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# Assessment of the AH-64D Longbow Apache's Handling Qualities for Instrument Meteorological Conditions/Instrument Flight Rules Flight

Michael J. Meely
*University of Tennessee - Knoxville*

To the Graduate Council:

I am submitting herewith a thesis written by Michael J. Meely entitled "Assessment of the AH-64D Longbow Apache's Handling Qualities for Instrument Meteorological Conditions/Instrument Flight Rules Flight." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

Ralph Kimberlin, Major Professor

We have read this thesis and recommend its acceptance:

Frank G. Collins, Richard Ranaudo

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Anne Mayhew
Vice Chancellor and Dean of Graduate Studies

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# Assessment of the AH-64D Longbow Apache’s Handling Qualities for Instrument Meteorological Conditions/Instrument Flight Rules Flight

A Thesis
Presented for the
Master of Science Degree
The University of Tennessee, Knoxville

Michael Jesse Meely
May 2004

## DEDICATION

This thesis is dedicated to my wife, DeAnn and my daughter Julianna, who endured my many hours of study and supported me in every way and gave me that little extra push that enabled me to complete this thesis. Also to my Mother who is not here today but through her I have been inspired to achieve my goals. She gave me the drive and determination to work hard and do things to the best of my ability and that has proved to be the major tools of my success.

# ACKNOWLEDGMENTS

I wish to thank all those who helped me complete my Masters of Science degree in Aviation Systems. I would like to especially thank Dr. Kimberlin and Dr. Lewis for their effort in familiarizing me with flight test techniques.

**ABSTRACT**

An assessment of the handling of the AH-64D for flight in IMC and under IFR was conducted. Testing was performed in the configurations listed in table 1 and under the conditions presented in tables 3 and 4. All test objectives were met. IMC mission maneuvers with all systems working resulted in satisfactory handling qualities with no excessive compensation required from the pilot (altitude and attitude holds ON). However, as the aircraft systems were progressively degraded the workload for the evaluating pilot increased significantly. The high workload coupled with the absence of a vertical speed indicator (VSI) and torque indication during an AC failure and the observed errors in the standby altimeter and airspeed indicators would most likely prevent flying a successful unusual attitude recovery, an airport surveillance radar (ASR) approach, or a precision approach radar (PAR) approach. The inadequacy of the standby instruments is a **deficiency**. The aircraft's longitudinal gust response with FMC OFF required extensive pilot compensation to maintain altitude and airspeed within adequate parameters, further increasing the overall pilot workload, and is a **deficiency**. Additionally, the aircraft's battery life does not meet the 30-min requirement for IMC/IFR flight that would be required in the unlikely event of an aircraft AC power failure and results in a **deficiency**. Engineering maneuvers conducted to quantify the handling qualities of the AH-64D with FMC OFF confirmed the high pilot workload and extensive compensation required. These maneuvers revealed an oscillatory divergent long-term mode, an oscillatory divergent lateral-directional oscillation (LDO), negative spiral stability when banked to the right, and significant coupling between pitch and roll. While conducting these maneuvers, excessive instrumentation lag was observed in the standby altimeter during climbs and descents. This resulted in errors of up to 300 ft between boom data and the standby altimeter. The excessive observed instrument lag and inaccuracy of the standby altimeter is a **shortcoming**. Other findings included the absence of any information on IMC/IFR procedures in the operator's manual was also found to be a **shortcoming**. Consequently a clearance for aircraft operation in IMC is not recommended. Plots of representative engineering data collected in the heavy weapons (configuration 3) and two-tank configurations (configuration 5) are in Appendix D.

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# NOMENCLATURE

| | |
|---|---|
| A&FC | airworthiness and flying characteristics |
| AATIS | advanced aircraft test instrumentation system |
| AC | Advisory Circular |
| AC | alternating current |
| ADF | automatic direction finder |
| AED | Aviation Engineering Directorate |
| ALT | altitude |
| AMCOM | Army Aviation and Missile Command |
| AOB | angle of bank |
| APU | auxiliary power unit |
| ARDD | automatic roller detent decouplers |
| ASI | airspeed indicator |
| ASN | army serial number |
| ASR | airport surveillance radar |
| ATM | aircrew training manual |
| ATT | attitude |
| ATTC | Aviation Technical Test Center |
| AWR | airworthiness release |
| AWS | area weapons system |
| BUCS | back-up control system |
| CAIS | common airborne instrumentation system |
| CAS | command augmentation system |
| cg | center of gravity |
| CPG | copilot gunner |
| DC | direct current |
| DH | decision height |
| DRVS | doppler radar velocity sensor |
| EGI | embedded global positioning system/inertial navigation system |
| FAA | Federal Aviation Administration |
| FCMC | flight control mechanical characteristics |
| FCR | fire control radar |
| FLT | flight |
| FMC | flight management computer |
| FS | fuselage station |
| GEM | GPS-embedded module |
| GPS | global positioning system |
| GS | ground speed |
| HADS | helicopter airdata system |
| HQR | handling qualities ratings |
| IAW | in accordance with |
| IBIT | initial built-in test |
| ICD | interface control document |

| | |
|---|---|
| IFR | instrument flight rules |
| IMC | instrument meteorological condition |
| INU | inertial navigation unit |
| ISAQ | interim statement of airworthiness qualification |
| ITO | instrument takeoff |
| KCAS | knots calibrated airspeed |
| KIAS | knots indicated airspeed |
| KTAS | knots true airspeed |
| LDO | lateral-directional oscillation |
| LVDT | linear variable differential transducer |
| MCP | maximum continuous power |
| MDA | minimum descent altitude |
| MPD | multipurpose displays |
| NAV | navigation |
| NDB | non-directional beacon |
| NOE | nap-of-earth |
| OFP | operational flight profile |
| PAR | precision approach radar |
| PCMCIA | personal computer memory card international association |
| PM | Program Manager |
| PNVS | pilot night vision system |
| RTE | route |
| RVDT | rotary variable displacement transducers |
| SAS | stability augmentation system |
| SCAS | stability and command augmentation system |
| SHSS | steady heading sideslip |
| SP | system processor |
| TADS | target acquisition designation system |
| TGT | turbine gas temperature |
| TSD | tactical situation display |
| TSO | Technical Standard Order |
| UHF | ultra high frequency |
| VAR | vibration assessment rating |
| VSI | vertical speed indicator |
| YAPS | yaw and angle-of-attack position sensor |

# 1. INTRODUCTION

## BACKGROUND

1. The AH-64D Longbow Apache helicopter, developed by The Boeing Company, Mesa, AZ, was designed to increase the U.S. Army's attack aircraft target engagement capability and survivability. The U.S. Army fielded the AH-64D Longbow Apache in 1998 and, until this test, the U.S. Army had not considered testing the aircraft's ability to fly in instrument meteorological conditions (IMC). The AH-64D Longbow Apache is currently restricted from IMC by the interim statement of airworthiness qualification (ISAQ) (ref 1). The Program Manager (PM)-Longbow Apache identified a requirement for AH-64D aircraft to be capable of IMC and instrument flight rules (IFR) operations in European airspace, so the requirement to test the aircraft was established. Two major questions were presented. 1) Is the Longbow Apache helicopter capable of being certified for IMC flight in its current production configuration? 2) If the Longbow Apache is not capable of being certified, what changes need to be done to the aircraft in order to achieve the IMC certification.

The approach to testing the Longbow Apache started with testing the handling qualities for the aircraft to determine if the aircraft exhibited the required handling qualities needed for IMC flight in accordance with (IAW) Federal Aviation Administration (FAA) Regulation (FAR) Part 29 (ref 2), Technical Standard Order (TSO) C129a (ref 3), a white paper published by the Boeing Company on IMC for the Longbow Apache (ref 4), and the Specification for the Longbow Apache (ref 5). Testing was to be accomplished with the flight control computer (FMC) off and on, because the FMC was considered to be a single point failure in the aircraft flight control system. The aircraft had been exhibiting some power reliability problems since its start of production. Additionally, due to these power problems resulting in the loss of the glass displays, so a test to determine if aircrews could fly on the stand instruments alone was also developed.

## TEST OBJECTIVES

2. The objectives of this test were to:

a. Identify and recommend an IMC flight envelope.

b. Evaluate and document the aircraft's handling qualities with the Flight Management Computer (FMC) OFF.

c. Qualitatively evaluate instrument flying tasks with the FMC OFF.

**DESCRIPTION**

3. The AH-64D test aircraft (U.S. Army serial numbers (ASNs) 99-05132 and 96-05018) were twin-engine, tandem-seat, aerial weapons platforms with a maximum gross weight of 23,000 lb if configured in a ferry mission or gross weight of 20260 lb if configured in a mission gross weight. The forward and center fuselage sections housed the crew, fuel cells, mission avionics, and main transmission and provided mounting points for the target acquisition designation system (TADS), pilot night vision system (PNVS), 30mm area weapon system (AWS), landing gear, wings, and engines. The aircraft can be equipped with a fire control radar (FCR) mounted on top or the main rotor head. The FCR is designed to provide the aircraft the capability of a completely fire and forget missile in addition to the laser guided missile provided in the legacy aircraft. The aft fuselage consisted of the tailboom that mounted the aft landing gear, horizontal and vertical stabilizers, and tail rotor. The wings provided four hard points for mounting up to four M261 (19-shot) 2.75-in. rocket pods, four M299 Hellfire missile launchers (each with a capacity of four missiles), four external 230-gal auxiliary fuel tanks, or any combination of weapons or fuel to support a given mission. The aircraft was equipped with a four-bladed, fully articulated main rotor system and semirigid tail rotor. The irreversible hydromechanical flight control system was mechanically activated with conventional controls in each crewstation. The flight controls provided inputs to the main and tail rotors through mechanical linkages that activated four airframe-mounted, hydraulic primary flight control servocylinders. The flight control system incorporated a stability and command augmentation system (SCAS) and an flight management computer (FMC). In combination, the SCAS and FMC provided rate damping and command augmentation to enhance the stability and handling qualities of the helicopter. An electrically actuated horizontal stabilator was attached to the lower portion of the vertical stabilizer. Trim feel systems were incorporated in both the cyclic and pedals to provide control force gradients with control displacement from selected trim positions. Primary flight instruments were provided through an electronic flight page display on the aircraft multipurpose displays (MPDs) (color) (fig 1). Standby flight instruments were provided to the rear seat pilot only and consisted of an attitude indicator (fig 2), altimeter (fig 3), airspeed indicator (fig 4), and a magnetic compass (fig 5). A turn-rate indicator and slip ball were

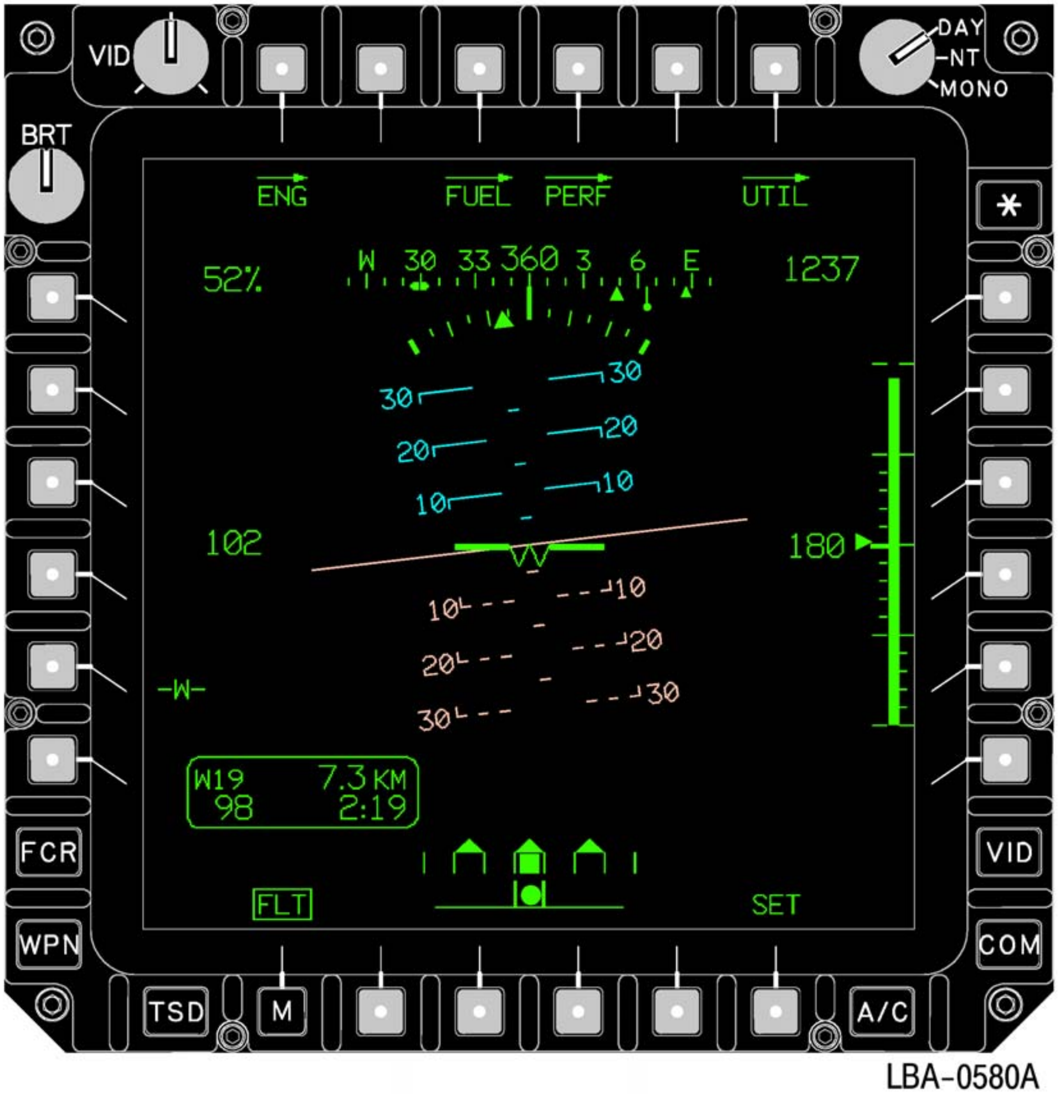



Figure 1. Multipurpose Display (MPD) Flight Page (6½ by 6½ in. display)

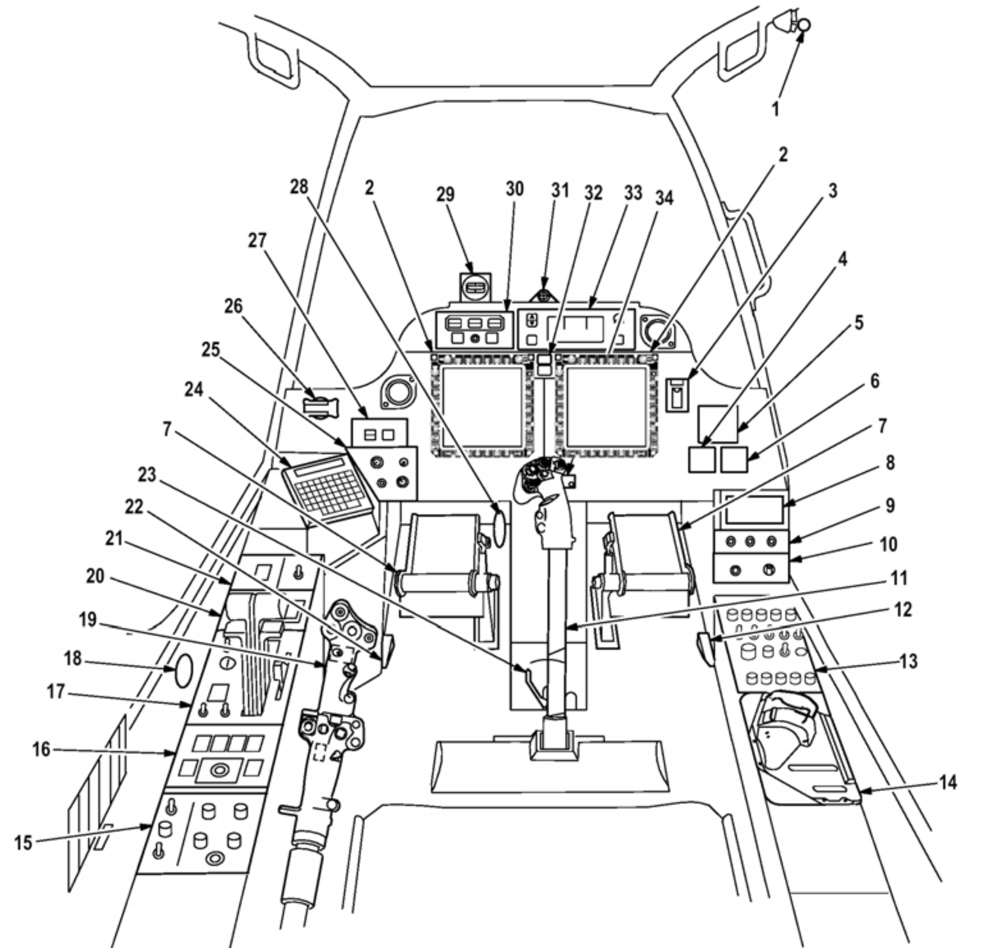
Figure 2.  Standby Attitude Indicator (2¾ in. diameter)

Figure 3.  Standby Altimeter (2 in. diameter)

Figure 4.  Standby Airspeed Indicator (2 in. diameter)

Figure 5. Magnetic Compass

incorporated in the standby attitude indicator. The standby instruments were located 3 in. lower than the center of the MPDs and 13¾ in. to the right side of center on the forward console/display panel. The viewing angle as measured from the design eye point was 22 deg right of center at a distance of 32¾ inches. The magnetic compass was attached on top of the glare shield (fig 6) just left of center. The aircraft electrical system consisted of two alternating current (AC) generators, either of which could provide full electrical power requirements to the aircraft, and a battery if the aircraft suffered a dual-generator failure. The battery could provide direct current (DC) power to the standby flight instruments and other flight safety critical systems for a minimum of 12 min at an 80-percent charged state. A more detailed flight control description is contained in Appendix B and a more detailed description of the aircraft is contained in the operator's manual (ref 6). Aircraft ASN 99-05132 had test instrumentation installed for data collection and recording during the assessment. Appendix C contains a detailed description of the instrumentation installed.



1. CANOPY DOOR RELEASE LEVER
2. MULTIPURPOSE DISPLAY UNIT
3. MASTER ZEROIZE
4. AIRSPEED INDICATOR
5. ATITUDE INDICATOR
6. ALTIMETER
7. DIRECTIONAL CONTROL PEDALS
8. DATA TRANSFER CARTRIDGE RECEPTACLE
9. CHECK OVERSPEED TEST/ GENERATOR RESET PANEL
10. WINDSHIELD WIPER CONTROL PANEL
11. CYCLIC STICK
12. ICS SWITCH
13. COMMUNICATIONS PANEL
14. HDU STORAGE
15. EXTERIOR/INTERIOR LIGHTING PANEL
16. STORES JETTISON PANEL
17. POWER LEVER QUADRANT
18. FREE AIR TEMPERATURE GAGE
19. COLLECTIVE STICK
20. EMERGENCY PANEL
21. TAIL WHEEL LOCK/ NVS MODE PANEL
22. PUSH-TO-TALK (PTT) SWITCH
23. PEDAL ADJUST LEVER
24. KEYBOARD UNIT
25. VIDEO PANEL
26. CANOPY JETTISON HANDLE
27. ARMAMENT PANEL
28. PARKING BRAKE HANDLE
29. STANDBY COMPASS
30. FIRE DETECTION/ EXTENGUISHING PANEL
31. BORESIGHT RETICLE UNIT
32. MASTER WARNING/ MASTER CAUTION LIGHTED PUSHBUTTONS
33. UP FRONT DISPLAY
34. RADIO CALL PLACARD

LBA-0455

Figure 6. Pilot Crewstation

## TEST SCOPE

4. The IMC testing of the Longbow Apache was conducted at Fort Rucker, Alabama in the local flying area. Representative data from this test are presented in Appendix D. This test was conducted from November 2002 to April 2003. Quantitative engineering data were obtained during the airworthiness and flying characteristics (A&FC) test using the instrumented AH-64D (ASN 99-05132) in two of the approved A&FC configurations taken from the phase 1 and II test plans (ref 7 & 8) shown in table 1: heavy weapons with 8 Hellfire inert missiles, 38 2.75-in. inert rockets, and 1,169 inert rounds of 30mm ammunition (all inert) (conf No. 3), and no weapons with two external tanks containing 184 gal of water each (conf No. 5) (184 gal of water equates to 230 gal of JP8). Mission representative IMC tasks were flown in configuration 3 only. Through the course of the test, a total of three pilots flew in the aft station of aircraft ASN 96-05018, a production representative AH-64D without radar, and gathered some of the qualitative mission maneuver data. The primary emphasis of testing was with the FMC OFF, simulating conditions expected following a major electrical malfunction on the aircraft. During this evaluation, 22.4 flight-hours were expended and 12.0 hours of chase aircraft support were used. The Aviation Technical Test Center (ATTC) provided two test aircraft, chase aircraft, and crews. The Aviation Engineering Directorate (AED) of the U.S. Army Aviation and Missile Command (AMCOM) provided an airworthiness release (AWR) (ref 9).

Table 1. Aircraft Test Configurations

| Configuration No.[1] | Takeoff Longitudinal cg[2] (FS[3]) | Engine Start Gross Weight (lb) | 30mm Gun Ammo[4] (rds) | External Stores[4] | | | | FCR[5] Installed |
|---|---|---|---|---|---|---|---|---|
| | | | | Left Outboard | Left Inboard | Right Inboard | Right Outboard | |
| 3 | 204.6 | 19,000 | 1,000 | 19-shot Rocket Pod | 4 Hellfire Missiles | 4 Hellfire Missiles | 19-shot Rocket Pod | YES |
| 5 | 204.1 | 19,500 | | Pylon | 230-gal Tank[6] | 230-gal Tank | Pylon | YES |

NOTES:
[1]Configuration numbers correspond to the numbers presented in the A&FC Phase I & II test plans (ref 7 & 8).
[2]cg - center of gravity (shown in inches)
[3]FS - fuselage station
[4]All missile, rocket, and 30mm loads were inert munitions.
[5]FCR - fire control radar
[6]6230-gal tanks were filled with a non-volatile solution during testing.

**TEST METHODOLOGY**

5. This test effort focused on two aspects of the aircraft's suitability for IMC/IFR operations: the stability and control of the aircraft in a degraded mode of operation, and representative IMC mission maneuvers in fully operational, partially degraded, and fully degraded modes of operation. In the fully operational mode, some mission maneuvers were flown with the SCAS hold modes engaged. The partially degraded mode was FMC OFF. The fully degraded mode was with FMC OFF and with the MPDs in the rear cockpit turned to night and dimmed to simulate a total AC electrical failure condition. Although simulating a total AC electrical failure, the stabilator remained functional throughout all tests conducted. The evaluating pilot in the rear cockpit wore an instrument flight training hood that when combined with paper masking material on the cockpit canopy removed all outside references from the pilot's view. Engineering flight test maneuvers, flown as described in reference 10, documented the aircraft's flight characteristics with the FMC OFF. The Vibration Assessment Rating (VAR) Scale was used to assign subjective vibration pilot ratings to specific tasks IAW ATTC Memorandum 70-12 (ref 11). Mission maneuvers were flown to assess the aircraft's characteristics and pilot interface during performance of IMC tasks with varying levels of flight control system augmentation and display degradation. These IMC tasks were flown with fully operational cockpit displays and on standby flight instruments. Instrument flying tasks were conducted per the conditions, standards, and applicable notes listed in the AH-64D aircrew training manual (ATM) (ref 12) and IAW the techniques and procedures listed in the field manual for instrument flight and navigation for U.S. Army aviators (ref 13). The evaluation was intended to identify shortcomings and deficiencies as they became apparent with system degradation, related specifically to the IMC/IFR flight condition. Handling qualities ratings (HQRs), as defined in reference 14, were used to identify conditions that were not satisfactory. Three pilots were used as assessing pilots for the IMC mission maneuvers and I as the test director was the safety/data pilot for each of the flights. All the pilots were experience experimental test pilots qualified to evaluate to handling qualities of the aircraft using the Cooper-Harper rating scales. The three assessing pilot's flight experiences are presented in table 2. Data plots were presented in the U.S. Army Aviation Technical Test Center's (ATTC) report (ref 15) and are use as the source data for this thesis. And again, I as the test director flew the engineering flights included in this report and authored the

Table 2.  Pilot Flight Experience

| Pilot Number[1] | Total AH-64 Time | Total Instrument/Hood | Total Flight Times |
|---|---|---|---|
| 1 | 520 | 41 | 2280 |
| 2 | 2850 | 53 | 3600 |
| 3 | 2140 | 48 | 2530 |

NOTES:
[1]To keep the names of those involved in the test private, the pilots will only be known as a number in this report.

ATTC test report.  To assess the relative accuracy of the standby instruments during the determination of trimmed flight control positions, the standby instrument readings were manually recorded.  Tests and test conditions for engineering tests and mission maneuvers are shown in tables 3 and 4, respectively.

Table 3. Test and Test Conditions for IMC/IFR

| Test[2] | Configuration/Mode of Operation | Subtask | Flight Condition | Average Gross Weight (lb) | Average Longitudinal Center of Gravity (FS[3])(in.) | Average Density Altitude (ft) | Average Outside Air Temperature (°C) | Trim Calibrated Airspeed (kts) | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| Trimmed Flight Control Positions and Standby Instrument Calibrations | 3[4] FMC[5] ON Trim ON | | Level | 18,090 | 203.0 | 5,910 | 6.5 | 78 to 112 | 10-kt increments. |
| | 3 FMC OFF Trim ON | | Level | 18,540 | 203.4 | 6,460 | 7.0 | 43 to 141 | |
| Longitudinal Dynamic Stability | 3 FMC ON Trim ON | Short-Term Response | Level | 18,020 | 202.8 | 6,050 | 7.0 | 80, 111 | 1-in. longitudinal cyclic pulse/doublet. |
| | | | Max Cont Q[6] Climb | 17,800 | 202.8 | 5,810 | 6.5 | 85, 111 | |
| | | | 1,000-fpm[7] Descent | 17,720 | 202.8 | 5,910 | 6.5 | 81, 111 | |
| | | Long-Term Response | Level | 18,220 | 202.8 | 5,980 | 7.0 | 81, 110 | Natural excitation or ±10 kt input. |
| | | | Max Cont Q Climb | 17,880 | 202.8 | 5,700 | 6.5 | 80, 109 | |
| | | | 1,000-fpm Descent | 17,730 | 202.8 | 6,170 | 6.5 | 84, 112 | |
| | 3 FMC OFF Trim ON | Short-Term Response | Level | 18,200 | 202.8 | 6,080 | 7.5 | 81, 110 | 1-in. longitudinal cyclic pulse/doublet. |
| | | | Max Cont Q Climb | 17,640 | 202.9 | 5,960 | 7.0 | 80, 109 | |
| | | | 1,000-fpm Descent | 17,570 | 202.9 | 6,310 | 7.5 | 91, 110 | |
| | | Long-Term Response | Level | 17,970 | 202.8 | 6,150 | 7.0 | 81, 110 | Natural excitation or ±10 kt input. |
| | | | Max Cont Q Climb | 17,730 | 202.9 | 5,400 | 6.5 | 79, 109 | |
| | | | 1,000-fpm Descent | 17,550 | 202.9 | 6,930 | 7.5 | 91, 110 | |

Table 3. Continued

| Test[2] | Configuration/Mode of Operation | Subtask | Flight Condition | Average Gross Weight (lb) | Average Longitudinal Center of Gravity (FS[3])(in.) | Average Density Altitude (ft) | Average Outside Air TEMPERATURE (°C) | Trim Calibrated Airspeed (kts) | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| Longitudinal Dynamic Stability | 5[8] FMC ON Trim ON | Short-Term Response | Level | 19,020 | 202.9 | 5,950 | 5.0 | 79 | 1-in. longitudinal cyclic pulse/doublet. |
| | | | Max Cont Q Climb | 18,100 | 202.4 | 6,490 | 5.5 | 82 | |
| | | | 1,000-fpm Descent | 19,030 | 203.0 | 5,970 | 4.5 | 80 | |
| | | Long-Term Response | Level | 19,110 | 203.5 | 6,060 | 4.5 | 79 | Natural excitation or ±10 kt input. |
| | | | Max Cont Q Climb | 18,220 | 202.4 | 5,320 | 6.5 | 81 | |
| | | | 1,000-fpm Descent | 18,150 | 202.4 | 6,690 | 3.5 | 80 | |
| | 5 FMC OFF Trim ON | Short-Term Response | Level | 18,870 | 202.4 | 6,050 | 5.0 | 81 | 1-in. longitudinal cyclic pulse/doublet. |
| | | | Max Cont Q Climb | 19,050 | 203.5 | 5,950 | 11.0 | 82 | |
| | | | 1,000-fpm Descent | 19,030 | 203.4 | 6,300 | 9.0 | 92 | |
| | | Long-Term Response | Level | 18,960 | 202.5 | 6,080 | 5.0 | 81 | Natural excitation or ±10 kt input. |
| | | | Max Cont Q Climb | 19,100 | 203.3 | 5,700 | 11.0 | 80 | |
| | | | 1,000-fpm Descent | 19,080 | 203.4 | 6,080 | 9.0 | 90 | |
| Lateral Directional Dynamic Stability | 3 FMC ON Trim ON | Short-Term Response | Level | 18,290 | 203.0 | 6,020 | 7.5 | 81, 111 | 1-in. pedal pulse/doublet; release from SHSS[9]. |
| | | | Max Cont Q Climb | 18,650 | 203.7 | 6,030 | 7.5 | 79 | |
| | | | 1,000-fpm Descent | 18,620 | 203.6 | 6,490 | 6.5 | 81 | |
| | | Spiral Mode | Level Turns | 18,250 | 203.1 | 6,000 | 6.5 | 82, 109 | 10-deg, 20-deg, and 30-deg AOB[10]. |

Table 3. Continued

| Test[2] | Configuration/Mode of Operation | Subtask | Flight Condition | Average Gross Weight (lb) | Average Longitudinal Center of Gravity (FS[3])(in.) | Average Density Altitude (ft) | Average Outside Air Temperature (°C) | Trim Calibrated Airspeed (kts) | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| Lateral Directional Dynamic Stability | 3 FMC OFF Trim ON | Short-Term Response | Level | 18,130 | 202.7 | 6,040 | 8.0 | 81 | 1-in. pedal pulse/doublet; release from SHSS. |
| | | | Max Cont Q Climb | 18,290 | 202.8 | 5,800 | 7.0 | 80 | |
| | | | 1,000-fpm Descent | 18,310 | 202.7 | 6,160 | 6.0 | 91 | |
| | | Spiral Mode | Level Turns | 17,950 | 202.7 | 6,020 | 8.0 | 80 | 10-deg, 20-deg, and 30-deg AOB. |
| | 5 FMC ON Trim ON | Short-Term Response | Level | 18,500 | 202.4 | 6,010 | 5.0 | 81 | 1-in. pedal pulse/doublet; release from SHSS. |
| | | | Max Cont Q Climb | 18,890 | 202.5 | 6,020 | 10.5 | 81 | |
| | | | 1,000-fpm Descent | 18,890 | 202.5 | 6,120 | 9.5 | 81 | |
| | | Spiral Mode | Level Turns | 18,760 | 202.4 | 6,040 | 5.0 | 80 | 10-deg, 20-deg, and 30-deg AOB. |
| | 5 FMC OFF Trim ON | Short-Term Response | Level | 18,870 | 202.4 | 6,050 | 5.0 | 81 | 1-in. pedal pulse/doublet; release from SHSS. |
| | | | Max Cont Q Climb | 18,730 | 202.5 | 6,260 | 10.5 | 81 | |
| | | | 1,000-fpm Descent | 18,710 | 202.5 | 6,040 | 9.0 | 91 | |
| | | Spiral Mode | Level Turns | 18,660 | 202.4 | 6,040 | 5.0 | 80 | 10-deg, 20-deg, and 30-deg AOB. |
| Maneuvering Stability | 3 FMC ON Trim ON | | Level | 18,270 | 203.0 | 6,130 | 8.0 | 81, 109 | Wind-up turns, pullup, and pushover. |
| | 3 FMC ON Trim ON | | | 18,110 | 202.9 | 6,090 | 7.0 | 81, 110 | |

Table 3. Continued

**NOTES:**

[1]IMC/IFR - instrument meteorological conditions/instrument flight rules
[2]Test procedures in accordance with (IAW) U.S. Naval Test Pilot School-Flight Test Manual (USNTPS-FTM) No. 107 (ref 10)
[3]FS - fuselage station
[4]Heavy weapons configuration from the A&FC phase I & II test plans (ref 7 & 8)
[5]FMC - flight management computer
[6]Q -torque
[7]fpm - feet per minute
[8]Two tank configuration from the A&FC phase I & II test plans (ref 7 & 8)
[9]SHSS - steady heading sideslip
[10]AOB - angle of bank

Table 4. Mission Maneuvers Tests and Test Conditions for IMC/IFR

| Maneuver | Configuration[2]/ Mode of Operation | Adequate Performance | Desired Performance | ATM[3] Flight Task Number |
|---|---|---|---|---|
| Instrument Takeoff | FMC[4] ON<br>MPD[5] ON | Heading ±10 deg<br>Pitch Attitude ±5 deg | Heading ±5 deg;<br>Pitch Attitude ±2 deg | 1200 |
| Radio Navigation | FMC ON and OFF<br>MPD ON | Altitude ±100 ft<br>Airspeed ±10 kt<br>Desired Track ± 10 deg | Altitude ±50 ft;<br>Airspeed ±5 kt;<br>Desired Track ±5 deg | 1205 |
| Precision Approach | FMC OFF<br>MPD ON and OFF | Altitude ±100 ft<br>Airspeed ±10 kt<br>Heading ±5 deg | Altitude ±50 ft;<br>Airspeed ± 5 kt;<br>Heading ±2 deg | 1215 |
| Nonprecision Approach | FMC OFF<br>MPD ON (ADF[6] Approach) and OFF (ASR[7] Approach ) | Altitude ±100 ft<br>Airspeed ±10 kt<br>Heading ±5 deg<br>Course Maint. ±5 deg | Altitude ±50 ft;<br>Airspeed ±5 kt;<br>Heading ±2 deg;<br>Course Maint. ±3 deg | 1220 |
| GPS[8] Approach | FMC OFF<br>MPD ON | Altitude ±100 ft<br>Airspeed ±10 kt<br>Heading ±5 deg<br>Course Maint. ± 5 deg | Altitude ±50 ft;<br>Airspeed ±5 kt;<br>Heading ±2 deg;<br>Course Maint. ±3 deg | 1240 |
| Unusual Attitude Recovery[9] | FMC OFF<br>MPD ON and OFF | Attitude, heading, airspeed, and torque set for level flight in 3 sec or climbing flight in 5 sec. | | 1245 |

NOTES:

[1]IMC/IFR - instrument meteorological conditions/instrument flight rules
[2]Configuration 3 as per A&FC test plans (ref 7 & 8).
[3]ATM - aircrew training manual
[4]FMC - flight management computer
[5]MPD - multipurpose display
[6]ADF - automatic direction finder
[7]ASR - airport surveillance radar
[8]GPS - global positioning system
[9]Unusual attitude test condition did not exceed ±20 deg in pitch, ±45 deg in roll

## 2. RESULTS AND DISCUSSION

### STANDBY INSTRUMENT COMPARISON

6. The test boom Pitot-static system of the instrumented aircraft (ASN 99-05132) was calibrated using a trailing Pitot-static device during the A&FC test. The standby altitude and airspeed instrument readings were compared to the data from the test boom system.

#### Standby Airspeed Indicator (ASI)

7. The standby ASI (fig 4) was graduated in 10-kt increments with a nonlinear scale. The scale was greatest between 50 knots indicated airspeed (KIAS) and 100 KIAS, the speed range normally used for instrument flight. The aircraft was stabilized at 6,600 ft density altitude ($H_d$) and 30 knots calibrated airspeed (KCAS). Airspeed was increased in approximately 10-kt increments to maximum level flight airspeed ($V_H$) at 116 KCAS, after which a maximum continuous power (MCP) dive was established to capture data to 142 KCAS. At 142 KCAS, the vibration levels were such that further acceleration was discontinued (Appendix D, fig D-1). Below 40 KCAS, the standby ASI was unusable with the reading fluctuating between 35 KIAS and 0 KIAS. The standby ASI generally gave readings between 8 and 10 kts lower than the boom KCAS. The maximum inaccuracy was observed in the unusable range and the minimum inaccuracy was 6 kts at 110 KIAS (116 KCAS). The standby airspeed was evaluated during climbs and descents from 3,000 to 7,000 ft pressure altitude. Target airspeeds were 80 and 50 KIAS for the climbs, and 90 and 50 KIAS for the descents. During descents, the standby airspeed indications appeared to be stable and consistent; however, during climbs below 70 KIAS, the standby ASI intermittently under read the test boom airspeed by up to 40 KIAS. When above 70 KIAS, the standby ASI readings correlated with the test boom indications. Using the standby ASI as a reference, indicated airspeeds above 70 KIAS could be maintained within ±5 kts. The ATM standard is ±10 kts for IMC tasks, and the standby ASI is satisfactory for IMC flight with the minimum airspeed restrictions stated in paragraph 9.

#### Minimum Speed On Standby Instruments

8. During the level speed sweep discussed in paragraph 8, the standby ASI was unusable at airspeeds less than 40 KIAS with the needle fluctuating between 35 KIAS and 0 KIAS. A pilot attempting to fly an accurate airspeed using standby instruments at airspeeds less than 40 KIAS would not have a usable

airspeed reference. Recommend minimum speed for level and descending flight on standby instruments is 50 KIAS. Recommend minimum airspeed for climbs is 70 KIAS.

**Standby Altimeter**

9. The standby altimeter indication (fig 3) was compared to the boom calibrated altimeter indication in level flight, climbs, and descents at altitudes from 3,000 ft indicated to 7,000 ft indicated. In level flight at 90 KIAS, the average difference between the two indications was approximately 50 ft with the standby altimeter being higher in every case (fig D-2). The minimum difference recorded was 23 ft and the maximum difference recorded was 77 ft, exceeding the specification tolerance (ref 5) of ±50 ft for speeds above 50 KCAS. During an approach using standby instruments, the aircraft was up to 60 ft lower than the standby altimeter indication. In climbs (fig D-3) and descents (fig D-4) flown at 90 KIAS, the standby altimeter was observed to lag the test boom indication. The lag increased with the rate of climb/descent, resulting in observed errors of 300 ft during a 1,500 fpm descent, 200 ft during a 1,000 fpm descent, and 100 ft during a 500 fpm descent. Both the static and lag errors caused the standby altimeter to read higher than the aircraft was above the ground. The errors associated with the standby altimeter could cause the pilot to unknowingly fly the aircraft below the published minima on an instrument approach, whereby the aircraft could impact the ground. The inaccuracy of the standby altimeter is a **deficiency**. Recommend the following warning be included in the operator's manual (ref 6):

**WARNING**

**Errors up to 300 ft could be present in the standby altimeter during climbs and descents resulting in the aircraft impacting the ground during an instrument approach in IMC conditions. When flying the aircraft in IMC conditions with the only reference being the standby instruments, the crew should, when flying a non-precision instrument approach, add 100 ft to the minimum descent altitude (MDA) or 200 ft for a precision approach's decision height (DH) to mitigate the static/dynamic error possibilities.**

## ENGINEERING MANEUVERS

10. All engineering maneuvers were flown in configurations 3 and 5 as presented in table 1. Configuration 3 represented the worst case for stability of the two configurations tested, and the results of that configuration are reported below. Results related to specific IMC mission tasks are discussed in paragraphs 19 through 50.

### Flight Control Mechanical Characteristics

11. The flight control mechanical characteristics (FCMCs) of the AH-64D Longbow Apache were fully documented during the A&FC phase 1 testing (not yet published). The FCMCs were evaluated qualitatively throughout the IMC/IFR evaluation. No issues attributable to FCMC shortcomings or deficiencies were identified.

### Trimmed Flight Control Positions

12. Trimmed flight control positions were recorded, with FMC ON and OFF, under the conditions presented in table 3. Forward cyclic was required with increasing forward airspeed in all cases, and all control forces could be trimmed to zero. No control margins were approached.

### Longitudinal Static Stability

13. The static longitudinal stability characteristics were evaluated in configuration 3 during the A&FC testing and exhibited the following results. Positive static longitudinal stability was exhibited by the requirement for increased forward longitudinal control displacement from trim to increase airspeed and increased aft longitudinal control displacement from trim to decrease airspeed for all configurations and conditions. Although the gradients were positive, they were shallow, which resulted in little to no control force or control displacement cueing to the pilot around the trim point alerting the pilot that an off trim condition was present. During flight requiring précised pitch control as needed during instrument meteorological conditions, the pilot workload will be higher because of the need to constantly move the cyclic forward and aft to maintain altitude and airspeed. However, with a fully operational system, the aircraft's hold modes reduced the workload by maintaining the aircraft's attitude when needed in those types of flight environments. Overall, the AH-64D exhibited positive longitudinal static stability, and with the aid of the aircraft's hold modes the longitudinal static stability was satisfactory.

**Longitudinal Dynamic Stability**

14. The longitudinal dynamic stability of the AH-64D Longbow Apache was evaluated with FMC ON and OFF under the conditions presented in table 3. Data are presented in Appendix D, figures D-5 through D-11. The short-term response was deadbeat at all conditions. The long-term response was always oscillatory divergent (fig D-5 through D-9). The period varied from 22 sec at 81 KCAS with FMC OFF to 40 sec at 112 KCAS with FMC ON. The response was highly coupled with pitch down-roll left and pitch up-roll right with both FMC ON and OFF. At 110 KCAS with the FMC OFF, the aircraft developed a divergent LDO response that was not the same as presented in paragraph 16 and therefore, the long-term pitch response was not identified (fig D-8). Maximum power climbs produced the most rapid development of the divergent response (fig D-9). With the pilot in the loop, the long-term response was easy to suppress and, although lightly damped in pitch, the aircraft was easily controllable with FMC OFF. The aircraft's longitudinal gust response with FMC OFF required extensive pilot compensation to maintain altitude and airspeed within adequate parameters, further increasing the overall pilot workload, and is a **deficiency**.

**Lateral Directional Dynamic Stability**

LATERAL DIRECTIONAL OSCILLATION (LDO)

15. The LDO tendency of the AH-64D Longbow Apache was evaluated during releases from steady heading sideslip and pedal doublets, followed by maintaining controls fixed under the conditions presented in table 3. Data are presented in Appendix D in figures D-12 and D-14. With FMC ON, the response was deadbeat; one or two small overshoots could be seen in instrumentation time histories but were imperceptible to the crew (fig D-12). With FMC OFF, the LDO was easily excited and varied from oscillatory convergent to nearly neutral (fig D-13). The LDO had a peak-to-peak period of approximately 4.3 sec and provoked a secondary response in the pitch axis. With the pilot in the loop, the LDO was controllable but was always perceptible. Controllability was not in question.

SPIRAL STABILITY

16. Spiral stability was evaluated with FMC ON and OFF under the conditions presented in table 3. Data are presented in Appendix D, figures D-15 through D-21. The aircraft was established in trimmed level flight, bank angles were increased to 10 and 20 deg left and right, and the cyclic was returned to the trim

position. Aircraft response was noted, and the time to half or double amplitude was recorded. Spiral stability at 80 KCAS with FMC ON (fig D-15) was weak but positive following return to trim from both left and right bank angles; return to half amplitude was slower from right bank angles than from left bank angles. FMC OFF showed the same results with the underlying LDO present (fig D-16). At 110-KCAS, target airspeed with FMC ON (fig D-17), turns to the left showed positive spiral stability, but turns to the right resulted in neutral to negative spiral stability. At 110-KCAS target airspeed with FMC OFF (fig D-18), the spiral stability was positive; however, the aircraft entered a divergent LDO that was not the same characteristics as presented in paragraph 15 when the cyclic was returned to trim from both left and right bank angles. With the pilot in the loop, the LDO was controllable but was always perceptible. Controllability was not in question.

SIDEFORCE CUES

17. Sideforce cues were evaluated during the setup for release from steady heading sideslips. Sideforce cues, as indicated by increasing bank angle with increasing sideslip, were weak but positive from trim to ±10-deg sideslip. Proprioceptive cues during out-of-balance flight were so weak at ±5-deg and below that the pilot was unaware of an out-of-balance condition without reference to the trim ball indicator.

**Maneuvering Stability**

18. Maneuvering stability was evaluated with FMC ON and OFF under the conditions presented in table 3. Data are presented in Appendix D, figures D-22 through D-25. Collective fixed wind-up turns and pullups and pushovers were used to document the maneuvering stability characteristics. At 80 KCAS with FMC ON (fig D-22), the aircraft exhibited positive maneuvering stability to the left and right during wind-up turns and during pullups and pushovers (fig D-23). With FMC OFF, the LDO was apparent and maintaining flight condition was difficult although the maneuver stability was positive. At 110-KCAS target airspeed with FMC ON (fig D-24), the maneuvering stability was positive during left wind-up turns and during right wind-up turns. Pullups and pushovers (fig D-25) indicated positive maneuvering stability at load factors of approximately 0.5 to 1.4. With FMC OFF, the wind-up turns were extremely susceptible to the LDO and were not stable enough for useful data collection. The FMC OFF pullups and pushovers indicated positive maneuvering stability at load factors of 0.2 to 1.8. At speeds greater than 110 KIAS

standby with FMC OFF, the LDO could not be suppressed. At the 40-deg bank angle, the aircraft exhibited a four-per revolution vibration (VAR 8) that quickly progressed to VAR 10 as the bank angle approached 50 deg. The aircraft's installed instruments and the instrumented display could not be read due to the vibrations. Recommend maximum angle of bank during flight in IMC be limited to 30 deg.

**MISSION MANEUVERS**

19. Mission maneuvers were flown from the pilot's station by three different pilots with no outside visual references. The canopy was masked approximately 2/3 up the side screens and completely across the forward screen. The pilot wore an instrument-training hood, and a safety pilot was in the front seat for all maneuvers. HQRs were used to quantify results when the results were other than satisfactory. No initial training or workup was included for the assessing pilots.

**Instrument Takeoff**

20. The instrument takeoff (ITO) was flown from the ground or hover with the FMC ON and hold modes disengaged. The maneuver consisted of torque increase with collective, heading maintenance with pedal, and attitude selection and maintenance with cyclic. All pilots found the maneuver easy to fly with only small adjustments to the controls required after the initial parameters were captured.

a. Heading maintenance was assessed during an ITO. During climb out, the collective was increased smoothly from full down to approximately 8 in. up within 6 sec to achieve a target torque of 90 to 95 percent. Maintaining heading within ±5 deg was easy requiring 1/2-in. pedal inputs. Heading maintenance during an ITO in the AH-64D helicopter was satisfactory.

b. Pitch attitude capture was assessed during an ITO. During climb out, the collective was increased smoothly from full down to approximately 8 in. up within 6 sec to achieve a target torque of 90 to 95 percent. During climb out, capturing pitch attitude within ±2 deg within 1 or 2 sec was easy, requiring one gross pitch input and one to two subsequent smaller inputs. Pitch attitude capture during an ITO in the AH-64D helicopter was satisfactory.

c. Pitch attitude maintenance was assessed during an ITO. During climb out, with the ATT hold mode OFF, the collective was increased smoothly from full down to approximately 8 in. up within 6 sec to achieve a target torque of 90 to 95 percent. During climb out, maintaining pitch attitude within ±5 deg required moderate pilot compensation (frequent 1/2- to 3/4-in. longitudinal cyclic inputs). Pitch attitude maintenance during an ITO in the AH-64D helicopter was satisfactory.

**Radio Navigation FMC On**

21. The Tri-County Airport, Bonifay, FL, nondirectional beacon (NDB) was selected for radio navigation. When the desired heading to the NDB had been established, the attitude and altitude holds were engaged and only minor course corrections were required.

a. Track maintenance was assessed during radio navigation with the FMC ON and the ATT and ALT hold modes activated. Determining an accurate track using the automatic direction finder (ADF) pointer on the ADF page was difficult due to the needle continually swinging left and right approximately ±5 deg and the nonconventional head of the pointer extending through the horizontal situation indicator (HSI) display. Track maintenance was augmented by navigating to a stored waypoint location of the NDB (RTE DIR) and using the digital heading display on the bottom of the tactical situation display (TSD) page. Although not initially perceptible to the pilot, the aircraft heading drifted off course within one minute. The heading had changed as much as 5 deg within 1 minute requiring frequent lateral cyclic inputs of one input approximately every 5 sec to return to the desired track. Maintaining track within ±5 deg while maintaining altitude within ±50 ft and airspeed within ±5 kt required constant attention and therefore increased pilot workload. Track maintenance during radio navigation in the AH-64D helicopter with the FMC ON and the ATT and ALT hold modes activated was satisfactory.

b. Altitude maintenance was assessed during radio navigation with the FMC ON, the ATT and ALT hold modes activated, and the aircraft in trim. Maintaining altitude within ±50 ft while maintaining ground track within ±5 deg and airspeed within ±5 kt was easy, requiring infrequent small longitudinal cyclic inputs. Altitude maintenance during radio navigation in the AH-64D helicopter with the FMC ON and the ATT and ALT hold modes activated was satisfactory.

c. Airspeed maintenance was assessed during radio navigation with the FMC ON, the ATT and ALT hold modes activated, and the aircraft in trim. Maintaining airspeed within ±5 kt while maintaining ground track within ±5 deg and altitude within ±50 ft was easy, requiring infrequent small longitudinal cyclic inputs. Airspeed maintenance during radio navigation in the AH-64D helicopter with the FMC ON and the ATT and ALT hold modes activated was satisfactory.

**Radio Navigation With FMC Off**

22. The FMC was selected OFF during the radio navigation to the Bonifay NDB.

a. Track maintenance was assessed during radio navigation with the FMC OFF. Determining an accurate track using the ADF pointer on the ADF page was difficult due to the needle continually swinging left and right approximately ±5 deg and the nonconventional head of the pointer extending beyond the HSI display. Track maintenance was augmented by navigating to the waypoint location of the NDB (RTE DIR) and using the digital display on the bottom of the tactical situation display (TSD) page. Without pilot input, the aircraft consistently turned slowly to the right as stated in paragraph 21(a) above. Occasional light turbulence caused a persistent lightly damped LDO that caused aircraft heading to migrate naturally approximately ±3 deg, requiring the pilot to stay in the loop to stabilize the track and suppress a secondary response in the pitch axis. Suppression of the pitch axis response required constant attention to avoid pilot induced oscillation. Maintaining track within ±5 deg while maintaining altitude within ±50 ft and airspeed within ±5 kt required a faster instrument scan and therefore, increased the workload of the pilot from that required for FMC ON. Track maintenance during radio navigation in the AH-64D helicopter with the FMC OFF was satisfactory.

b. Altitude maintenance was assessed during radio navigation with the FMC OFF. In light turbulence, the aircraft gust response in the pitch axis was easily excited. Although the response was controllable, the pilot was required to constantly adjust the frequency and size of cyclic control inputs to avoid pilot induced oscillation about the pitch axis. The pitch excursions were more difficult to control in light turbulence and during turning flight due to the highly coupled aircraft response while making off-axis (roll and yaw) corrections. Maintaining altitude within ±50 ft while maintaining ground track within ±5 deg and airspeed within ±5 kt required frequent 1/2- to 3/4-in. longitudinal cyclic inputs. Altitude maintenance during radio navigation in the AH-64D helicopter with the FMC OFF was satisfactory.

c. Airspeed maintenance was assessed during radio navigation with the FMC OFF. In light turbulence, the aircraft gust response in the pitch axis was easily excited. Although the response was controllable, the pilot was required to constantly adjust the frequency and size of cyclic control inputs to avoid pilot induced oscillation. Maintaining airspeed within ±5 kt while maintaining ground track within ±5 deg and altitude within ±50 ft required frequent 1/2- to 3/4-in. longitudinal cyclic inputs. Airspeed maintenance during radio navigation in the AH-64D helicopter with the FMC OFF was satisfactory.

**NDB Approach**

23. A full NDB approach was flown FMC OFF by each pilot to the Bonifay NDB, followed by a missed approach.

a. Heading capture was assessed during an NDB approach with the FMC OFF. The extreme sensitivity of the digital heading readout on the FLT page and TSD page caused the pilot to rely on the turn indicator on the FLT page and the HSI display (disregarding the digital readout). Capturing heading within ±5 deg while maintaining altitude within ±100 ft and airspeed within ±10 kt increased pilot workload requiring a more precise crosscheck than during radio navigation with FMC ON. Heading capture during an NDB approach in the AH-64D helicopter with the FMC OFF was satisfactory.

b. Heading maintenance (to maintain ground track) was assessed during an NDB approach with the FMC OFF. The ADF page was a crowded display, and determining an accurate track using the ADF pointer on the ADF page was difficult due to the needle continually swinging left and right approximately ±5 deg and the nonconventional head of the pointer extending beyond the HSI display. Track maintenance was augmented by navigating to the waypoint location of the NDB (RTE DIR) and using the digital display on the bottom of the TSD page. Without pilot input while in occasional light turbulence, a lightly damped LDO was persistent, causing the aircraft heading to fluctuate naturally approximately ±3 deg. Desired performance was not attained. Maintaining heading within adequate performance (±5 deg) while maintaining altitude within ±50 ft and airspeed within ±5 kt required frequent (every 1 to 1.5 sec) small pedal and cyclic movements and a faster instrument scan than with FMC ON (HQR 5). The combination of increased workload having FMC OFF during an approach, tracking an ADF needle that naturally oscillates ±5 deg, and maintaining a heading that should result in a good inbound track was very difficult. Heading maintenance during an NDB approach in the AH-64D helicopter with the FMC OFF was unsatisfactory.

c. Altitude maintenance was assessed during an NDB approach with the FMC OFF. Without pilot input, the aircraft gust response in the pitch axis was easily excited, requiring the pilot stay in the loop to maintain pitch control while continually adjusting the frequency and size of cyclic control inputs to avoid pilot induced oscillation. Pitch attitude variation was the primary cause of altitude excursions and the pitch axis was identified as the highest workload axis in straight and level and turning level flight. Maintaining altitude within ±100 ft while maintaining ground track within ±3 deg and airspeed within ±10 kt required extensive pilot compensation, demanding a faster instrument scan than with FMC ON and frequent 1/2- to 3/4-in. longitudinal cyclic inputs (HQR 6). The pitch excursions were more difficult to control in light turbulence and during turning flight due to the highly coupled aircraft response while making off-axis (roll-and-yaw) corrections. The easiest technique for altitude control was to fly a fixed power setting and correct any excursion with longitudinal cyclic. The sensitivity and the resolution (to 10 ft) of the digital altitude on the FLT page made the pilot aware of the error, which prompted him to continually correct any altitude excursions and thereby exacerbated the tendency of the pilot to enter a pilot induced oscillation (PIO). Altitude maintenance during an NDB approach in the AH-64D helicopter with the FMC OFF was unsatisfactory. The aircraft's longitudinal gust response with FMC OFF is a **shortcoming**, requiring extensive pilot compensation to maintain altitude within adequate parameters.

d. Airspeed maintenance was assessed during an NDB approach with the FMC OFF. Without pilot input, the aircraft gust response in the pitch axis was easily excited, requiring the pilot make constant cyclic control inputs to maintain pitch attitude. Excursions of up to ±7 kt were observed in smooth air. The pitch excursions were more difficult to control in light turbulence and during turning flight due to the highly coupled aircraft response while making off-axis (roll-and-yaw) corrections. Maintaining altitude within ±50 ft while maintaining ground track within ±3 deg and airspeed within ±10 kt required a faster instrument scan than with FMC ON and frequent 1/2- to 3/4-in. longitudinal cyclic inputs (HQR 6). Airspeed maintenance during an NDB approach in the AH-64D helicopter with the FMC OFF was unsatisfactory. The aircraft's longitudinal gust response with FMC OFF is a **shortcoming**, requiring extensive pilot compensation to maintain airspeed within adequate parameters.

e. Bank angle maintenance was assessed during an NDB approach with the FMC OFF. Although no performance targets were identified for bank angle maintenance while attempting to maintain a standard rate or half standard rate turn was identified, all evaluation pilots noted high workload in the lateral axis. Constant lateral cyclic inputs of 1/4 in. to 1/2 in. were required to maintain the selected roll attitude, particularly during turns to the right when the aircraft tended to continue into the turn without pilot input. Additionally, the standard-rate turn indicator on the FLT page was very sensitive to any control movement prompting constant roll attitude adjustment in an effort to maintain a standard rate turn. Descending turns further increased pilot workload to the point where maintaining a standard rate turn during descent was not possible. This mission maneuver data confirms the engineering spiral data obtained and referenced in paragraph 16 above. Recommend that during IMC flight with FMC OFF all turns should be conducted in level flight before descending.

f. Trim control was assessed during an NDB approach in the AH-64D helicopter with the FMC OFF. Following power changes, it was moderately difficult for the pilot to discern the aircraft trim without reference to the trim ball indicator on the aircraft's FLT page. The pilot was consequently forced to bias his instrument scan around the trim ball indicator reducing the time spent on other flight instruments. This aircraft characteristic was also noted during the engineering maneuvers presented in paragraph 17. Trim maintenance during an NDB approach in the AH-64D helicopter with the FMC OFF was satisfactory.

**Global Positioning System (GPS) Approach**

24. The GPS approach was flown to Tri-County Airport, Bonifay, with the FMC OFF. The crew entered the coordinates of the NDB as a waypoint, and a direct inbound route was selected. This provided the crew with a symbolic stick representation of the route on the display resulting in better situational awareness to the pilot of the aircraft's position during the approach. In general, the characteristics of the GPS approach were similar to those of the NDB approach except as noted below. NDB approach findings are in paragraphs 23a through 23f. The absence of the ADF needle on the TSD page reduce the pilot's instrument scan requirements to the point that the emergency GPS approach was easier to perform than the ADF approach. A means of displaying torque and VSI should be provided in the event of a total AC electrical failure. Differences are detailed below.

a. Maintaining altitude within ±100 ft while maintaining ground track within ±3 deg and airspeed within ±10 kt required frequent 1/2- to 3/4-in. longitudinal cyclic inputs and a faster instrument scan than with FMC ON (HQR 6). Altitude maintenance during a GPS approach in the AH-64D helicopter with the FMC OFF was unsatisfactory. The aircraft's longitudinal gust response with FMC OFF is the same as previously stated in paragraph 23c.

b. Maintaining airspeed within ±10 kt while maintaining ground track within ±3 deg and altitude within ±100 ft required frequent 1/2- to 3/4-in. longitudinal cyclic inputs and a faster instrument scan than with FMC ON. Airspeed maintenance during a GPS approach in the AH-64D helicopter with the FMC OFF was unsatisfactory. The aircraft's longitudinal gust response with FMC OFF is the same as previously stated in paragraph 23d.

c. Maintaining heading within ±3 deg while maintaining airspeed within ±5 kt and altitude within ±50 ft required frequent 1/2- to 3/4-in. longitudinal cyclic inputs and a faster instrument scan resulting in increased workload than with FMC ON. However, maintaining heading during the GPS approach was aided symbolically by having the inbound course presented on the ADF or TSD page. The pilot was able to fly the heading required to maintain the aircraft on the desired track presented on the display. The TSD/ADF display increased the pilot's situational awareness and therefore decreased the pilot's workload. Heading maintenance during a GPS approach in the AH-64D helicopter with the FMC OFF was satisfactory.

**Unusual Attitude Recovery Using Standby Instruments Only**

25. Unusual attitude recovery was conducted with a simulated dual-generator failure (only 28 volts direct current (Vdc) power available). The recovery was conducted using the pilot's standby instrumentation only (magnetic compass, barometric altimeter, attitude indicator, and airspeed indicator).

a. Effecting the initial step of the unusual attitude recovery was easy and intuitive, and the pilot easily selected a level attitude using the standby instrumentation within 3 sec.

b. Significant difficulty was experienced, however, during subsequent steps of the recovery. Due to the absence of immediate altitude trend information (VSI) or a perceptible downward acceleration, the pilot was unaware of any descent for 3 to 5 sec due to the lag in the altimeter. Furthermore, without any torque indication, establishing a climb within 5 sec was difficult and required considerable pilot compensation. The pilot adjusted the collective to the best estimate of maximum torque to arrest any descent and waited for either a noticeable upward acceleration or a climb on the altimeter (approximately 5 sec) (HQR 5). The perception of upward or downward acceleration will most likely not be available following pilot disorientation. Where the aircraft is turbine gas temperature (TGT) limited (e.g., high density altitude), the pilot will have difficulty estimating maximum torque. Increasing torque beyond this value will cause main rotor-droop. The combination of disorientation and the absence of torque and timely vertical speed information would make it improbable that the pilot could attain and maintain performance parameters as precisely as necessary to effect a successful radar recovery. Although attaining a level attitude was possible, establishing a climb in the AH-64D helicopter during an unusual attitude recovery with a simulated FMC failure and dual-generator failure (only 28 Vdc power available) using the pilot's standby instrumentation was not satisfactory. The pilot had no immediate awareness of how much power was applied to the aircraft other than the collective movement, and that coupled with the altimeter lag that was noted in paragraph 10 above, made the experienced pilot apprehensive and worried about over torquing the aircraft. The standby instrument suite in the AH-64D Longbow Apache is inadequate to recover safely from an unusual attitude with a dual-generator failure. The inadequate standby instrument suite is a **deficiency**. Recommend redesigning the standby instrumentation in the AH-64D Longbow Apache.

**Airport Surveillance Radar (ASR) Approach Using Standby Instruments Only**

26. A simulated No-Directional Gyro ASR approach was flown to Cairns Army Airfield (AAF), Fort Rucker, with vectors to final provided by Cairns Airfield Radar Approach Control (ARAC).

a. Altitude and airspeed maintenance, altitude capture, and heading maintenance were assessed during an ASR approach with FMC OFF using the pilot's standby instrumentation only (magnetic compass, barometric altimeter, attitude indicator, and airspeed indicator). Details of radio navigation (No Directional Gyro) are in paragraphs 22a through 22c. In general, altitude, airspeed, and heading maintenance were more difficult than simple radio navigation due to the approach involving turning and descending flight. Because of the absence of trend information and the errors associated with the standby instruments, an operational pilot would not be able to perform a successful ASR approach and level off at minimum descent altitude (MDA), which could result in the aircraft impacting the ground/obstacles during the approach.

b. Altitude capture was assessed during an ASR approach with FMC OFF using the pilot's standby instrumentation. Due to the absence of any altitude trend information (VSI), the pilot was unaware of any residual climb/rate of descent for 3 to 5 sec due to the lag in the altimeter, and altitude excursions of 100 to 300 ft often occurred. Pitch attitude excursions accompanying a power change to arrest a climb/descent made capturing the altitude more difficult. Although controllability was not in question, the combination of limited altitude trend information, no torque indication, and pitch sensitivity to collective inputs made stopping the aircraft within 300 ft of the target altitude following a climb/descent not possible even with maximum pilot compensation. The pilot adjusted the collective to his best estimate and waited approximately 5 sec for the altimeter to indicate that the climb/descent had stopped. The ability of the pilot to capture an altitude was further aggravated by the lag noted in the standby altimeter as noted in paragraph 10 above. Because of the absence of trend information and the errors associated with the standby instruments, an operational pilot would not be able to perform a successful ASR approach and level off at minimum descent altitude (MDA), which would result in the aircraft impacting the ground/obstacles during the approach. Altitude capture in the AH-64D helicopter following a climb/descent during an ASR approach with FMC OFF using the pilot's standby instrumentation was not satisfactory. The inadequate standby instrument suite, which would prevent the pilot from flying a successful ASR approach, is a **deficiency**. Recommend redesigning the standby instrumentation in the AH-64D Longbow Apache.

**<u>Precision Approach Radar (PAR) Using Standby Instruments Only</u>**

27. A No Directional Gyro PAR approach was flown to Cairns AAF with vectors to final provided by Cairns ARAC.

a. Altitude, airspeed and heading maintenance, and altitude capture were assessed during a PAR approach with FMC OFF using the pilot's standby instrumentation (magnetic compass, barometric altimeter, attitude indicator, and airspeed indicator). Details of the ASR approach are in paragraphs 26a and 26b. The workload when maintaining altitude, airspeed, and heading during the PAR approach was equal to the workload experienced during the ASR approach with the same results.

b. Glideslope maintenance was assessed during a PAR approach with FMC OFF using the pilot's standby instrumentation. As detailed during the ASR approach 26a and 26b, the absence of any altitude trend information (VSI) and torque indication, the pilot was unaware of the rate of descent for 3 to 5 sec due to the lag in the altimeter (para 10). Maintaining glideslope within "slightly above/slightly below" glideslope was difficult and required extensive pilot compensation. The pilot adjusted the collective to his best estimate and waited for the controller to make subsequent corrections. Without more extensive cues from the standby instrument suite, an operational pilot would unlikely be able to perform a successful PAR approach. Glideslope maintenance in the AH-64D helicopter following a climb/descent during a PAR approach with FMC OFF using the pilot's standby instrumentation was not satisfactory. The inadequate standby instrument suite, which would prevent the pilot from flying a successful PAR approach in a fully degraded mode, is a **deficiency** and resulted in the same results and recommendation as paragraph 26b.

## OTHER FINDINGS

28. The following findings related to IMC/IFR flight resulted from this flight test effort:

### Battery Life

29. The current AH-64D Longbow Apache battery has a stated minimum life of 12 min following a dual-generator failure if the battery is at least 80 percent charged. The Federal Aviation Administration (FAA) Regulation (FAR) Part 29 (ref 2) requires a 30-min power supply for a standby attitude indicator. While flying in an IMC environment and a power failure occurs, the crew would not have any reliable instruments and no communications available to fly the aircraft to visual meteorological conditions (VMC) and would result in the loss of aircraft and crew. The design of the battery installed in the AH-64D Longbow Apache does not meet the 30-min requirement for IMC/IFR flight and results in a **deficiency**. An independent power supply, capable of providing at least 30 min power for standby instruments and flight safety critical systems, is recommended.

### GPS Database

30. The GPS currently installed in the AH-64D Longbow Apache does not contain a noncorruptible database, which is a requirement for compliance with the FAA Technical Standard Order (TSO) C129a (ref 3) for a supplemental navigation system. The GPS associated with the embedded global positioning

system/inertial navigation system (EGI) in the AH-64D Longbow Apache does not meet the requirements of the FAA TSO C129a (ref 3). A TSO C129a-compliant navigation system is recommended.

**Training**

31. If crews are to perform IMC/IFR flight in the AD-64D Longbow Apache, a thorough and regular training is essential, particularly with respect to the standby instruments. Recommend maximum use of simulators be made to train crews for IMC/IFR flight and that the AH-64 ATM (ref 12) include a requirement to train regularly in the use of standby instruments. Consideration should be given to setting a minimum training requirement for IMC/IFR currency.

**Operator's Manual**

32. The AH-64D operator's manual paragraph 8.33 (ref 6) incorrectly states that the aircraft is cleared for flight in IMC.

The operator's manual paragraph 8.34 titled "INSTRUMENT FLIGHT PROCEDURES" contains the following: "Refer to FLIP, AR 95-1, FAR Part 91 and FM 1-240." A Boeing report on the AH-64D Longbow Apache requirements for operations in IMC (ref 1n) identifies a requirement for specific IMC/IFR information to be included in the operator's manual (ref 6). Such information would include instrument $V_y$ (best climb speed), $V_{MIN}$ (minimum speed on instruments), special instrument procedures, and IFR emergency procedures. The absence of any information on IMC/IFR procedures in the operator's manual (ref 6) is a **shortcoming**. Paragraph 8.34 of the operator's manual (ref 6) should be written to provide specific advice on IMC/IFR flight operations and procedures.

# 3. CONCLUSIONS

## GENERAL

33. An assessment of the handling of the AH-64D for flight in IMC and under IFR was conducted. Testing was performed in the configurations listed in table 1 and under the conditions presented in tables 3 and 4. All test objectives were met. IMC mission maneuvers with all systems working resulted in satisfactory handling qualities with no excessive compensation required from the pilot (altitude and attitude holds ON). However, as the aircraft systems were progressively degraded the workload for the evaluating pilot increased significantly. The high workload coupled with the absence of a vertical speed indicator (VSI) and torque indication during an AC failure and the observed errors in the standby altimeter and airspeed indicators would most likely prevent flying a successful unusual attitude recovery, an airport surveillance radar (ASR) approach, or a precision approach radar (PAR) approach. The inadequacy of the standby instruments is a **deficiency**. The aircraft's longitudinal gust response with FMC OFF required extensive pilot compensation to maintain altitude and airspeed within adequate parameters, further increasing the overall pilot workload, and is a **deficiency**. Additionally, the aircraft's battery life does not meet the 30-min requirement for IMC/IFR flight that would be required in the unlikely event of an aircraft AC power failure and results in a **deficiency**. Engineering maneuvers conducted to quantify the handling qualities of the AH-64D with FMC OFF confirmed the high pilot workload and extensive compensation required. These maneuvers revealed an oscillatory divergent long-term mode, an oscillatory divergent lateral-directional oscillation (LDO), negative spiral stability when banked to the right, and significant coupling between pitch and roll. While conducting these maneuvers, excessive instrumentation lag was observed in the standby altimeter during climbs and descents. This resulted in errors of up to 300 ft between boom data and the standby altimeter. The excessive observed instrument lag and inaccuracy of the standby altimeter is a **shortcoming**. Other findings included the absence of any information on IMC/IFR procedures in the operator's manual was also found to be a **shortcoming**. Consequently a clearance for aircraft operation in IMC is not recommended. Plots of representative engineering data collected in the heavy weapons (configuration 3) and two-tank configurations (configuration 5) are in Appendix D.

**DEFICIENCIES**

34. The inaccuracy of the standby altimeter is a **deficiency** (para 9).

35. The aircraft's longitudinal gust response with FMC OFF is a **deficiency** (para 14).

36. The inadequate standby instrument suite is a **deficiency** (para 25b).

37. The inadequate standby instrument suite, which would prevent the pilot from flying a successful ASR approach, is a **deficiency** (para 26b and 27b).

38. The design of the battery installed in the AH-64D Longbow Apache does not meet the 30-min requirement for IMC/IFR flight and results in a **deficiency** (para 29).

**SHORTCOMINGS**

39. The absence of any information on IMC/IFR procedures in the operator's manual is a **shortcoming** (para 32).

## 4. RECOMMENDATIONS

**SPECIFIC**

40. Recommend the following warning be included in the operator's manual (para 9):

**WARNING**

> **Errors up to 300 ft could be present in the standby altimeter during climbs and descents resulting in the aircraft impacting the ground during an instrument approach in IMC conditions. When flying the aircraft in IMC conditions with the only reference being the standby instruments, the crew should, when flying a non-precision instrument approach, add 100 ft to the minimum descent altitude (MDA) or 200 ft for a precision approach's decision height (DH) to mitigate the static/dynamic error possibilities.**

41. Recommend redesigning the standby instrumentation in the AH-64D Longbow Apache (para 25b and 26b).

42. An independent power supply, capable of providing at least 30 min power for standby instruments and flight safety critical systems, is recommended (para 29).

43. A TSO C129a-compliant navigation system is recommended (para 30).

44. Recommend maximum use of simulators be made to train crews for IMC/IFR flight and that the AH-64 ATM (ref 12) include a requirement to train regularly in the use of standby instruments. Consideration should be given to setting a minimum training requirement for IMC/IFR currency (para 31).

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7. Test Plan, *Airworthiness and Flight Characteristics Evaluation of the AH-64D Longbow Apache (Phase 1),* U.S. Army Developmental Test Command (DTC) Project No. 4-AI-100-LBA-056/KF (AMCOM Project No. 99T-07), U.S. Army Aviation Technical Test Center (ATTC), December 2001.

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15. Report, *Assessment of AH-64D Handling Qualities for Instrument Meteorological Conditions/Instrument flight Rules Flight,* U.S. Army Developmental Test Command (DTC) Project No. 4-AI-100-LBA-056/KF, U.S. Army Aviation Technical Test Center (ATTC), 12 May 2003.

**APPENDIXES**

## APPENDIX A.  FLIGHT CONTROL DESCRIPTION

**GENERAL**

1. The AH-64D helicopter is equipped with a dual hydraulically boosted, irreversible flight control system. The system is designed to be controlled by dual conventional flight controls installed in the tandem cockpits. The hydromechanical system is mechanically activated with conventional cyclic, collective, and directional controls, and through a series of push-pull tubes and bellcranks that activate four hydraulic servocylinders (fig A-1) controlling longitudinal/lateral cyclic, main rotor collective, and tail rotor pitch. The servocylinders incorporate integral stability and command augmentation system (SCAS) actuators that are designed to be active whenever the flight management computer (FMC) is ON. Linear variable differential transducers (LVDTs) are incorporated into each of the flight control axes. The LVDTs measure the position of the controls and provide this information to the FMC. Two independent hydraulic pumps that are mounted on the accessory gearbox of the main transmission supply hydraulic power. The FMC is designed to provide rate damping, command augmentation, attitude and altitude hold within the ± 10% (20% forward pitch) authority of the system, and a back-up control system (BUCS). The BUCS is designed to provide an emergency fly-by-wire capability in the event of jammed or severed flight controls. An electrically actuated horizontal stabilator is attached to the lower aft portion of the vertical stabilizer. Movement of the stabilator is commanded by the FMC in the automatic mode and provided a manual mode to enable the crew to position the stabilator manually. A trim-feel system is incorporated in both the cyclic and pedals, and provides a control force gradient with a trim release switch that allowed for momentary disengagement of the trim feel system.

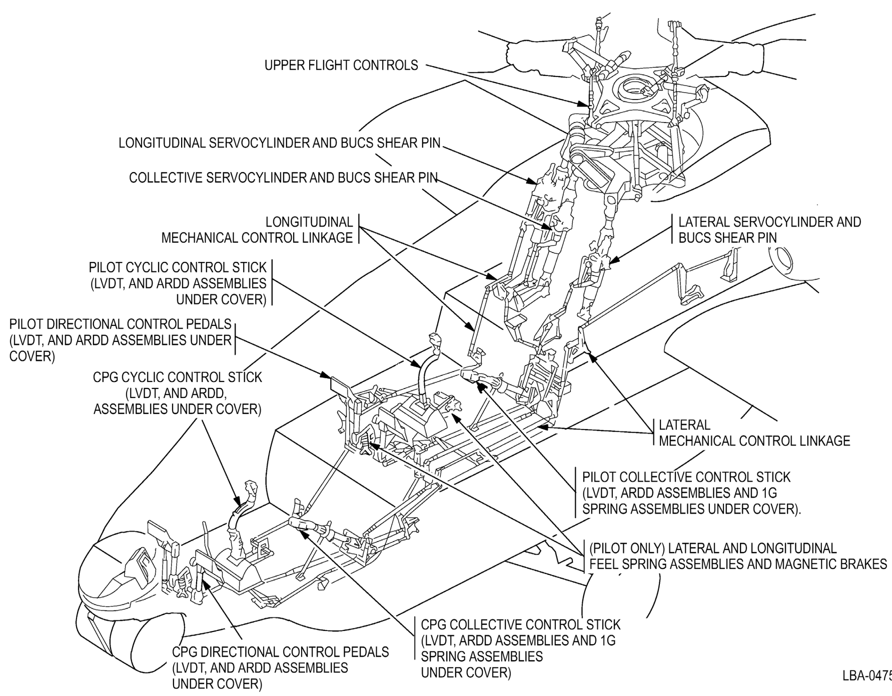


Figure A-1.  AH-64D Flight Control System

## HYDRAULIC SYSTEM

### General

2. Aircraft hydraulic power is provided by two separate systems: the primary system and the utility hydraulic system. Both systems are pressurized to 3,000 psi by constant-pressure variable-delivery pumps mounted on the accessory drive case of the main transmission. Each system is designed to provide pressure to the four flight control hydraulic servoactuators and incorporated manifolds and a hand pump. The function of the manifold is to store, filter, supply, and regulate the flow of hydraulic fluid to each system. Fluid level indicators are provided to allow preflight visual inspection. Reservoir low-level indicating switches and pressure sensing switches are incorporated and designed to inform the pilot of system problems. A hand pump is installed next to the ground servicing equipment (GSE) panels to provide a method for ground crews to fill the manifold reservoirs. The utility hand pump also serves as a method of charging the utility accumulator fluid pressure.

### Primary System

3. The primary hydraulic system, shown schematically in figure A-2, is designed to provide hydraulic power to the primary side of each servoactuator. Only the primary sides of these servoactuators had electrohydraulic valves that are designed to allow the FMC to affect the flight controls; consequently, if the primary system failes, the FMC will be lost. The FMC is designed to control the stability augmentation system (SAS), command augmentation system (CAS), and BUCS provisions of each actuator. The system components, except for the servoactuators and ground service panel, are installed on the left side of the main transmission. The ground service panel is mounted on the right rear side of the transmission deck and is used to service and bleed the primary system. By connecting a ground power unit to the panel, a complete system checkout can be preformed.

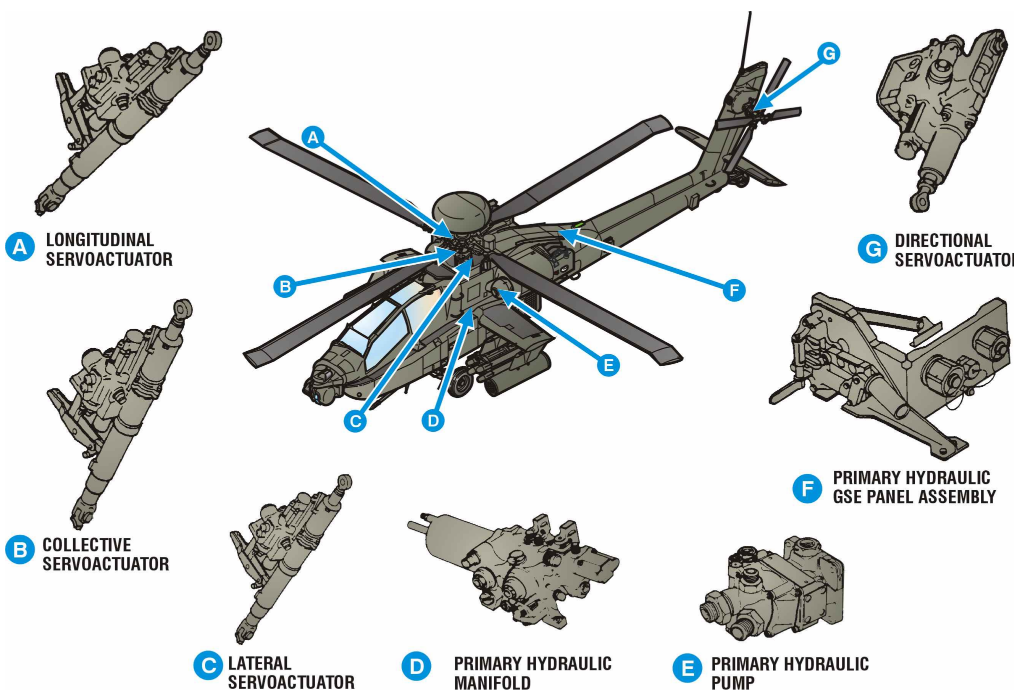


Figure A-2. Primary Hydraulic System

**Utility System**

4. The utility system is designed as the backup power for control of the servoactuators and provides power to the following components: rotor brake, 30-mm turret drive, ammunition handling system, auxiliary power unit (APU) start, tail wheel unlock, external stores elevation, and the emergency hydraulic system. The utility hydraulic system components are depicted schematically in figure A-3. The utility hydraulic accumulator is designed to supply peak flow demands (such as APU start), dampen fluid pressure surges, and provide limited hydraulic power for emergency flight control operation. The accumulator is a moveable piston design and is operated by nitrogen gas supplied at 1,650 psi from a storage bottle. The emergency hydraulic system uses components of the utility system to store 3,000 psi pressure for emergency use of the flight controls. The hydraulic power available is limited to one 180-deg turn and four full collective stick applications. The emergency hydraulic pushbuttons on the pilot and copilot/gunner (CPG) emergency panels control the emergency system activation.

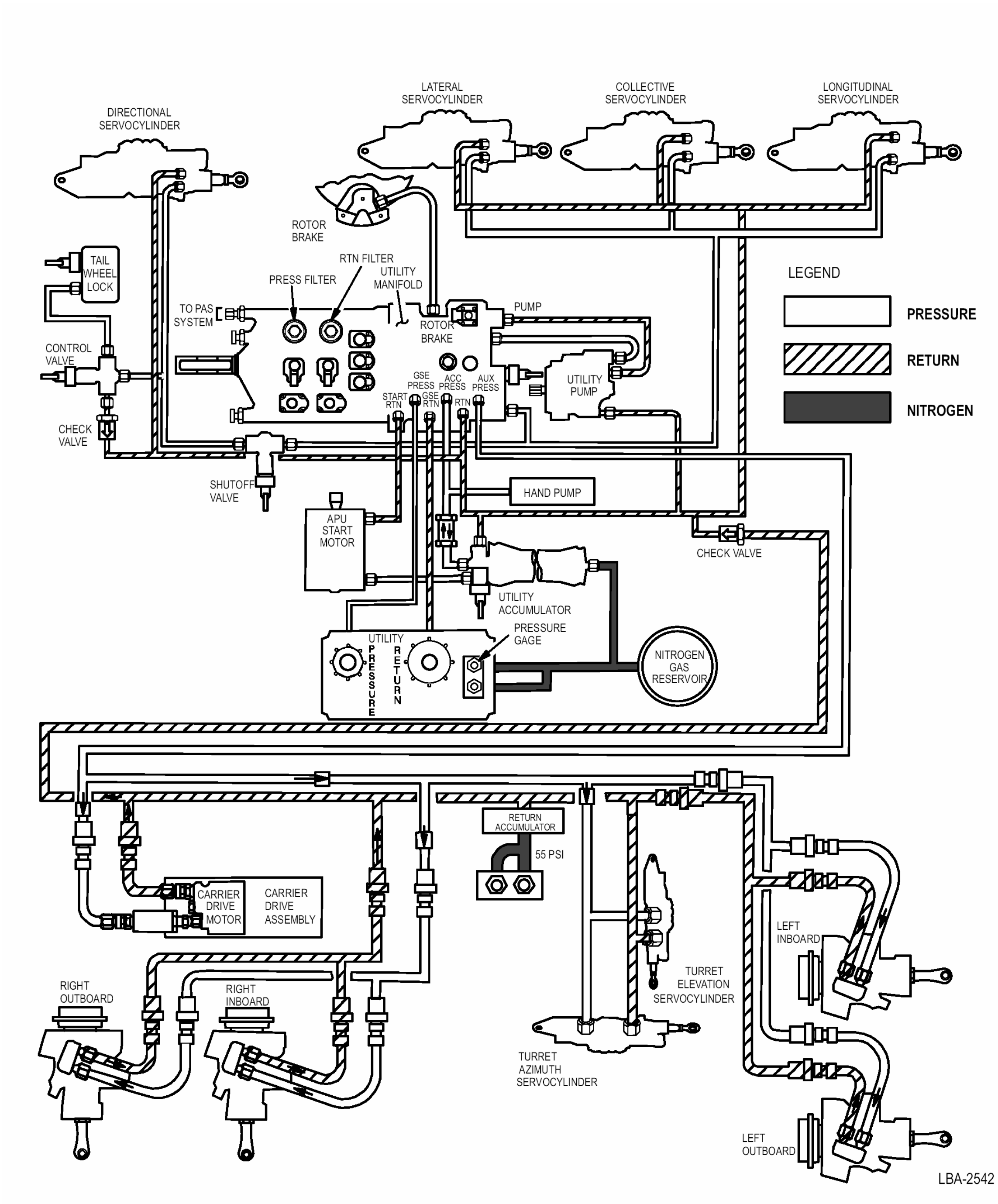


Figure A-3. Utility Hydraulic System

## Servoactuators

5. The hydraulic servoactuators are designed to provide the power boost necessary to move the main and tail rotor swashplates (paras 13 and 14). Longitudinal, lateral, collective, and directional servoactuators are provided. A hydraulic servoactuator schematic is presented in figure A-4. The actuators are powered by hydraulic pressure entering the inlet pressure port through the filter. From the filter, the pressure passes to the SAS or the BUCS solenoid. When the mechanical input is made, the manual servo valve is moved in the controlled direction, which allow hydraulic fluid under pressure to flow into the left or right side of the piston. If the SAS is energized, the SAS solenoid would open, thus providing hydraulic pressure to the electrohydraulic (EH) valve. The EH valve is positioned by SAS commands from the FMC (para 15). Hydraulic pressure from the valve would be transmitted to either end of the stability augmentation actuator sleeve. Movement of this sleeve causes the actuator primary piston to move in response to FMC commands. The SAS LVDT provides SAS actuator position to the FMC. The BUCS (para 18) servoactuator operation is similar to SAS operation except that hydraulic pressure is routed to the BUCS plunger (which locks the manual servo valve in the neutral position) and to the EH valve. The BUCS have 100% actuator authority vice 10% for the SAS. Only the primary sides of the servoactuators have the EH valves that allowed the SAS and BUCS to provide inputs.

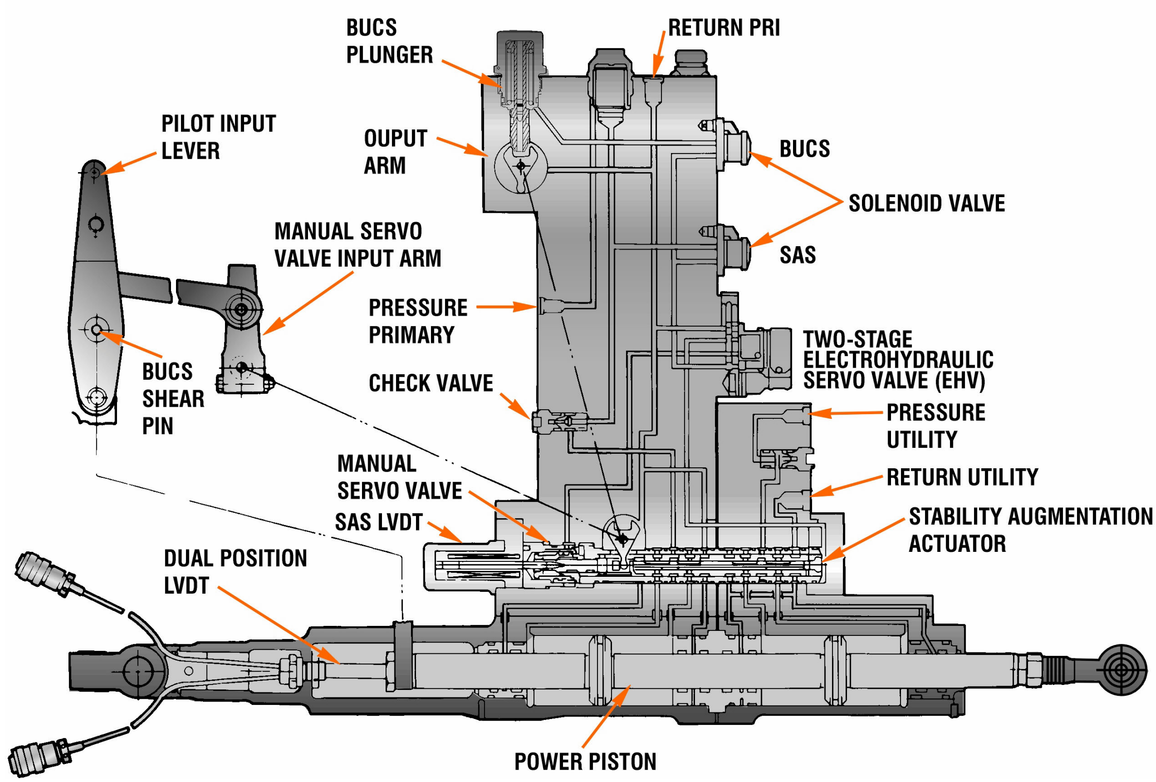


Figure A-4. Hydraulic Servoactuator

## FLIGHT CONTROLS

### Cyclic Controls

6. The cyclic provides longitudinal and lateral control of the helicopter through push-pull rods, bellcranks, and hydraulic servoactuators to the main rotor. Cyclic movement in any direction tilts the tip path plane of the main rotor by cyclically changing the pitch of each blade as it rotates. Cockpit cyclic controls consist of pilot and CPG cyclic sticks that are mechanically coupled as depicted in figure A-1. The CPG cyclic stick can be folded down while employing the aircraft weapons system and for ease of ingress/egress. The stick remains functional in this position. Each cyclic stick grip incorporates numerous switches as shown in figure A-5. Forward and aft cyclic inputs are transmitted from the sticks to the longitudinal control linkage. The longitudinal linkage is routed along the right side of the forward fuselage section and consists of pushrods and bellcranks. The motion is transmitted to the hydraulic servoactuator (para 5), then through the mixer assembly (para 9) to the swashplate (para 13). Tilt of the swashplate results in a corresponding tilt of the main rotor. Lateral cyclic movement is transmitted to the main rotor in the same manner; however, the lateral stick linkage is routed along the left side of the fuselage. The entire control linkage system is shown schematically in figure A-1. An LVDT is connected to each cyclic stick. These transducers are designed to measure the amount of stick travel and provides inputs to the FMC. These inputs are used for pitch and roll SAS and CAS (paras 15 and 16) solutions and for BUCS (para 19) control. The linkages at both crewstations incorporate longitudinal and lateral automatic roller detent decouplers (ARDDs) (fig A-6). The ARDDs are designed to enable the pilot or CPG to fly the aircraft if the controls became jammed. The ARDDs' design breakout forces are shown in table A-1. The BUCS will engage when a ARDDs roller has been rolled from its detent.

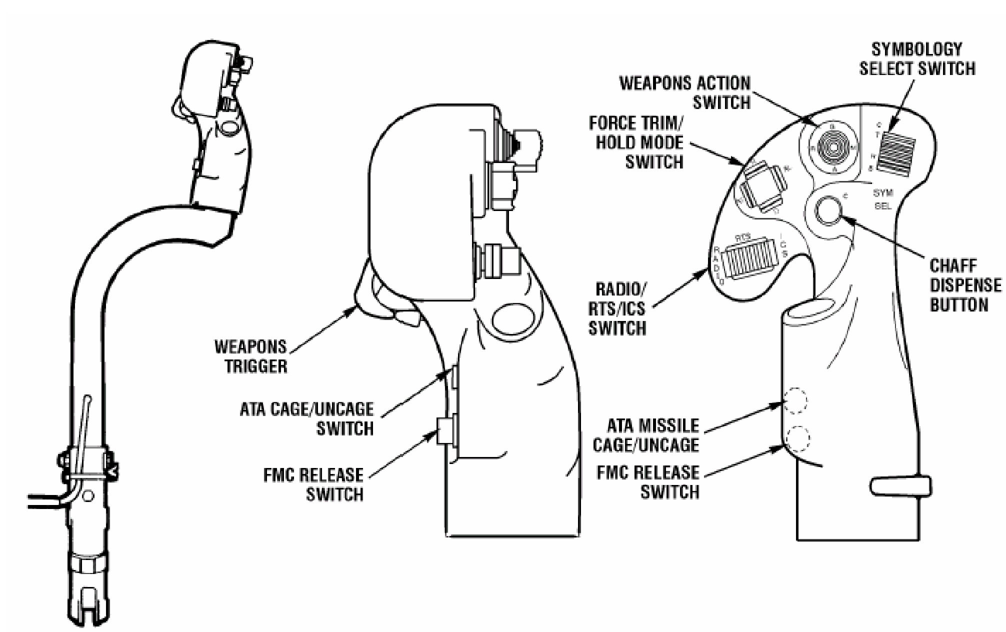


Figure A-5. Cyclic Controls

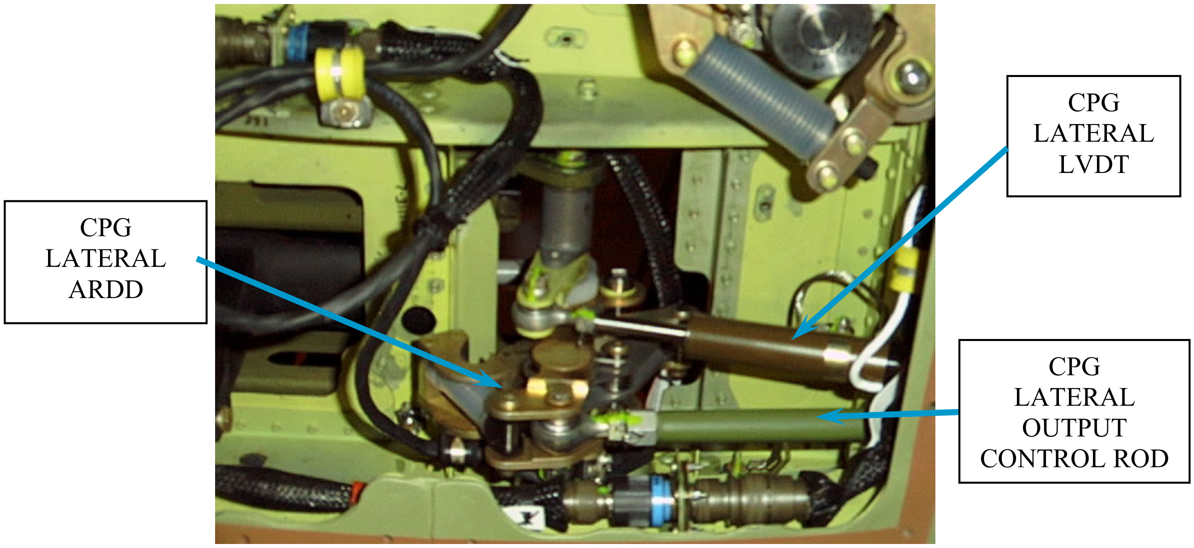


Figure A-6. CPG Lateral Automatic Roller Detent Decoupler (ARDD) Placement

Table A-1. ARDD[1] Nominal Breakout Loads

| Axis | Pilot Breakout Load (lb) | CPG[2] Breakout Load (lb) |
|---|---|---|
| Longitudinal | 42.5 | 50 |
| Lateral | 25.5 | 30 |
| Directional | 76.5 | 90 |
| Collective | 38.5 | 45 |

NOTES:
[1]ARDD – Automatic roller detent decoupler
[2]CPG – Copilot gunner

**Collective Control**

7. The collective control system provides vertical control of the helicopter by simultaneously changing the pitch of all the main rotor blades. Pulling up on the collective lever results in an increase in pitch of the main rotor blades. Collective control inputs are transmitted to the main rotor in a manner similar to the cyclic control. Pushrods, bellcranks, and a hydraulic servoactuator are used. The collective incorporates an LVDT to provide position information to the FMC and an ARDD to allow breakout into BUCS operation (fig A-6). An engine chop device installed on each collective stick grip is designed to permit both engines to be reduced to idle without moving the engine power levers (fig A-7). Both collective levers have friction controls that can be adjusted to prevent the collective levers from creeping.

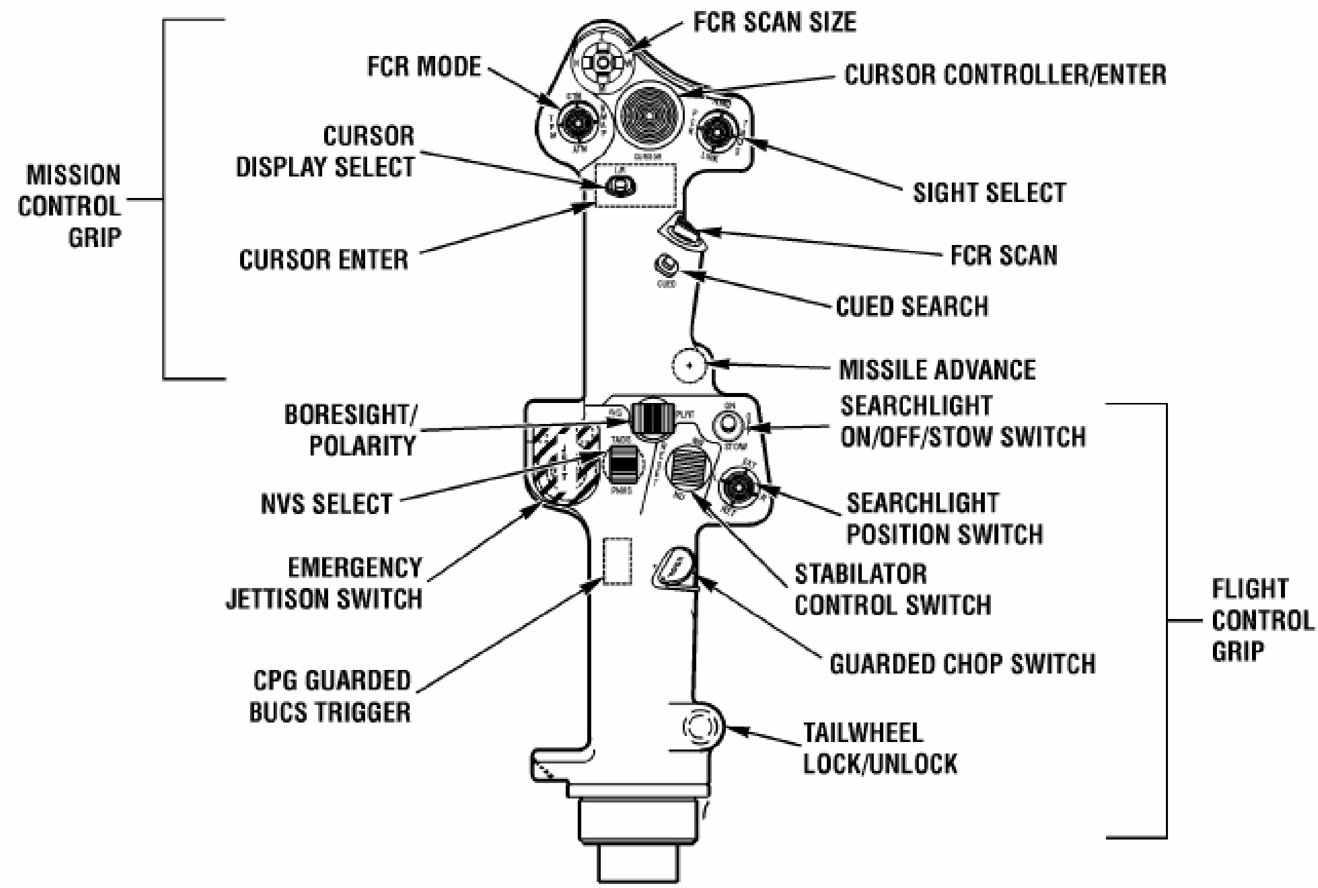


Figure A-7. Collective Controls

**Directional Control**

8. The directional control system provides directional control of the helicopter by varying the pitch of the tail rotor blades to move the aircraft about the yaw axis. Pedal inputs are transmitted through a series of control tubes and bellcranks along the left side of the helicopter until aft of the main rotor. The control tubes are then directed toward the aircraft centerline and through the tail boom to the directional servoactuator mounted on the tail rotor gearbox. To transmit control inputs to the tail rotor blades, a swashplate assembly is used in a manner similar to the main rotor swashplate assembly. A directional control LVDT provides pedal position data to the FMC for the yaw SAS, CAS, BUCS, and heading-hold systems. Both sets of pedals are adjustable by releasing the pedal adjust lever and applying equal foot pressure to the pedals. The main landing gear brakes are also controlled by the directional pedals activated by pressing on the upper portion of the pedals.

**Mixer Assembly**

9. Mechanical mixing of inputs to the main rotor is accomplished by the mixer assembly (fig A-8). The mixer assembly is mounted on the stationary mast. The inputs from the collective, lateral, and longitudinal servoactuators are mixed, and the output is transmitted to the main rotor stationary swashplate. The mixer is connected to the stationary swashplate by a torque link that is designed to provide longitudinal control and prevent stationary swashplate rotation. Two lateral links connect the mixer to the stationary swashplate and are designed to provide lateral control. Both the torque link and the lateral links provides vertical control of the swashplate.

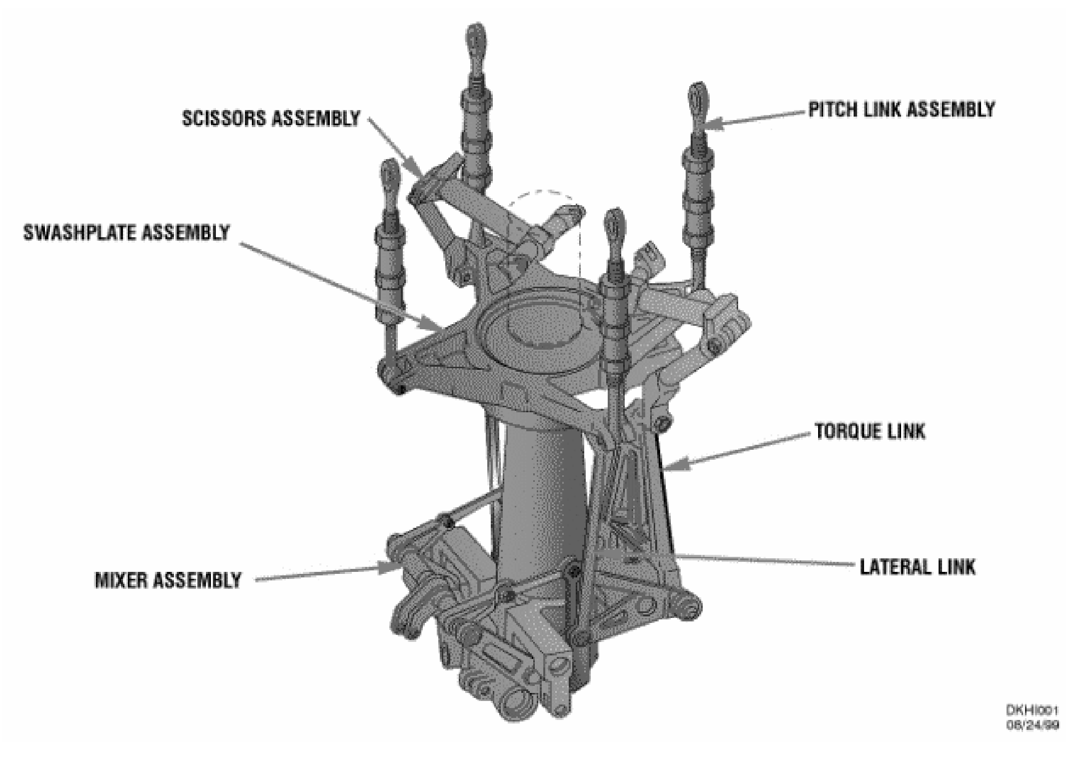


Figure A-8. Main Rotor Mixer Assembly

## Trim

10. The cyclic stick and pedal controls each incorporates a trim feel system consisting of a double-acting spring bungee and a magnetic brake. The magnetic brakes and spring assemblies are connected to the control linkage below the pilot's station. Movement of the cyclic or directional controls with the trim system on causes the spring assemblies to compress and provides feel to the controls. The trim system is designed to return the control to the trimmed position when the control pressure is released. Trim is accomplished by using the force trim/hold mode switch on either the pilot or CPG cyclic grip. Moving the switch up releases the magnetic brake, which allows the spring assemblies to move to the new control position called centering. Pushing the force trim release switch for at least one sec resets the mechanical portion of the force trim to a zero force state, but does not provide enough time to recenter the SAS. Activating the trim for three seconds allows the wash-out or recentering of the SAS. Releasing the button, re-engages the magnetic brakes and provides trim feel at the new control position. The trim system is designed to be operable throughout the full cyclic and pedal control envelope. The trim system has to be engaged for the attitude hold (para 17) capability of the FMC to be functional.

## MAIN ROTOR SYSTEM

### Main Rotor Head

11. The main rotor head is a fully articulated system containing four blades (fig A-9). The blades are allowed to independently flap, feather, lead, and lag. The hub assembly is constructed of steel and aluminum and is designed to support and drive the main rotor blades. The hub is driven by the main rotor drive shaft and rotated about the static mast. The hub incorporates grease-lubricated and sealed roller bearings that are designed to transfer the hub loads to the static mast. The hub assembly is secured to the static mast by a lock nut and lock ring. A plunger assembly indicates proper installation of the locking nut and ring. Centrifugal loads from the main rotor blades to the hub are transmitted by the strap assemblies, which also provides the blades with a flapping and feathering capability. The strap assemblies pass through the pitch housings. Swashplate (para 13) movements are transmitted to the pitch housings by pitch links. Elastomeric feathering bearings installed on the pitch housings allows both feathering and flapping motions. Mechanical droop stops are incorporated and are designed to limit blade droop to 7 deg. Lead and lag blade motions are accomplished through lead/lag links attached to the outboard end of the pitch housings. The lead/lag motions are controlled by the main rotor damper assemblies, which consist of two side plates bonded together by an elastomeric material.

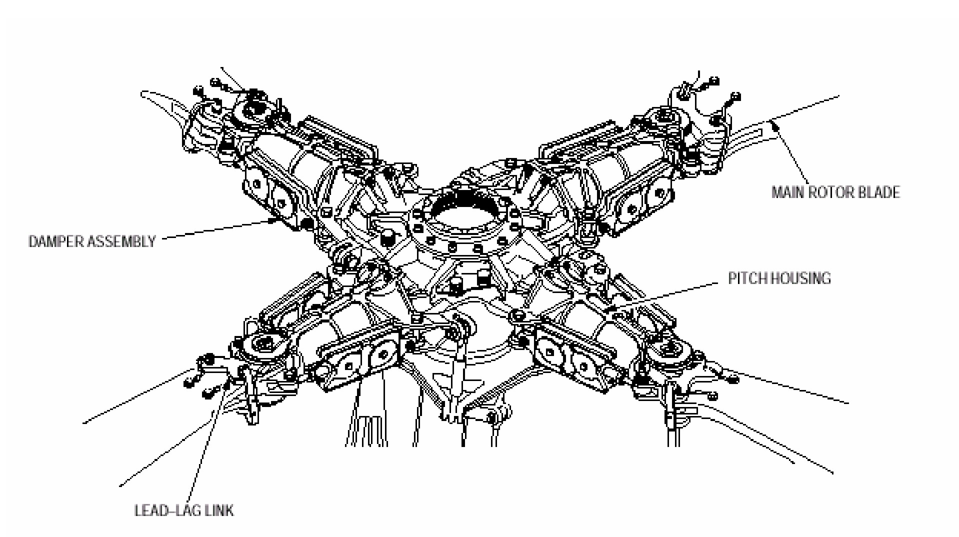


Figure A-9. Main Rotor Head

**Main Rotor Blades**

12. The aircraft incorporates four main rotor blades that are constructed of steel, fiberglass, titanium, and nomex honeycomb. The main rotor airfoil is an HH-02 at the inboard portion, transitioning to an NACA 64A006 at the tip. The primary load-carrying portion of the blade is a four-cell, stainless steel structural box. Each cell has fiberglass filament tubes bonded to the inner surface that are designed to retard crack propagation. The aft portion of the blade is constructed of nomex honeycomb filler with a layered fiberglass skin. A stainless steel trailing edge strip ran the full span of the blade. Each blade is a constant chord with the outer 7% of the blade span swept aft 20 deg. Removable leading edge tip caps, tip weights, and leading edge heater blankets for deicing are incorporated; however, the leading edge heater blankets are disconnected in the AH-64D model helicopters due to a program cost reduction initiative. Titanium blade retention fittings are provided for attachment to the lead/lag links. The blades can be folded manually by removing one of the blade's retaining bolts, which can be accomplished without tools.

**Swashplate Assembly**

13. The swashplate assembly consists of a rotating and a stationary swashplate. The assembly is mounted on a Teflon spherical slider bearing that allows the swashplate to tilt in any direction responding to cyclic control inputs. Vertical motion of the swashplate assembly is provided for collective control inputs. The rotating swashplate, mounted above the stationary swashplate, is supported by a double row of ball bearings. Two scissor assemblies connects the rotating swashplate to the main rotor hub. Control inputs are received at the stationary swashplate from the hydraulic servoactuators (para 5) through the mixer assembly (para 9). Tilt or vertical motion of the stationary swashplate is transmitted to the rotating swashplate. Four pitch links connect the rotating swashplate to the blade pitch horn assemblies transmits control motion inputs to the main rotor blades.

**TAIL ROTOR SYSTEM**

14. The tail rotor system is designed to provide anti-torque action and directional control for the helicopter (fig A-10). The tail rotor system is a dual semirigid, teetering design. The tail rotor assembly is attached to, and driven by, the tail rotor gearbox output shaft, which passes through the static mast. The four tail rotor blades are mounted to the tail rotor fork. The hub assembly is supported by ball bearing sets in the static mast. The blades are mounted to the hub so the angle formed by the intersection of the closest blades is 55 deg. Blade pitch change is accomplished by pitch links that are to connected to the rotating swashplate and the blade pitch horns. Blade pitch movement is made about the pitch change bearings. The tail rotor blades are constructed of a stainless steel forward spar plus aluminum center and aft spars. Unidirectional fiberglass liners, bonded to the inner surface of the two forward spars, are designed to retard crack propagation. The tail rotor blades also incorporates electrical deicing blankets.

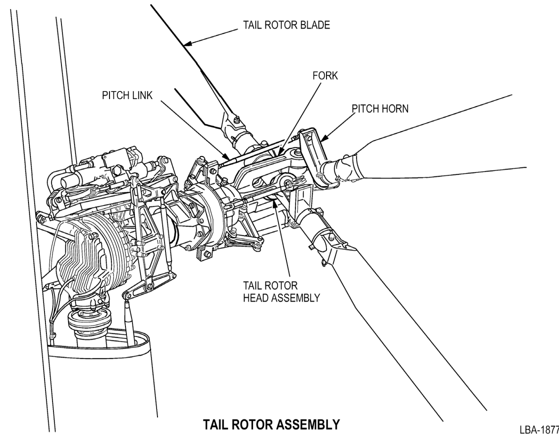


Figure A-10. Tail Rotor Assembly

## FLIGHT MANAGEMENT COMPUTER

### Stability Augmentation System

15. The SAS is designed to reduce pilot workload by providing rate damping. The rate damping is used in the pitch, roll, and yaw axes to reduce airframe movement caused by turbulence or weapon recoil. The SAS is also designed to provide turn coordination above 40 knots true airspeed (KTAS) and attitude hold (para 17), if engaged. An FMC release button at the base of each cyclic grip disengages all three channels simultaneously. SAS actuator inputs in the hydraulic servoactuators are controlled by the FMC. The SAS actuators are limited to ± 10% authority in each axis except for longitudinal cyclic, which has 20% authority. The SAS operates independently of the flight control linkage and, therefore, its damping action is not fed back through the flight controls.

### Command Augmentation System

16. The CAS is designed to prevent the aircraft motions from being sluggish in response to the control inputs required for maneuvering flight. The CAS enables the SAS to recognize control inputs from the pilot or CPG to ensure that these inputs will not be damped. When a control input is initiated, the LVDT sends a signal to the FMC proportional to the control movement.

### Stabilator System

20. The stabilator provides pitch trim angle control and improves over-the-nose field of view at low airspeeds. The stabilator has both an automatic and a manual mode. The automatic mode is engaged following power-up of the aircraft and is controlled by the FMC. Two modes are available within the automatic control system. The auto mode provides automatic scheduling in accordance with collective position, airspeed, and pitch rate. The nap-of-the-earth/approach (NOE/A) mode commands the stabilator to 25 deg trailing edge down up to a speed of 80 KTAS. At speeds greater than this, the stabilator schedule reverts to the auto mode. Manual mode is selectable at airspeeds less than 80 KTAS, or is engaged when the automatic system has failed. Manual control or stabilator reset is affected through the stabilator control switch on the collective flight grip. Depressing the stabilator control switch would reset the stabilator to AUTO mode and the NOE/A mode will be turned OFF if it is engaged. Stabilator positioning is

accomplished by two, in series, direct current (DC) motor actuators. Stabilator position information (in deg) is presented on the SYS page, and relative position information is presented on the flight (FLT) and the FLT SET pages. The stabilator trailing edge incorporates gurney flaps for increased aerodynamic stabilization.

**AIR DATA REVERSION LOGIC**

21. In previous FMC software (7-511D00006-11) load, when the helicopter air data system (HADS) failed or the data is declared failed by the system processor (SP), the FMC reverted to a combination of inertial navigation unit (INU) groundspeed (GS) and left Pitot data for control law calculations and total true airspeed displayed to the pilot. When this reversion took place, the FMC now uses INU longitudinal GS to determine if it is in the low-speed region where INU GS is used for the longitudinal component, or in the high-speed region where the FMC Pitot airspeed is used. In the current A&FC (7-511D00006-13 (-13)) software configuration, the FMC Pitot airspeed is used to determine if the aircraft is in a high- or low-speed environment. This reversion methodology is designed to provide an additional guard against inappropriate INU data affecting the stabilator or the displayed airspeed.

**EMBEDDED GLOBAL POSITIONING SYSTEM/INERTIAL NAVIGATION SYSTEM**

24. The test aircraft has two EGIs that used internal accelerometers, rate gyro measurements, and external sensor measurements to estimate the aircraft's state (fig A-11). One EGI is a GPS-embedded module (GEM) III system and has the -004 operational flight profile (OFP) software version 20; the other EGI is a GEM IV with version 11 software. Only one EGI provides aircraft state information to aircraft systems; the second EGI is for backup incase the primary fails. The external sensor measurements includes range and range rate from the GPS, velocity from the doppler radar velocity sensor (DRVS), barometric altitude, and manual position updates from the SP. Incorporated within the EGIs are an inertial measurement unit (IMU) and the processing functions for performing the inertial navigation computations, GPS navigation solutions, receiver management, and Kalman filter estimates that supports all aircraft and weapon systems requirements. The data derived from the EGIs includes acceleration, angular rate, altitude, heading, velocity, position, and position error estimate. The EGIs are a velocity-aided, strap-down, ring laser gyro-based inertial unit. The EGI unit houses the five–channel GPS receiver for GEM III and a twelve-channel GPS receiver for the GEM IV units. The ring laser gyro operated on an optical principle called the Sagnac Effect, which deals with the properties of light beams traveling in opposite directions around a closed loop. The primary SP upon generator power-up of the aircraft automatically controls initialization and alignment of the EGIs. Upon power-up, the SP provides the boresight numbers stored in nonvolatile memory for each EGI and doppler and the last navigation (NAV) mode stored (i.e., land or sea) at power-down of the aircraft. When the EGIs are given a present position, the NAV system provides an alignment command to the EGIs. The EGI's alignment time is approximately four min on the ground. When an in-flight alignment is performed by an INU reset, the alignment time (with the GPS tracking satellites with crypto keys verified and doppler velocities available) is approximately 35 sec. If an in-flight alignment is performed aided by doppler velocity only (no GPS), the alignment time is approximately six min. The time to alignment is not significantly affected by temperature. The heading tape symbology is displayed, and tactical situation display (TSD) map frozen cue is removed when the primary EGI completes alignment. The secondary EGI reaching alignment is noted by the removal of the inhibit selection bar beside the primary INU selection on the TSD UTIL page. There is no effect on the NAV system accuracy when the engines are started or when the main rotor is turning during alignment. The EGI's handling of velocity information from the GPS or doppler is automatic. If the different sources of velocity information becomes absent or of low quality for use by the EGI, the EGI is designed to automatically determine the quality of each of the velocity sources and uses the highest quality velocity source. The EGI's Kalman filter uses the velocity sources and its accelerometers to calculate the ultimate aircraft state information. The primary EGI provides this aircraft state information to those onboard systems requiring it via the 1553 data bus. The velocity vector, acceleration cue, vertical speed indicator, and heading tape are driven by the primary EGI aircraft state information.

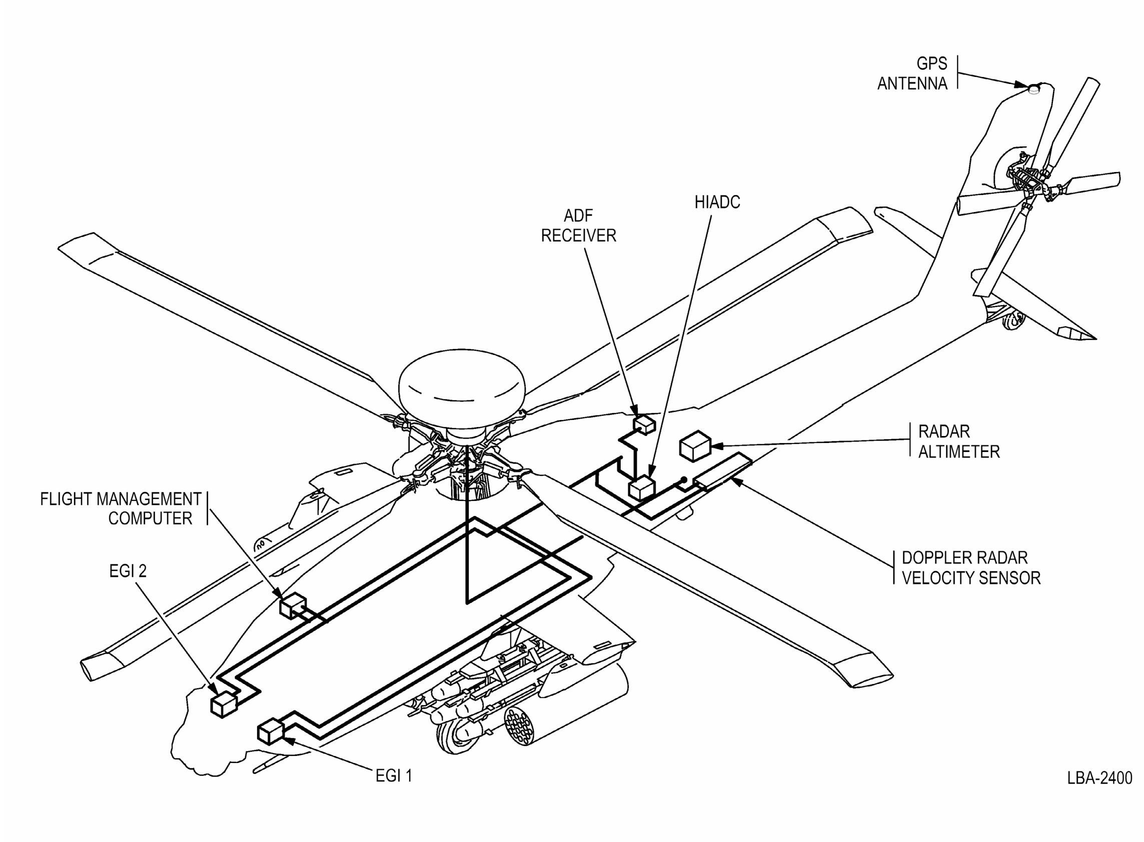


Figure A-11. Navigation Subsystem

## APPENDIX B. INSTRUMENTATION

### GENERAL

1. A flat plate design approach was used for the airborne data acquisition system instrumentation installed on the AH-64D Longbow Apache. The majority of the package was installed on a flat plate located in the aft storage compartment to meet limited space and weight restrictions. The instrumentation acquisition package consisted of an advanced aircraft test instrumentation system (AATIS) and the DataMARS 104 data acquisition and replay system. Signal conditioning and pressure transducers were mounted in other locations on the airframe that provided inputs to the data acquisition package. The following devices were installed on the data acquisition package:

TrueTime inertial rate integrating gyrometer (IRIG)-B time generator
DataMARS Military Standard (MIL-STD)-1553B multiplex (MUX) data bus monitor
Merlin/TEAC video recorder
Miniature system control unit (miniSCU)
Miniature analog discrete acquisition units (miniADAUs) (2)
Power distribution box
Voltage standard

2. In addition, the following measuring devices were integrated into the AH-64D Longbow Apache aircraft:

Sensotec pressure transducers (2)
Rosemont air data sensors (2)
Fuel flow temperature amplifiers (2)
Flow Technology fuel flow turbines with smart integral linearizer (2)
Space-age yaw and angle-of-attack position sensor (YAPS) head
Longitudinal and lateral cable angle potentiometers (tethered hover only)
Cargo hook load cell (tethered hover only)

### DATAMARS 104

3. The DataMARS 104 data acquisition and replay system manufactured by AMPOL Systems Inc. was capable of collecting selected data from the four MIL-STD-1553B MUX bus channels and collecting voice data at 4 to 21.5 kHz. The DataMARS 104 used imported or manually-defined interface control document (ICD) engineering units and had the capability to decode real-time engineering units data from monitored communications. The DataMARS 104 used industry-standard Personal Computer Memory Card International Association (PCMCIA) ATA-drive, Flash™-based media. Data were analyzed and post-processed with special DataMARS software using a personal computer configured with Windows 95™, Windows 98™, Windows NT™, or MS Windows™ operating systems. The post-processing enabled data extraction, processing, and export, generates engineering units reports, and enabled voice playback.

### ADVANCED AIRCRAFT TEST INSTRUMENTATION SYSTEM (AATIS)

4. The suite of AATIS equipment consisted of two subsystems: signal conditioning and encoding. The two systems were interdependent, each with its own unique functional characteristics. The total system complement of equipment included the prepackaged signal conditioning, pulse code modulation (PCM) encoder, onboard recording media, radio frequency telemetry, and cockpit readout devices. The package consisted of two miniADAUs (used for signal conditioning) and a miniSCU. Each miniADAU was card-configurable and could accept a wide range of signals for conditioning. The number of available channels depended on the input card requirements. All communications (address and data) between the miniADAUs and the miniSCU were controlled by the common airborne instrumentation system (CAIS) bus.

5. The AATIS data were recorded on a Merlin/TEAC Hi-8mm tape recording system and was transmitted to the ground via an L-band ultra high frequency (UHF) telemetry transmitter. The AATIS measurement capacity included the following:

Rotary speed parameters (5)
Fuel flow and 2 fuel temperatures (2)
Anti-alias filtered analog signal-conditioned parameters (10)
MIL-STD-1553B data bus parameters (29)

**COCKPIT INDICATORS/GAUGES**

6. The following instruments were installed in the pilot/copilot stations:

Boom sensitive airspeed indicator (pilot station)
Boom sensitive altitude indicator (pilot station)
Angle-of-sideslip indicator (pilot station)
Master control for the data acquisition system (pilot station)
Slave control for data acquisition system (copilot gunner station)
Datum time code display (copilot gunner station)
Run counter (copilot gunner station)
Programmable cockpit display system

**INSTRUMENTATION CONFIGURATION**

7. Complete documentation necessary to configure the AATIS data acquisition system was provided in Volume 1, AH-64D 5132 Nonstandard Book. Additional documentation available for reference was listed below and was updated to include the additional instrumentation upon installation:

Instrumentation electrical drawing log
AH-64D Longbow Apache power analysis
Drawing list for the AH-64D Longbow Apache instrumentation
Signal conditioner configuration and utilization sheets
Data cycle map

**PARAMETERS LIST**

8. Installed instrumentation parameters are presented in the following lists ("*" delineates data obtained from the aircraft's system):

a. Cockpit Displays:

Pressure altitude (boom)
Airspeed, sensitive analog display (boom)
Vertical speed*
Angle-of-sideslip (boom)
Turn needle and ball*
Normal acceleration (center of gravity)*
Main rotor speed*
Control positions*
  Longitudinal cyclic
  Lateral cyclic
  Directional
  Collective

Engine torque (both engines)*
Engine turbine gas temperature, power turbine inlet (both engines)*
Engine power turbine speed (both engines)*
Engine gas producer speed (both engines)*
Radar altitude*
Stabilator incidence angle*
Altitude*
Airspeed*
Fuel quantity (forward and aft tank) *
Engine fuel flow (each engine)
Total air temperature*
Time code display
Event switch
Data system controls
Longitudinal cable angle (tethered hover only)
Lateral cable angle (tethered hover only)
Cargo hook load cell (tethered hover only)

b. Parameters obtained from PCM/MIL-STD-1553B data bus:

IRIG-B time code
Record number
Event (pilot and copilot)
Altitude - ship
Airspeed - ship (pilot and copilot)
Static pressure - boom
Pitot pressure - boom
Angle-of-attack - boom
Angle-of-sideslip - boom
Main rotor speed
Control positions
- Longitudinal cyclic
- Lateral cyclic
- Directional
- Collective

Engine fuel flow (each engine)
Engine total fuel used (both engines)
Fuel temperature (both engines)
Engine torque (both engines)
Engine turbine gas temperature, power turbine inlet (both engines)
Engine power turbine speed (both engines)
Engine gas producer speed (both engines)
Engine compressor discharge pressure (both engines)
Fuel quantity (forward and aft tank)
Radar altimeter
Stabilator incidence angle
Angular attitudes
- Pitch
- Roll
- Yaw

Angular rates
- Pitch
- Roll
- Yaw

Total air temperature
Actuator positions
- Longitudinal
- Lateral
- Directional
- Collective

Stability and command augmentation system (SCAS) actuator positions
- Longitudinal
- Lateral
- Directional
- Collective

Helicopter air data system (HADS) pressure altitude
- HADS lateral airspeed
- HADS longitudinal airspeed
- HADS total airspeed
- HADS angle-of-sideslip
- HADS probe angles (pitch, yaw)

## APPENDIX C. TEST DATA

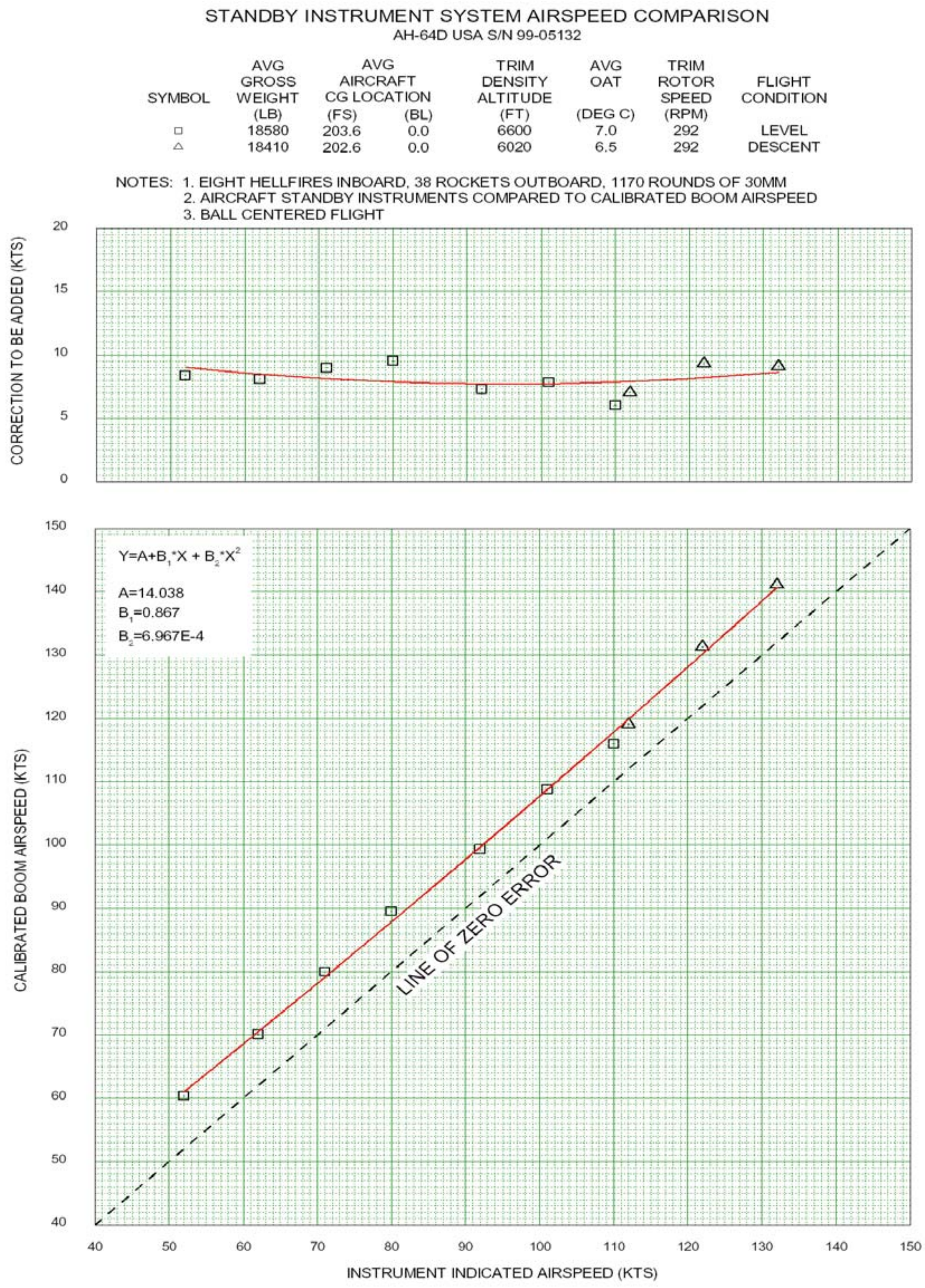


Figure C-1. Standby Instrument System Airspeed Comparison

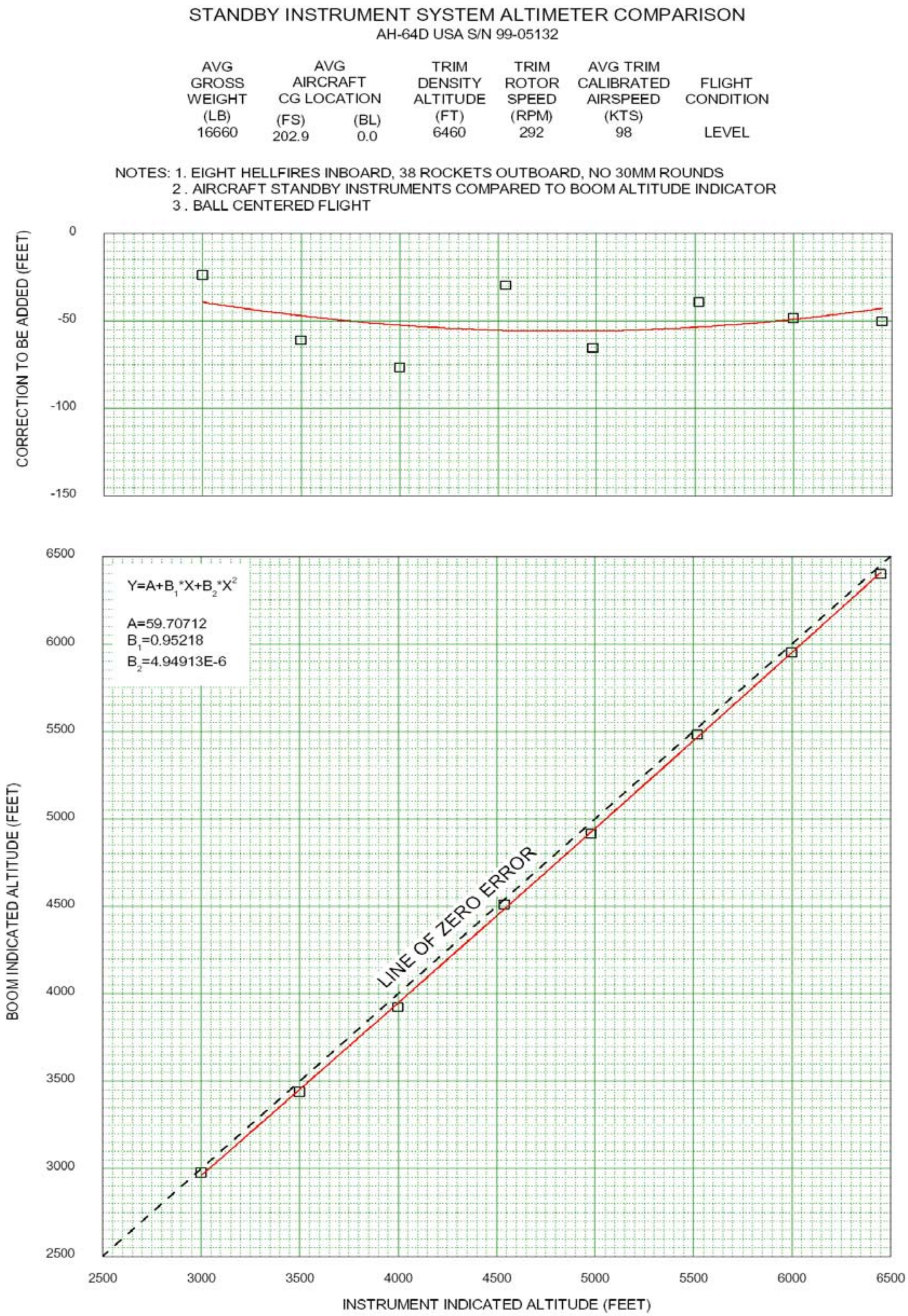


Figure C-2. Standby Instrument System Altimeter Comparison (1)

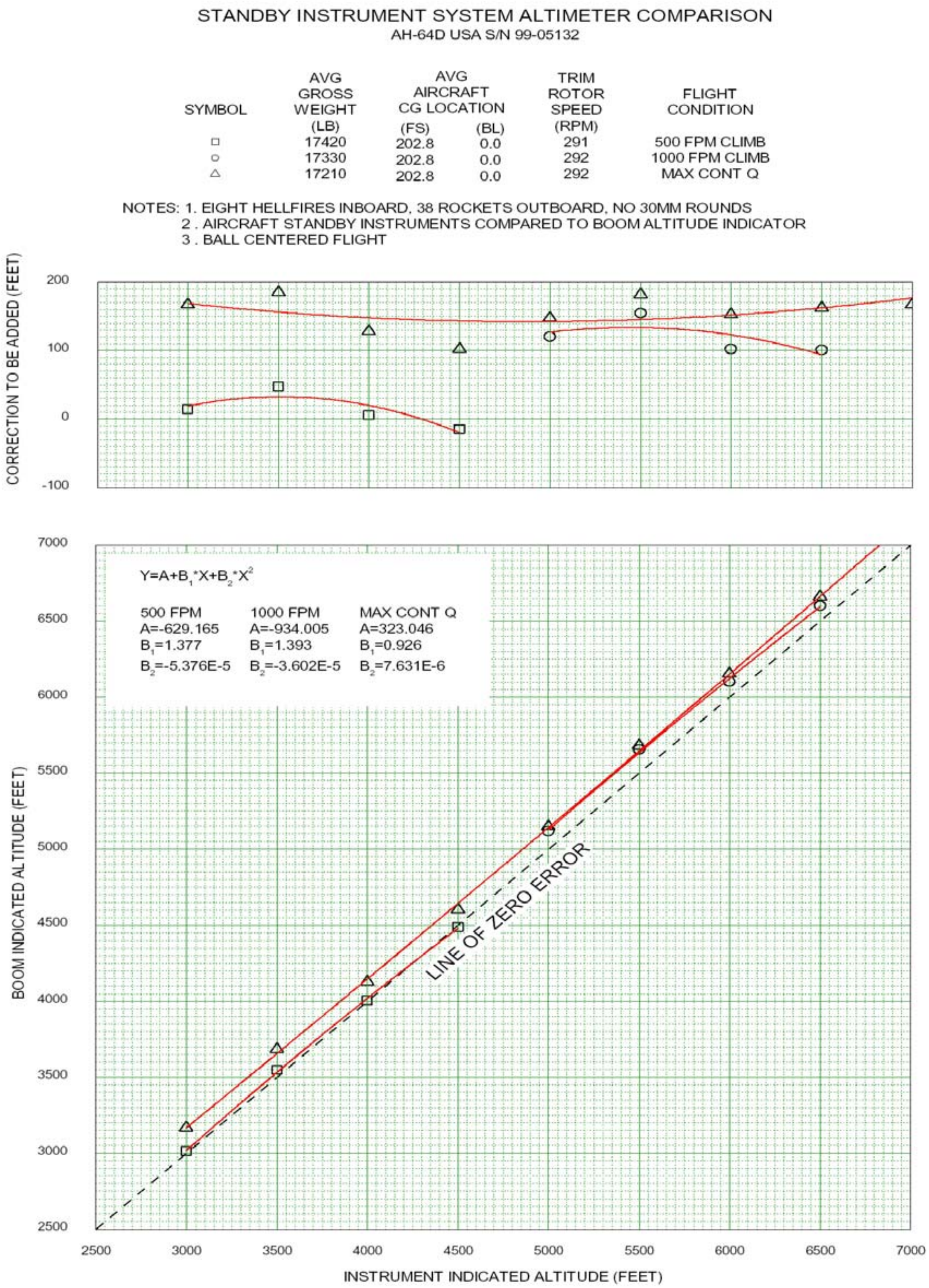


Figure C-3. Standby Instrument System Altimeter Comparison (2)

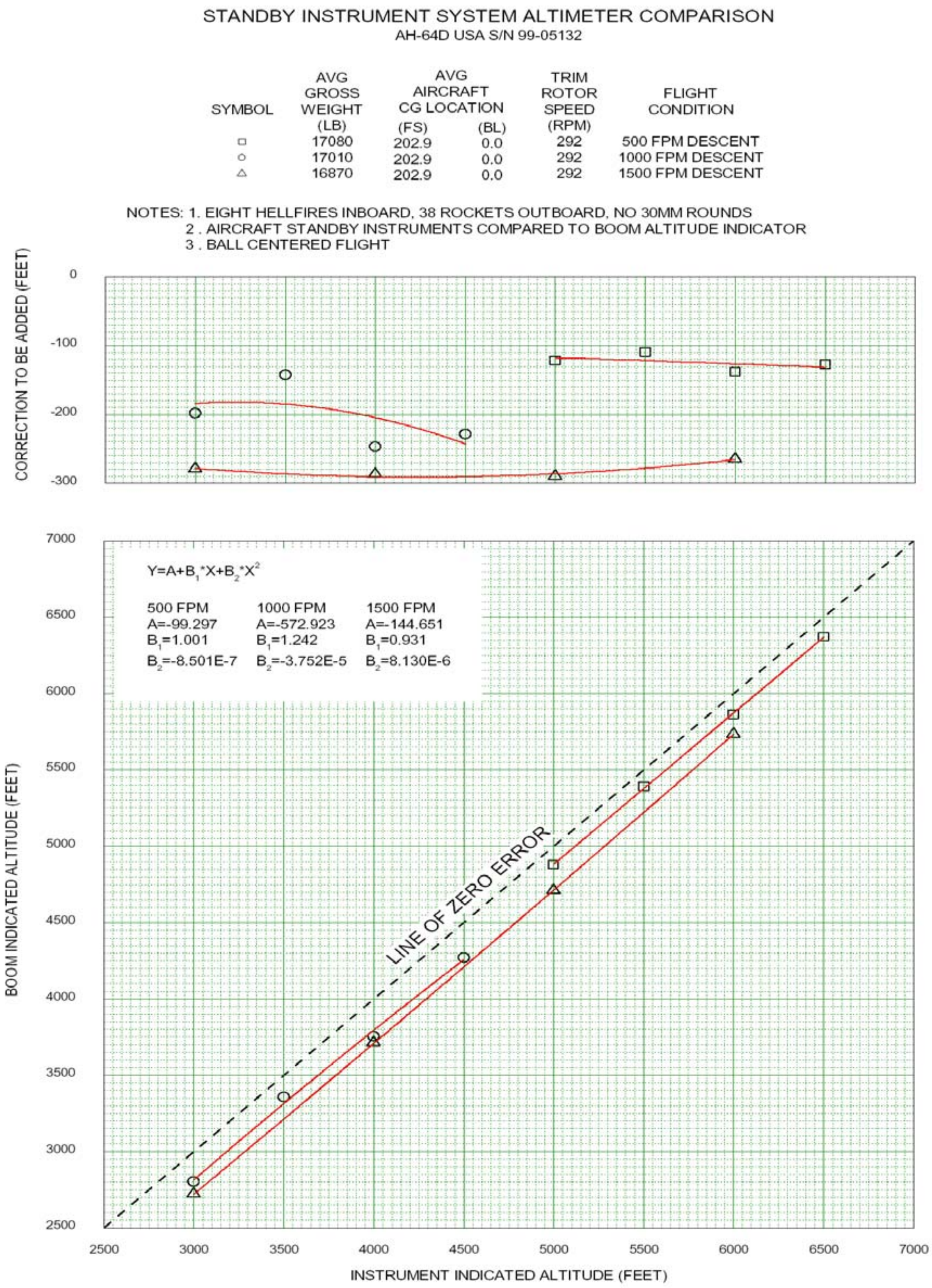


Figure C-4.  Standby Instrument System Altimeter Comparison (3)

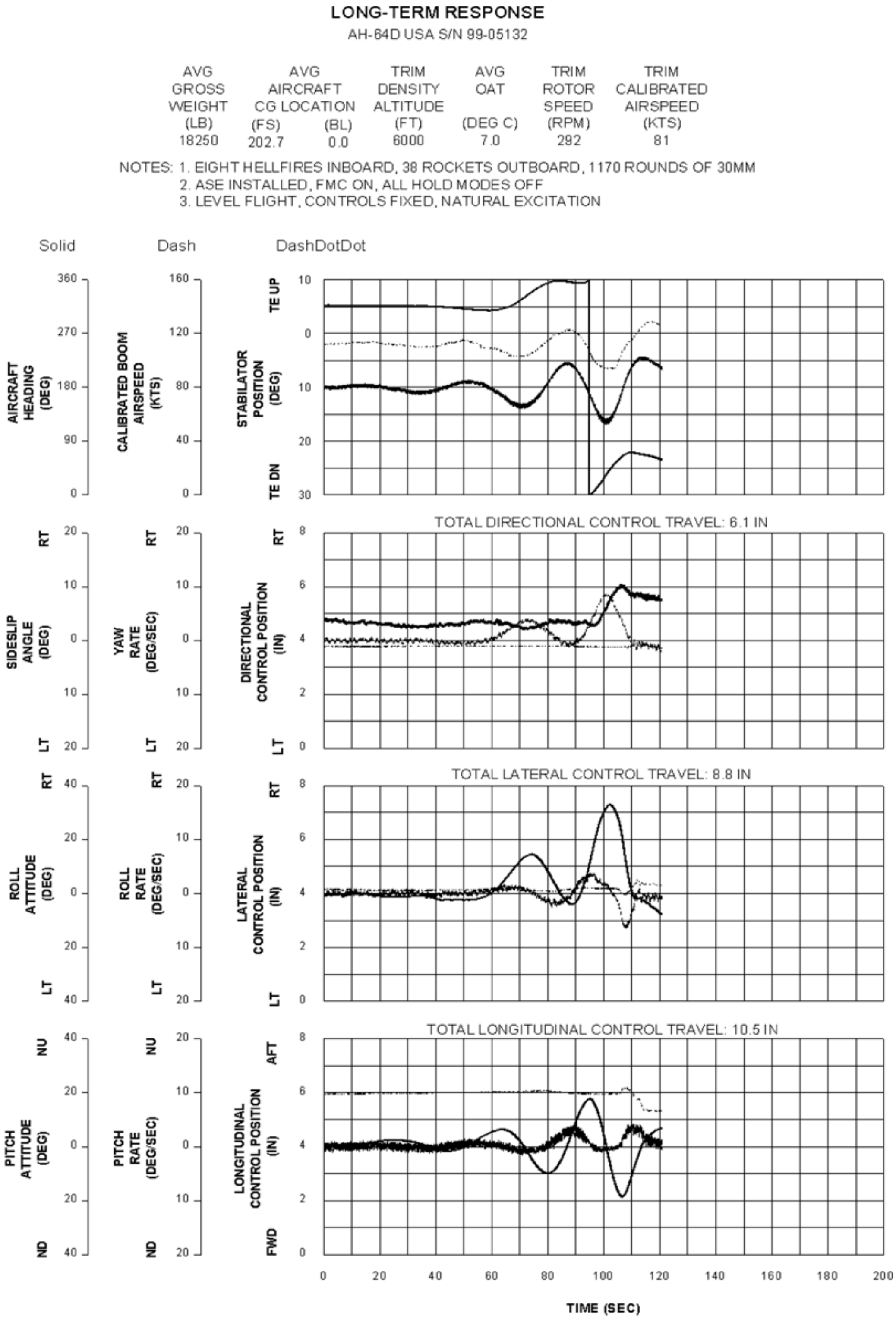


Figure C-5. Long-Term Response (1)

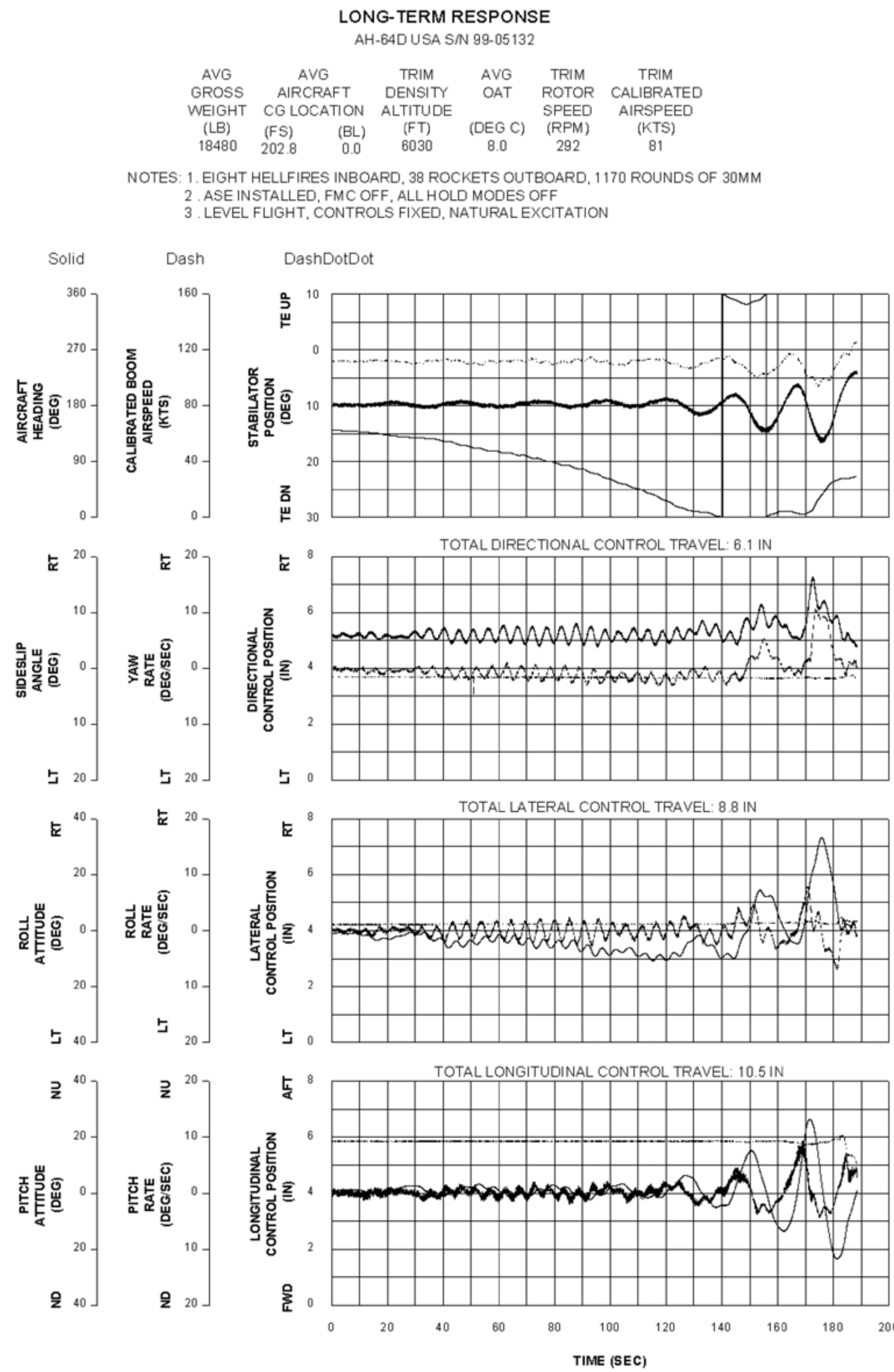


Figure C-6. Long-Term Response (2)

**LONG-TERM RESPONSE**

AH-64D USA S/N 99-05132

| AVG GROSS WEIGHT (LB) | AVG AIRCRAFT CG LOCATION (FS) | (BL) | TRIM DENSITY ALTITUDE (FT) | AVG OAT (DEG C) | TRIM ROTOR SPEED (RPM) | TRIM CALIBRATED AIRSPEED (KTS) |
|---|---|---|---|---|---|---|
| 18100 | 202.7 | 0.0 | 5930 | 7.5 | 292 | 112 |

NOTES: 1. EIGHT HELLFIRES INBOARD, 38 ROCKETS OUTBOARD, 1170 ROUNDS OF 30MM
2 . ASE INSTALLED, FMC ON, ALL HOLD MODES OFF
3. LEVEL FLIGHT, LONGITUDINAL CONTROL FIXED, NATURAL EXCITATION

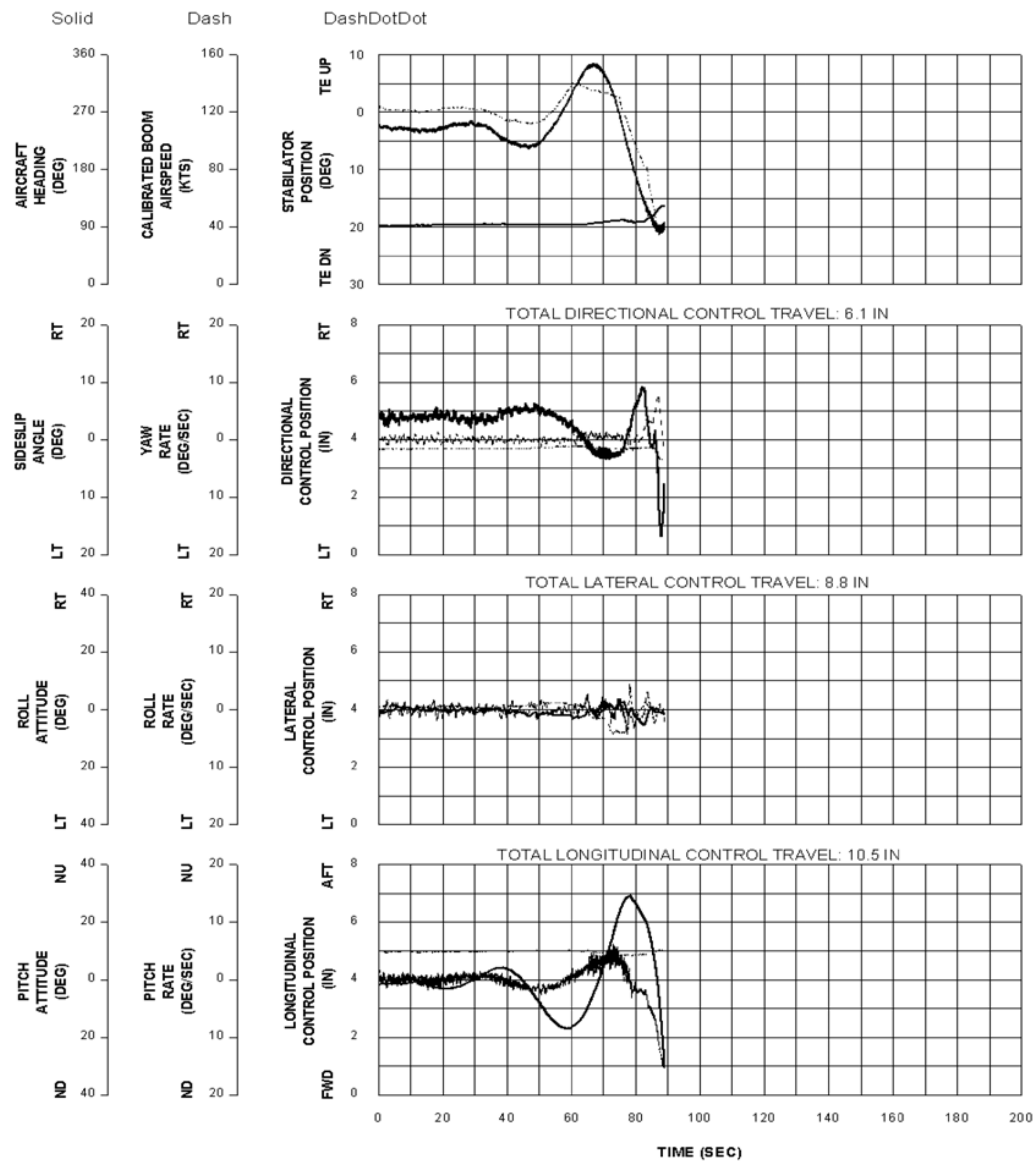


Figure C-7. Long-Term Response (3)

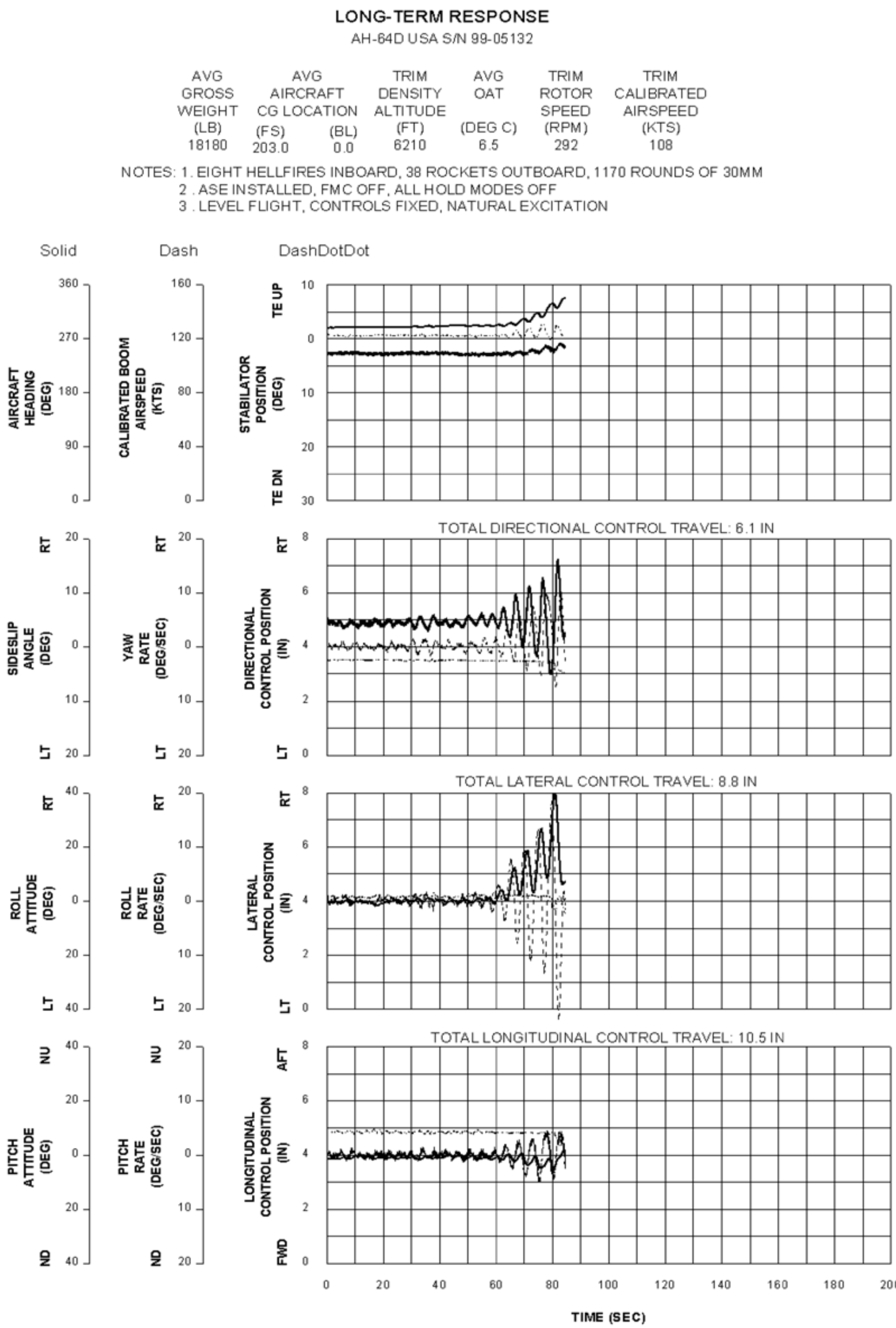


Figure C-8. Long-Term Response (4)

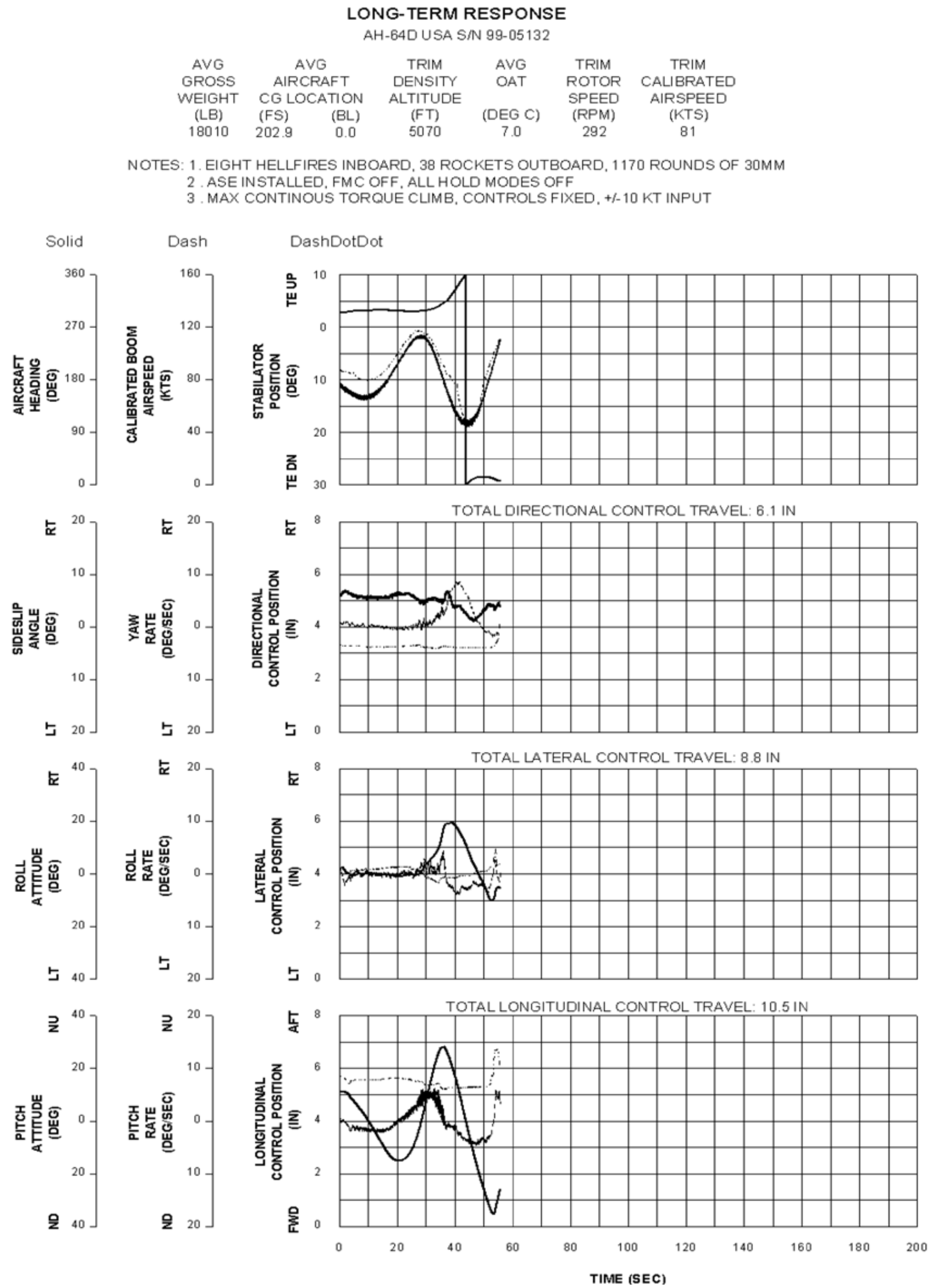


Figure C-9. Long-Term Response (5)

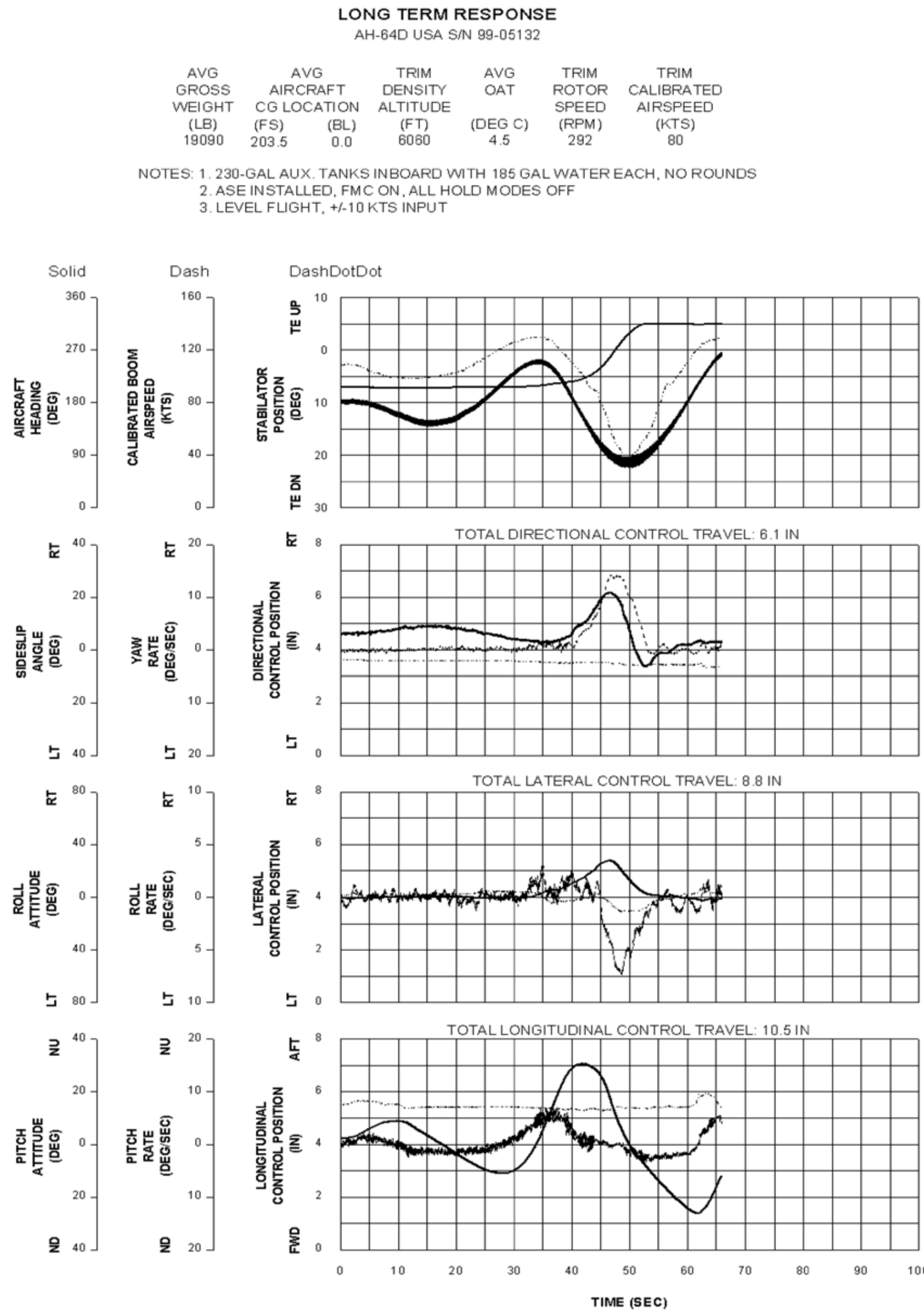


Figure C-10. Long-Term Response (6)

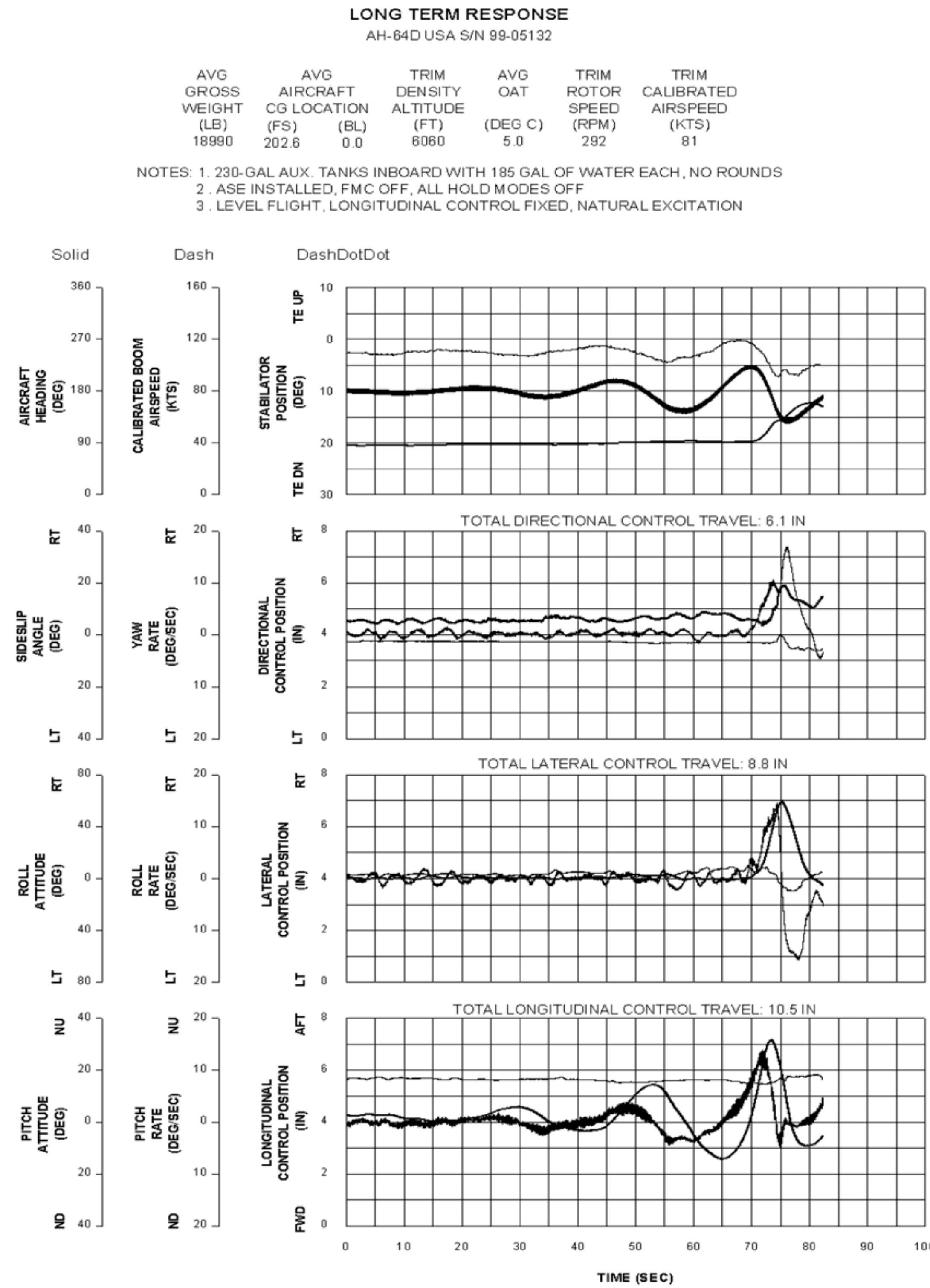


Figure C-11. Long-Term Response (7)

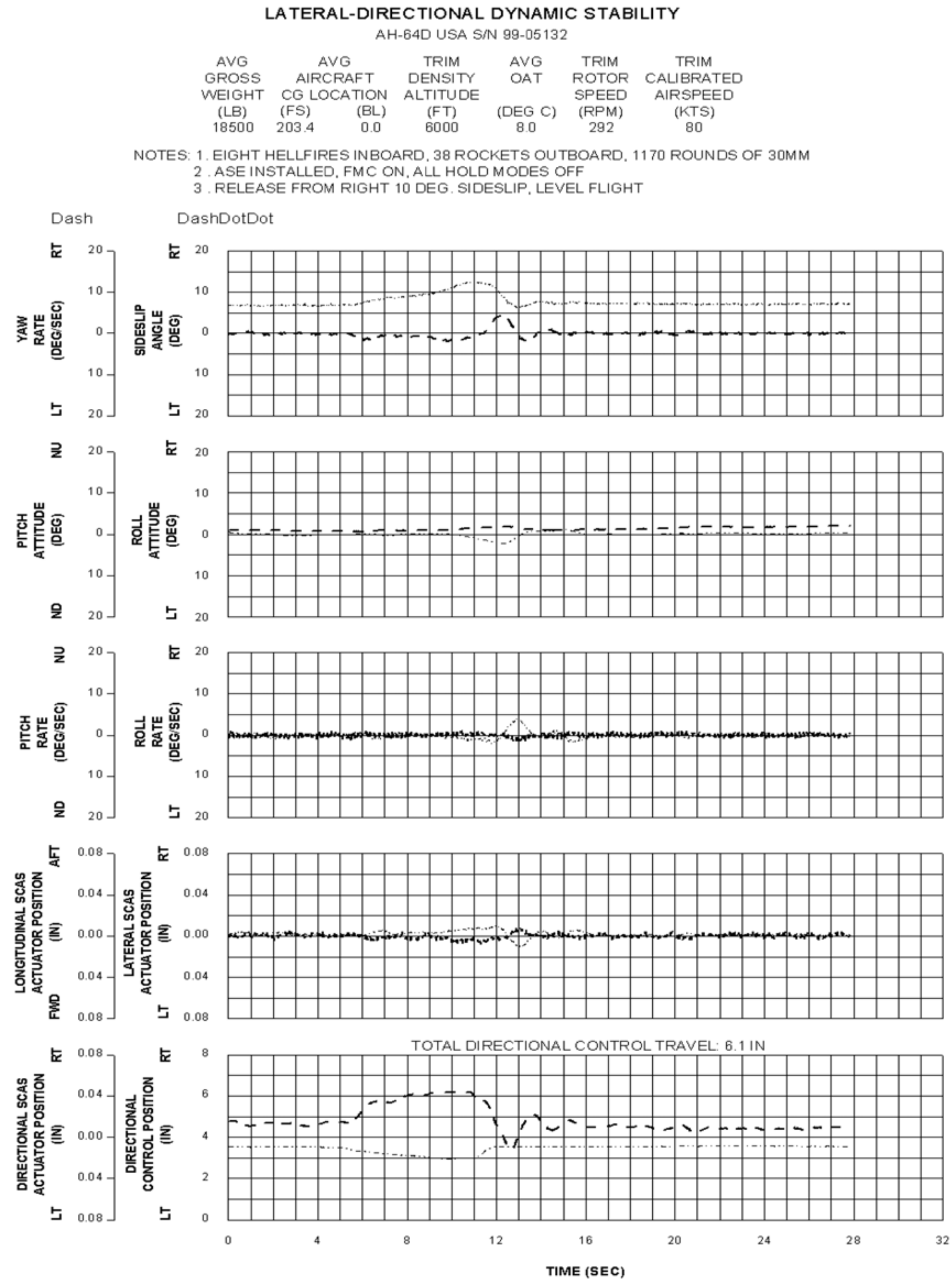


Figure C-12. Lateral-Directional Dynamic Stability (1)

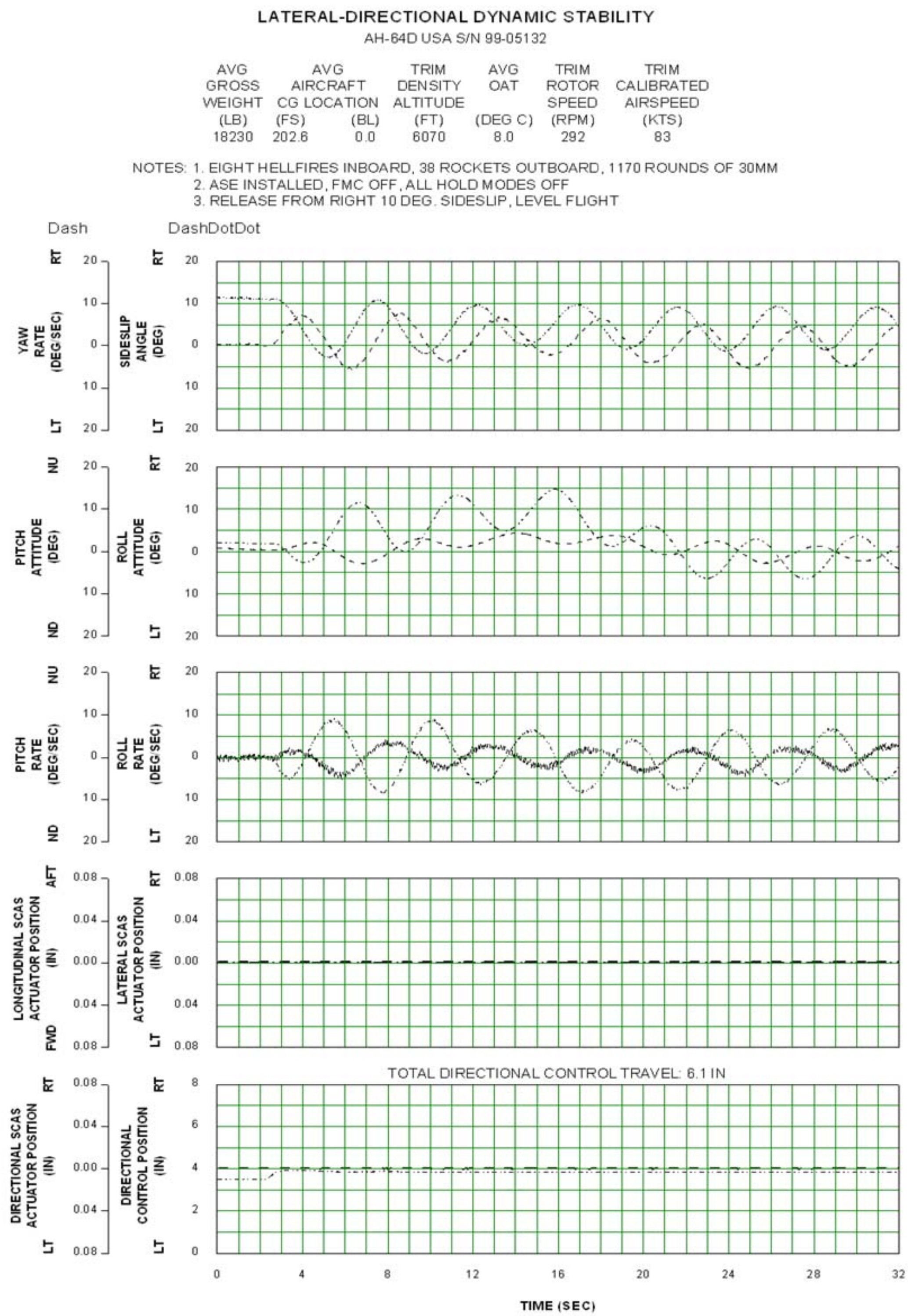


Figure 13. Lateral-Directional Dynamic Stability (2)

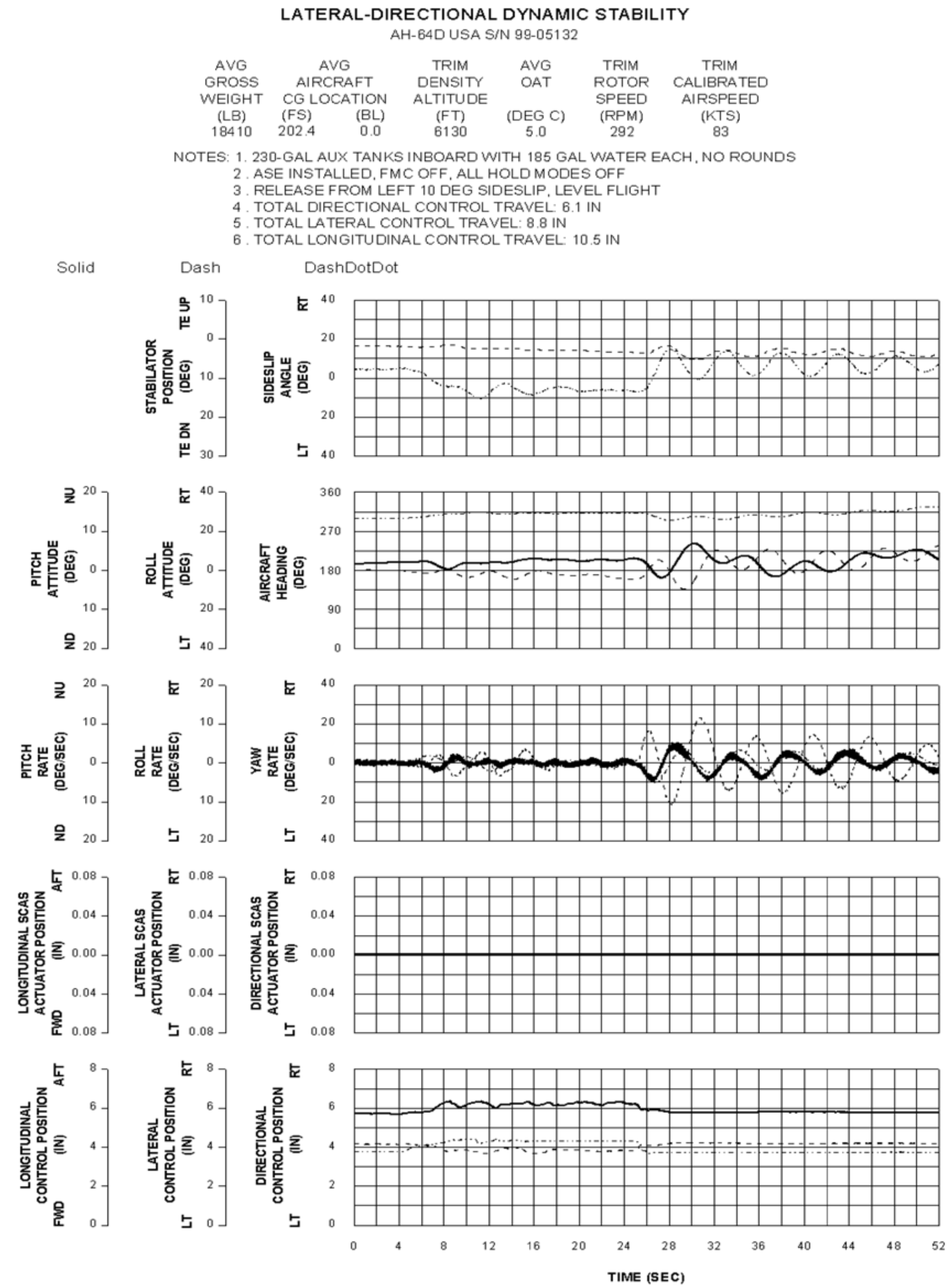


Figure C-14. Lateral-Directional Dynamic Stability (3)

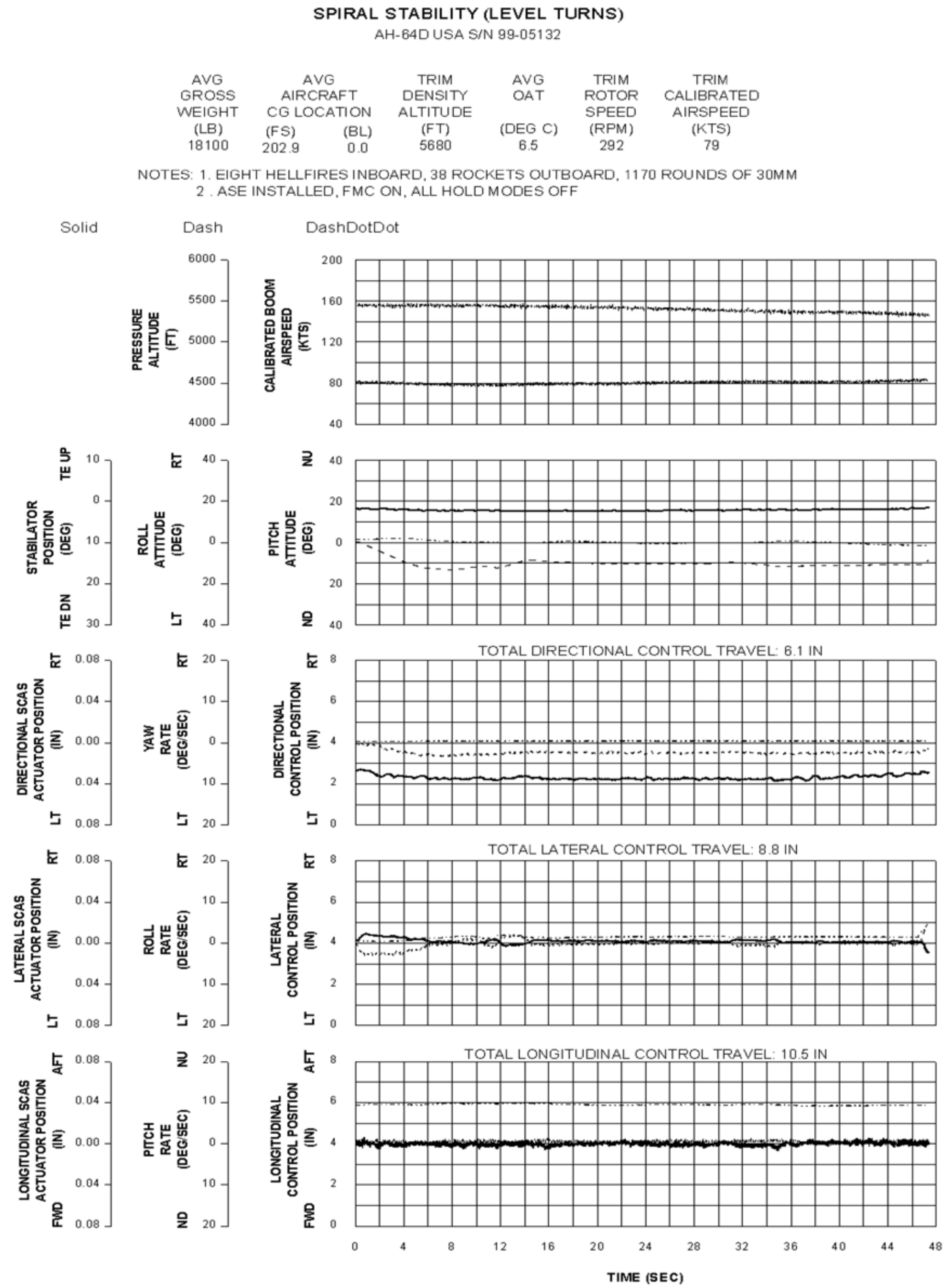


Figure C-15. Spiral Stability (Level Turns) (1)

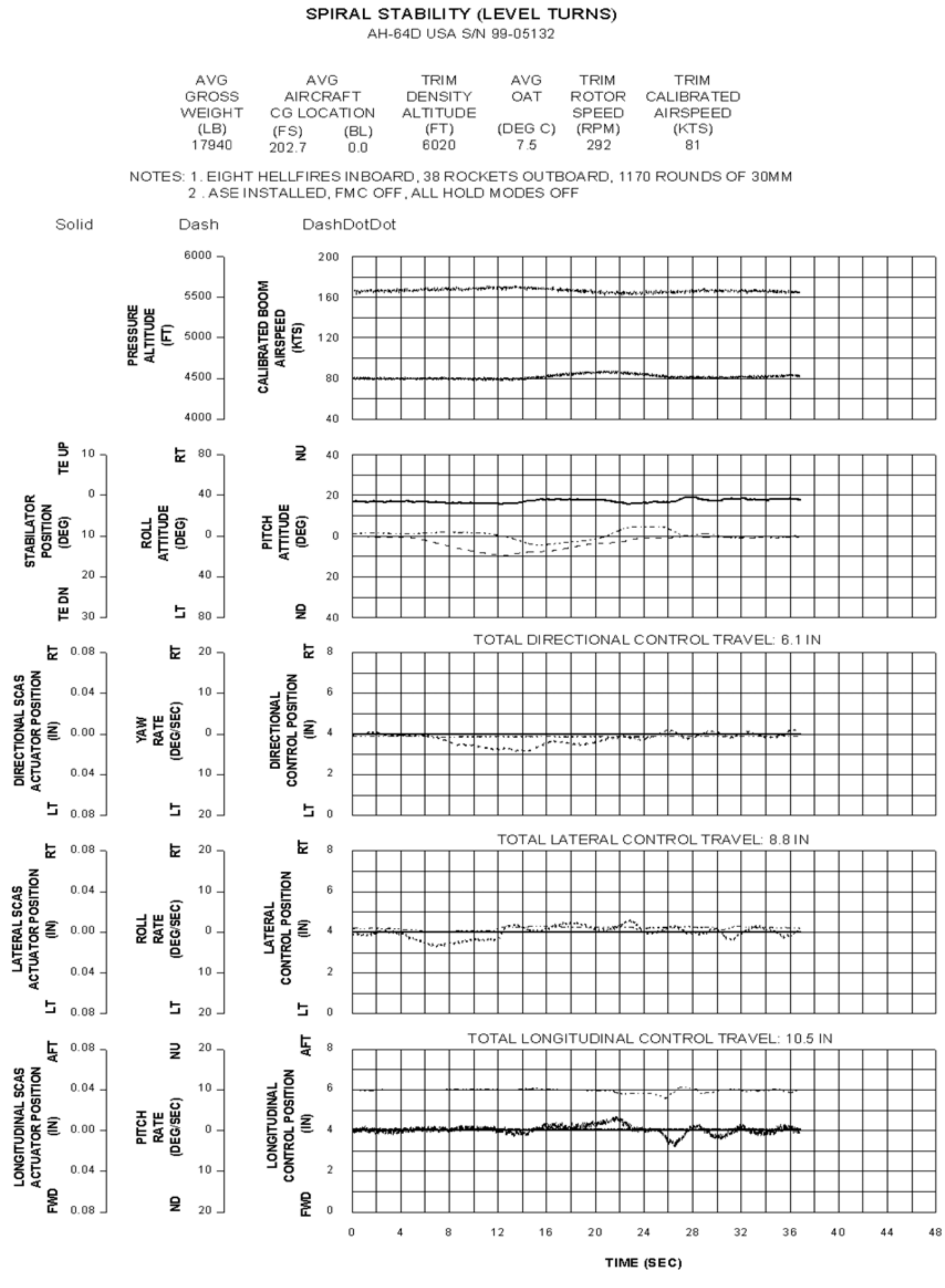


Figure C-16. Spiral Stability (Level Turns) (2)

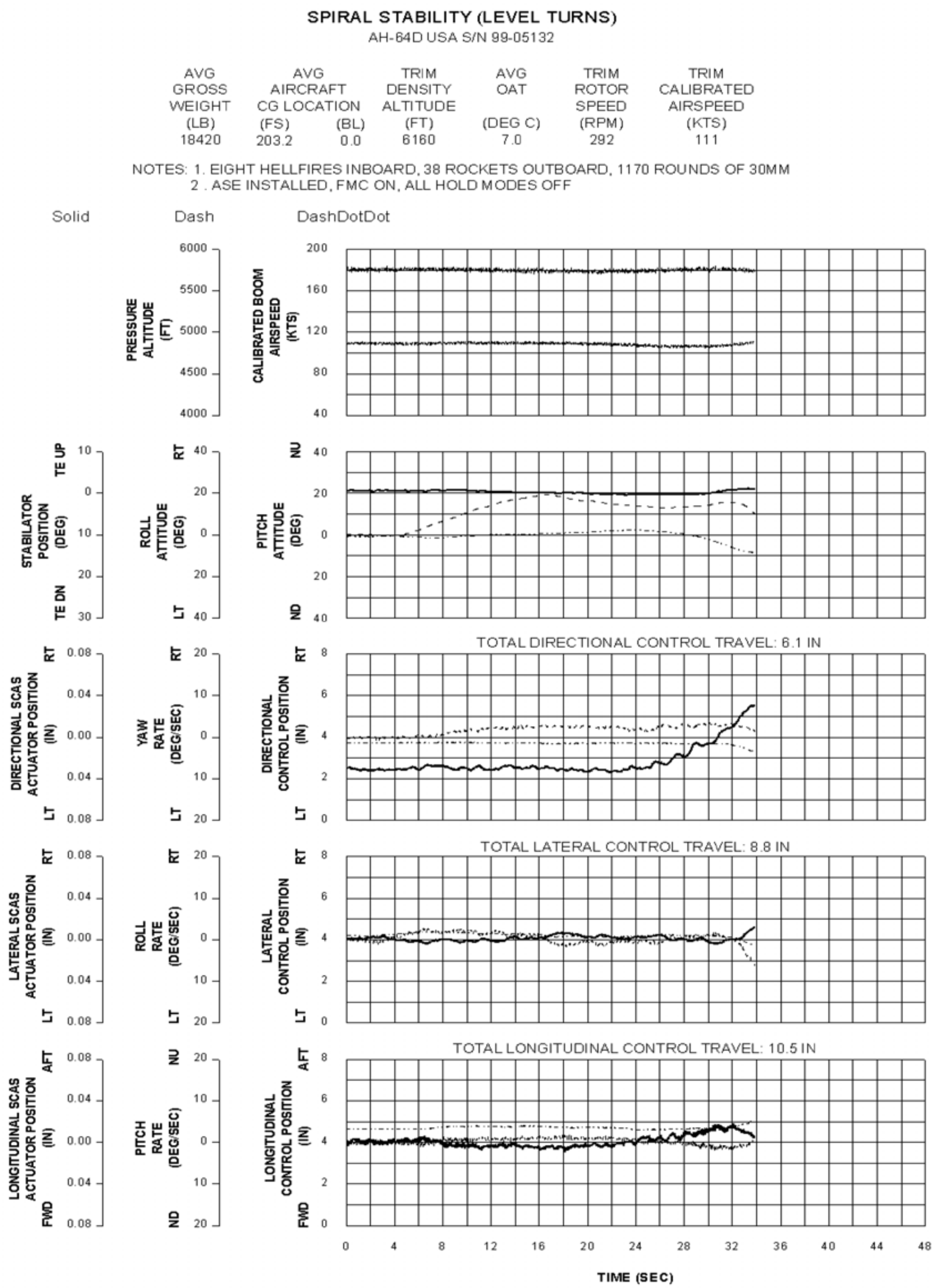


Figure C-17. Spiral Stability (Level Turns) (3)

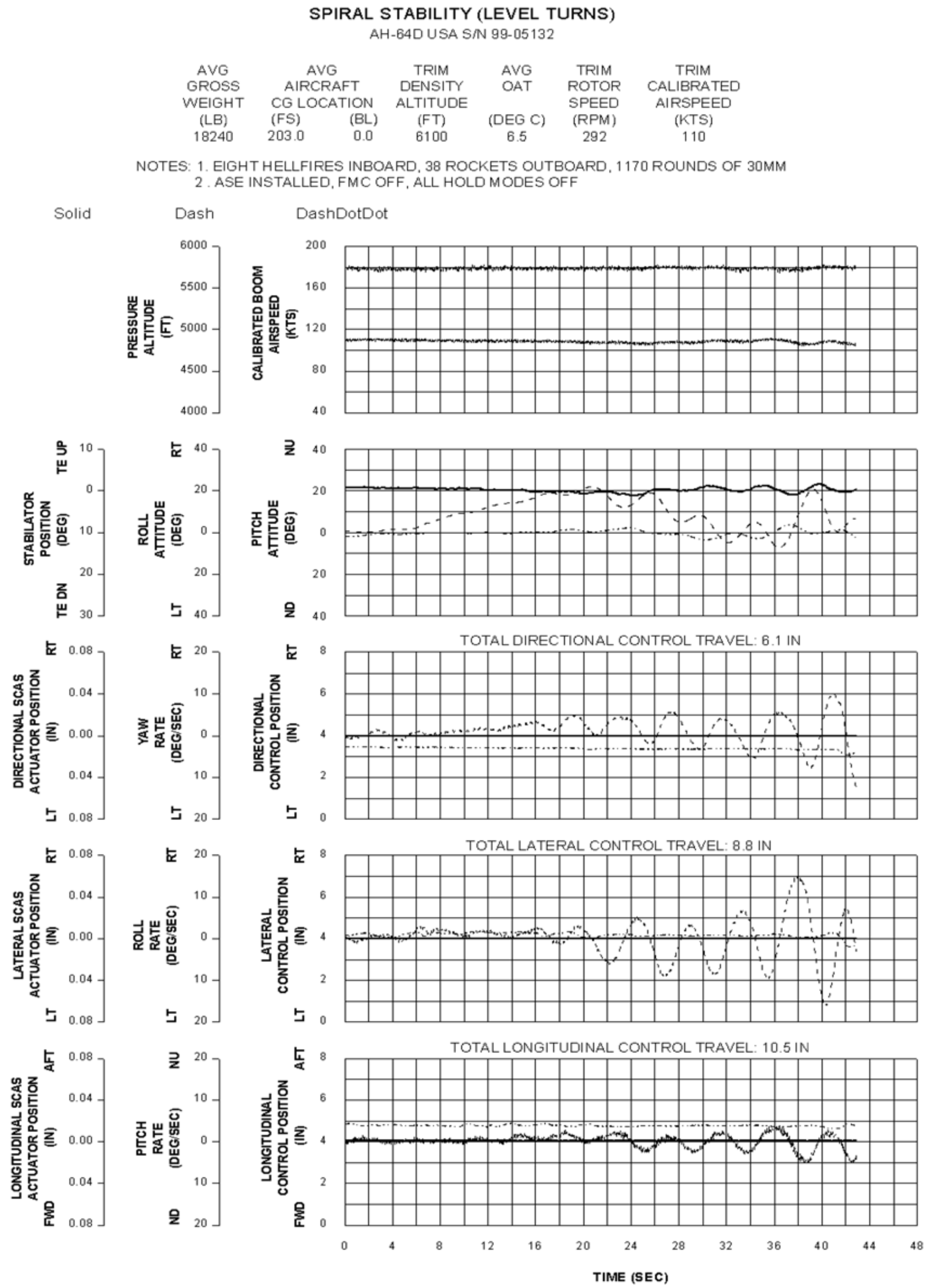


Figure C-18. Spiral Stability (Level Turns) (4)

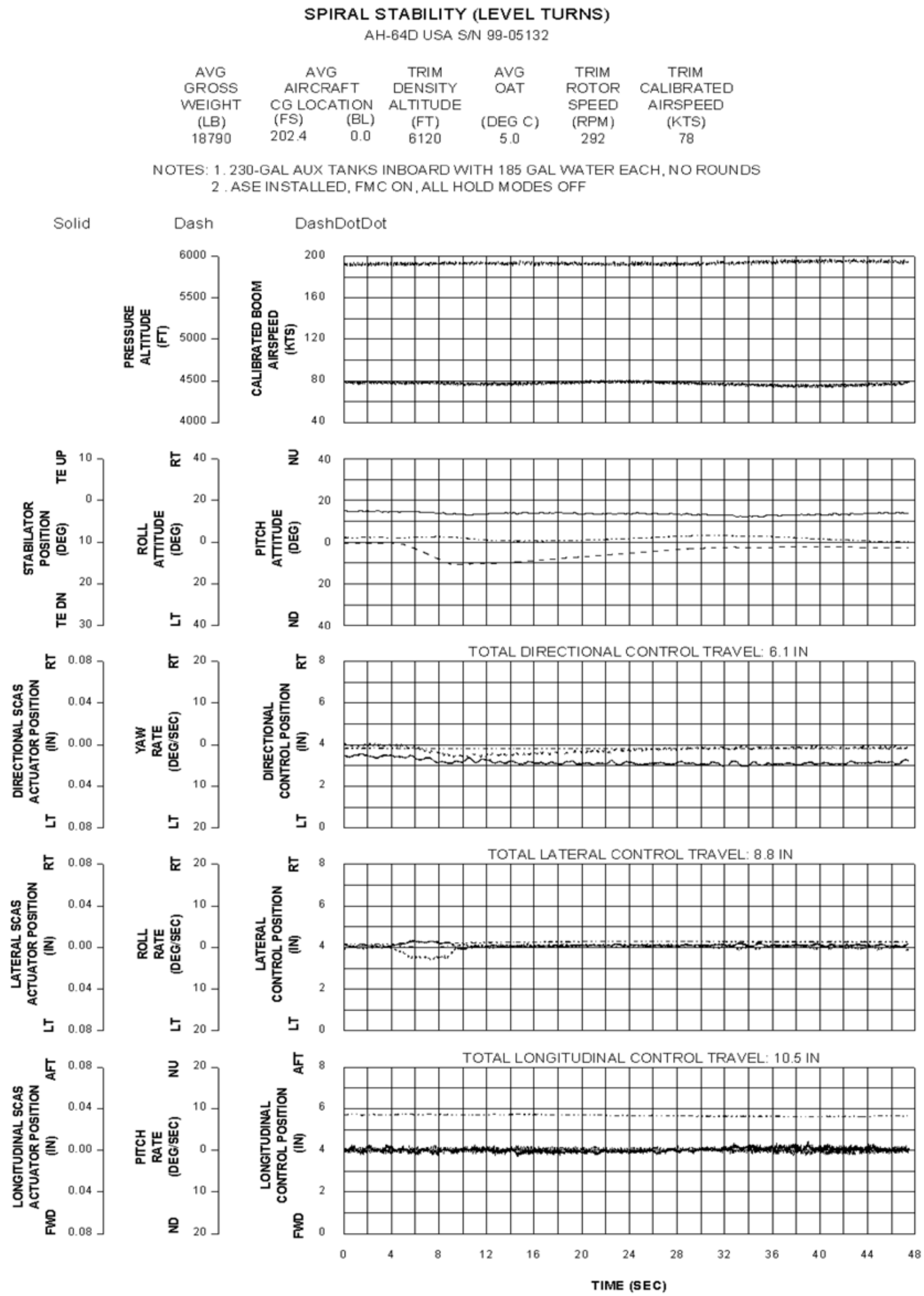


Figure C-19. Spiral Stability (Level Turns) (5)

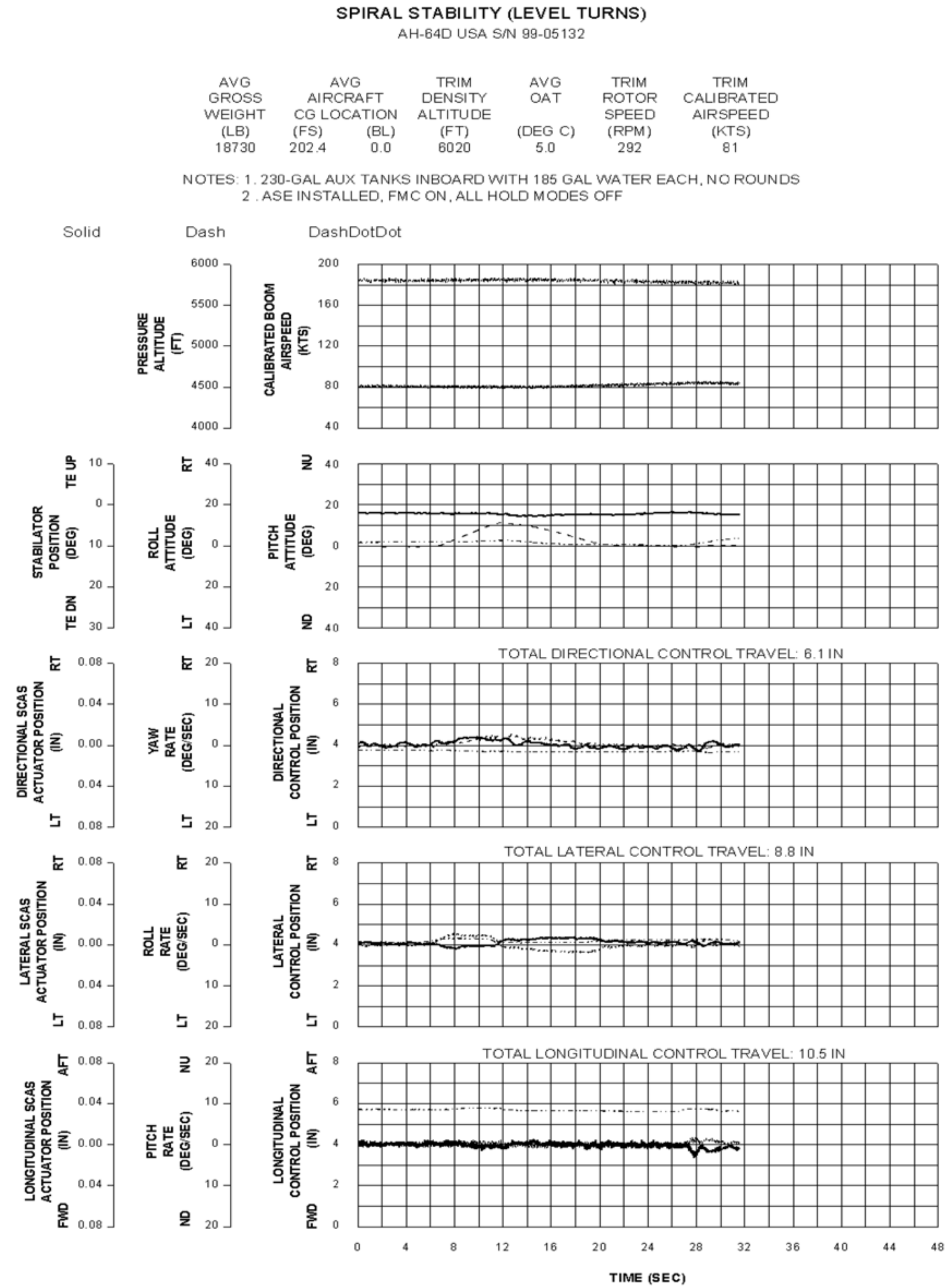


Figure C-20. Spiral Stability (Level Turns) (6)

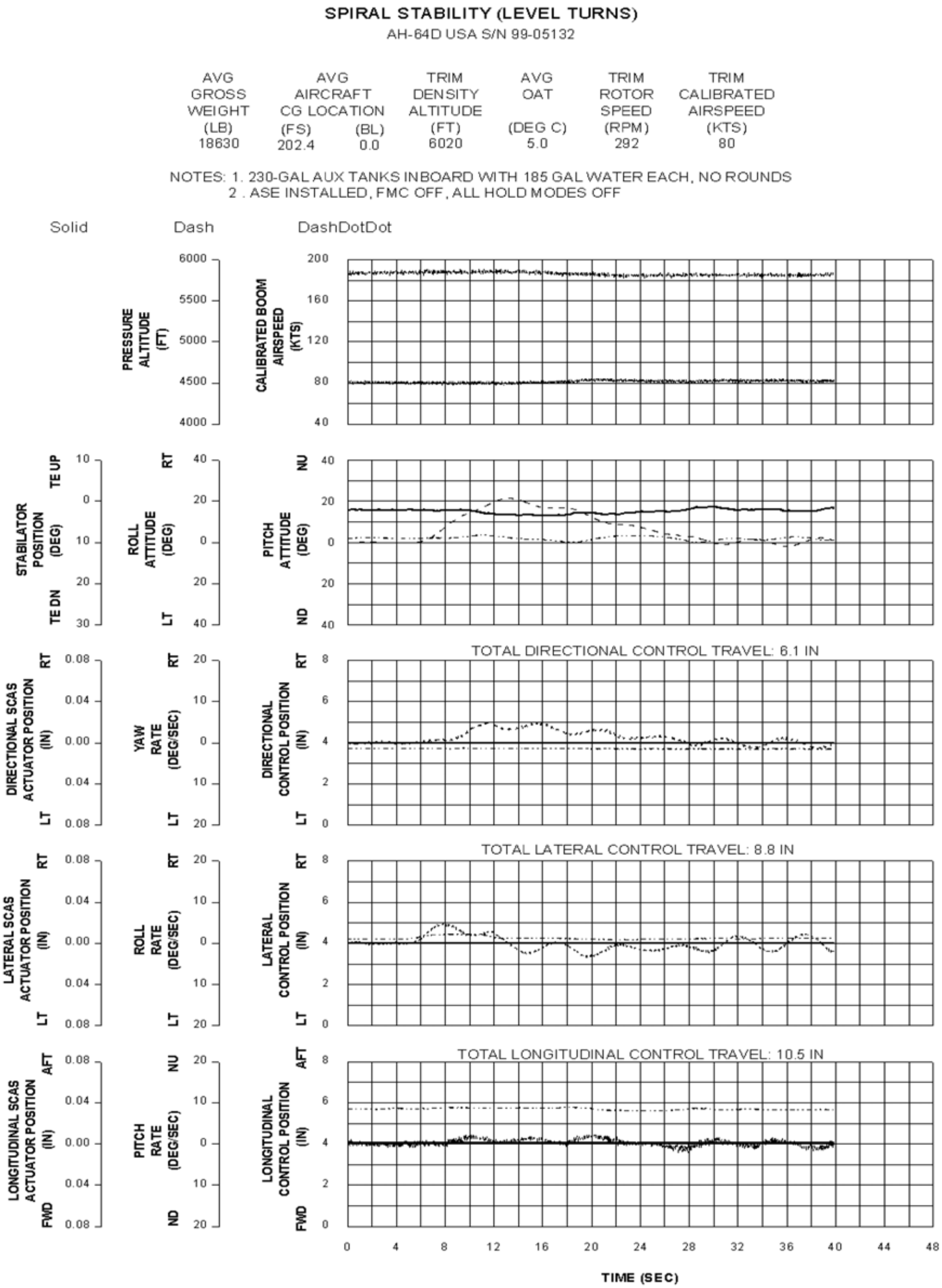


Figure C-21. Spiral Stability (Level Turns) (7)

## MANEUVERING STABILITY
AH-64D USA S/N 99-05132

| SYMBOL | AVG GROSS WEIGHT (LB) | AVG AIRCRAFT CG LOCATION (FS) | AVG AIRCRAFT CG LOCATION (BL) | TRIM DENSITY ALTITUDE (FT) | AVG OAT (DEG C) | TRIM ROTOR SPEED (RPM) | TRIM CALIBRATED AIRSPEED (KTS) | FLIGHT CONDITION |
|---|---|---|---|---|---|---|---|---|
| □ | 18460 | 203.2 | 0.0 | 5930 | 8.5 | 292 | 81 | LEFT TURN |
| ○ | 18270 | 202.8 | 0.0 | 6170 | 8.0 | 292 | 81 | RIGHT TURN |

NOTES: 1. EIGHT HELLFIRE INBOARD, 38 ROCKETS OUTBOARD, 1170 ROUNDS OF 30MM
2. ASE INSTALLED, FMC ON, ALL HOLD MODES OFF
3. COLLECTIVE FIXED
4. SHADED SYMBOLS DENOTE TRIM POINT

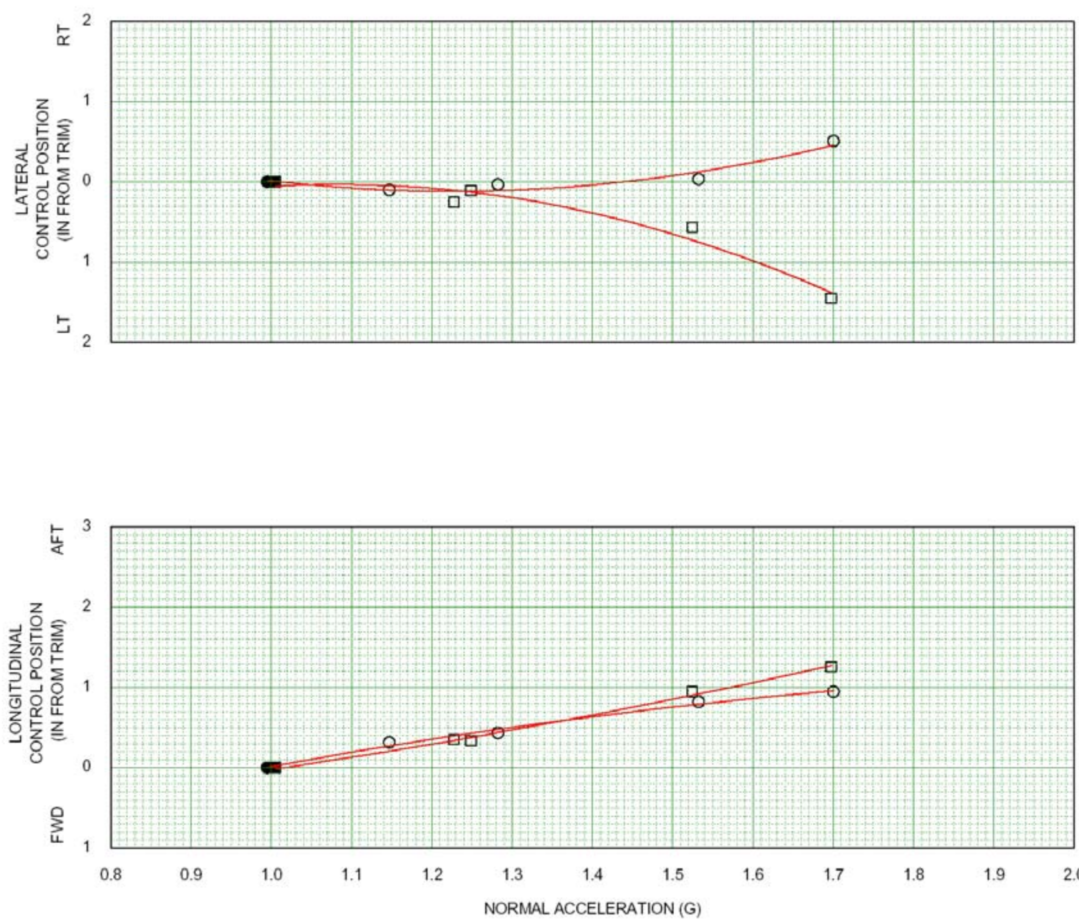


Figure C-22. Maneuvering Stability (Turns) (1)

MANEUVERING STABILITY
AH-64D USA S/N 99-05132

| SYMBOL | AVG GROSS WEIGHT (LB) | AVG AIRCRAFT CG LOCATION (FS) | (BL) | TRIM DENSITY ALTITUDE (FT) | AVG OAT (DEG C) | TRIM ROTOR SPEED (RPM) | TRIM CALIBRATED AIRSPEED (KTS) | FLIGHT CONDITION |
|---|---|---|---|---|---|---|---|---|
| □ | 17580 | 202.8 | 0.0 | 6260 | 9.0 | 293 | 80 | PULL UP |
| ⬠ | 18560 | 203.4 | 0.0 | 6110 | 7.5 | 293 | 80 | PULL UP |
| ○ | 18590 | 203.6 | 0.0 | 5820 | 8.0 | 290 | 80 | PUSH OVER |

NOTES: 1. EIGHT HELLFIRE INBOARD, 38 ROCKETS OUTBOARD, 1170 ROUNDS OF 30MM
2. ASE INSTALLED, FMC ON, ALL HOLD MODES OFF
3. COLLECTIVE FIXED
4. SHADED SYMBOLS DENOTE TRIM POINT

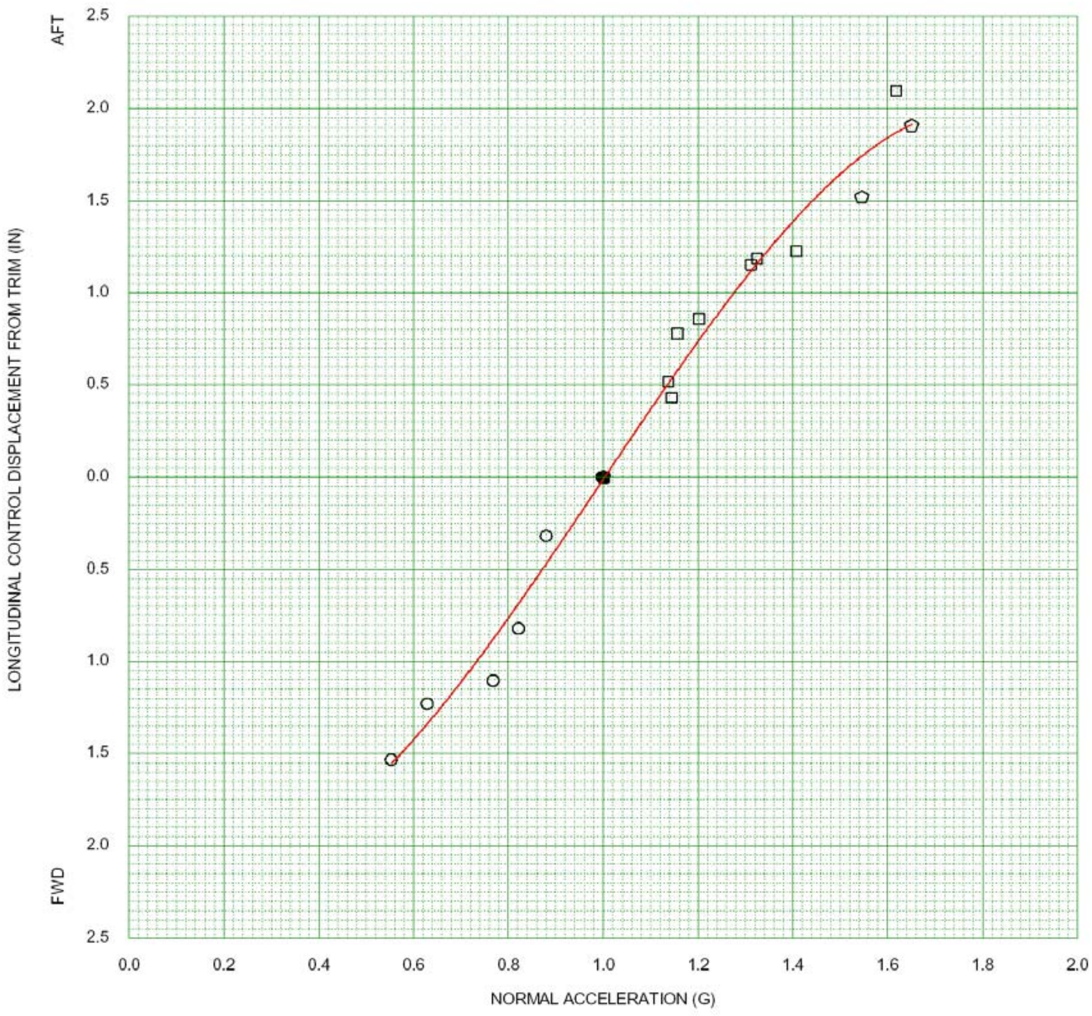


Figure C-23. Maneuvering Stability (Pull Ups and Push Overs)

MANEUVERING STABILITY
AH-64D USA S/N 99-05132

| SYMBOL | AVG GROSS WEIGHT (LB) | AVG AIRCRAFT CG LOCATION (FS) | (BL) | TRIM DENSITY ALTITUDE (FT) | AVG OAT (DEG C) | TRIM ROTOR SPEED (RPM) | TRIM CALIBRATED AIRSPEED (KTS) | FLIGHT CONDITION |
|---|---|---|---|---|---|---|---|---|
| □ | 17970 | 202.9 | 0.0 | 6000 | 8.0 | 292 | 109 | LEFT TURN |
| ○ | 17800 | 202.9 | 0.0 | 6350 | 7.5 | 292 | 108 | RIGHT TURN |

NOTES: 1. EIGHT HELLFIRE INBOARD, 38 ROCKETS OUTBOARD, 1170 ROUNDS OF 30MM
2. ASE INSTALLED, FMC ON, ALL HOLD MODES OFF
3. COLLECTIVE FIXED
4. SHADED SYMBOLS DENOTE TRIM POINT

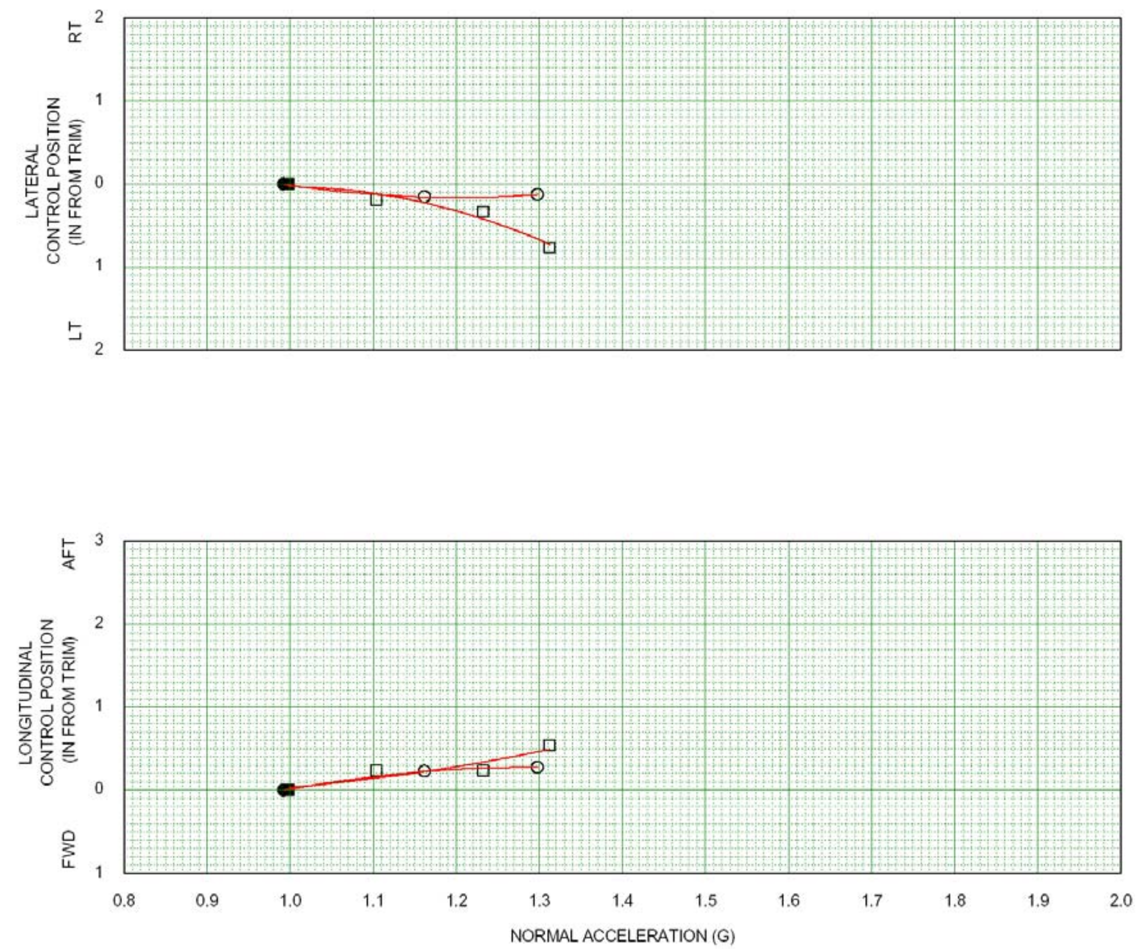


Figure C-24. Maneuvering Stability (Turns) (2)

MANEUVERING STABILITY
AH-64D USA S/N 99-05132

| SYMBOL | AVG GROSS WEIGHT (LB) | AVG AIRCRAFT CG LOCATION (FS) | (BL) | TRIM DENSITY ALTITUDE (FT) | AVG OAT (DEG C) | TRIM ROTOR SPEED (RPM) | TRIM CALIBRATED AIRSPEED (KTS) | FLIGHT CONDITION |
|---|---|---|---|---|---|---|---|---|
| □ | 18090 | 202.8 | 0.0 | 6190 | 8.0 | 292 | 110 | PULL UP |
| ○ | 17570 | 202.8 | 0.0 | 6020 | 8.5 | 292 | 109 | PUSH OVER |

NOTES: 1. EIGHT HELLFIRE INBOARD, 38 ROCKETS OUTBOARD, 1170 ROUNDS OF 30MM
2. ASE INSTALLED, FMC ON, ALL HOLD MODES OFF
3. COLLECTIVE FIXED
4. SHADED SYMBOLS DENOTE TRIM POINT

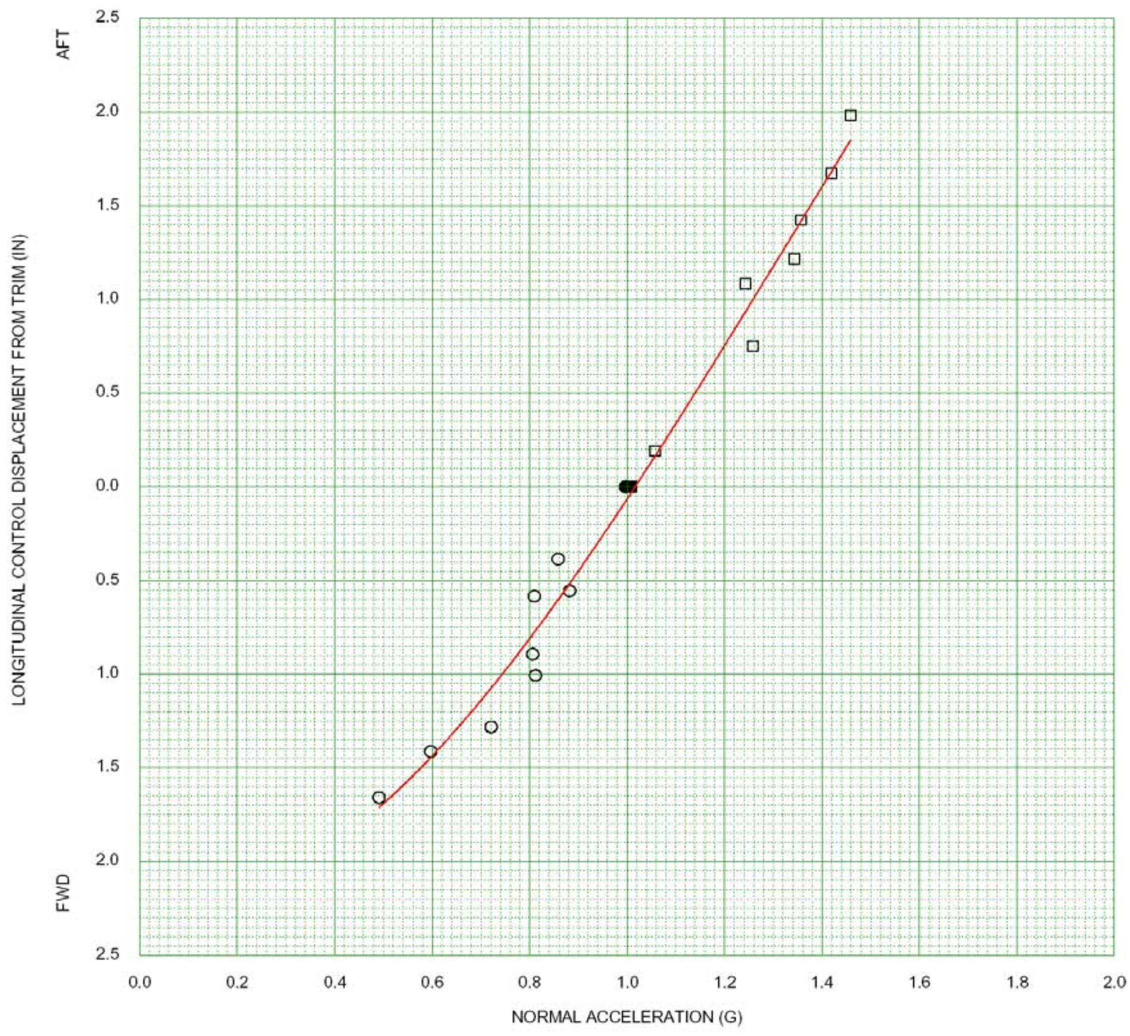


Figure C-25. Maneuvering Stability (Pull Ups and Push Overs) (2)

## VITA

The author of the thesis is a Chief Warrant Officer 5 in the United States Army. He is now in his 28th year of service with the Army and has been involved in flying for over 21 years of his chosen profession. He has accumulated more that 4800 hours of flying with over 3000 hours in the Army's AH-64 Apache helicopter. Growing up in rural South Carolina and a high school graduate of a small town school called Slater-Marietta High, he decided to join the Army to see the world and make something of himself. Opportunities to attend night schools and finally to attend a degree completion program at Embry-Riddle Aeronautical University in Daytona Beach, Florida, enabled Mr. Meely to attain his Bachelor of Science Degree in Aeronautical Science. Then, after applying and being selected for the Army's Experimental Test Pilot Program, he attended the University of Tennessee Space Institute in Tullahoma, TN. He has been working as an experimental test pilot for the Army now for over 3 years, using his Apache helicopter experience to provide the Army's soldiers a better, more lethal flying weapons platform. He is proud to be a member of the team that is responsible for ensuring the Army gets the best equipment and this Master of Science in Aviation Systems lends him the credibility to perform that job.