The Role of Controls and Dynamics Engineers During Software Development and Testing

Robert Clarke

April 29, 2015

NASA Armstrong Flight Research Center

Software Classification (NASA)

Governing Document: NASA Procedural Requirements 7150.2B NASA Software Engineering Requirements

NASA-Wide Software Classifications

Class A	**Human-Rated Space Software Systems**
Class B	**Non-Human Space-Rated Software Systems or Large-Scale Aeronautics Vehicles**
Class C	**Mission Support Software or Aeronautic Vehicles, or Major Engineering/Research Facility Software**

(e.g., Classes A through C are mostly software developed or acquired for Highly Specialized IT systems)

Class D	**Basic Science/Engineering Design and Research and Technology Software**
Class E	**Design Concept and Research and Technology Software**
Class F	**General Purpose Computing, Business and IT Software (Multi-Center or Multi-Program/Project)**
Class G	**General Purpose Computing, Business and IT Software (Single Center or Project)**
Class H	**General Purpose Desktop Software**

Notes: It is not uncommon for a project to contain multiple systems and subsystems having different software classes.

Software Classification (AFRC)

Governing Document: DPR-7150.2 Armstrong Software Engineering Requirements

- Software Classification (either Safety Critical “-S” or Non-Safety Critical)
  - Class I: Catastrophic
  - Class II: Critical
  - Class III: Minor (not applicable for Safety Critical Software)
  - Class IV: Negligible (not applicable for Safety Critical Software)
- Software Criticality (determined using a Preliminary Hazard Analysis preformed during the system architectural development)
  - Safety Critical: any condition, event, operation, process, equipment, or system that could cause or lead to severe injury, major damage, or mission failure if performed or built improperly, or allowed to remain uncorrected.
  - Non-Safety Critical: anything that is not Safety Critical
- Categories of requirements include the following:
  - **Compliance**
  - **Project formulation**
  - **Software life cycle**
  - **Software plans**
  - **Software requirements**
  - **Software design**
  - **Peer reviews/inspections**
  - **Software implementation**
  - **Software testing**
  - **Software verification and validation**
  - **Software configuration**
  - **Software measurement**
  - **Software operations, maintenance, and retirement**

What Are Verification and Validation? (… and how are they different?)

- V&V testing looks at the entire system, both software and hardware, as the system to be tested
- Verification
  - Proving that the system does exactly what it was designed to do
  - Follow the specification (even if that is not the right thing to do)
- Validation
  - Proving that the behavior of the system is acceptable
- Configuration control is a key element
  - Control the thing being tested, document all changes
  - Document results of all tests conducted
- Types of testing
  - Software-in-the-loop (SIL)
  - Brass-board-in-the-loop (BBIL)
  - Hardware-in-the-loop (HIL)
  - Iron-bird or airplane-in-the-loop (AIL)

Background

- X-29 - SIL, HIL, AIL (Class I-S – 1984-1992)

  – Low AOA and high AOA control law development & control law improvements
  – XAIDS ARINC 429 bus monitor, (2) 8 channel stripchart recorders, limited simulation recording capability
  – (2) RC engineers required during test (pilot and stripchart marker)
  – (2) RC engineers reviewed test data

- X-33 - SIL, BBIL, HIL (Class I-S – never flown)

  – Lab development only, program was ended before V&V testing was completed
  – Hardware 1553 bus monitors & extensive recording capability

- AAW - SIL, HIL, AIL (Class I-S – 2002-2005)

  – OBES, closed-loop control laws & control law improvements
  – Hardware 1553 bus monitors, extensive recording capability & simulated PCM stream with IADS for data monitoring
  – Initially (1) RC engineer required during test and (2) RC engineers for review
  – Changed to (3) RC engineers for test and real-time review (except for time history and frequency responses which required post test analysis)

X-29 No. 2 Software Testing Team/Schedule

- Team
  - Flight Systems
    - D. McBride, M. Earls, L. Ramey, J. Sitz, M. Thomson, and T. Vernon
  - Flight Controls
    - B. Clarke, F. Webster, J. Bauer, M. Brenner, J. Burken, and J. Ellinwood
  - Simulation Engineering and Tech Support
    - M. Pickett, D. Logan, and D. Simon
  - Pilots
    - S. Ishmael, D. Purifoy, R. Smith, and R. Wormer
- Schedule
  - BLK-IX-AA-00 (approximately 28 weeks for testing and reviewing data)
    - Started March 9, 1989 - Finished September 28, 1989
  - BLK-IX-AA-01 (approximately 5 weeks for testing and reviewing data)
    - Started February 22, 1990 - Finished March 27, 1990
  - BLK-IX-AA-02 (approximately 4 weeks for testing and reviewing data)
    - Started November 15, 1990 - Finished December 11, 1990

AAW Phase I Software Testing Team/Schedule

- Team
  - Flight Systems
    - J. Baca, M. Earls, P. Gonia, and T. Quach
  - Flight Controls
    - B. Clarke, M. Allen, R. Dibley, and B. Reed
  - Simulation Engineering and Tech Support
    - M. Pickett, G. Patterson, and L. Kelly
  - Pilots
    - D. Ewers & D. Purifoy
- Schedule
  - Phase I (approximately 30 weeks for testing and reviewing data and 8 weeks for fixing hardware)
    - Started November 27, 2001 - Stopped December 3, 2001
    - Fixed problems with simulation hardware
    - Re-started February 6, 2002 - Stopped March 14, 2002
    - Reviewed post-test data
    - Repeats July 22, 2002 - Finished September 12, 2002

AAW Phase II Software Testing Team/Schedule

- Team
  - Flight Systems
    - J. Baca, M. Earls, F. Reaux, T. Quach, and E. Becker
  - Flight Controls
    - B. Clarke, M. Allen, R. Dibley, J. Gera, J. Hodgkinson, C. Diebler, I. Anchondo, and A. Matuszeski
  - Simulation Engineering and Tech Support
    - M. Pickett, G. Patterson, and L. Kelly
  - Pilots
    - D. Ewers & D. Purifoy
- Schedule
  - Phase II (approximately 6 weeks for testing 4 weeks for fixing software)
    - Started August 11, 2004 - Stopped August 27, 2004
    - Fixed problem with transient free switches and rudder trim gain
    - Re-started October 4, 2004 - Finished November 5, 2004
  - Phase IIA (5 days)
    - Started March 18, 2005 (Friday) - Finished March 24, 2005 (Thursday)

Software Development Role

- Develop flight control system design
  - Normal control system (or backup)
    - Everything – “The whole enchilada”, ex. X-56A: J. Schaefer
    - New portion of the flight envelope (such as high angle of attack), ex. X-29 No. 2: R. Clarke/F. Webster
    - Limited scope update to existing control laws (usually to fix a problem or optimize the control response)
  - Specialized research control system
    - Research Flight Control System (RFCS) - may or may not be safety critical, ex. AAW: R. Dibley, et. al.
    - Quicker updates to the control laws typically allowed, especially if the control system is not safety critical

Software Testing Role

- Assist in the development of the test matrix
  - Help to choose the flight conditions for testing
  - Pick flight conditions that have been shown to have small margin(s) or would otherwise exhibit the most critical response(s)
  - Provide assessment of Failure Modes and Effects Test (FMET) test points and relationship to critical flight conditions
  - Assist in the development of piloted simulation test plans, execution, and data analysis

X-29 AIL Tests

National Aeronautics and
Space Administration
Ames Research Center
Dryden Flight Research Facility
P.O. Box 273
Edwards, California 93523-5000

NASA

Reply to Attn of:

REPLY: OFV/RC July 6, 1989

TO: OFF/X-29 Systems Engineer

FROM: OFV/X-29 Controls Engineer

SUBJECT: X-29 Number Two Block IX Ground Test Requirements

An informal meeting was held to discuss tests which should be performed using X-29 ship two airplane-in-the-loop simulation. The results of these discussions are summarized below:

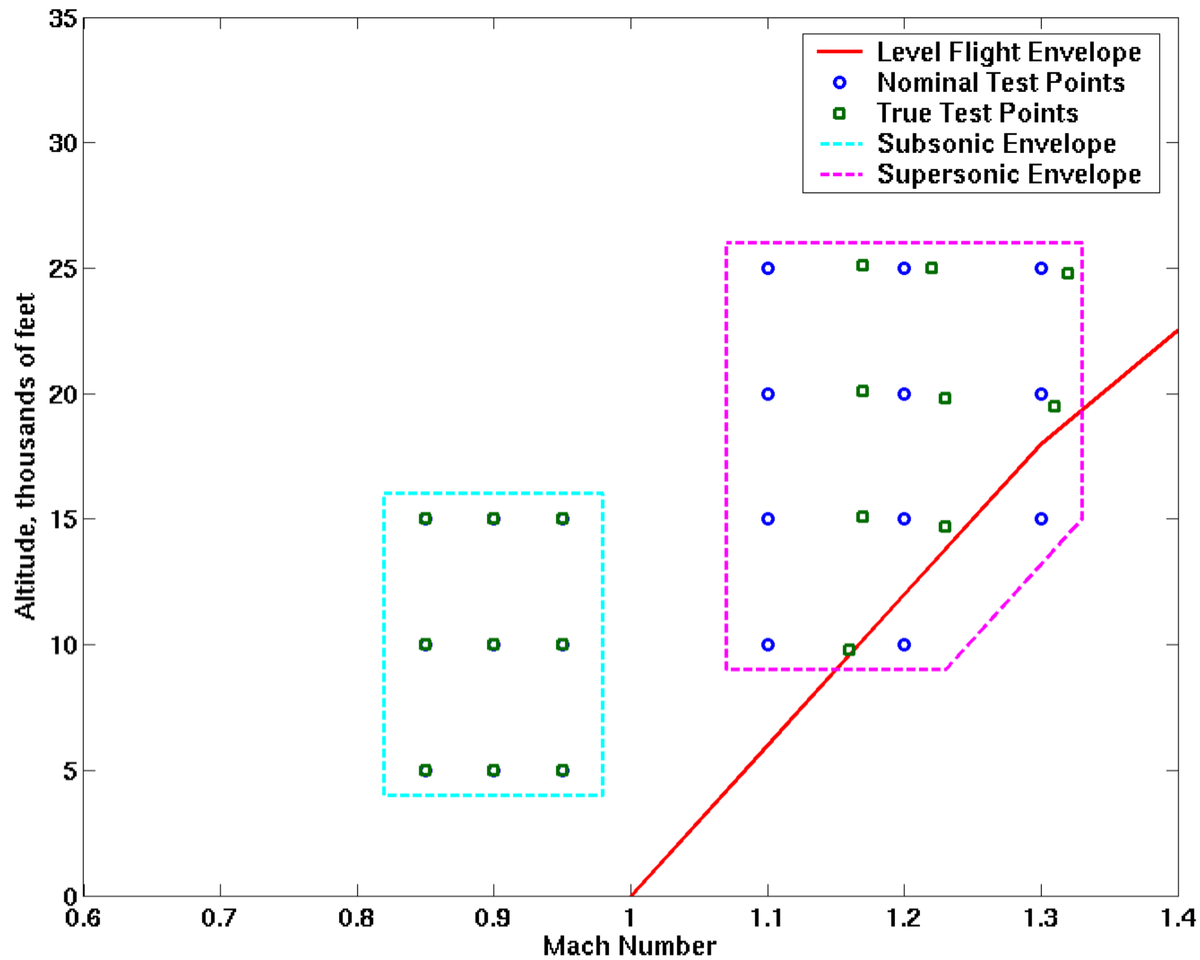
- SID steup and calibration – Hook the simulation to the airplane and calibrate the various systems. (2 or 3 days)
- Limit cycle tests – These tests should be simulated at low dynamic pressure and 1 gee straight and level condition. At most, two flight conditions should be checked (25 and 35 degrees angle-of-attack and 25,000 feet altitude). The tests should be conducted in all axes and should be run to 6 db or limit cycle to verify margins. These tests should also be conducted on the landing gear. These are the only type of vibration tests which are required to be run. No ground vibration tests using soft support systems are required by the Structural Dynamics Group. (1 day)
- Hydraulic model verification – This series of tests should verify flow rates under limited flow conditions of the combined and flight systems. It should also show system behavior under conditions of depleted accumulators. (3 days)
- Actuator frequency responses – Actuator frequency responses should be run. Analog breakout boxes and SID should both be used. Loaded vs. unloaded and small amplitude vs. large amplitude should be investigated. (1 day)
- Piloted simululation – Run some piloted simulation of spins, departures, and high angle-of-attack rolls. (1 day)
- Time history checks – Conduct time history against the hardware-in-the-loop and linear predictions. (1 day)
- Frequency response checks – Conduct open and closed checks against hardware-in-the-loop and linear predictions. (3 days)
- Test spin lights and frequency response of the α vanes – These tests would be used as filler to be run when the computer system is down due to problems. (no additional time)

Robert Clarke

Robert Clarke

cc: Mike Earls
Mike Thompson
Marlin Pickett
Todd Vernon
Jeff Bauer
Marty Brenner
John Burken

AAW Design Test Points



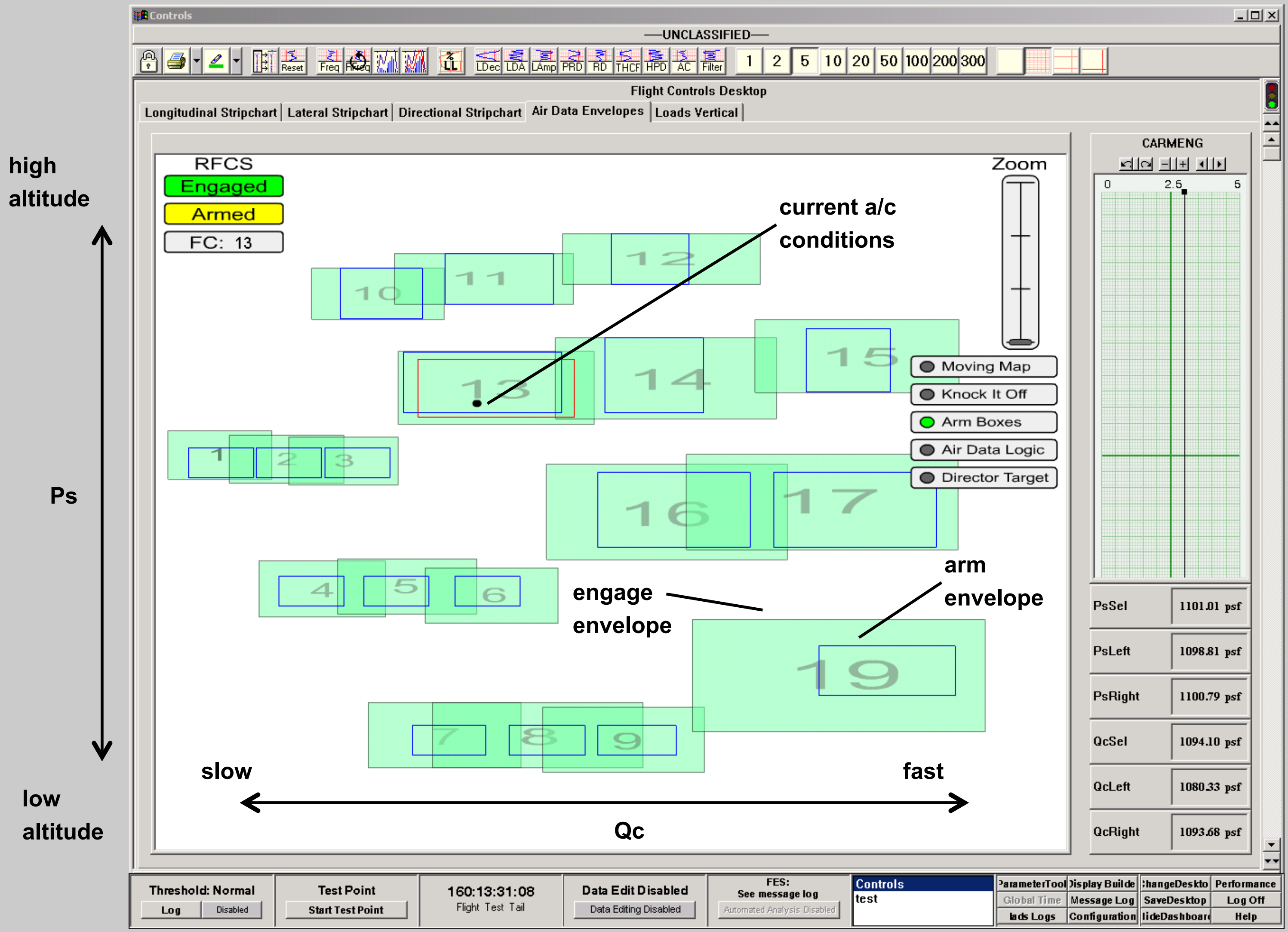
Software Testing Role

- Assist in verification testing (particularly for the control law parts of the system)
  - Verified the AAW Control Law Design Description (CLDD) text against the CLDD block diagrams
  - Verified Matrix-X block diagrams against the AAW CLDD block diagrams
  - Verified that each control system Configuration Change Request (CCR) had been implemented
  - Participate in AAW code walk-thru of the Phase II Matrix-X autocoded Ada control laws (comparison against CLDD)
  - Documented in a Code Inspection Issue log

Software Testing Role

- Assist in development of analysis tools (if new ones are needed)
  - Modified generic linearizer to work on X-29 project (X-29 1983)
  - Incorporated FFT and getData I/O routines into Fortran "Classic" **MATLAB** to compute frequency response from simulation data files (X-29 1988)
  - Built stand-alone program, called "getdiff", to compare getData files (X-33 1997)
  - Built **MATLAB** routines to decode 1553 bus messages (AAW 2001)
  - Incorporated IADS displays into sim lab and developed special displays (AAW 2004)

AAW Phase II RFCS Envelopes



Software Testing Role (Continued)

- Assist in assessment of the fidelity of the aircraft simulation(s) and help make improvements
  - Assess the fidelity of individual simulation model(s)
    - Compare with hardware test data (if available)
    - Compare with independent models
  - Assist in the development of higher fidelity model(s) as required
    - Provide actual code or block diagram implementation
    - Provide check cases
    - Provide model dispersion data (if required)
    - Review check case comparisons and sign STR's

Simulation Model Assess/Update/Test

- X-29
  - Flight control system
  - Actuators - hydraulic system
  - Sensors - air data
  - Miscellaneous - mass properties & inlet ram drag
- X-33
  - Flight control system
  - Actuators - EMA & pneumatic
  - Miscellaneous - gravity, geodetic, mass properties, landing gear model
- AAW
  - Flight control system
  - Actuators - hinge moments
  - Sensors - air data probes
  - Miscellaneous - air data computer, aerodynamic model

Software Testing Role (Continued)

- Compare time history and frequency response data (verification testing)
  - Generate the independent data (usually from MATLAB or Matrix-X)
  - Collect the hardware-in-the-loop simulation data and plot along with simulation results
  - Review and interpret results
  - Provide assessment in writing of the results

Software Testing Role (Continued)

- Provide the piloting function during all aspects of testing (validation testing)
  - This allows the systems engineer to concentrate on verification of the proper test results
  - It provides the flight controls engineer an opportunity to see first-hand the airplane response (from the pilot's point of view)
  - The flight controls engineer shall assess the airplane response and validate that the response is proper and correct
    - Subjective assessment
    - Look for things that don't "feel right"
    - Write DR's as required if problems are found in the simulation
  - Recognize limits on piloting ability and call in "real pilots" as required
  - Provide assessment in writing of significant deviations from the "expected response"

Software Testing Role (Continued)

- Assist in fixing problems in the FCS as required
  - Discover
  - Understand
  - Design
  - Analyze
  - Implement (This one is done by the flight systems engineers!)
  - Test

Software Testing Role (Continued)

- Sign off on individual V&V STR's
  - Is the airplane "Safe to Fly" with the Flying Qualities (not Handling Qualities) that have been seen in the simulation?
  - Have new Hazards been identified? Are any of the hazards worse than previously thought?
  - Are piloting aids (LSPI), warning indications (aural tone), and procedures adequate?
  - Are additional ones needed or does the design require changes?

X-29 System Test Report and Test Procedures

NASA National Aeronautics and Space Administration
Ames Research Center
Dryden Flight Research Facility

SYSTEM TEST REPORT

PROJECT	TITLE	DATE	STR NO.
X-29 #2	FMET: PITCH RATE GYRO FAILURES		S F - 1

ORIGINATOR/ORG	RELEASE	SYSTEM CONFIGURATION
M. R. Earls/OFF	See Remarks	H/W-In-Loop Simulation

OBJECTIVE	CCR NO. (REF.)	D.R. NO. (REF.)	PCN NO. (REF.)	WORK ORDER NO.

To observe the effect of pitch rate gyro failures on the system performance and flying qualities of the aircraft.

CONT'D ON PAGE

TEST SETUP

SEE CONTINUATION PAGES

CONT'D ON PAGE

SUMMARY RESULTS

Negligible transients.

(concur)

CONT'D ON PAGE

CONCLUSIONS

No problems.

Robt Clarke (concur) 9/19/89

SIG: Martin J Brenner DATE: 4/18/89

CONT'D ON PAGE

REVIEWED BY:	DATE:	RETEST REQUIRED	YES	NO
Robt Clarke	9/19/89			X

REMARKS

DR ISSUED: YES	DR ISSUED: NO	DR NO.:	DR DATE:

FCC
IOP: BLK-IX-IOP-AA-00+PATCH 0 0 $C00,$C01 A583,1B53
CLP: BLK-IX-CLP-AA-00 $C00,$C01 965F,A454

SIMULATION RELEASE: CFH000~~38~~ 39, 41
XAIDS VERSION: 05 SEP 85

REFERENCES:
NASA S/W Spec. X-89-003
HONEYWELL Spec. DS-32443-01

CCB OFFICIAL:	DATE:	CCB OFFICIAL:	DATE:

ADFRF STR FORM (8/26/87)

March 2, 1989

SYSTEM TEST REPORT

Page 2

FMET-SF1

Rerun 5/8 CFH00041

1. Trim the aircraft for level flight at 0.59/5000 ft., gear up, ACC, Digital Normal mode (switch to center).
   a. Perform a 2-G turn
   b. Fail Ch A primary pitch gyro to +10 volts (SIBLINC 07)* — *FAILED TO -10 VOLTS
   c. Observe FS/CP SENSOR A light on ✓ ✓
   d. Remain in 2-G turn
   e. Fail Ch A backup pitch gyro to +10 volts (SIBLINC 08)*
   f. Observe FS/CP SENSOR A and AR A lights on ✓ ✓
   g. Reset

2. Trim the aircraft for level flight at 0.95/20K, gear up, ACC, AR mode, UA gains
   a. Perform a 2-G turn
   b. Fail Ch B backup pitch gyro to +10 volts (SIBLINC 10)
   c. Observe FS/CP SENSOR B and AR B lights on ✓ ✓
   d. Reset

3. Trim the aircraft for level flight at 0.95/20K, gear up, ACC, Normal mode (switch to center).
   a. Perform a 2-G turn
   b. Fail the Ch B primary pitch gyro to +10 volts (SIBLINC 09)
   c. Observe FS/CP SENSOR B light on ✓ ✓
   d. Continue 2-G turn
   e. Fail Ch B backup pitch gyro to +10 volts (SIBLINC 10)
   f. Observe FS/CP SENSOR B and AR B lights on ✓ ✓
   g. Continue 2-G turn
   h. Fail the Ch C primary pitch gyro to +10 volts (SIBLINC 11)
   i. Observe FS/CP SENSOR A, SENSOR B, SENSOR C, AR B lights on ✓ ✓
   j. Reset

4. Trim the aircraft for level flight at 0.25/1250 ft., gear up, ACC, Digital Normal mode (switch to center) RAV to ADI needles engaged.
   a. Perform a normal approach
   b. Fail Ch C primary pitch gyro to +10 volts (SIBLINC 11)
   c. Observe FS/CP SENSOR C light on ✓ ✓
   d. Remain in normal approach
   e. Fail Ch C backup pitch gyro to +10 volts (SIBLINC 12)

AAW System Test Report and Test Procedures

National Aeronautics and Space Administration

Dryden Flight Research Center

System Test Report

Project: AAW Phase IIA		Date: 3/18/2005	STR No: FM-17.5.2.1-1
Title: Quad Sensor Failures at Flight Conditions 6, 14, 15 and 17			
Originator/Org.: Thang Quach / RF	Release: RFCS 4.1.3, 4.1.4, 4.1.5	System Configuration: F/A-18 HILS	C.I.: 2B
CCR No.: (Ref) N/A	DR No.: (Ref) N/A	PCN No.: (Ref) N/A	Work Order No.: N/A

Objective:
Conduct small subset of HILS FMET at flight conditions where gains were modified in RFCS Version 4.1.3

Cont'd on page:

Test Setup:
See attached procedure: FMET-17.5.2.1-1

Cont'd on page:

Summary Results: TESTED ON V4.1.3

Cont'd on page:

Conclusions: no transients noted safe to fly

Cont'd on page:

Signature:	Date: 3/28/05
Reviewed By:	Date: 3-28/05

DR Issued ☐ Yes ☒ No	Retest Required ☐ Yes ☒ No	DR No.:	DR Date:

Remarks:

CCB Official:	Date:	CCB Official:	Date:

DFRC 11 (05/2002) Page 1 of 2 Previous versions are obsolete.

PROJECT	TITLE	DATE	STR NO.
AAW	FMET: Quad Sensor Failures @ Gain Index 6	June 29, 2004	FMET-17.5.2.1.6

Test Setup (Continued from STR cover sheet)

Note: to perform all steps under one script, run script /sim/aaw/PII_Scripts/FMET/Quad_Sensors/17.5.2.1.6

1. Perform or verify AAW Simulation Start-Up Procedure (Required only at simulation start-up).
2. Single yaw rate hardover failure with RFCS Armed. Verify RFCS disengages. (ID 17.5.40.1.1)
   - A. (Run script /sim/aaw/PII_Scripts/FMET/Quad_Sensors/17.5.2.1.6s2)
   - B. At note display,
     1. Verify gain index = 6
     2. Arm RFCS
     3. Trim throttles
   - C. Depress Pause Script button to go to operate, start recording and insert failure at time two seconds
   - D. Fly straight and level
     1. After approximately 2 seconds verify the following failure indications
        - Yaw CAS "X" - Channel 1 ✓
        - BLIN 424 - Channel 1 ✓
        - BLIN 440 - Channel 1 (not required) ✓
        - RFCS disengages (de-arms) ✓
        - M17, W31 (Not Arm Reasons) indicates Quad Sensor Failure ✓
   - E. Depress Pause Script button to reset the sim, and remove and clear FCS failures

NOTES: O/C

	COMPLETED BY:	DATE:
Test Conductor	TQ	3/18/05
Test Director		

3. Dual hardover pitch rate failures while RFCS Engaged. Verify RFCS disengage. (ID 17.5.40.1.2)
   - A. (Run script /sim/aaw/PII_Scripts/FMET/Quad_Sensors/17.5.2.1.6s3)
   - B. At note display,
     1. Verify gain index = 6
     2. Arm and Engage RFCS
     3. Trim throttles
   - C. Depress Pause Script button to go to operate, start recording and insert failures at times five and ten seconds

2

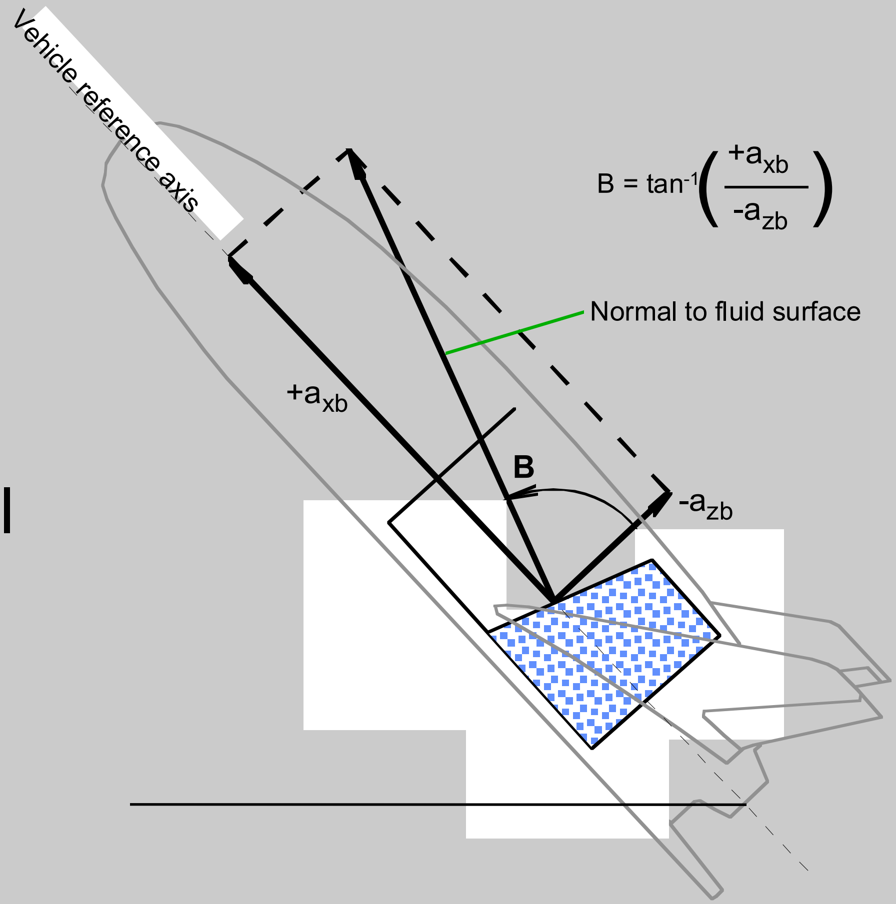
3

Story Time

- Some examples of simulation model updates
  - X-33 mass properties model
  - AAW aerodynamic model update
- Some examples of problems found in previous tests
  - Undetected dual null roll-rate gyro failure leading to loss of control (X-29)
  - Air data within tolerance failures leading to control system instability (X-29)
  - Data anomalies in HIL (F/A-18 AAW)
  - Aerodynamic instability due to highly nonlinear pitching moment (F/A-18 AAW)
  - Not so transient free switches (F/A-18 AAW)

X-33 Mass Properties Model

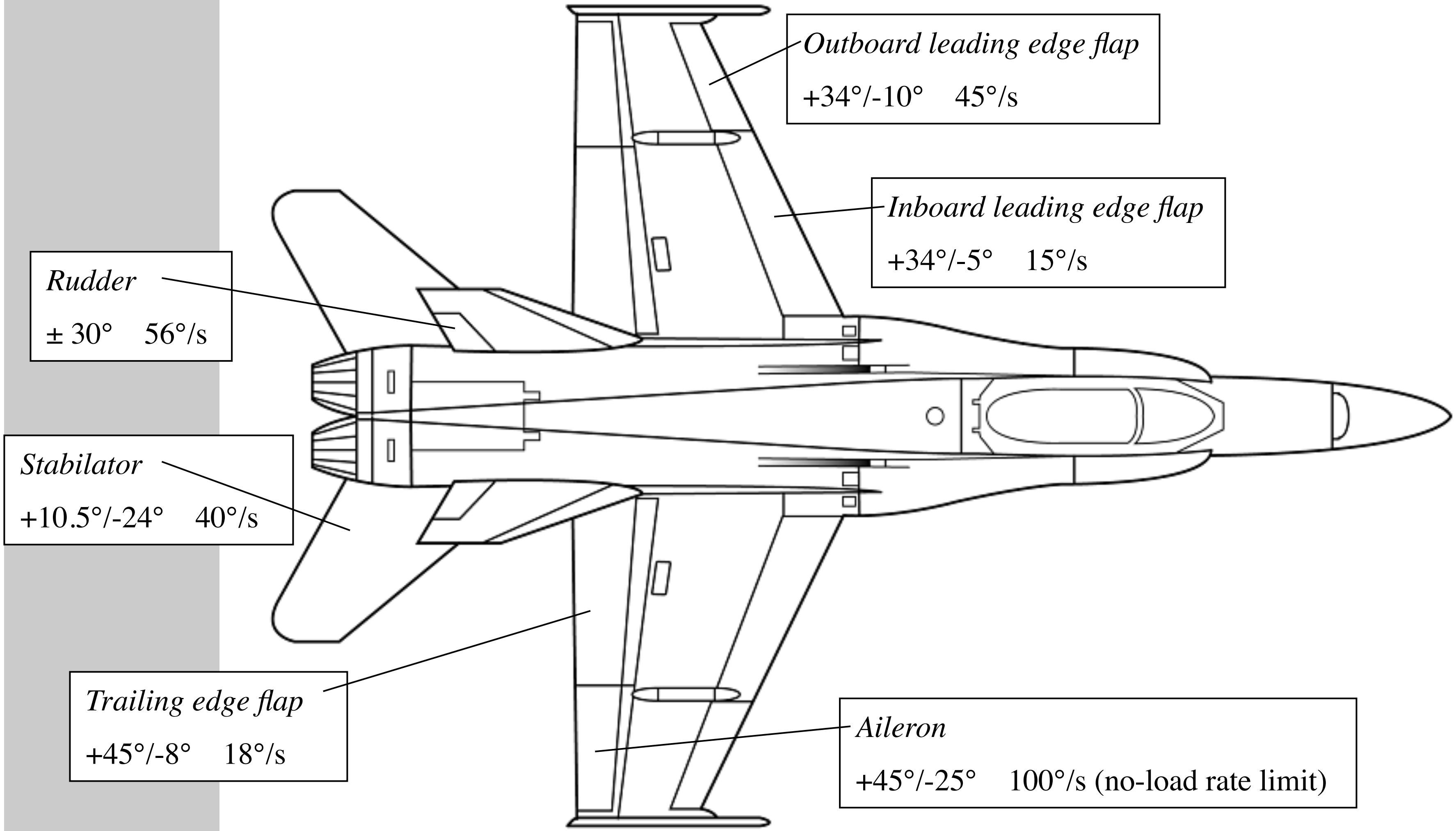
- Tank designers (Structures) provided model in terms of pitch and roll attitude
- Needed to translate from static attitude based model to dynamic acceleration based model
- Model did not include slosh dynamics



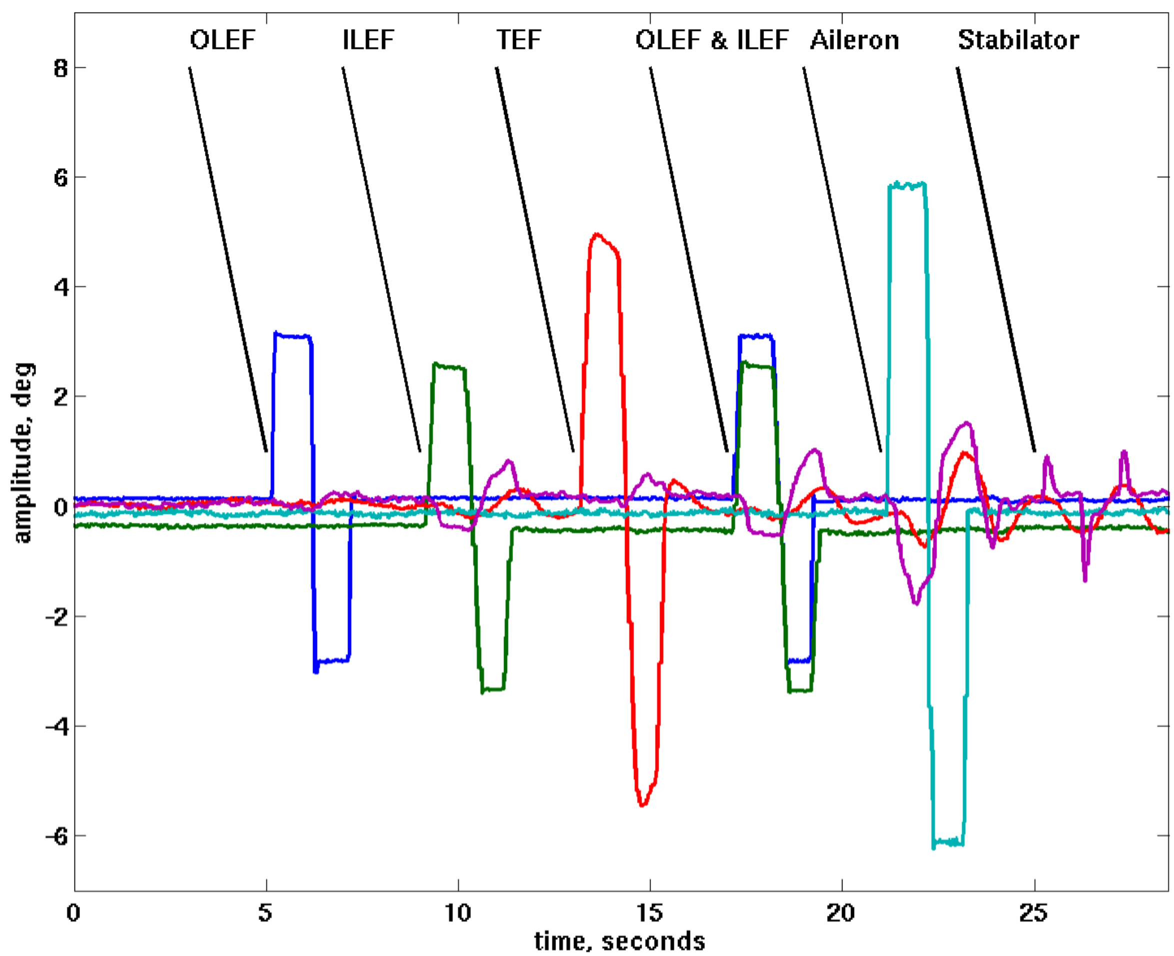
AAW Aerodynamic Model Update

- AAW aerodynamics needed to be updated at the 18 flight conditions which would be tested with new control law designs
  – In-flight PID results showed substantial error in some aero coefficients when compared with Boeing baseline
  – Needed aero model update for control law design, not just for a report
  – Needed simulation to match small PID inputs and larger amplitude maneuvers
  – Previous SRA aero model update (Phase 0) used only small PID maneuvers and utilized CPT measurements of control surface positions
  – As part of Phase II activity an AAW Aerodynamic Model Sensitivity Analysis/Failure Analysis report was produced examining the NASA design using Monte Carlo methods

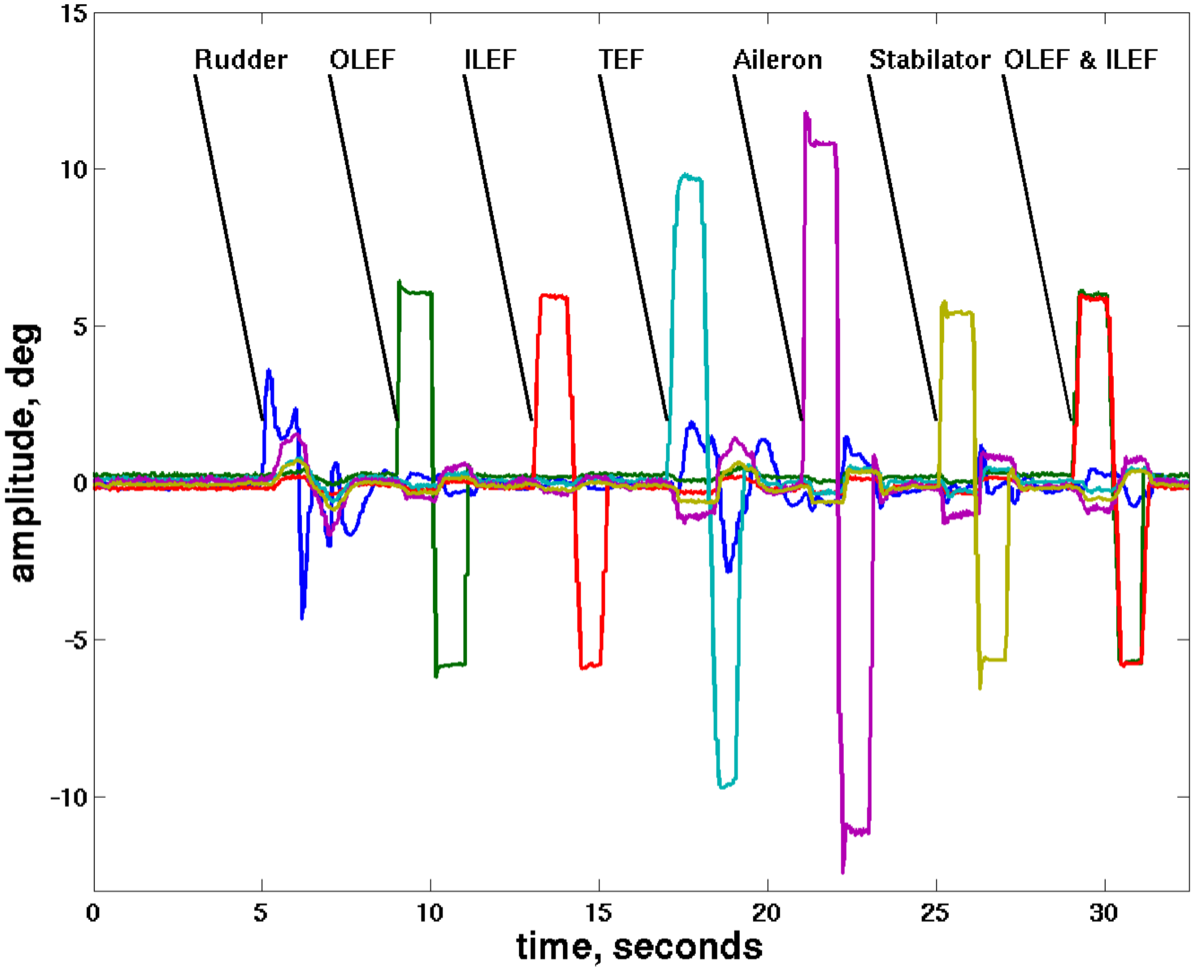
F/A-18 AAW Control Surfaces



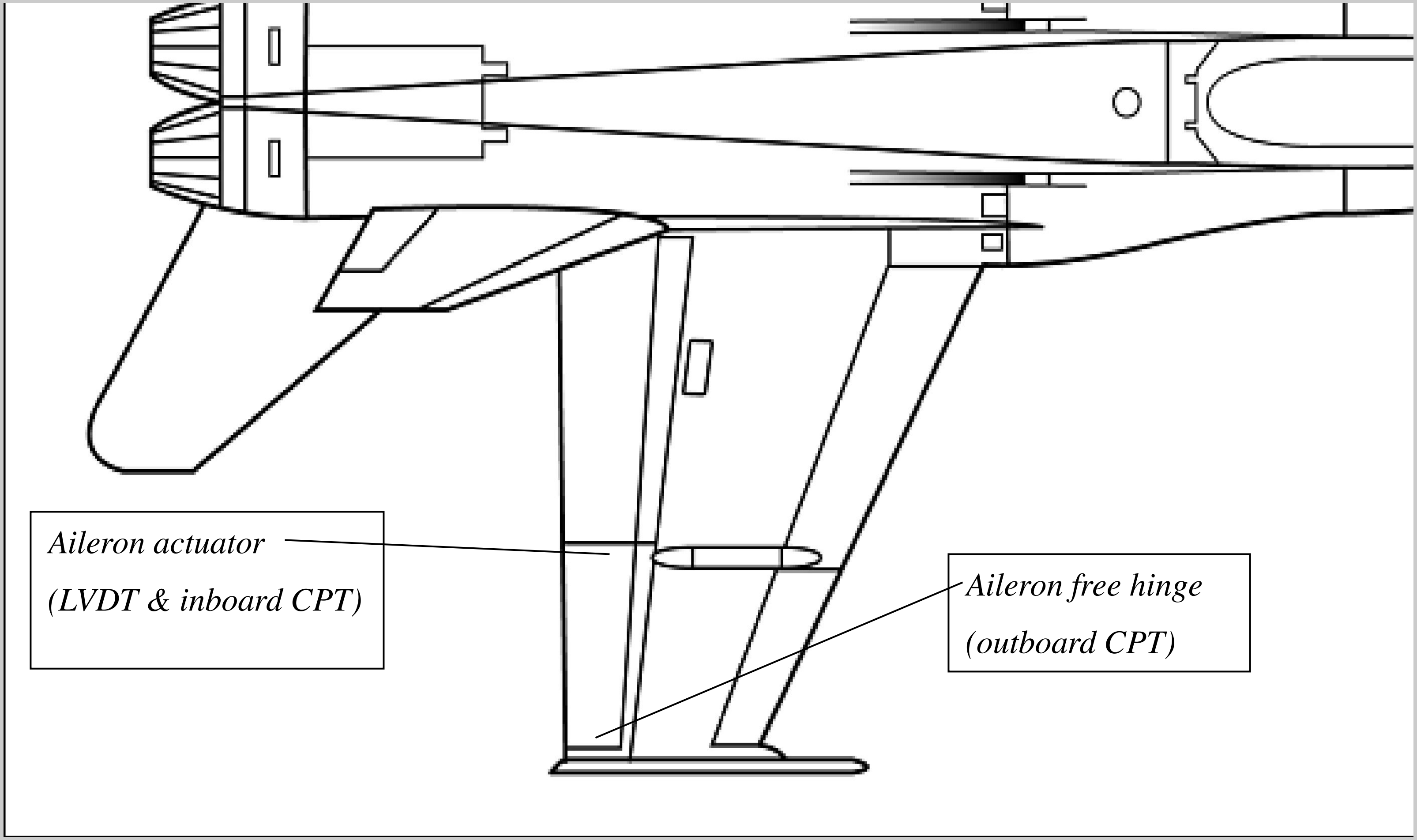
AAW OBES Pitch Doublets



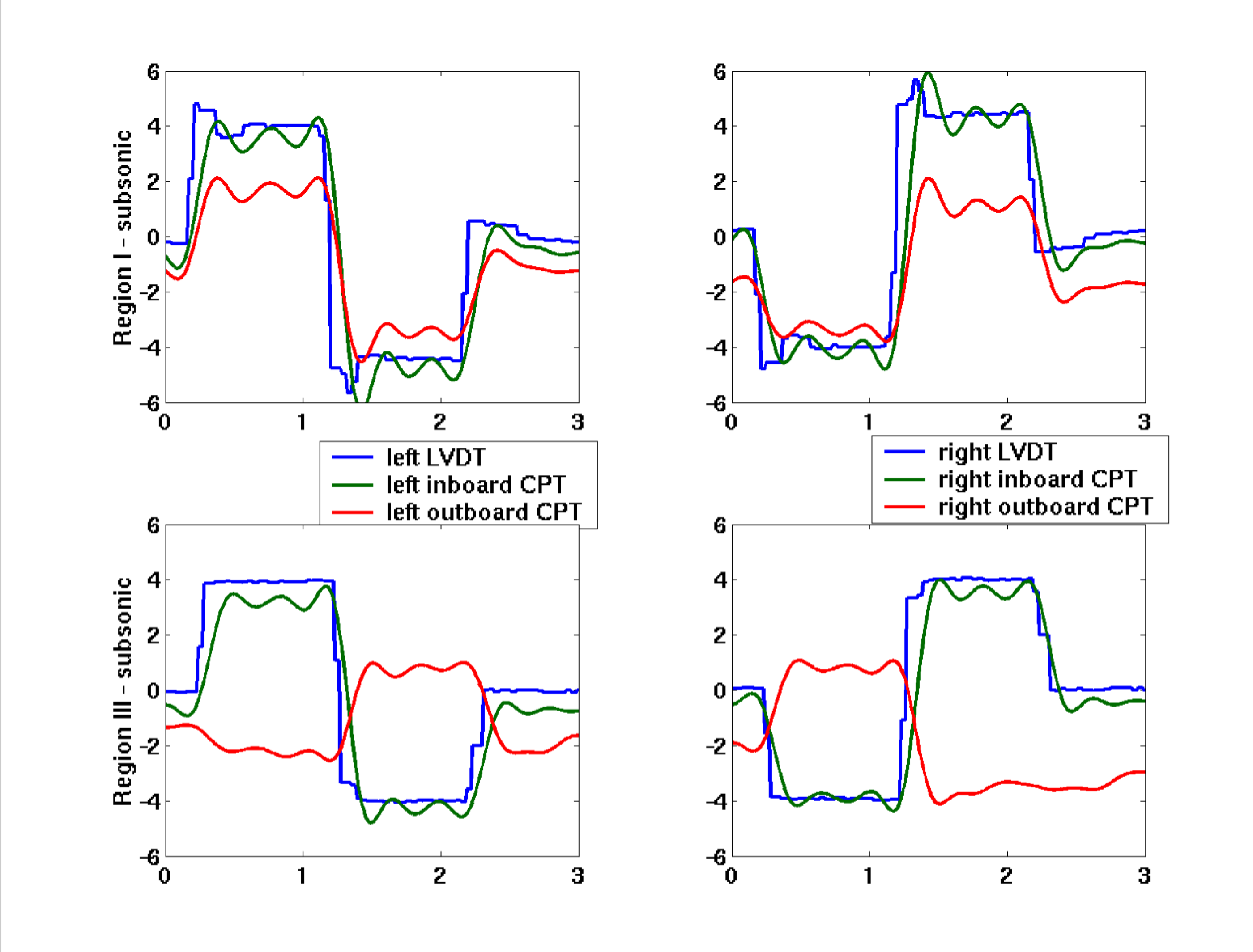
AAW OBES Roll Doublets



AAW Aileron Details



AAW Aileron Flexibility



X-29 Undetected Dual Null Roll Rate Gyro Failure Leading to Loss of Control

- RF engineer identified that dual roll rate gyros failed to null results in loss of roll rate feedback resulting in unacceptable roll PIO (1984)
- Carried as a Cat I/D hazard by the X-29 program until July 1990 when the project desired to fly to the Dayton and Oshkosh airshows for static display (flight without control room monitoring)
- In-flight incident with failed roll rate gyro was still on everyone's mind (so no pushback on the probability estimate of the hazard would be allowed)
- Severity had to be reduced or airshows were out

What We Discovered

- The problem was caused by loss of roll rate feedback and the forward-loop integrator (With no feedback, pilot control changes from rate command to acceleration command!)
- Once this was known, a fix was possible (using only procedures)
  - Pilot could recognize the problem with (3) sensor lights, (3) AR lights, degraded normal indications, and horrible flying qualities in the roll axis
  - Without roll rate feedback the AHRS analytic monitor would not track and AHRS would be failed
    - Without AHRS speed stability will no longer engage
    - No speed stability will affect the landing, but simulation still showed 15 knot crosswind was still no problem
  - Pilot needed to select TW 9 and get his airspeed below 300 knots
  - Get wings level and stay out of the loop until airspeed dropped below 300, where the forward-loop integrator drops out
  - At that point the control reverts to rate command again

X-29 Cockpit (Ship No. 2)

Degraded Normal Indication

(3) AR lights

(3) Sensor lights

Select TW 9

X-29 Air Data Within Tolerance Failures and Control System Instability

NASA National Aeronautics and Space Administration
Ames Research Center
Dryden Flight Research Facility

DISCREPANCY REPORT (DR
SOFTWARE/HARDWARE CONTROL MANAGEMENT

PROJECT: X-29A	ORIGINATOR/ORG: JOEL SITZ / HI	SITE: HARDWARE-IN LOOP SIMULATION	DATE & TIME OF DISC 07/27/88 9:00PM	DR. NO. 283

☒ VEHICLE ☐ CONTROL ROOM ☒ SIMULATION ☐ OTHER	A/C FACILITY:	A/C S/N:	FLT NO OR TEST NO(S)	CRITICALITY 1	ASSIGNED TO: R. Clark
	OTHER	PART NAME BLK-VIII-AD&AE	PART NO	SERIAL NO	CI NO. (SYSTEM): 3

TITLE: SINGLE POINT AIRDATA FAILURE

DISCREPANCY:

DURING V&V TESTING OF THE NEW BLK-VIII-AE SOFTWARE RELEASE A SINGLE FAILURE TO NULL OF THE DIGITAL QC INPUT (HADS) RESULTED IN LOSS OF CONTROL OF AIRCRAFT. THE V&V TEST BEING RUN AT TIME OF FAILURE WAS SF 10,11,12 AT .6/15K. THE SAME FAILURE OCCURRED WITH THE BLK-VIII-AD RELEASE. THE .6/15K WAS A NEW STEP ADDED TO TEST GAIN CHANGES FOR BLK-VIII-AE.

SIG: Joel Sitz DATE: 8/1/88

DISPOSITION

CAUSE: Longitudinal gain was too high because of within tolerance air data failure. Too large of a feedback gain degraded the stability margins until an instability resulted in loss of control of the airplane

SIG: Robert Clark DATE: 9/19/88

REQUIRED FIX: (WORK-AROUND:)

Tolerances on air data failures and biases on the side probe systems have been changed to assure stability. Significant linear and nonlinear analysis have been done to examine the stability margins

SIG: Robert Clark DATE: 9/19/88

CLOSING ACTION:

Closed by STR 396

WORK ORDER:	PCN NO.: 58-2054
CCR NO.: 446	STR NO.: 396

TESTED BY: DATE: WITNESSED BY: DATE:

CCB OFFICIAL: D P Kux DATE: 9/30/88 CCB OFFICIAL: DATE:

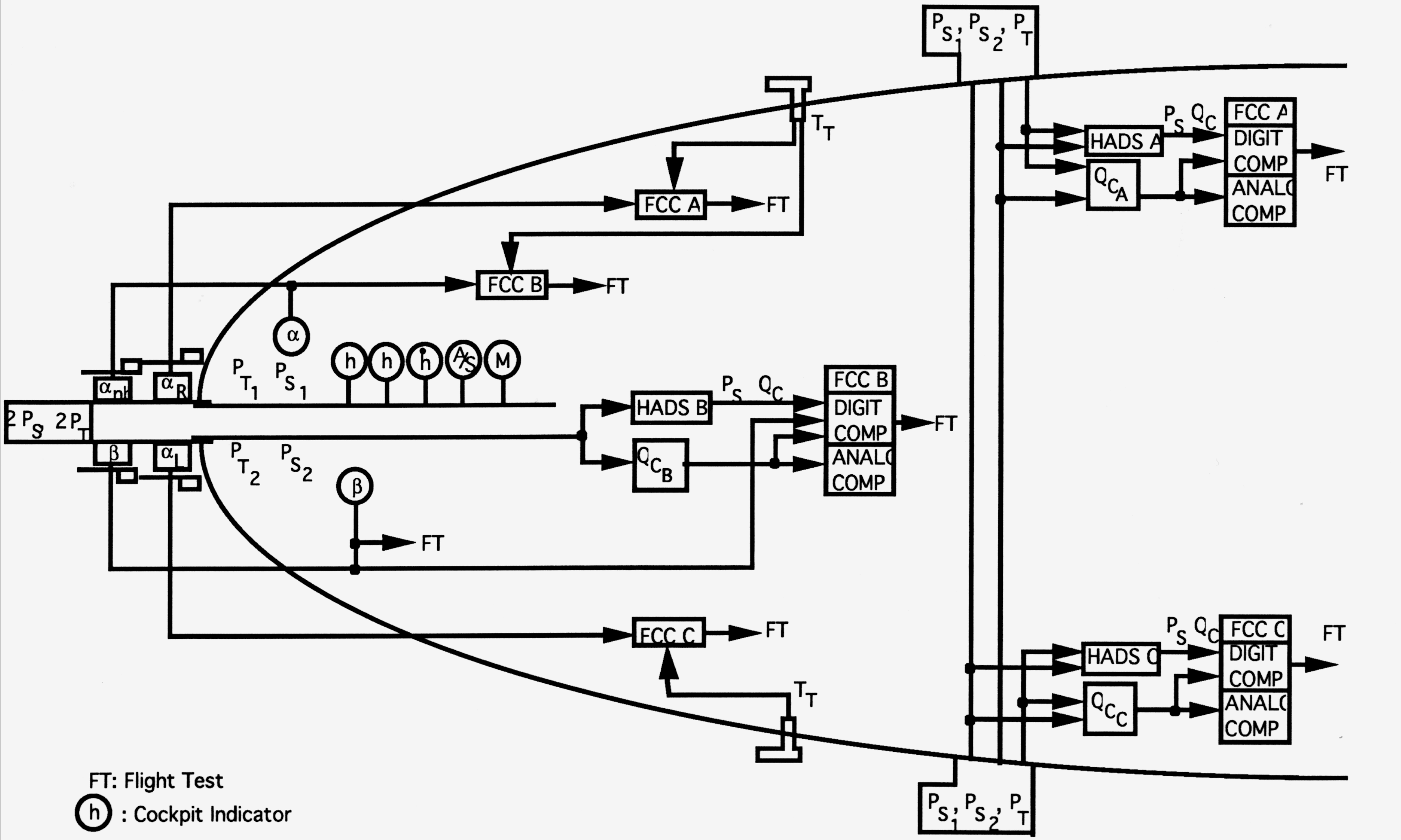
DFRF DR FORM (8/27/87)

X-29 Air Data Within Tolerance Failures and Control System Instability

Chronology

- July 11, 1984 - DR002
  - Undetected null second P_T fail caused limit cycle at 0.59/5K. Trip level 9.8 in.Hg.
- October 1984
  - Changed trip level to 5.0 in.Hg. and the system passed the tests
- December 14, 1984 - First flight
- February 1986 - CCR148 (Flight 38)
  - Large sideprobe errors, $f(M,\alpha,\beta)$, caused selection of sideprobes for gain scheduling which resulted in reduced transonic stability margins
  - Logic was changed to compare the noseboom against the selected mid value and choose the noseboom value if it was "ok" (within tolerance of this mid value), otherwise use an average of the sideprobes
- July 27, 1988 - DR283
  - Single failure to null of noseboom air data causes loss of control
- August 17, 1988 - CCR446
  - Add bias of 1.5 in.Hg. To sideprobe corrected measurements of P_T
  - Change P_S trip level to 1.5 in.Hg. (from 2.5 in.Hg.)
  - Change P_T trip level to 2.0 in.Hg. (from 5.0 in.Hg.)

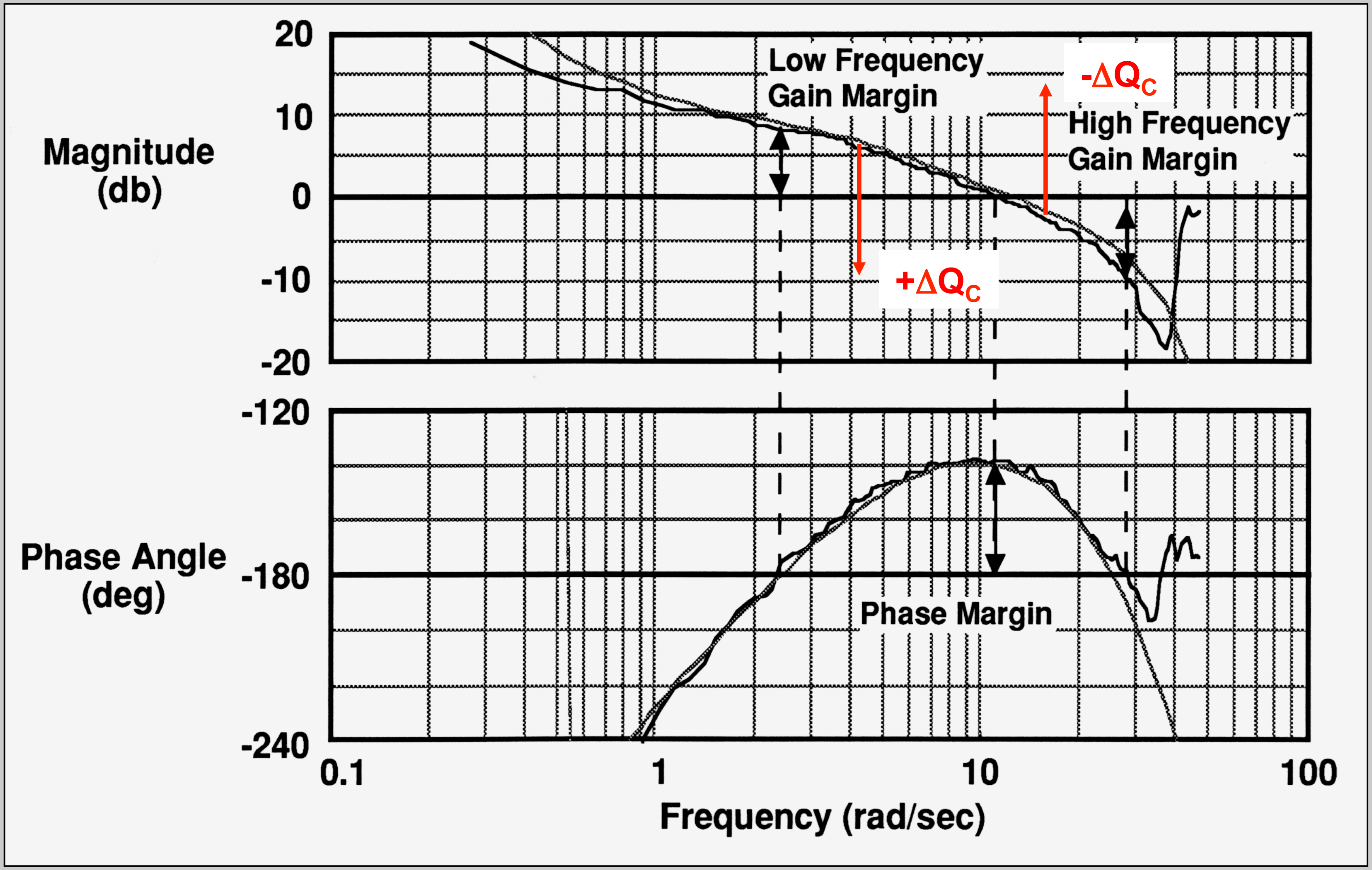
X-29 Air Data Configuration



FT: Flight Test

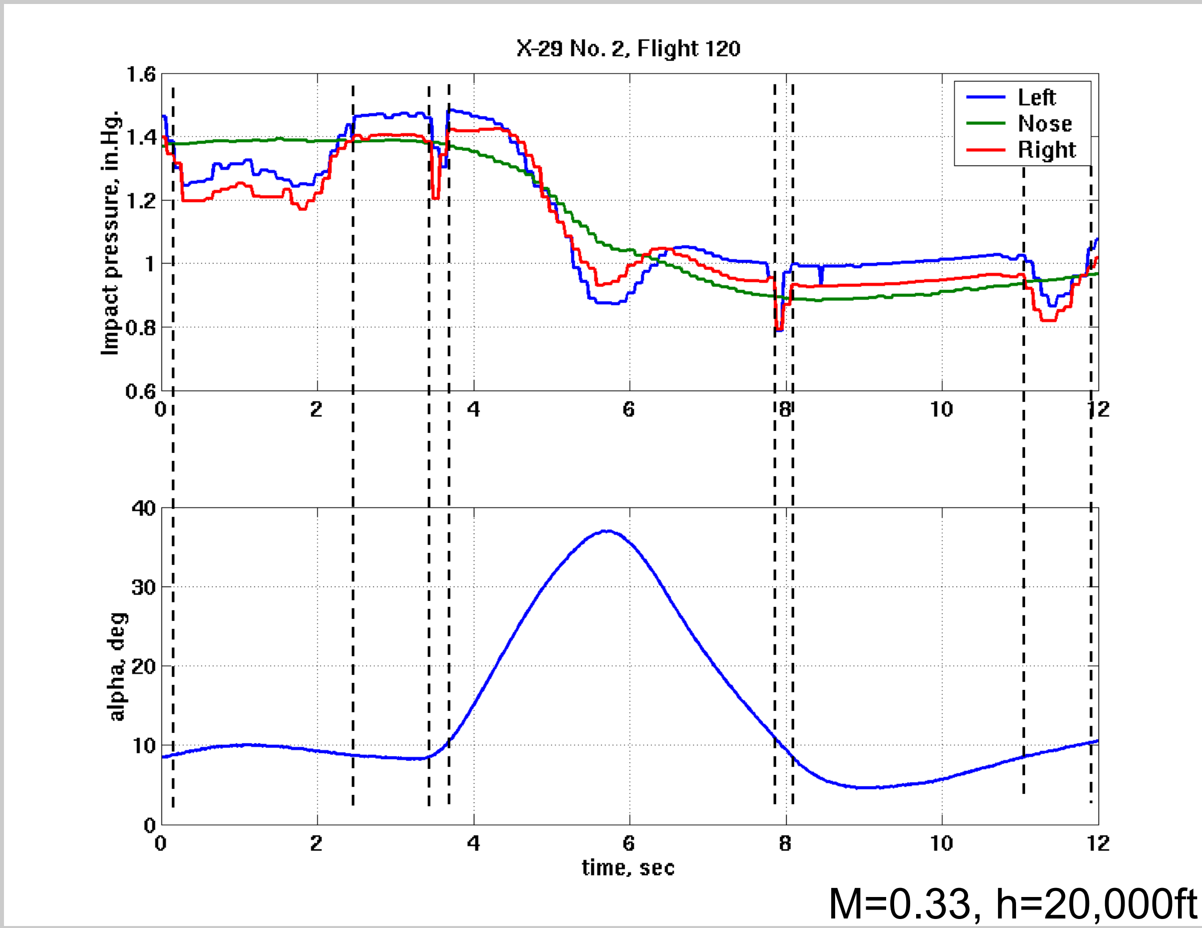
(h) : Cockpit Indicator

X-29 Typical Pitch Axis Bode Plot

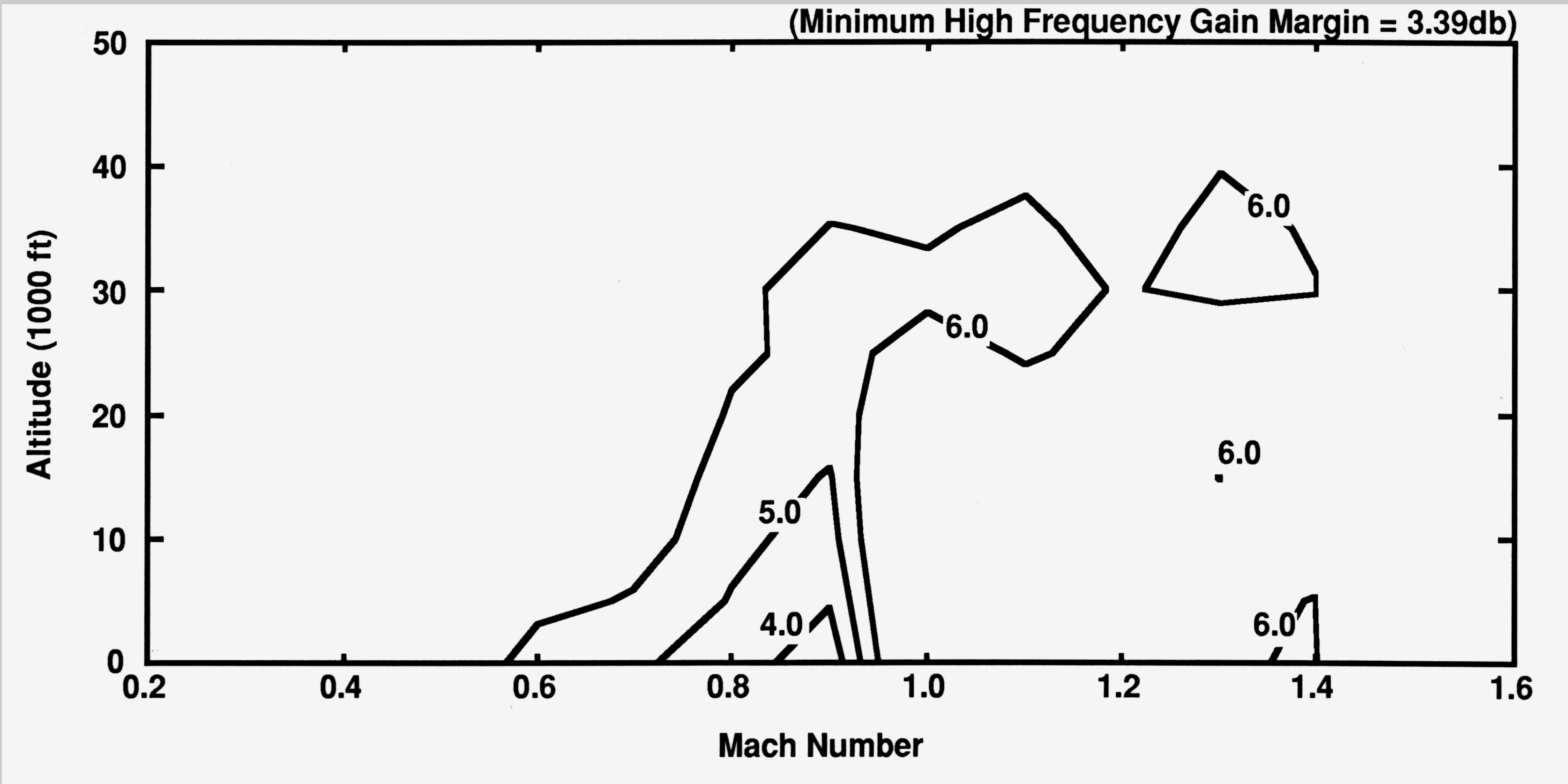


X-29 Flight Test Data

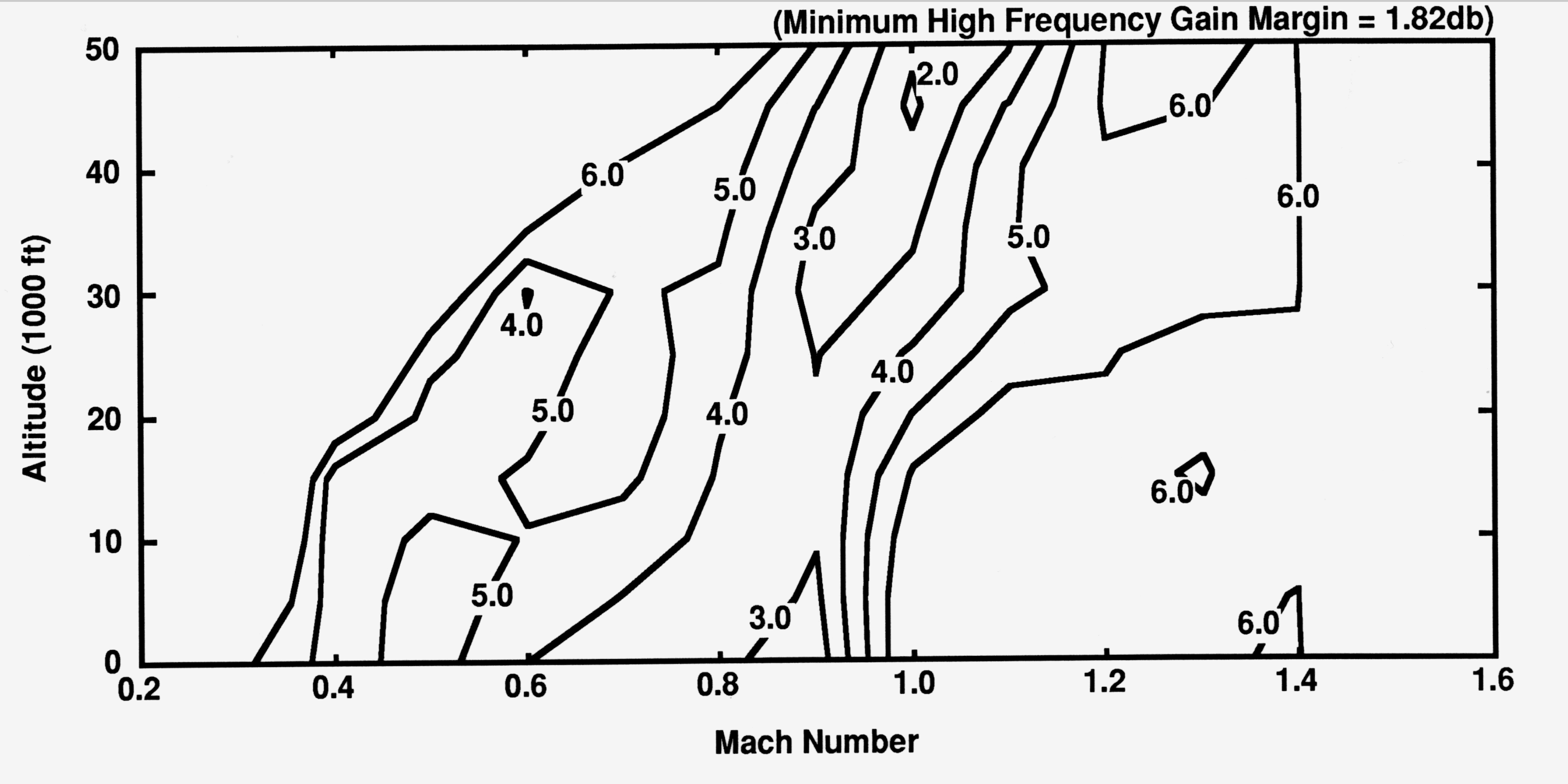
This is about -0.3 in.Hg., but worst case was found to be 1.3 in.Hg.



X-29 Baseline Pitch Axis Gain Margin

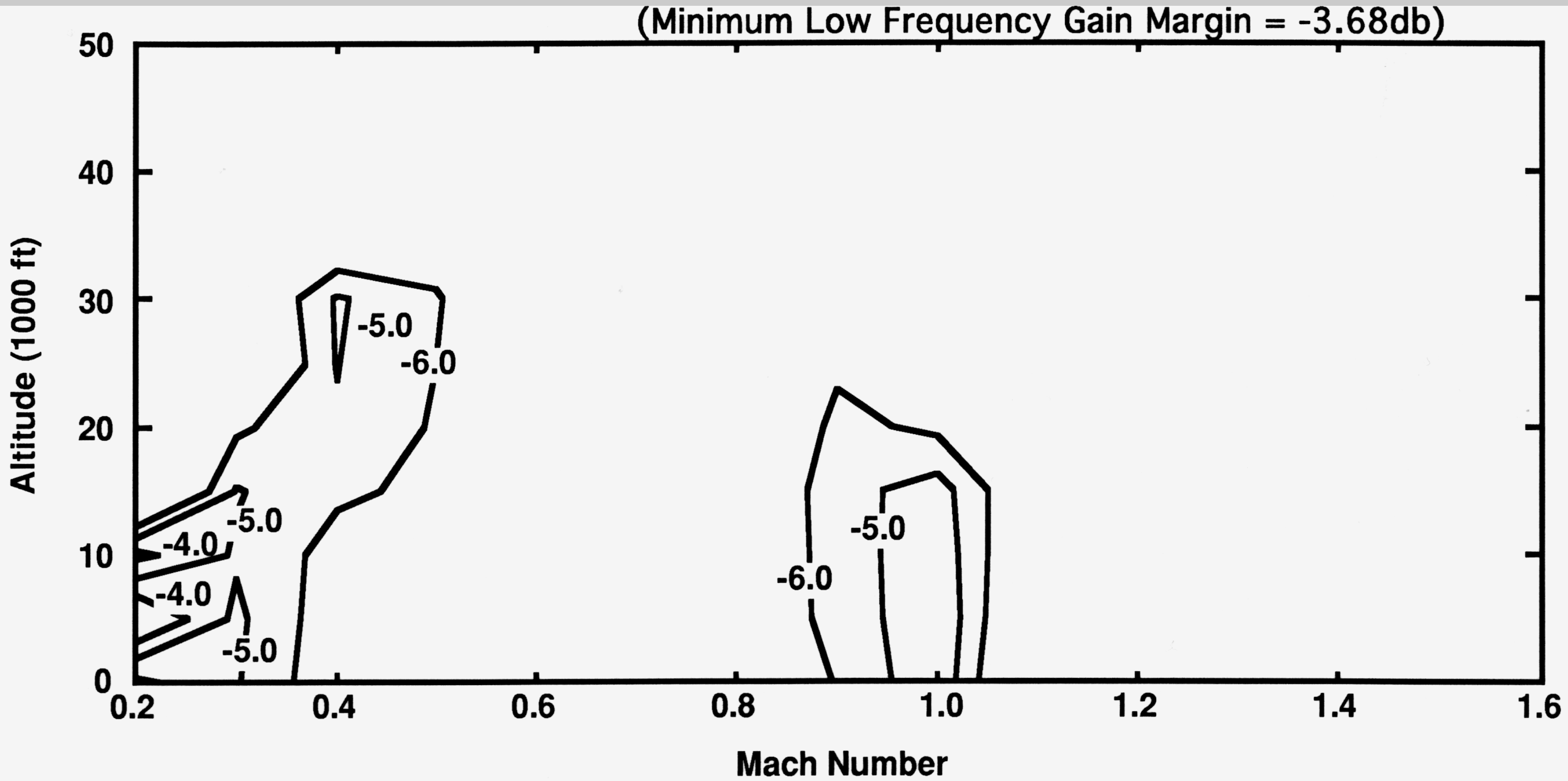


X-29 Air Data Sensitivity Analysis
ΔQ_C = -1.5 in.Hg. High Frequency Gain Margin



X-29 Air Data Sensitivity Analysis

ΔQ_C = +1.5 in.Hg. Low Frequency Gain Margin



X-29 Air Data System
What We Found Out Several Years Later

X-29 No. 2 Flight 107 13:06:05.500 α=9.7°, β=0° M=0.294

AAW Data Anomalies in Phase I HIL
RC Engineer's Record Book Entries

6

loads model was running but no outputs at most runs
since we are not at an AAW flight condition.

0.4/5K no peak recorded
0.9/5K 12g's
0.6/10K 7.2g's
1.2/10K 7.5g's
0.4/20K no peak recorded
0.7/20K 5.3g's
1.2/20K 6.6 g's
0.8/35K 4.8 g's
1.6/35K 7.2g's
0.6/40K no peak recorded
0.8/40K " " "
1.2/40K 6.4g's

piloted 701E
0.4/5K no peak recorded
0.4/20K " " "
0.7/20K " " "
1.2/20K " " "
0.6/40K " " "
0.8/40K " " "
1.2/40K " " "

tried to run unpiloted pass-through test cases, but we kept getting RFCS disengages, need to figure out why? piloted pass-through runs should work (we did one and it was ok, but ran out of time to complete all so we stopped)

no problems flying any of the 701E maneuvers, just keep inputs small and more open-loop

Rob Clarke

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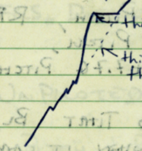
29-Nov-01

fixed problem with test bay ATD converters with a board swapout. Problem exhibited in flat spots on control surfaces (these parameters are sampled on the test bay computer and sent up through scramnet)

data looked like this:



Rob Clarke

Still looking for the problem that causes the "data dropout" type problem on these same control surface deflections. Looks like problem with Scramnet, but Marlin & Ken are still looking.

30-Nov-01

moved problem around with SCRAMNET, reconfigured (reversed direction of ring) smaller number of data spikes which requires that we examine the data runs to rerun those with spikes

1:30 – 2:15 pm ran piloted 701E

Rob Clarke

30 Nov 01 1415 – 1745

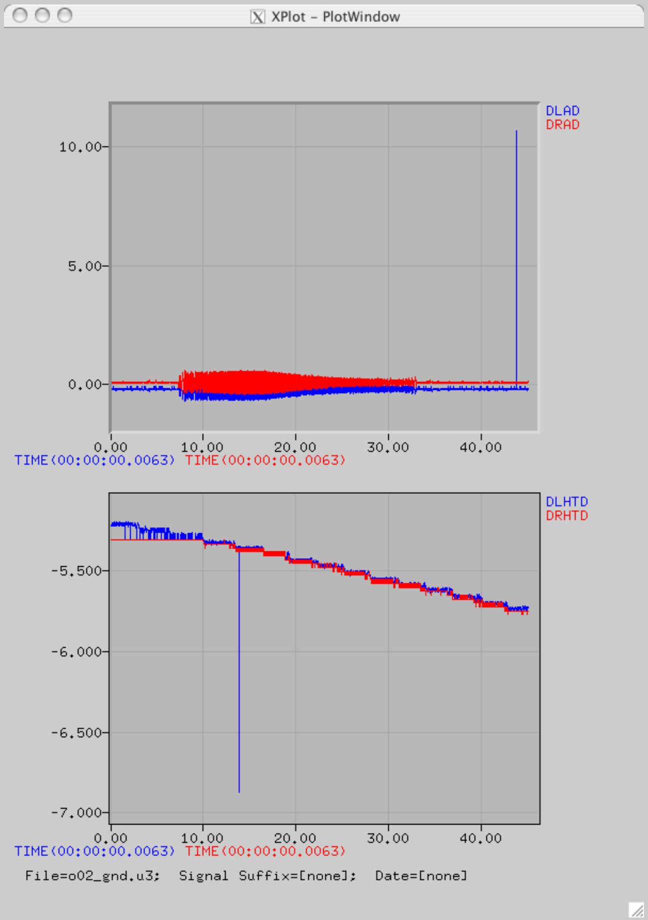
RERAN 701E UNPILOTED

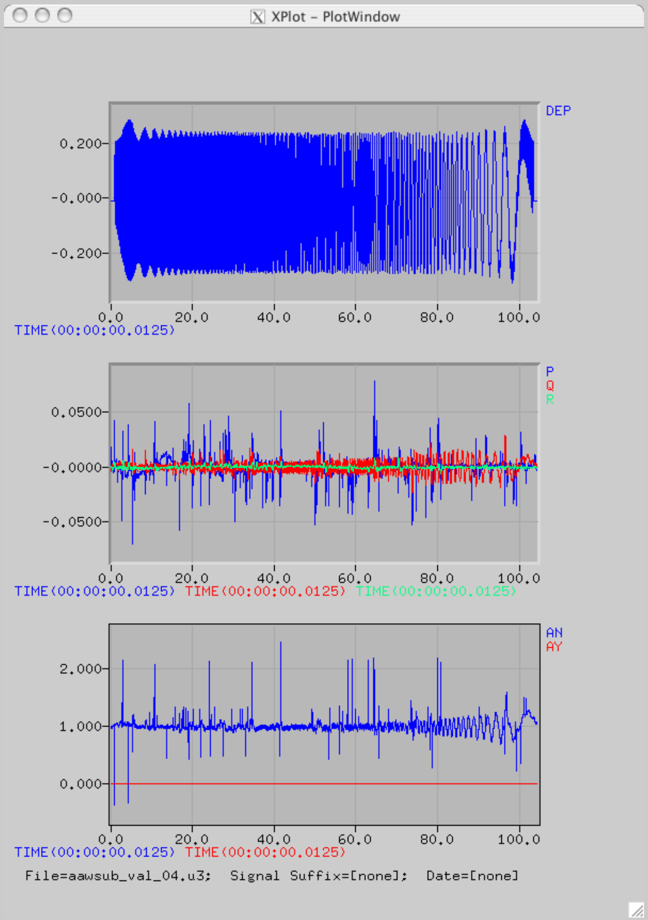
DATA LOCATED AT /home/f18sim/earls/Data/C_cases/701e_f18_env/701e_vel_xx.u3

.4/20K YAW MC BLIN 2 000016

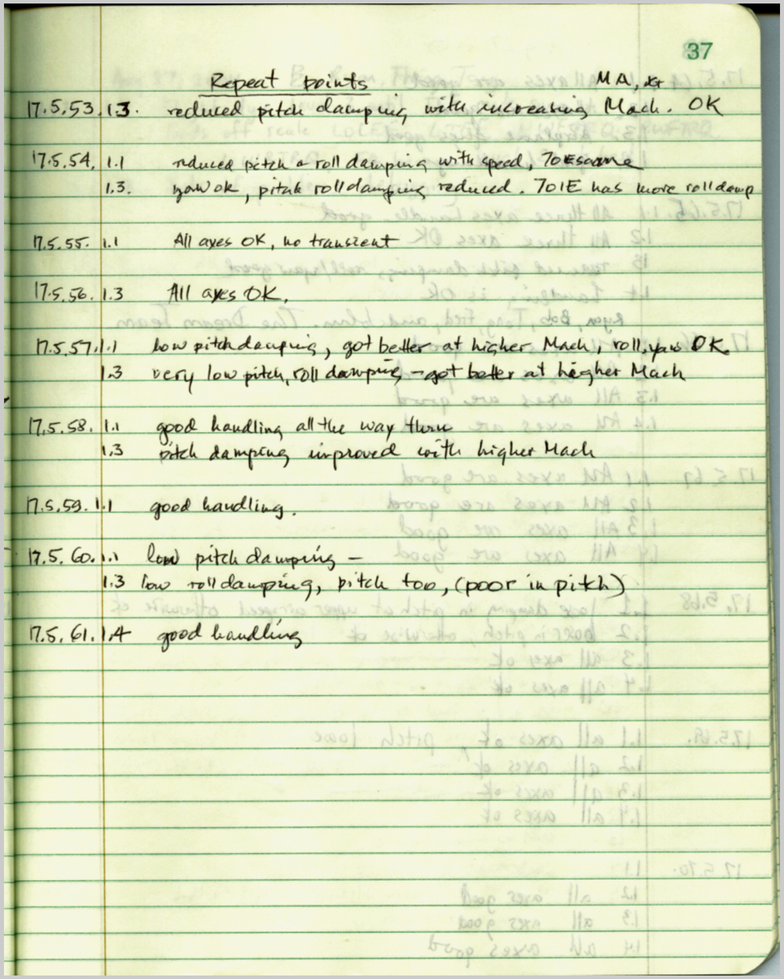
AAW Data Dropouts in the High-Speed Fiber-Optic Simulation to Hardware Interface

- Nuisance at first which grew to "Must fix before testing can continue!"





AAW Phase II Transient Free Switch RC Engineer's Record Book Entries



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Repeat points MA, Kt

17.5.53. 1.3. reduced pitch damping with increasing Mach. OK

17.5.54. 1.1 reduced pitch & roll damping with speed, 70E same
1.3. yaw ok, pitch roll damping reduced. 701E has more roll damp

17.5.55. 1.1 All axes OK, no transient

17.5.56. 1.3 All axes OK.

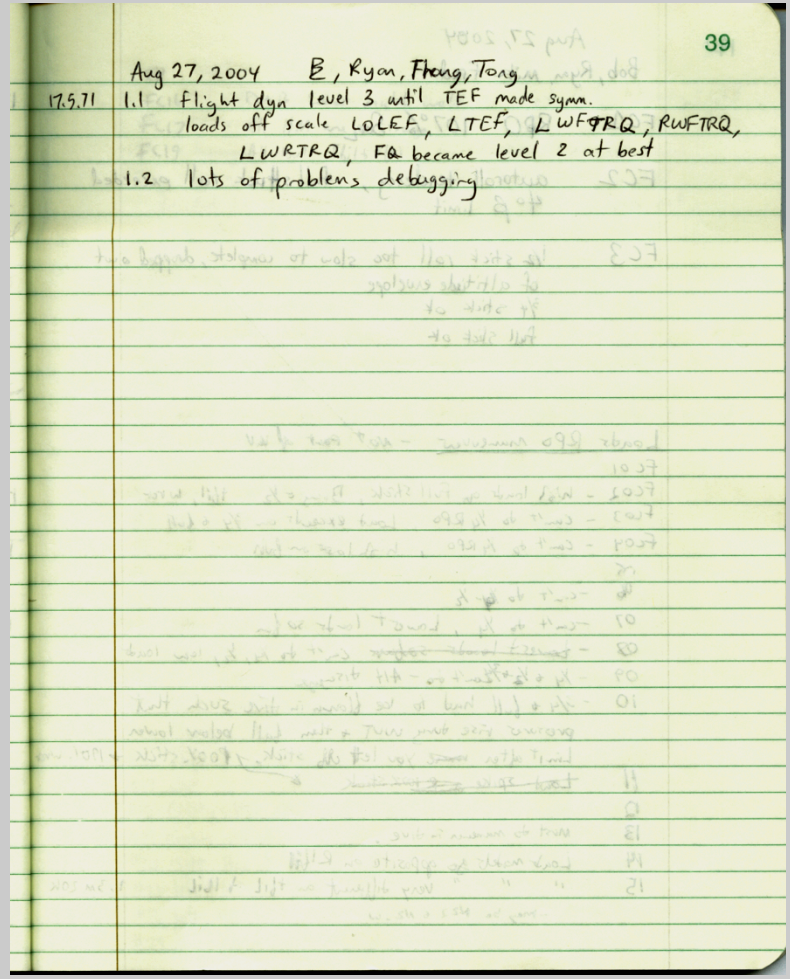
17.5.57. 1.1 low pitch damping, got better at higher Mach, roll, yaw OK.
1.3 very low pitch, roll damping – got better at higher Mach

17.5.58. 1.1 good handling all the way thru
1.3 pitch damping improved with higher Mach

17.5.59. 1.1 good handling.

17.5.60. 1.1 low pitch damping –
1.3 low roll damping, pitch too, (poor in pitch)

17.5.61. 1.4 good handling



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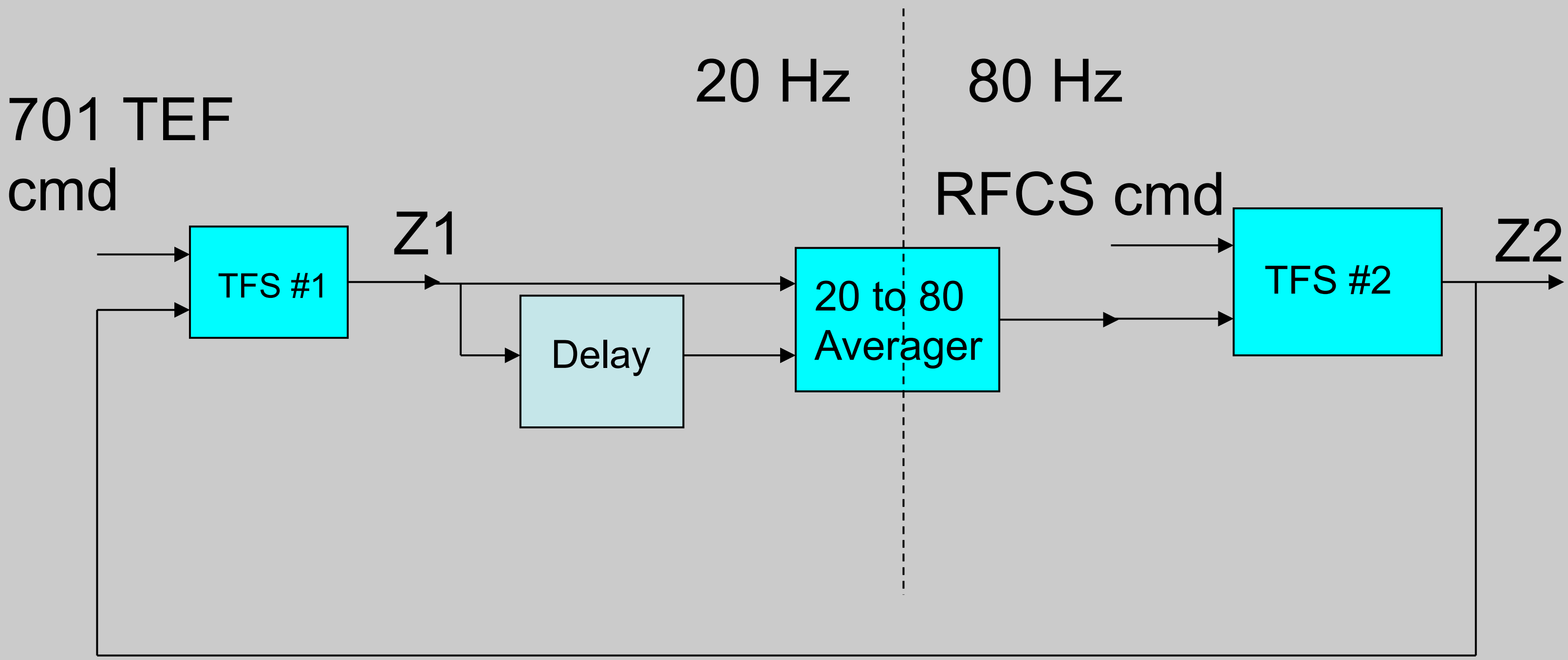
Aug 27, 2004 E, Ryan, Fhong, Tong

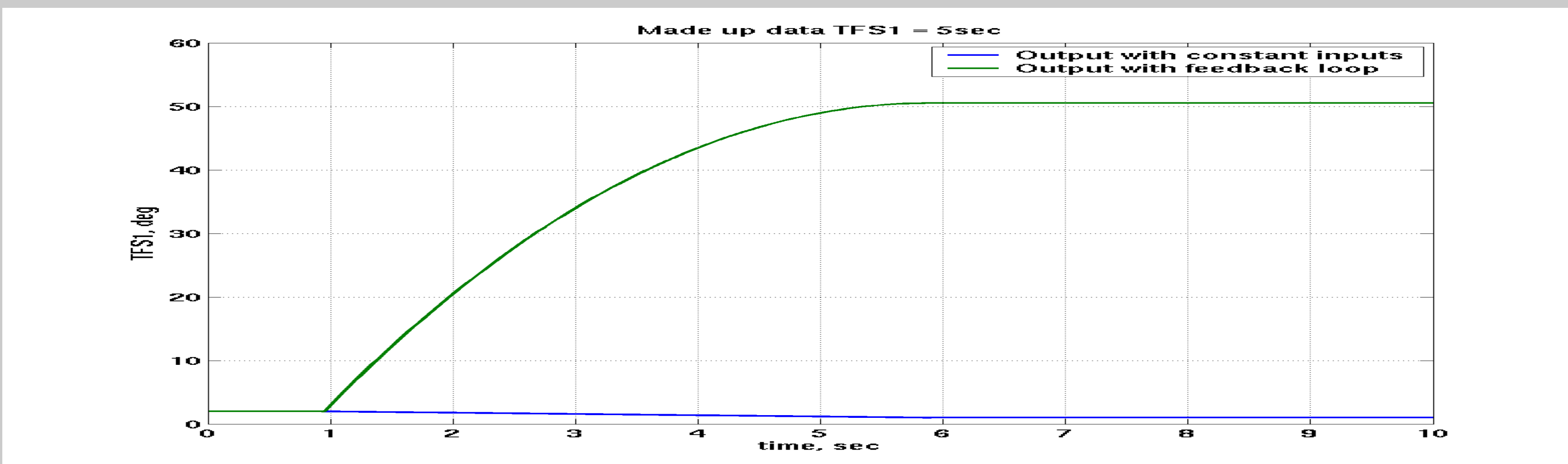
17.5.71 1.1 flight dyn level 3 until TEF made symm.
loads off scale LOLEF, LTEF, LWFTRQ, RWFTRQ,
LWRTRQ, FQ became level 2 at best
1.2 lots of problems debugging

AAW Transient Free Switch Block Diagram



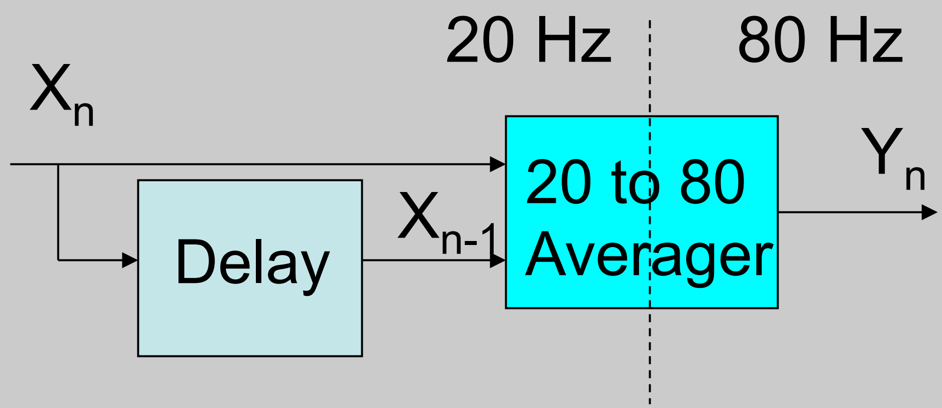
Not-So-Transient Free Switch

- Let X1 be the input prior to switching, X2 be the input after switching, T_F is the transition time in seconds, t is the time in seconds, and t = 0 at the time of switching
- Let Z be the output and Δ = X1-X2 at the time of switching (Δ shall remain constant after switching)
- $Z = \{ X2 + \Delta(1 - t/T_F); \quad t < T_F$
  $\quad\quad X2; \quad t \geq T_F \}$



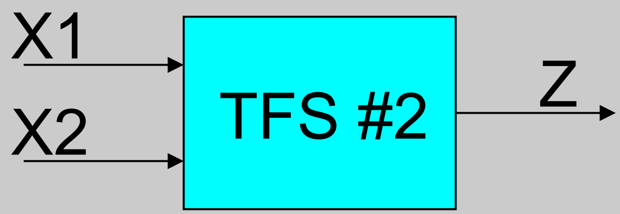
AAW 20 to 80 Averager

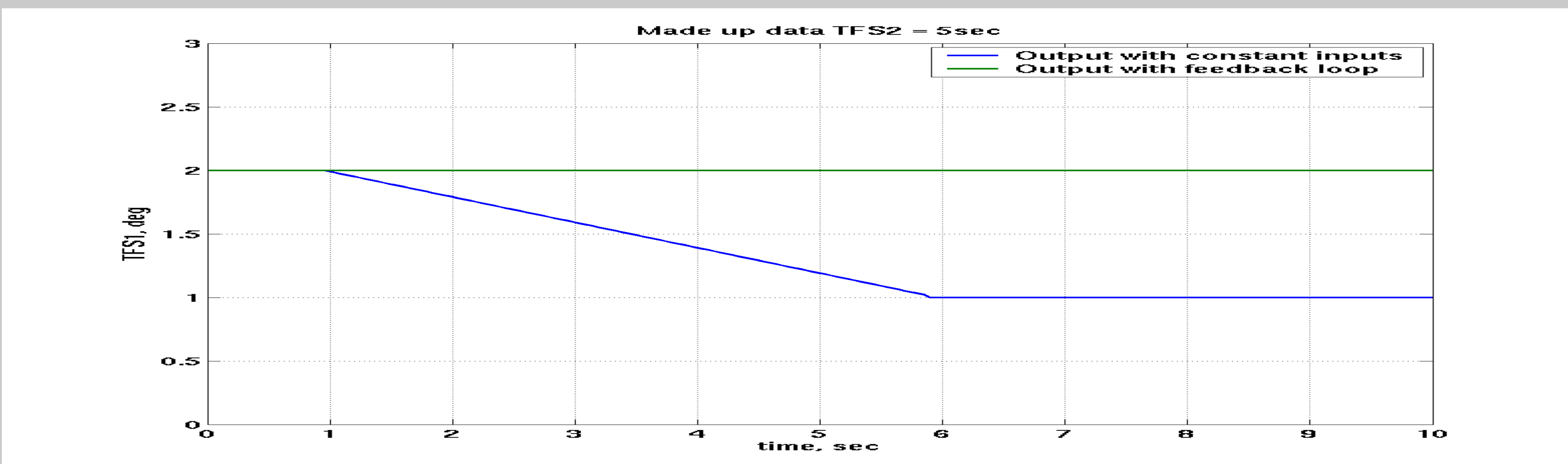
- Let X_n be the current input, X_{n-1} be the previous input and $\Delta = (X_n - X_{n-1})/4$, at 20 Hz
- Let the current output, $Y_n = Y_{n-1} + \Delta$, at 80 Hz



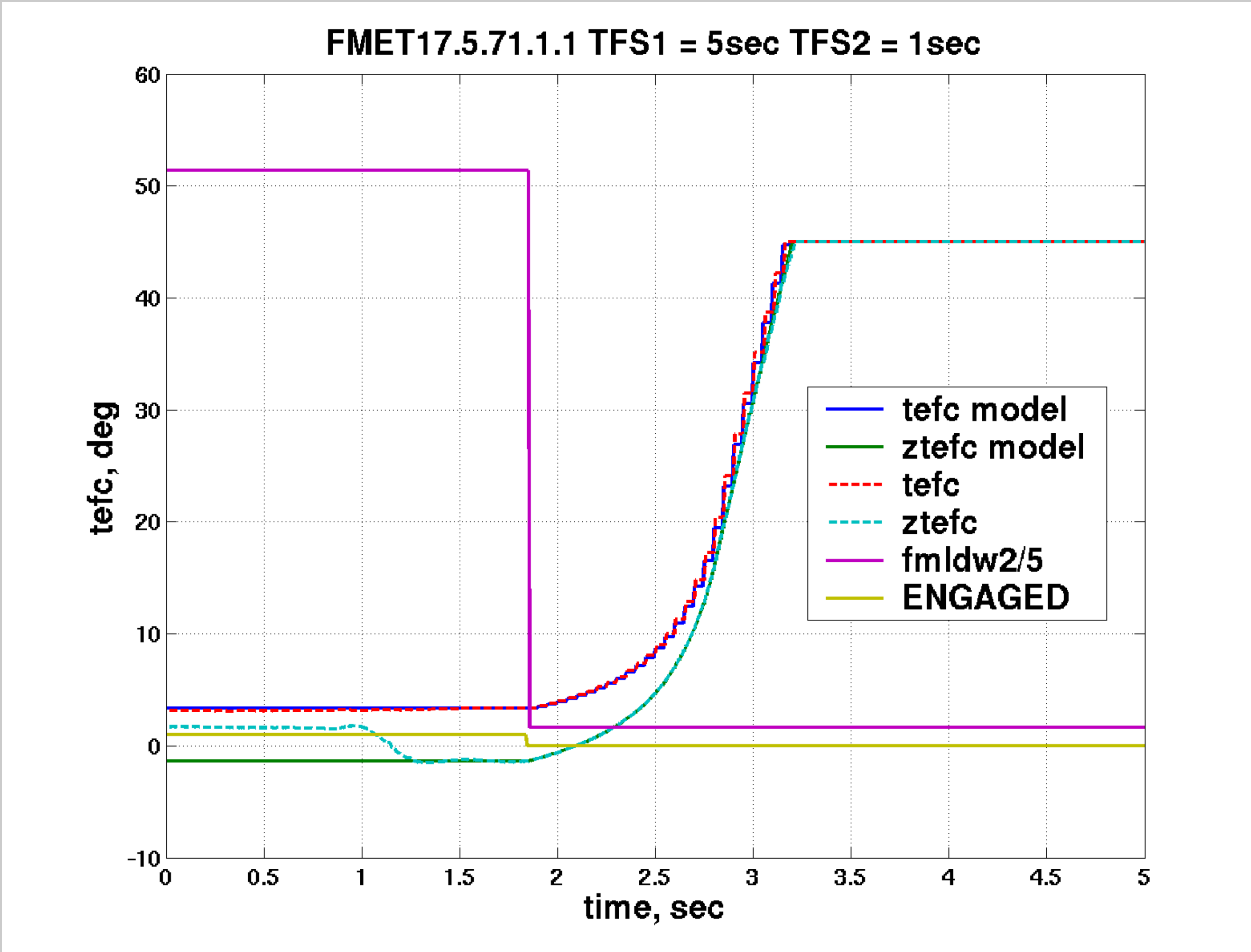
Second Transient Free Switch

- Let X1 be the input prior to switching, X2 be the input after switching, T_F is the transition time in seconds, t is the time in seconds, and t = 0 at the time of switching
- Let Z be the output and $\Delta = X1 - X2$ (X1 shall remain constant from the time of switching, but X2 can vary)
- $$Z = \begin{cases} X2 + \Delta(1 - t/T_F); & t < T_F \\ X2; & t \geq T_F \end{cases}$$

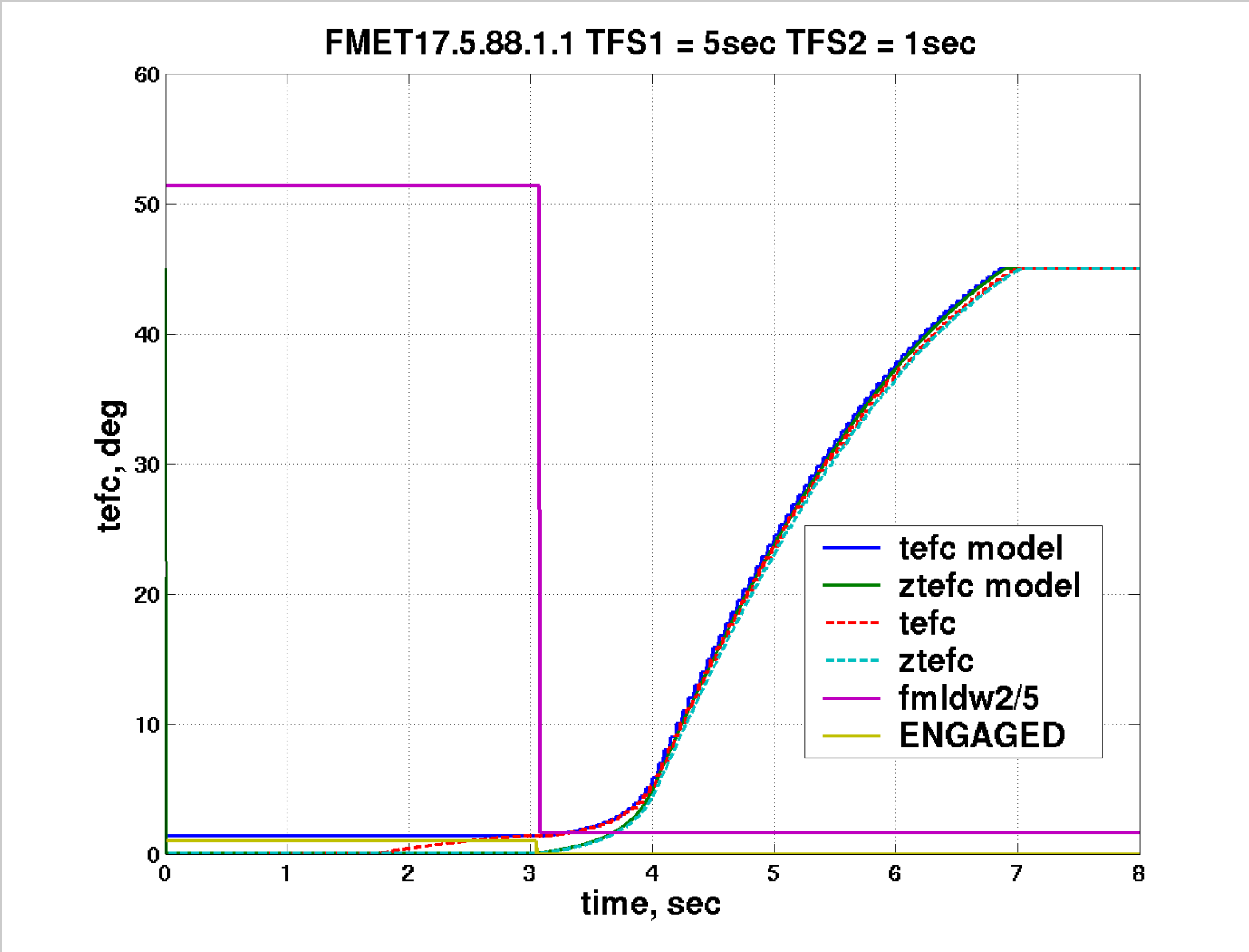




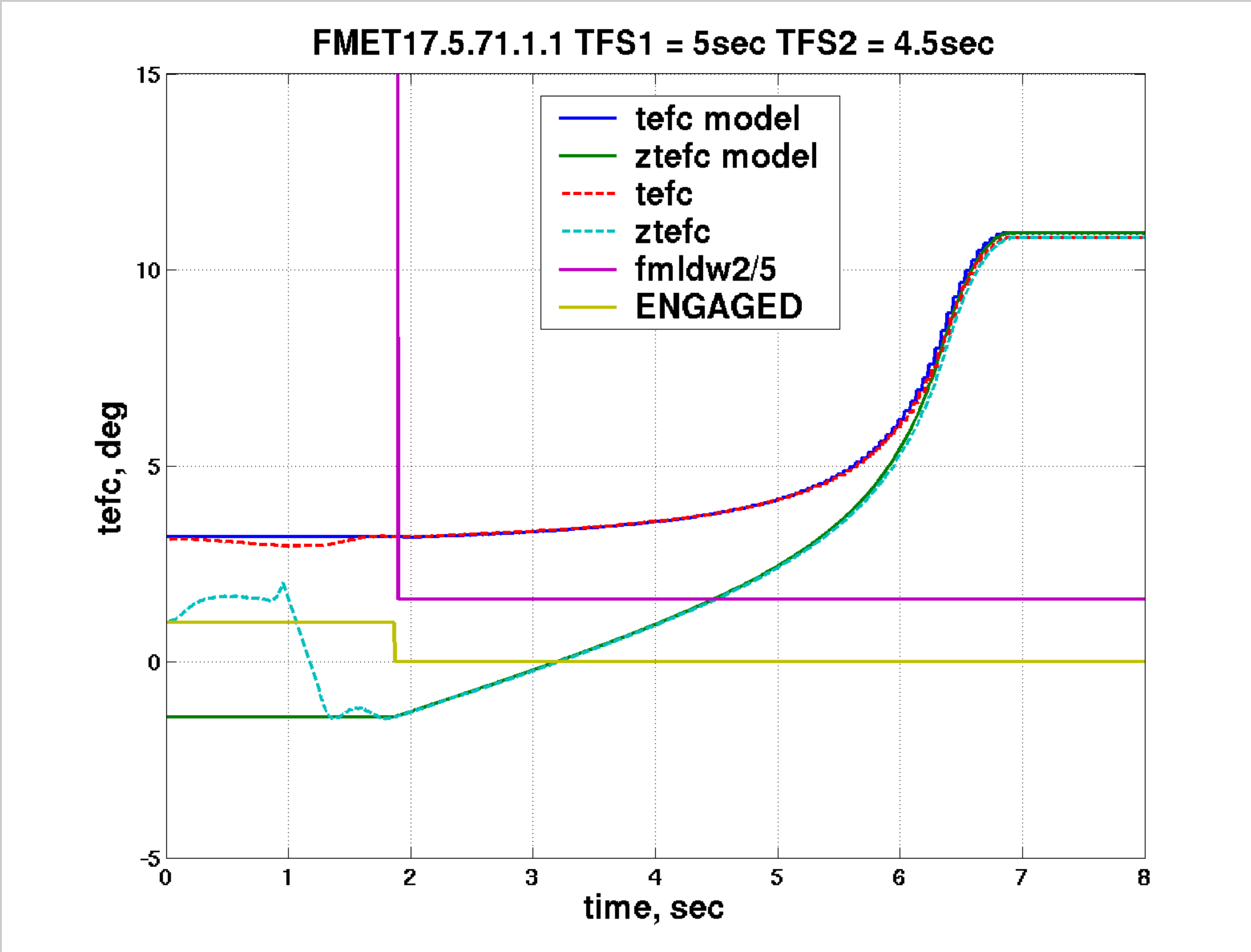
AAW TFS Model Response Compared with Sim Lab Results



AAW TFS Model Response Compared with Sim Lab Results

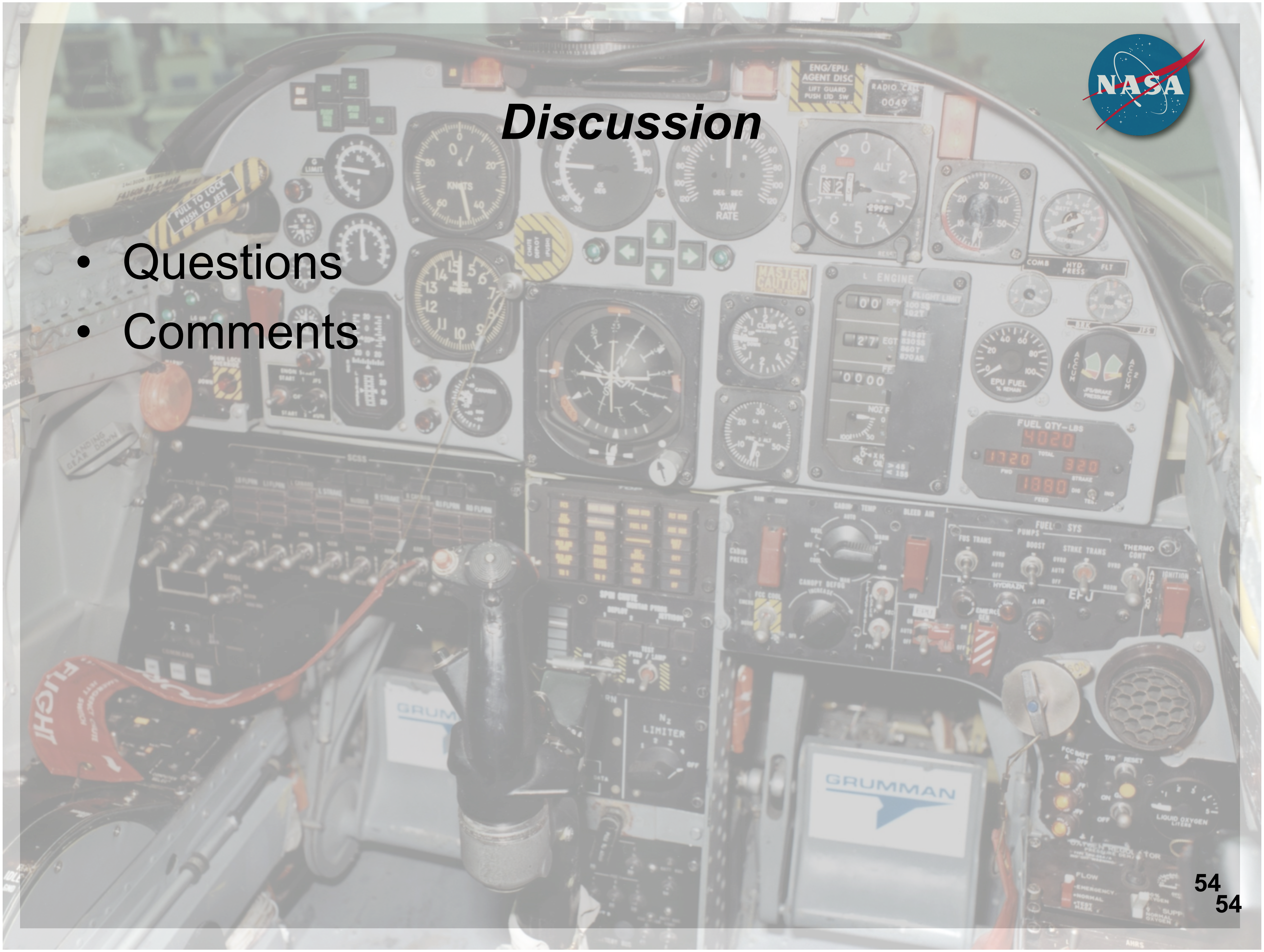


AAW TFS Model Response Compared with Sim Lab Results



Discussion

- Questions
- Comments



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