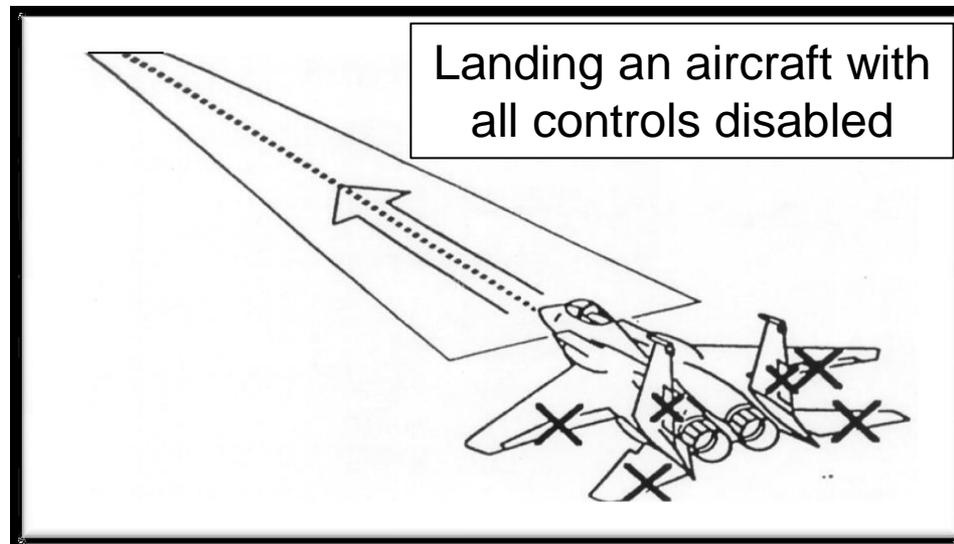


Integrated Propulsion Control with Aircraft Systems to Provide Increased Performance



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Jim Urnes, Sr.
The Boeing Company
james.m.urnes-sr@boeing.com

Flight Control using Propulsion Changes

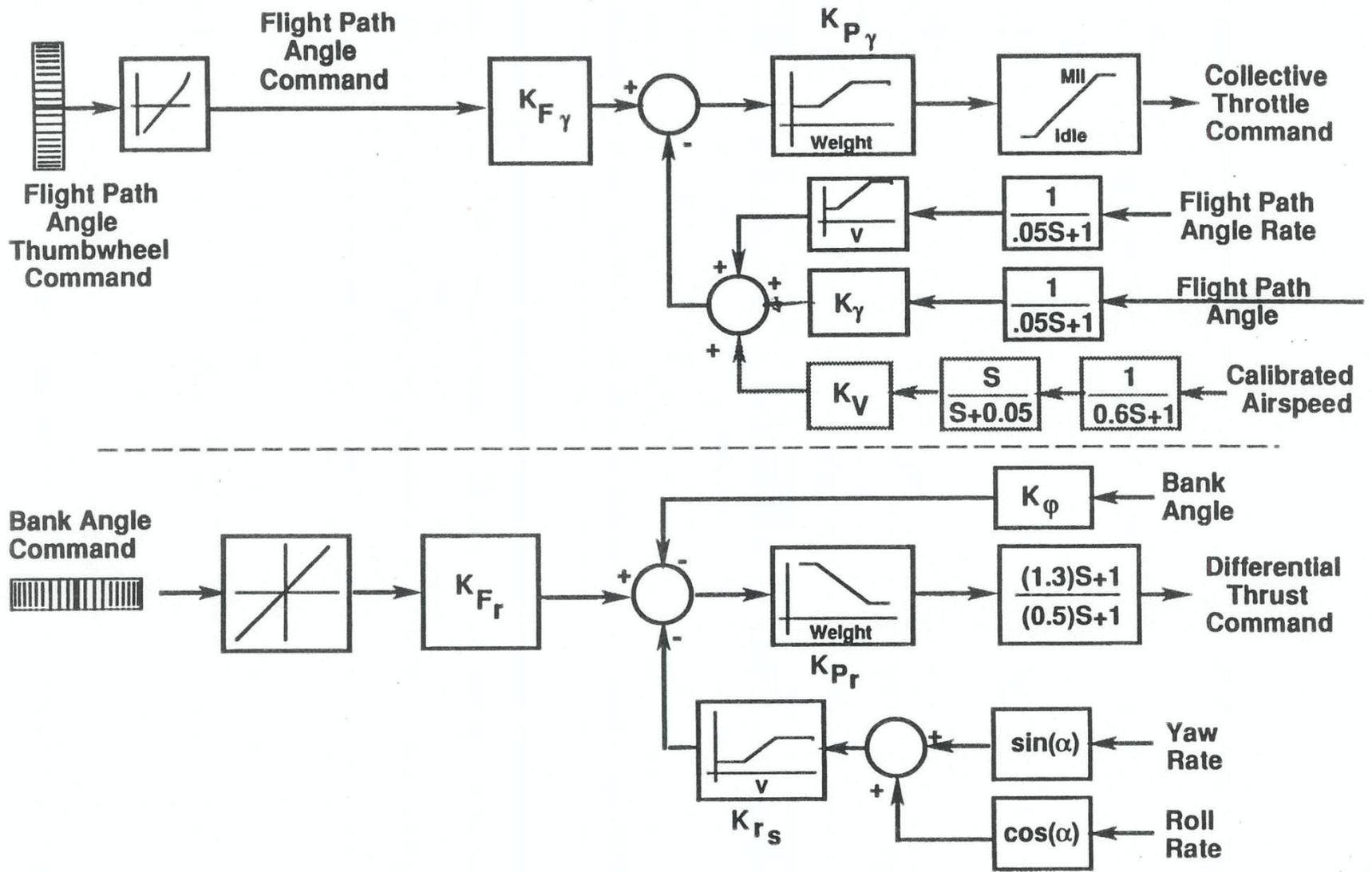
- Augment conventional flight control effectors with thrust effectors
- Enhance flight path control at extreme angle of attack and sideslip conditions
- Safety: Enables better performance for damaged flight control situations
- Certification for propulsion control more direct than conventional flight control effectors
- Flight path control for UAV aircraft
- Improved carrier landing for Navy tactical and UAV aircraft by integrating Approach Power Control with flight path control

Integrated Propulsion / Flight Control Example: The PCA Program

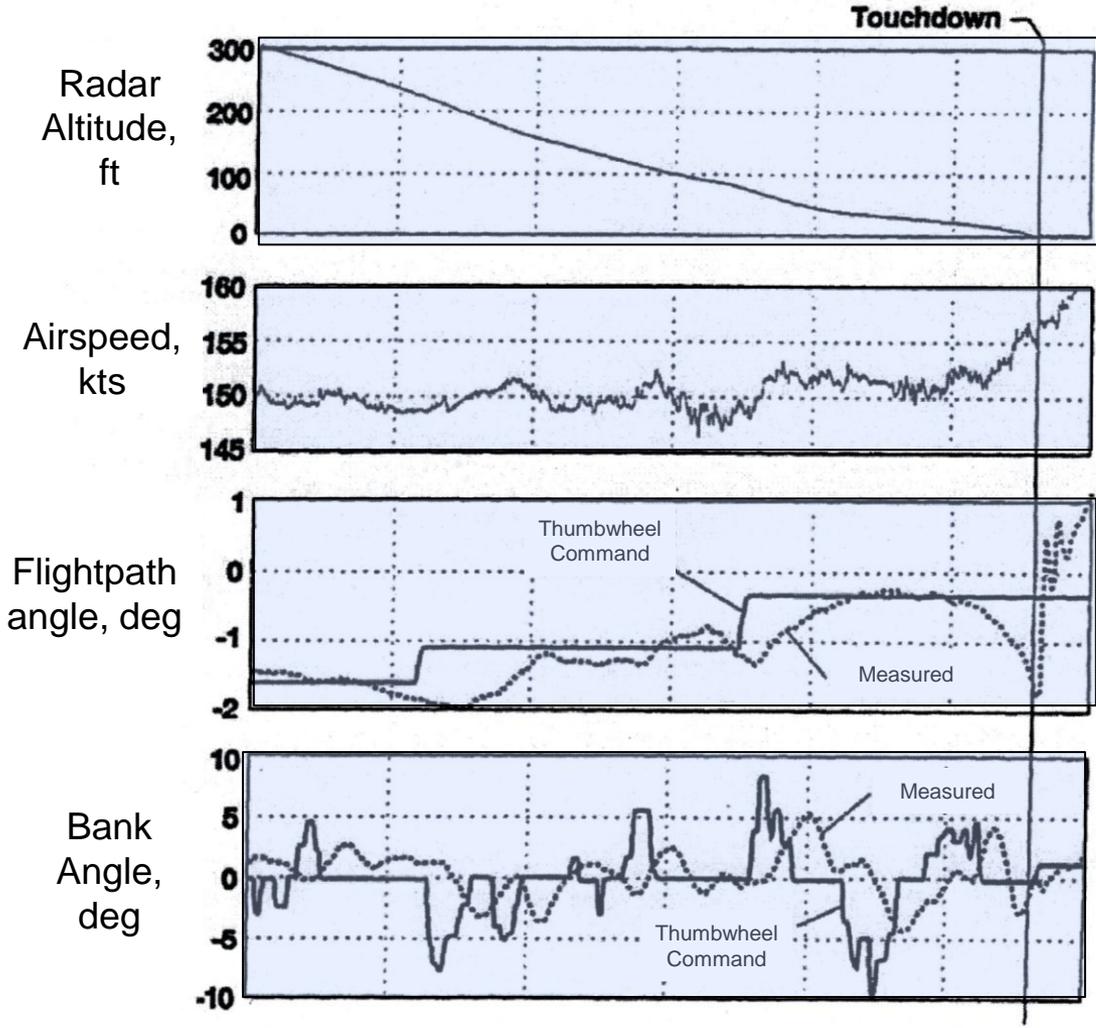


- **Program initiated after United Flight 262 lost all flight control and landed at Sioux City, Iowa**
 - Direct throttle control used, very difficult to control Phugoid and Dutch Roll Oscillations
- **Boeing developed a Propulsion Controlled Aircraft (PCA) flight mode for a NASA F-15 Test Aircraft**
 - Lead compensation applied in roll/yaw to increase thrust dynamic response
 - Thumbwheel controller for pitch and roll/yaw control instead of stick
 - Flight commands directly to engine controllers
 - No backdrive to throttles
 - Special HUD display to counter large lag in flight path response
- **Successful flight test results for navigation, letdown and landing with PCA**

Example of Integrated Flight and Propulsion Control



F-15 First PCA Landing at EAFB

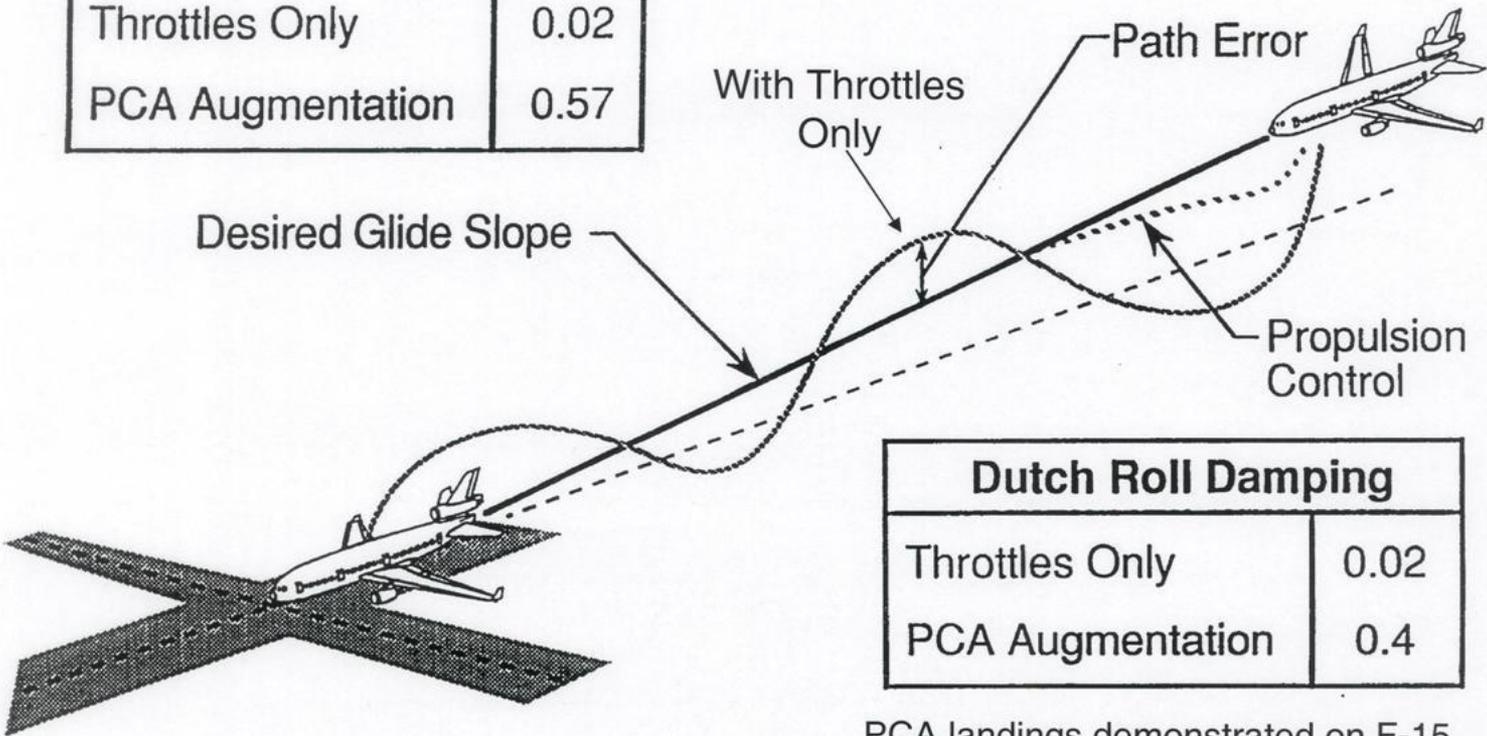


Landing
Flown by
Gordon Fullerton
NASA F-15
Test Pilot

Propulsion Control Provides Necessary Path Damping Improvement



Phugoid Damping Ratio	
Throttles Only	0.02
PCA Augmentation	0.57



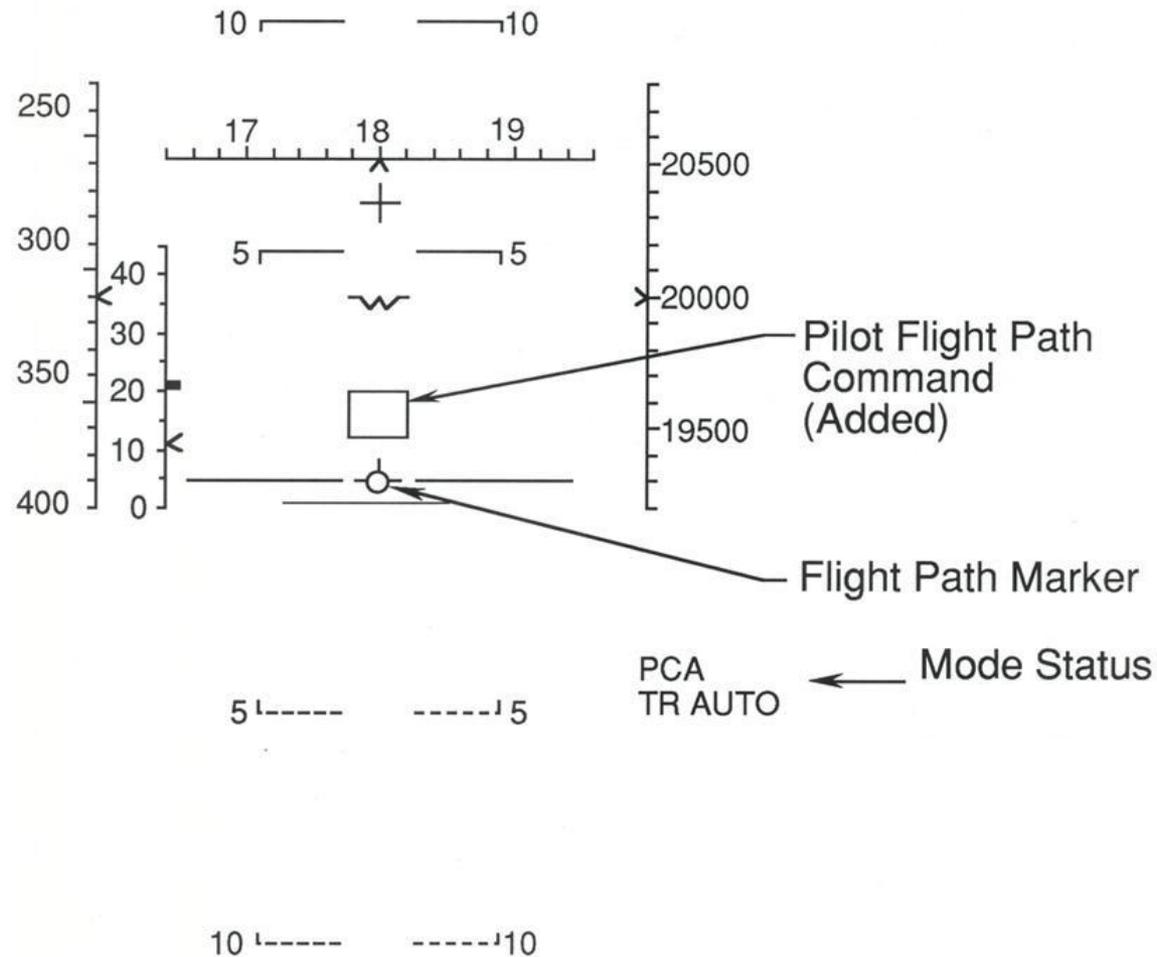
Dutch Roll Damping	
Throttles Only	0.02
PCA Augmentation	0.4

PCA landings demonstrated on F-15 and MD-11 aircraft at Edwards AFB

HUD Display for Slower PCA Response



Provides UAV Pilot with accurate prediction of flight path



- **Loss of Control**
 - Flight crew inattention can lead to exceeding aircraft flight envelope limits
 - Propulsion changes can limit pitch or roll excursions, provide safe maneuver boundary
 - After exceeding flight envelope limits, very difficult to recover
 - Engine thrust more effective than aileron or rudder control at extreme angle of attack
 - Must keep the engines operating at large angle of attack or sideslip conditions

Roll Attitude Excursions and the Attitude at which Pilot Inputs were Initiated



Event	Airplane	Attitude when recovery attempt was initiated*	Attitude goes to	Roll rate **
Perm, Russia	737-500	30° L	>270° L; 65° ND	40° in 30 sec
Douala, Cameroon	737-800	34° R	115° R	2°/sec to 35°
Sulawesi, Indonesia	737-400	35° R	100° R; 60° ND	1°/sec to 35°
Sochi, Russia	A320	--		
Sharm el-Sheikh, Egypt	737-300	30° R	>60° R; ND	1-2°/sec to 40°
Irkutsk, Russia	Tu154 M	45° L	>70° L; ND	above threshold
Bahrain	A320	--		
Zurich, Switzerland	Saab 340B	no recovery		2-5°/sec
London	747-200	no recovery		
Hsin-Chu, Taiwan	Saab 340B	48° R; 8° ND	??	sub-threshold
Khabarovsk, Russia	Tu154	40° R	80° R	<1°/sec for 41 sec
Charlotte, USA	DC-9-31	--		
Mezhduretshensk, Russia	A310-300	50° R	90° R	initially 1°/sec
Guilin, China	737-300	50° R	155° R	1-2°/sec
Tucuti, Panama	737-200	insufficient data		
Toledo, USA	DC-8	60° L; ND	80° L; 30° ND	??
Belvidere, USA	Convair 580	no recovery		sub-threshold

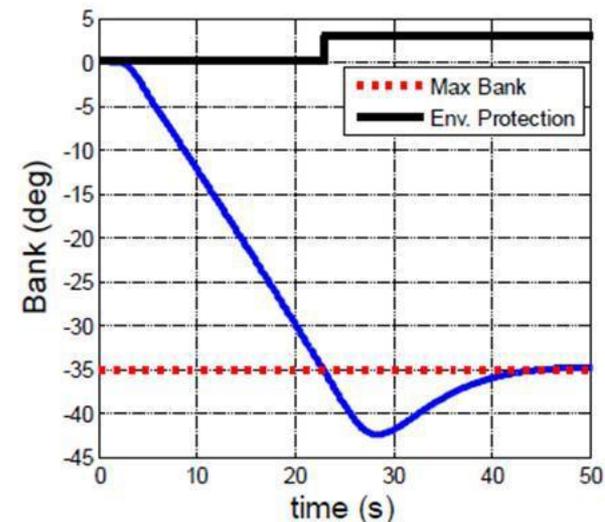
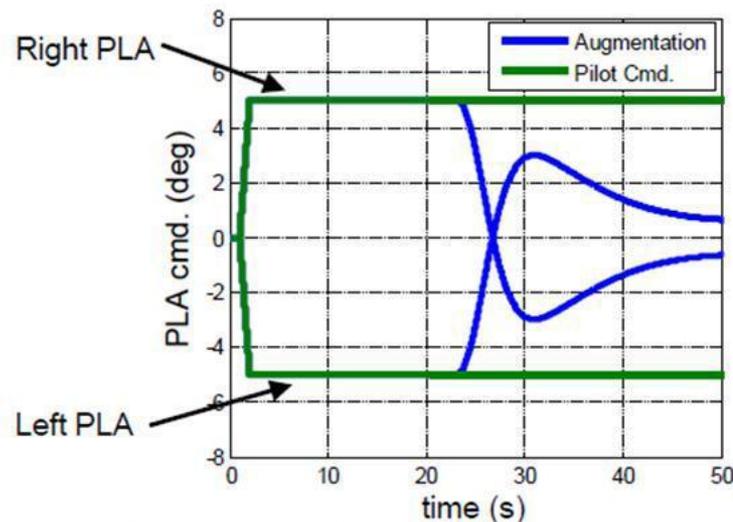
* Approximations of attitude at a particular point

** Threshold for perception of roll rate $\approx 2^\circ/\text{sec}$

Thrust Augmentation Limits and Aircraft Bank Angle



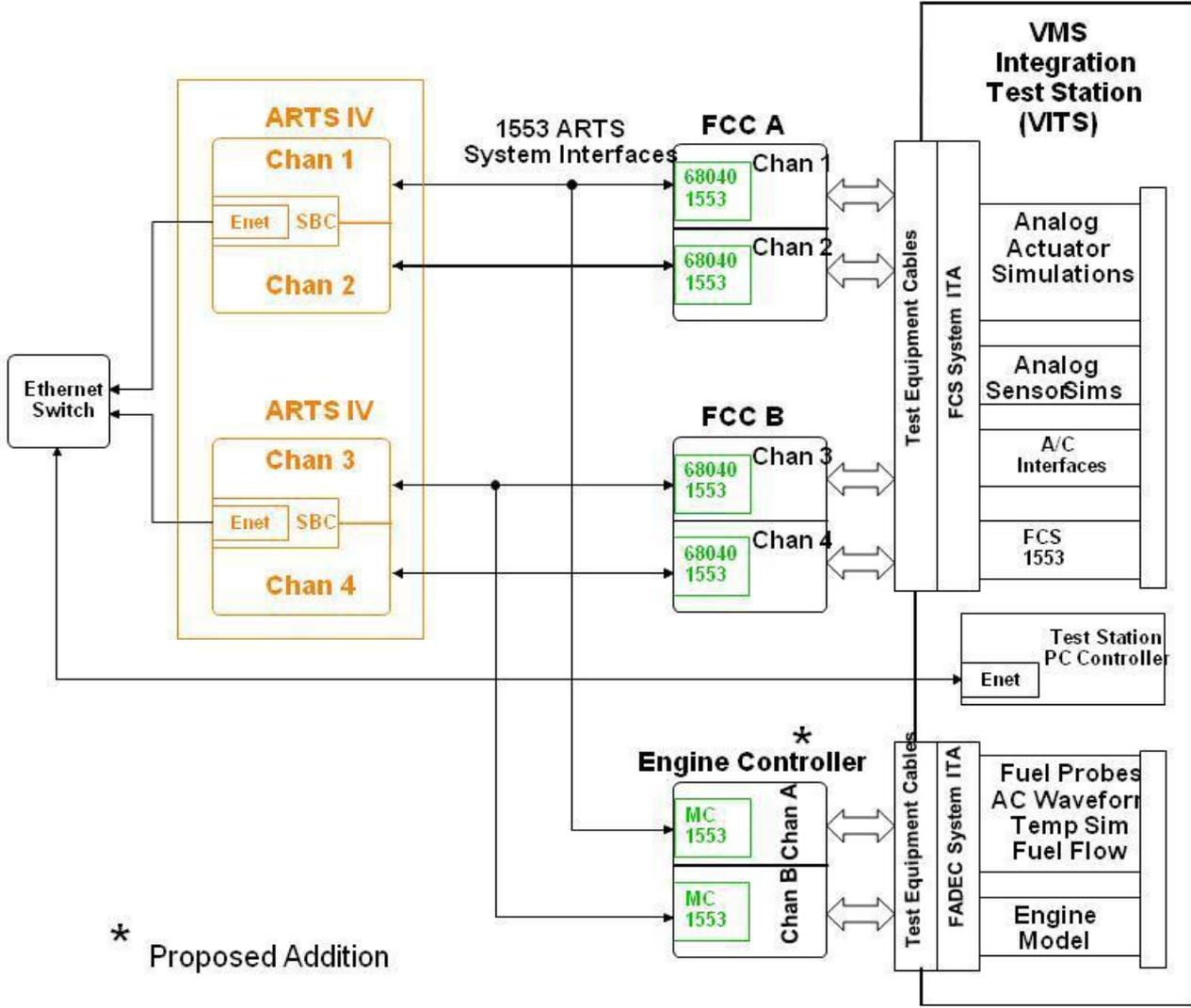
- **Bank Angle Limiting Simulation Scenario:**
- Throttle split of 10 deg. differential induces unwanted bank excursion.
- Bank angle increases
- When max bank angle is exceeded, thrust augmentation drives bank angle back to the boundary limit value



Initial Step: Integrate the function of flight control and engine control

- Link or combine the flight and propulsion controllers
- Enhances propulsion performance
 - Modes for takeoff, cruise, landing
 - Better schedules for fuel economy
 - Better control of emissions
- Keep engine operating at extreme inlet airflow angles or obstructed inlet due to ice, bird strike
- Improves engine health monitoring, diagnostics
- Enables reconfigurable control for failed engine components

F/A-18 Research Flight Control System with Engine Controller Research Capability



* Proposed Addition

Summary: Integrating Propulsion Control with Aircraft Systems



- **Integration benefits flight and propulsion control**
- **Enables optimum engine operating modes**
- **More choices for alternate paths or components during flight with failed or marginal components**
- **Enhances Vehicle Health Management**
- **Can result in increased fuel efficiency, engine life**
- **Advances Environmental Control for better cooling, power distribution**
- **Future (N+3) aircraft with lighter weight, Distributed Electric Propulsion, wing shaping for drag reduction**