control system

Acknowledgment

- Megan D. Bastian, Undergraduate Student Research Program, Summer 2009