F/A-18A/B/C/D Flight Control Computer Software Upgrade

Military Aircraft System Verification and Validation
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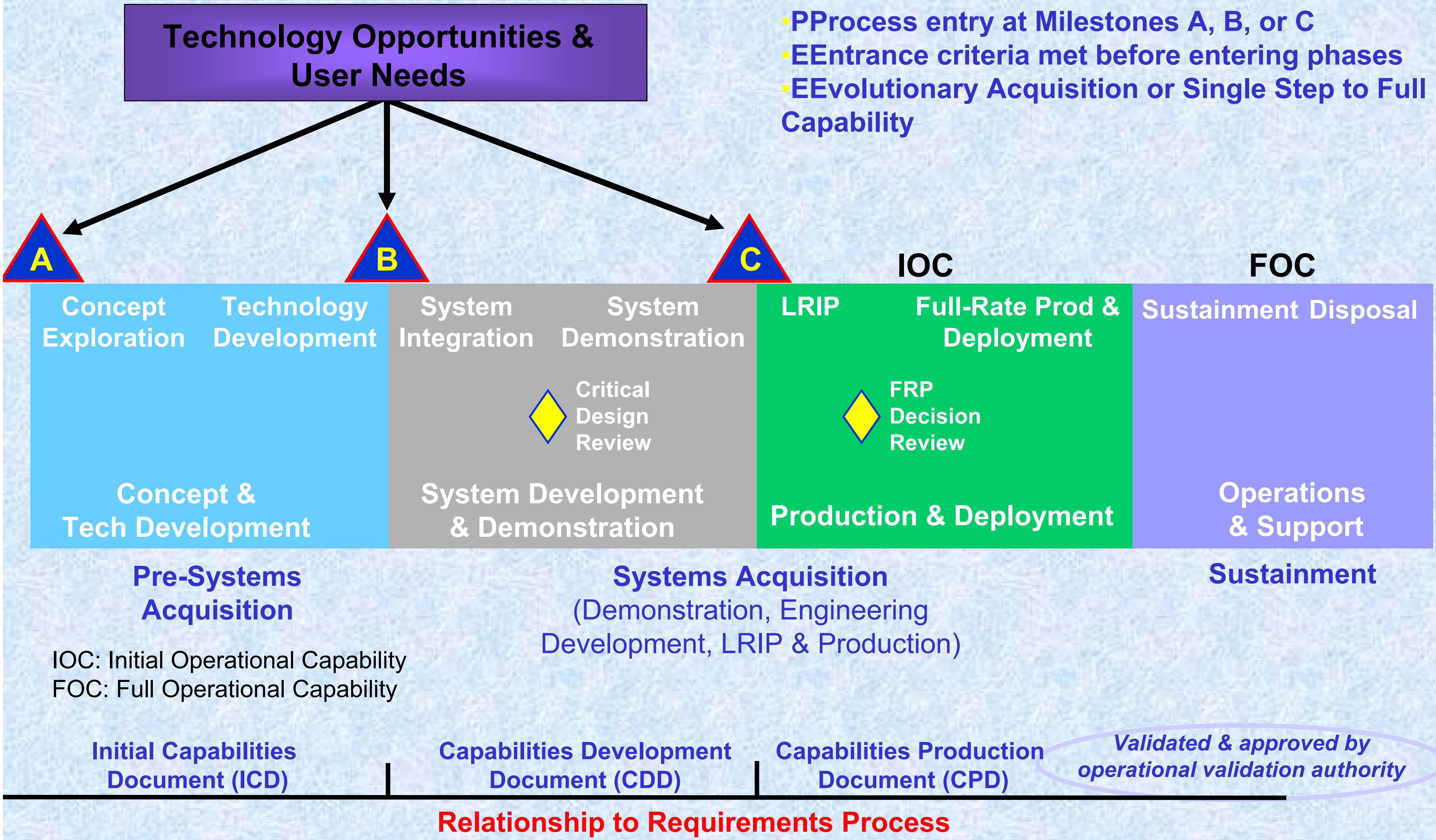
Briefing Summary

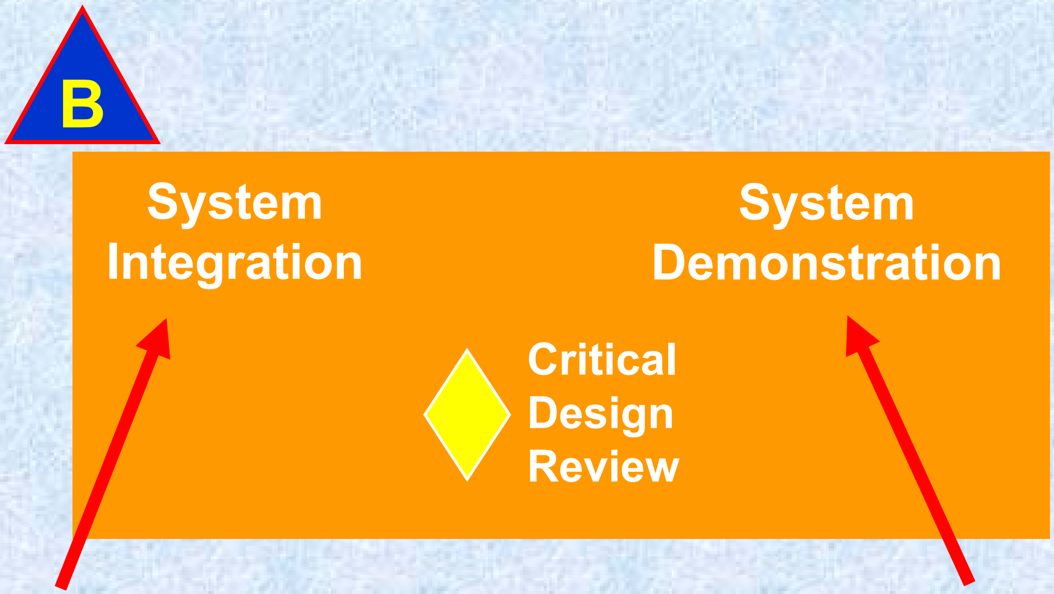
- US Navy Acquisition Process Overview
- F/A-18 Aircraft Overview
- Flight Control Law Software Upgrade Program
  - Requirements
  - Constraints and Challenges
  - Results
- Conclusions

Defense Acquisition Management Framework

- PProcess entry at Milestones A, B, or C
- EEntrance criteria met before entering phases
- EEvolutionary Acquisition or Single Step to Full Capability



System Development & Demonstration Phase



System Integration

Enter: PM has technical solution but has not integrated subsystems into complete system

- **Activities:** System Integration of demonstrated subsystems and components. Reduction of integration risk

Exit: Demonstration of prototypes in relevant environment

System Demonstration

Enter: Prototypes demonstrated in intended environment

- **Activities:** Complete development. DT/OT/LFT&E

Exit: System demonstration in intended environment using engineering development models; meets validated requirements

System Development & Demonstration Phase

Purpose:

- To develop a system
- Reduce program risk
- Ensure operational supportability
- Ensure design for producibility
- Assure affordability
- Demonstrate system integration, interoperability, and utility

System Integration

- **<u>Purpose</u>:** **Integrate subsystems – reduce systems-level risk**
- **<u>Key Activities</u>:**
  - **Demonstrate prototype articles**
  - **Conduct an Early Operational Assessment (EOA)**
  - **Prepare for Critical Design Review (CDR)**
  - **Prepare RFP for next effort/phase**

System Demonstration

- **Purpose**: Demonstrate the ability of the system to operate in a useful way consistent with the validated KPPs.
- **Key Activities**:
  - Conduct extensive testing: developmental, operational, and survivability/lethality testing, as appropriate
  - Conduct technical reviews, as appropriate
  - Demonstrate system in its intended environment
  - Prepare RFP for Low Rate Initial Production
  - Prepare for Milestone C
  - Update: Information requirements

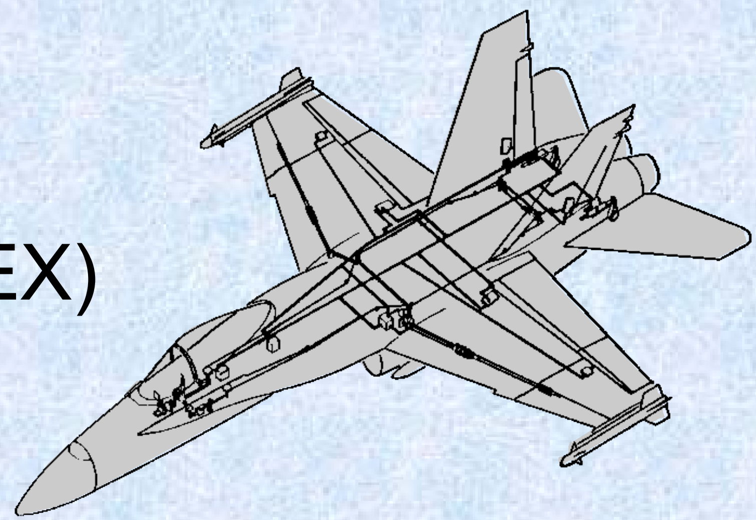
Summary: System Development & Demonstration Phase

- **May consist of System Integration *and* System Demonstration depending on:**
  - ***technology maturity***
  - ***affordability***
- **System demonstrated in the intended environment; meets validated requirements; industrial capability available; meets exit criteria**
- **Manufacturing risk low**

Bottom Line: System ready to begin LRIP?

F/A-18A/B/C/D “Hornet”

- Supersonic, Multi-role, Combat Aircraft
  - Introduced to fleet in 1983
- Relevant Design Features
  - “Fly-by-wire” Flight Controls
  - Twin Vertical Stabilizers
  - Leading Edge Extension (LEX)
  - Two Turbofan Engines
- SuperHornet (E/F Models)
  - Introduced to fleet in 2001



Flight Control System

- Two Digital Flight Control Computers (FCC)
  - Four separate channels
- Control Augmentation System
  - Augments basic airframe stability
  - Gains scheduled to *enhance flying qualities*
  - *Provides departure resistance*
  - Provides protection against overstress
  - Actively controls structural mode interaction

Program Origin

- Need to upgrade the FCC software
  - Mishap Prevention
    - Suppress out of control flight modes
    - Improve departure resistance
  - Improve maneuverability at high AOA
    - Improve roll performance above 30° AOA
    - Implement “Pirouette” Feature

The Main Problem

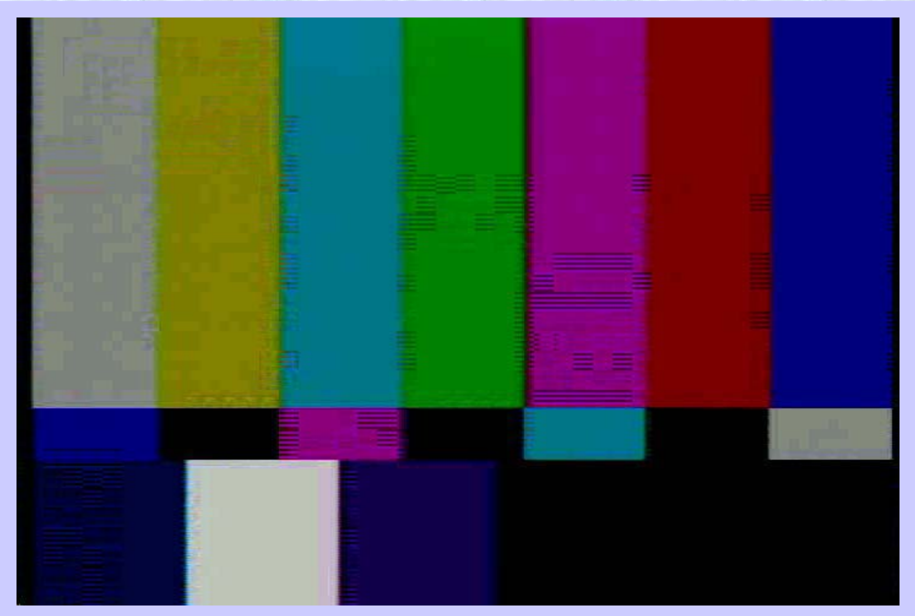
Twenty F/A-18 aircraft lost due to Out-of-Control flight

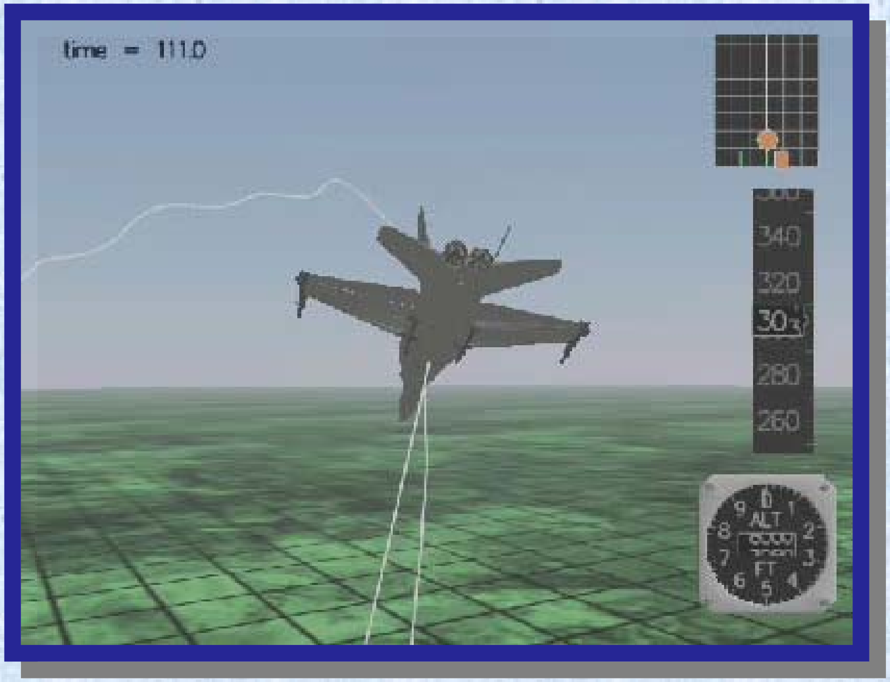
Ten aircraft were projected to be lost during the remaining lifecycle without modifications

NAVAIR

The Main Problem

Sustained Out of Control Flight Motion
Following Nose-High, Banked, Zero Airspeed Flight





Eventual Recovery - Significant Altitude Loss

Loss of Aircraft

F/A-18 Out of Control Flight Modes

- Departure
  - Aircraft no longer responding to pilot commands
- Post Departure Gyrations
  - Random oscillations (AOA, Airspeed, Sideforces)
- Fully Sustained OOCF Modes
  - Falling Leaf Modes
  - Spin Modes

Departure Resistance

The Usual Cause of a Departure:

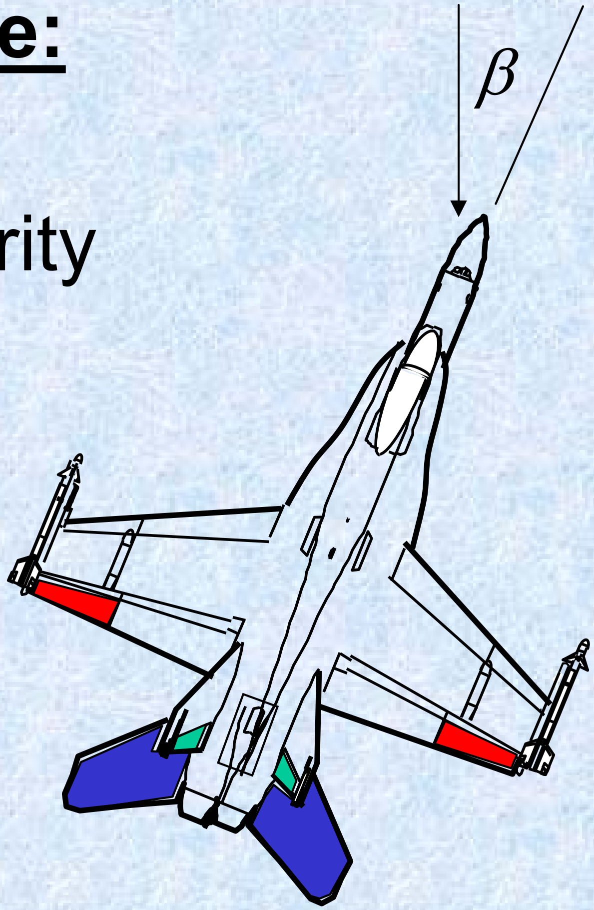
Roll or yaw due to sideslip (β) overcomes control surface authority

Key to Controlled Flight:

Minimize β with control surfaces

"Sideslip is the root of all evil"

β = Sideslip = 



Another Reason for Sideslip Control

Roll (Coupled) Departure

Program Overview

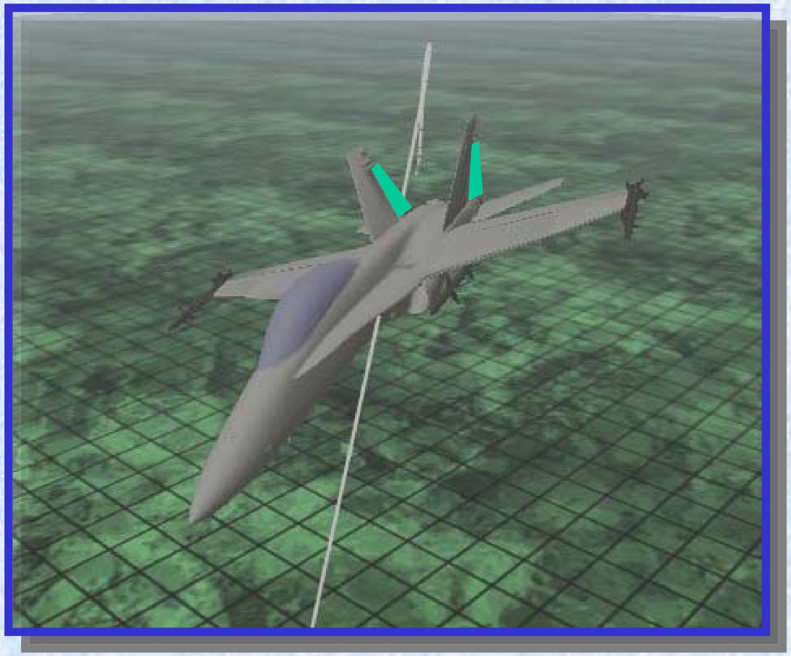
- $15 Million dollars
- Program Timeline
  - Improved control laws developed (1988-90)
  - Baseline design used in SuperHornet (1993)
  - SuperHornet Developmental Test (1995-99)
  - “Heritage Hornet” upgrade proposed (2000)
  - New Control Law Developmental Test (2001-02)
  - Release to Fleet (June 2003)

Major Design Goals

- Control sideslip buildup
  - Add sideslip rate ($\dot{\beta}$) feedback
  - Enhance sideslip (β) feedback
- Generate additional yaw rate
  - Use Adverse Yaw to our advantage
    - Command opposite differential-stabilator

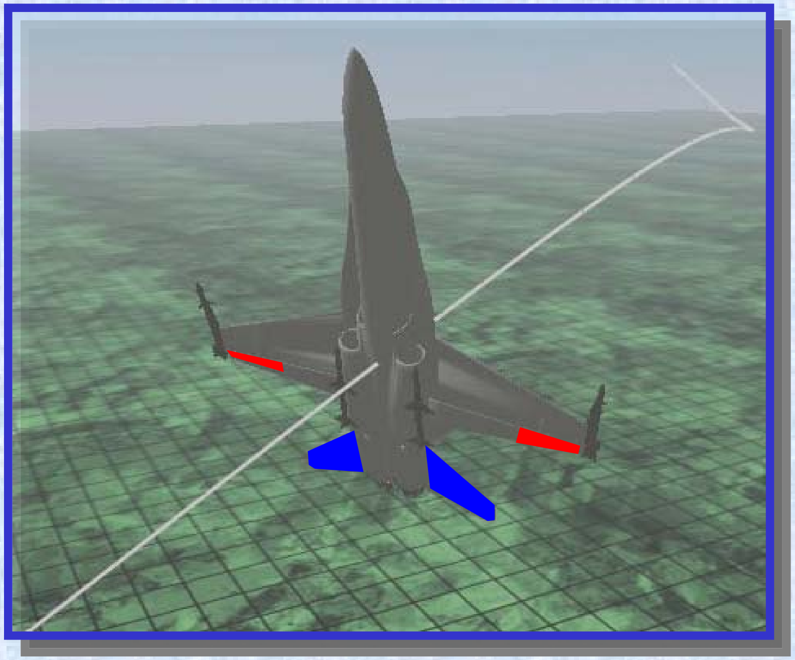
Sideslip Control at High AOA

At low AOA…



Yawing motion produces sideslip
Rudder deflection controls sideslip

At high AOA…



Rolling motion produces sideslip
Rolling surfaces control sideslip

Design Process

- Implement E/F High AOA Architecture
- Adapt for A/B/C/D Architecture
- Tailor Gains to A/B/C/D Aerodynamics
- USN/Contractor Test Team Involvement
  - Integrated Test Team Philosophy
    - Team Members able to review all documentation

Program Constraints

- No hardware changes
  - FCC software changes ONLY
- No software changes to Mission Computer
- No changes to Air Data System
  - No modification to AOA Probes
  - No provision for Sideslip Probe

Program Challenges

- High Risk Flight Test
  - Intentional Out of Control Flight Maneuvers
    - Tailslides
    - Spins
    - Aggravated Inputs
  - Risk Mitigation
    - Extensive Simulations and Bench Tests
    - Spin Chute Study

Program Challenges

- No direct measurement of Sideslip
  - Must develop software to estimate Sideslip

- AOA Probe Range = -14° to 35° AOA
  - Need to estimate AOA above 35° degrees
    - AOA estimate required to generate the new feedback signals (Sideslip and Sideslip Rate)
    - Also needed to schedule gains at high AOA

Developmental Flight Test

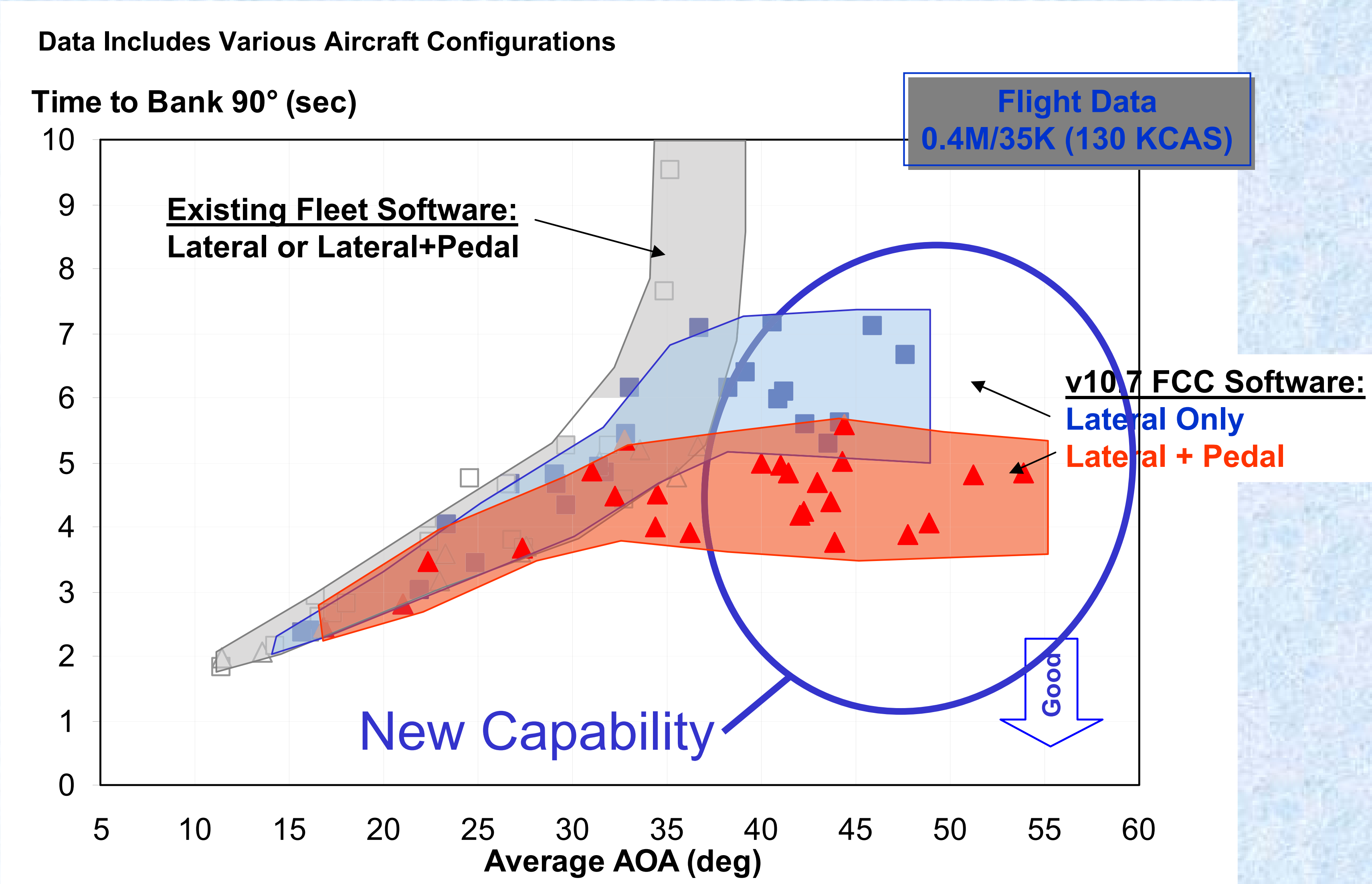
- 70 flights for 100 hrs
  - Used both two-seat and single-seat aircraft
- 8 external store loadings
- Approximately 600 test points
  - 400 Rolls
  - 48 Spins
  - 63 Tailslides
  - 1v1 Operational Maneuvering
  - Aggravated Control Inputs
  - Failure Modes

Recovery from Zero Airspeed Events

Recovery from Intentional Zero-Airspeed Tailslide

Old Control Laws	New Control Laws
	
Excessive Uncontrolled Motion	**Motion Not Excessive**

Roll Performance Enhancement



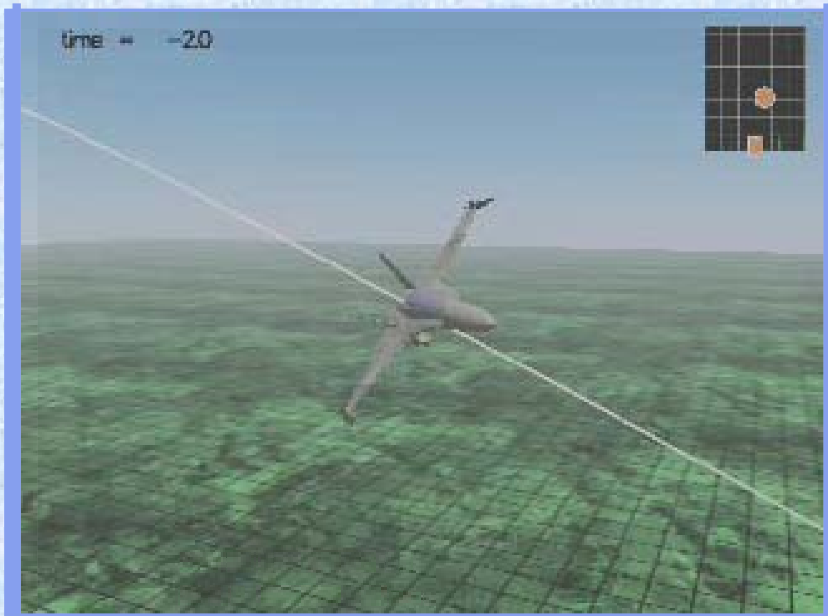
Improved Roll Performance at High AOA

0.4 Mach/35K

AOA = 35 deg.

Old Control Laws

Lateral Stick Only 2 Seat Clean



New Control Laws

Lateral Stick + Pedal 2 Seat +Cl Tank

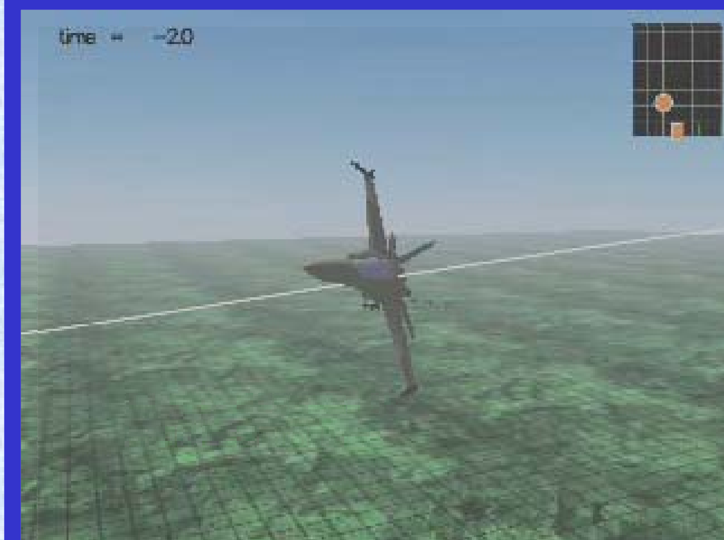
New Roll Capability at High AOA

0.4 Mach/35K

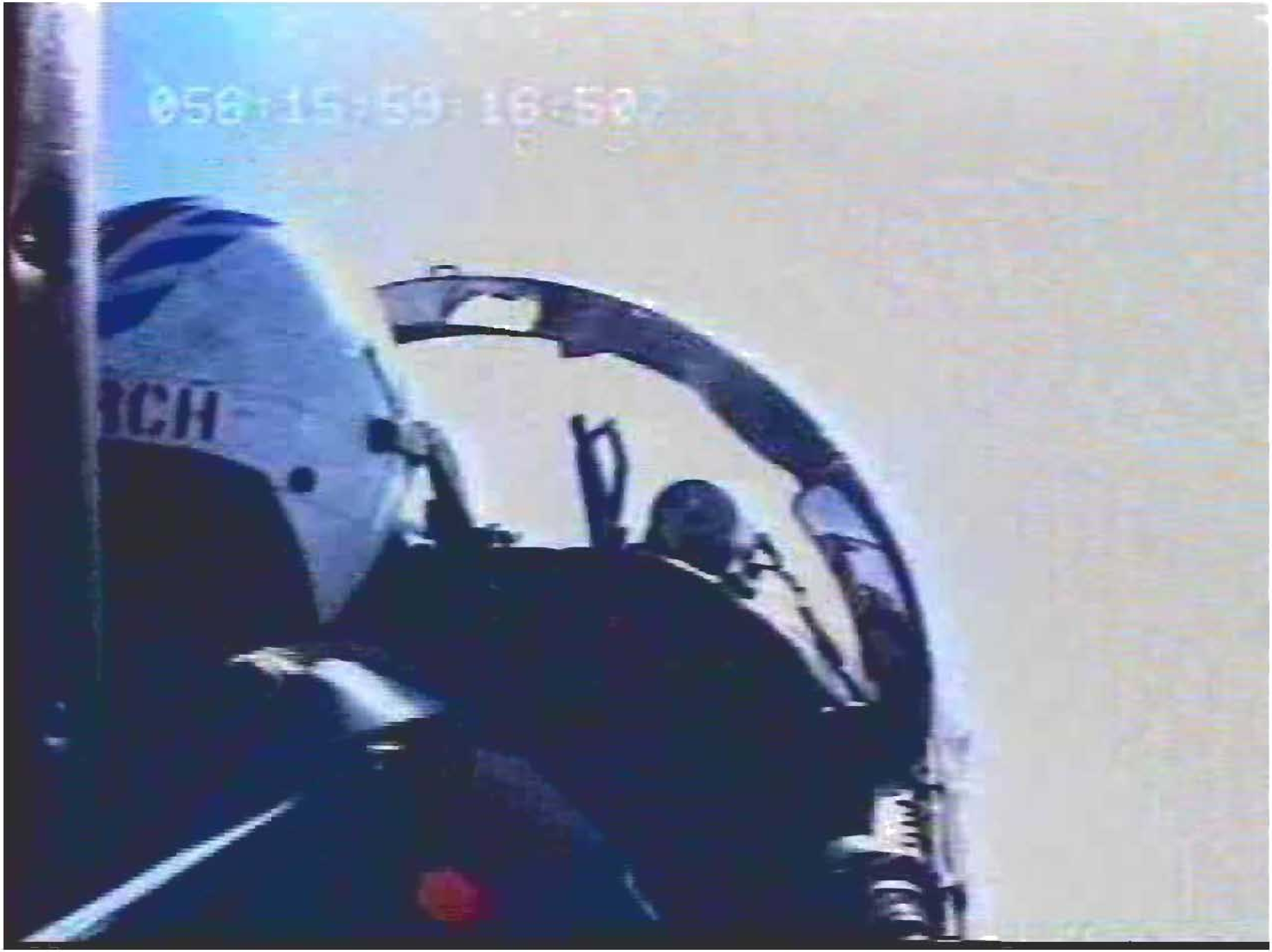
AOA=45 deg.

Lat Stick + Pedal **2 Seat Clean**

Lateral Stick + Pedal



2 Seat + C_L Tank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