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

Technology Opportunities & User Needs

- IOC: Initial Operational Capability
- FOC: Full Operational Capability

- Process entry at Milestones A, B, or C
- Entrance criteria met before entering phases
- Evolutionary Acquisition or Single Step to Full Capability

Concept & Tech Development
- Concept Exploration
- Technology Development

System Development & Demonstration
- System Integration
- System Demonstration
- Critical Design Review

LRIP
- Full-Rate Prod & Deployment
- FRP Decision Review

Production & Deployment
- Operations & Support
- Sustainment

Pre-Systems Acquisition
- Sustainment Disposal

Systems Acquisition
- (Demonstration, Engineering Development, LRIP & Production)

Initial Capabilities Document (ICD)

Capabilities Development Document (CDD)

Capabilities Production Document (CPD)

Validated & approved by operational validation authority

Relationship to Requirements Process
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

Critical Design Review

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

• **Purpose:** Integrate subsystems – reduce systems-level risk

• **Key Activities:**
  - 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
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

- **Falling Leaf Modes**
  - Upright
  - Inverted

- **Spin Modes**
  - Upright
  - Inverted
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 ($\beta$) 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

Vertical Recovery

Excessive Uncontrolled Motion

Motion Not Excessive
Roll Performance Enhancement

Data Includes Various Aircraft Configurations

Time to Bank 90° (sec)

Existing Fleet Software: Lateral or Lateral+Pedal

v10.7 FCC Software: Lateral Only
Lateral + Pedal

New Capability

Flight Data 0.4M/35K (130 KCAS)
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 +CI Tank
New Roll Capability at High AOA

0.4 Mach/35K

AOA=45 deg.

Lat Stick + Pedal  2 Seat Clean

Lateral Stick + Pedal

Lateral + Pedal 360 deg Roll
Target 0.4M/35K/AOA=45
SD120 FCC v10.6.1
Fighter Escort Loading

2 Seat + $C_L$ Tank