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LONGBOW APACHE
A TOTAL WEAPONS SYSTEM
FOR THE MODERN BATTLEFIELD

by

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The United States Army has stated a need for an Advanced Attack Helicopter that can operate and survive on the modern battlefield. This helicopter must be able to successfully locate and engage multiple armored targets while operating under darkness or minimum visibility conditions. The aircraft must also be able to maintain high readiness rates while reducing operational and support costs. To meet this need, the Army requires a total weapon system that includes;

- Improved navigation capabilities to operate independently on deep strike operations,
- Advanced communications which provide reliable secure voice and digital data communications allowing for rapid transfer and coordination of tactical information and battle management,
- Integrated crewstations to provide improved situational awareness and automated on board mission planning for real-time battle management,
- Increased system automation and aircraft management that reduces crew workload allowing the crew to focus on the mission,
- Flight controls with three-axis hover position hold capability for accurate station keeping,
- The capability to detect and classify 256 moving and stationary ground and air targets that are obscured by smoke, dust, rain, fog, snow, etc., prioritize the targets from highest to lowest, and engage these targets within threat timelines.

The Longbow Apache was designed to meet this need through the infusion of advanced technologies into the battle-proven AH-64A Apache. Technology infusion allows the Longbow Apache in just 30 seconds to; 1) detect and classify 256 targets and/or threats that are obscured by darkness, weather or battlefield conditions, 2) divide the target array, 3) assign priority fire zones for each attack team member, 4) transmit the targets and zones to team members, and 5) initiate the attack by launching the first of 16 RF Hellfire fire-and-forget missiles against the automatically prioritized targets. This paper identifies the Longbow Apache System Specification requirements for the nine Longbow Apache avionics subsystems (listed below and shown in figure 1) and describes the systems that were designed to meet these requirements. The paper than reviews the results of the test surveys and demonstrations that were used to document the Longbow Apache's performance.

1. Communications subsystem
2. Navigation subsystem
3. Aircraft systems management (ASM) subsystem
4. Controls and displays subsystem (CDS)
5. Sights subsystem
6. Weapons subsystem
7. Data management subsystem (DMS)
8. Aircraft survivability equipment (ASE) subsystem
9. Flight control subsystem (FCS)

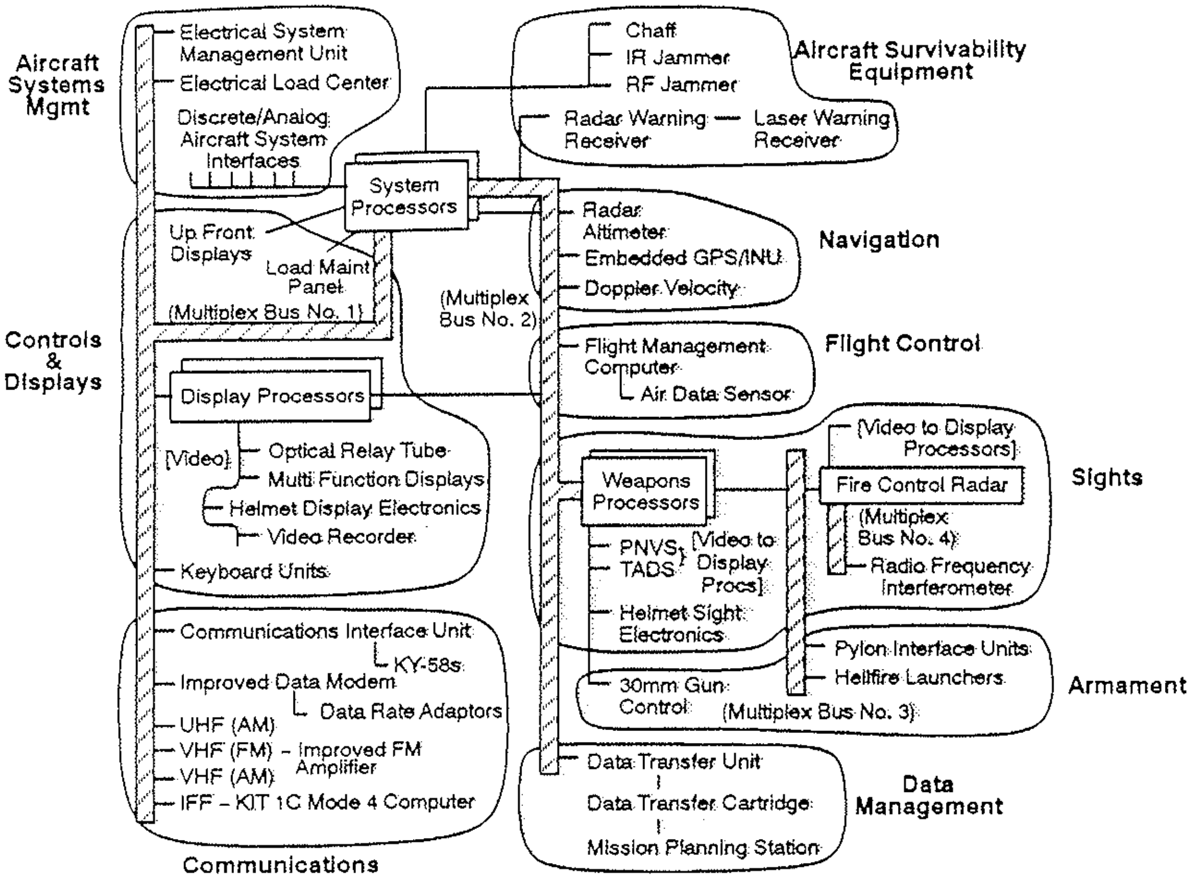


Figure 1. Nine Avionics Subsystem

<u>Communications Subsystem</u>. The Longbow Apache communications subsystem provides reliable voice and digital data transmissions between the aircraft and other battlefield tactical elements in normal, crypto-secure, and antijamming modes. This subsystem includes the following major functions: VHF-FM, VHF-AM, and UHF-AM radio communications, digital data transmission and reception, voice warning messages, warning tones, identification friend or foe (IFF), and crewstation intercommunications. The major elements of the communications subsystem include the communications interface unit, UHF-AM (AN/ARC-164), VHF-AM (AN/ARC-186) and VHF-FM (AN/ARC-201) radio sets, IFF transponder (AN/APX-100), communications security units, FM power amplifier, and improved data modem (IDM).

The improved data modem brings the modern digital battlefield to the Longbow Apache. This unit allows the aircraft to transmit and receive battle management information such as fire control RADAR targets, team member priority fire zone assignments, and no fire zones around friendly forces. In addition, this unit allows transfer of all on board mission data such as flight routes, waypoints, communications electronic operating instructions, and threat intelligence information.

In nonsecure and nonantijamming modes, the Longbow Apache communications subsystem is required to provide reliable UHF-AM and VHF-FM line-of-sight communications with a range of 35 nautical miles at 1200 feet AGL (long range) and 25 kilometers at 100 feet AGL (low altitude). The results of the communications demonstration are tabulated in table I. As shown, the results met or exceed the long range and low altitude specifications. In addition, the system was able to provide reliable communications at long range and low altitude when operating in secure and antijamming modes. The U.S. Army representative monitoring the demonstration reported the performance of the Longbow Apache communications subsystem as one of the Army's best.

Table I. Voice Communications Performance

Demonstrated Performance for Two-Way Communications†						
Channel Under Test	FM #1 ARC-201 (amplifier off)		FM #2 ARC-201		UHF-AM ARC-164	VHF-AM ARC-186
Frequencies Tested	10 (30 to 87 MHz)				9 (226 to 400 MHz)	7 (122 to 150 MHz)
Test Conditions / Mode	Long Range 35 nm 1200 ft	Low Altitude/ Hover 25 km 100 ft	Long Range 35 nm 1200 ft	Low Altitude/ Hover 25 km 100 ft	Long Range 35 nm 1200 ft	Long Range 35 nm 1200 ft
Single Channel	35 nm	100 ft	35 nm	100 ft	35 nm	21 nm
Secure	35 nm	250 ft	33 nm		35 nm	
Frequency Hopping	35 nm	100 ft	35 nm		27 nm	

† The test points selected reflect the U.S. Army spec for single channel voice performance. The VHF-AM spec is 20 nmi, max range was 21 nmi.

There is no specific requirement for range performance of digital data transmissions so actual performance was documented in two improved data modem surveys as shown in tables II and III. The survey showed that reliable digital data transfer can be made at the same long ranges and low altitudes even when in the secure and antijamming modes.

Table II. IDM Phase 1 Survey Results

		FM #1 (IFM off) (two-way communication)		FM #2 (two-way communication)	
Protocol	Mode	35 nm (nominal) 1200 ft AGL	25 km 100 ft AGL (nominal)	35 nm (nominal) 1200 ft AGL	25 km 100 ft AGL (nominal)
TACFIRE	Plain	✓	✓	✓	✓
	Cipher	✓	✓	✓	✓
	Freq Hop Cipher	✓	✓	✓	✓
AFAPD	Cipher	✓	✓	✓	✓
	Freq Hop Cipher	27 nm	150 ft	✓	✓
EAFAPD	Plain	⊠	150 ft	✓	✓
	Cipher	✓	150 ft	✓	✓
	Freq Hop Cipher	✓	✓	✓	✓

Check (✓) indicates where two-way communication was obtained at the four cardinal headings at the initial test point of
(1) 35 nm, 1200 feet or
(2) 25 km, 100 feet

⊠ not tested

Table III. IDM Phase 2 Survey Results

AIR-TO-GROUND: ARC-164 AND ARC-186 SURVEY TEST POINTS			
Protocol	Mode	ARC-164 35nm (nominal) 1200 ft AGL	ARC-186 20 nm (nominal) 1200 ft AGL
TACFIRE	Plain	✓	13 nm
	Cipher	✓	⊠
AFAPD	Plain	✓	18 nm
	Cipher	✓	⊠
EAFAPD	Plain	✓	✓
	Cipher	✓	⊠

⊠ not available

Navigation Subsystem. The navigation subsystem provides aircraft heading, attitude, present position, ground and air mass velocity, altitude, waypoint and target steering, and distance information for piloting and navigating the aircraft. The major elements of the navigation subsystem include the inertial navigation unit (INU) which utilize ring laser gyros, Doppler radar velocity sensor, air data system, global positioning system (GPS), and radar altimeter. The system processor performs the control and status logic for the navigation subsystem along with performing earth-to-aircraft referenced coordinate conversions, waypoint and target data file management, and navigation data validation. Navigation calculations such as time, distance, and bearing to a waypoint, are performed by the system processor.

The heart of the navigation subsystem is the inertial navigation unit which uses a McDonnell Douglas-designed 23-state Kalman filter. This filter combines inertial gyro and accelerometer information with GPS and Doppler data to provide an accurate navigation solution. The navigation subsystem provides robust system performance by performing automatic alignment and moding, and by gracefully switching between the best available sensors data.

The navigation subsystem is required to provide the following data accuracies:

Position	30 meters spherical error
Velocity	0.1 meters/second
Heading	<3.0 milliradians
Altitude	<2.0 milliradians

These accuracies are 95 percent probable regardless of mission elapsed time of distanced traveled.

In combination with the flight control subsystem, the navigation subsystem is also required to provide the following hover position accuracies:

Horizontal hover drift	<5 meters radial error after 1 minute
	<8 meters radial error after 5 minutes.

The navigation demonstration results are depicted in tables IV and V. The results demonstrated that the Longbow Apache was easily able to meet its specified accuracies. The system worked so well that when the pilots followed the aircraft displays to the designated check point, they could not initially find the check point marker. It turned out that they were hovering directly over the marker.

Table IV. Position Accuracy Summary

Condition	95% Probable Specification	Flight Test Results
GPS/Doppler-aided	30m spherical	18.6 meters average
Doppler-aided with 5 minutes of GPS available	0.5% of distance traveled	0.21% average
Doppler-aided GPS never available	0.7% of distance traveled	0.25% average
Free inertial for 12 minutes after inflight loss of both GPS and Doppler	500 meters	99 meters average
Free inertial after a 3-minute ground alignment, GPS and Doppler never available (average time and distance between waypoint updates of 7.8 minutes and 19 kilometers)	Not specified	181 meters average radial error
Doppler-aided over water (Colorado River)	Not specified	0.84% of distance traveled (not compensated for water motion)

Table V. Automatic Hover Hold Performance Summary

Condition	95% Probable Specification	Flight Test Results (including TADS error)
GPS/Doppler-aided	2 meters after 1 minute 8 meters after 5 minutes	0.99 meters average after 1 minute 3.55 meters average after 5 minutes
GPS (no Doppler)	5 meters after 1 minute 25 meters after 5 minutes	2.00 meters average after 1 minute 9.50 meters average after 5 minutes

Aircraft Systems Management (ASM) Subsystem. The ASM subsystem controls the functions related to aircraft flight management, engine control, and aircraft utility systems control. The ASM subsystem provides processing and enhanced automated operation and control processing for the anti-ice and de-ice, auxiliary power unit, electrical power management system, fuel, hydraulics, integrated pressurized air system, drive train, engine, and fire extinguishing systems. ASM provides both automatic and manual control of these systems, monitors the status of the systems, and notifies the crew of any abnormal conditions. Aircraft checklists are stored in the system and can be displayed to the crew either automatically, such as in an emergency condition, or by crew selection.

ASM is required to provide automated performance planning for aircraft performance, engine fuel, weapons, navigation, etc., such as torque available in-ground effect (IGE) and out-of-ground effect (OGE) torque required, IGE and OGE ceilings, IGE and OGE torque margins, true airspeed (TAS) for maximum range, TAS for maximum endurance, and never exceed velocity (V_{NE})

U.S. Army flight crews flying the Longbow Apache during its Preliminary Airworthiness Evaluation cited automation features such as single-step APU starts and system initialization as an "enhancing characteristic". The crews further commented that when they went back to flying other aircraft, they were disappointed in having to manually initialize and start up the aircraft.

Controls and Displays Subsystem (CDS). The controls and displays subsystem provides day and night viewable multifunction displays and audio-visual cues to the crew. The primary displays for each pilot and copilot crewstation are the integrated helmet and display sight subsystem (IHADSS), two multifunction display (MFD) units, and an up-front display (UFD) as shown in figures 2 and 3. The multifunction displays are large high-resolution monochrome direct sunlight viewable displays that provide easy to understand status displays and sensor video for fast target recognition. Subsystem controls for the crewstations are provided by the MFD bezel buttons, keyboard units, and cursor control buttons located on the collective hand grips. In addition, the copilot/gunner is provided with an optical relay tube (ORT) that contains the necessary controls and displays required to monitor and operate the target acquisition and designation sight (TADS).

The tactical situation display (see figure 4) provides the crew with a view of the digital battlefield. On this single display is depicted, fire control radar targets, threat intelligence information, currently detected threats, team member current locations (automatically updated through the improved data modem), priority fire zone assignments, and other battle management information. This display allows a Longbow Apache to plan and coordinate the battle for the entire team.

The U.S. Army Preliminary Airworthiness aircrews cited the architecture of the controls and displays subsystem as being intuitive and "easily understood".

A controls and displays demonstration was performed under day and night conditions to ensure that the displays are readable under all conditions and are compatible with night vision goggles. Table VI summarizes the results of the night demonstration which show that the system was rated Good to Very Good by the test subjects.

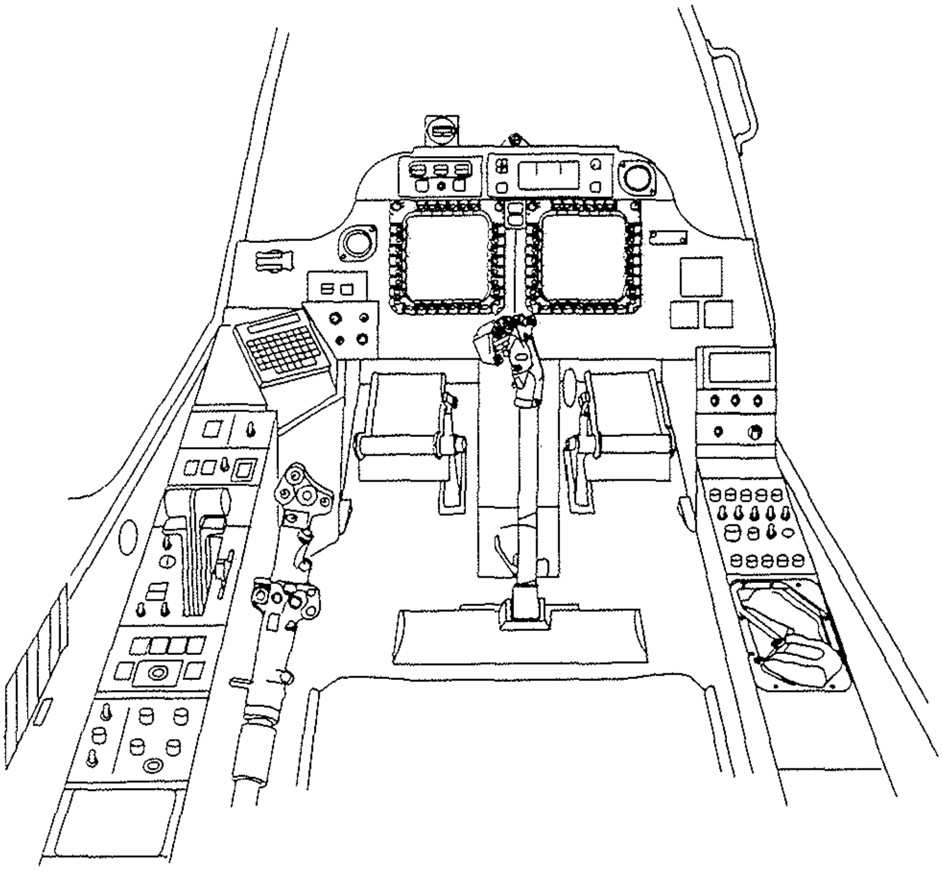


Figure 2. Pilot Crewstation

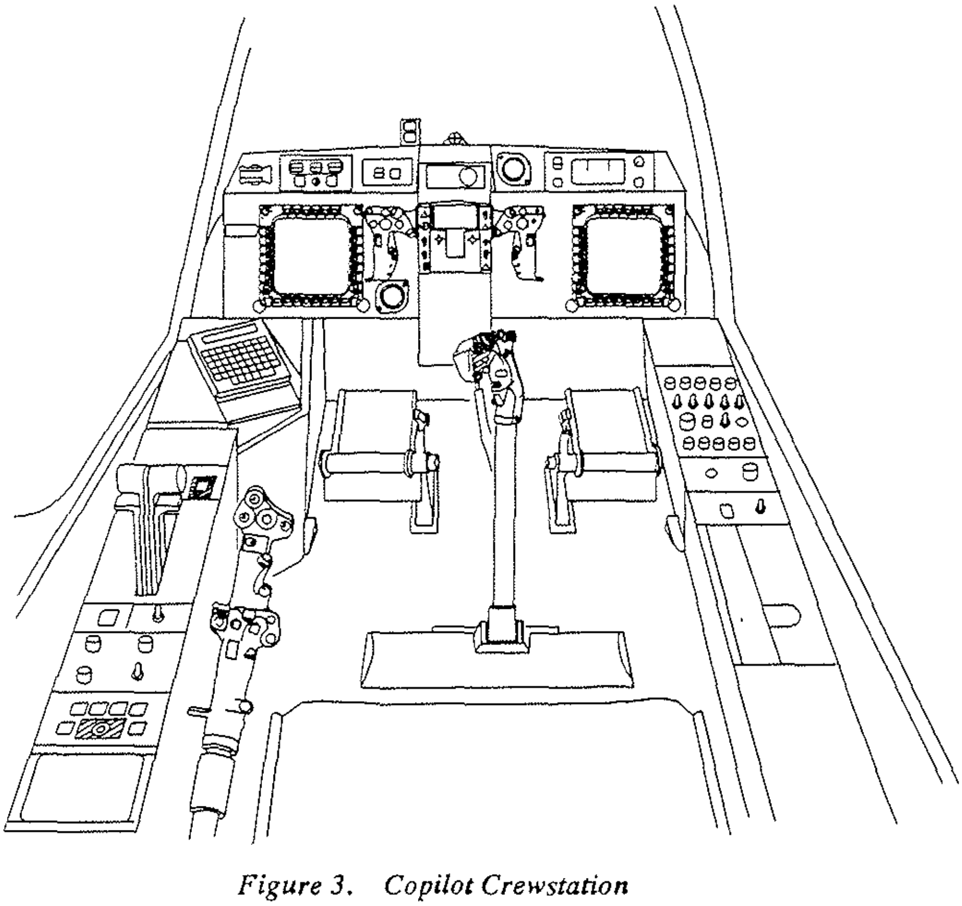


Figure 3. Copilot Crewstation

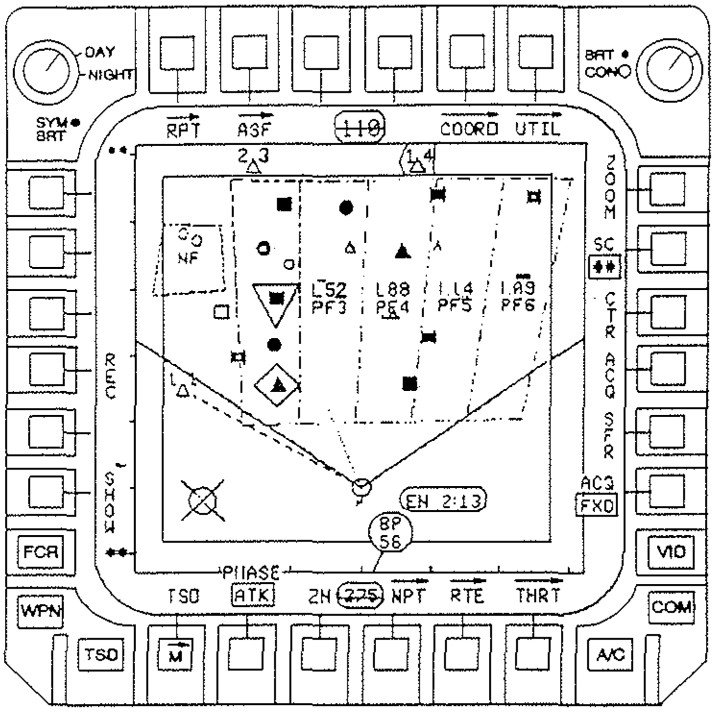
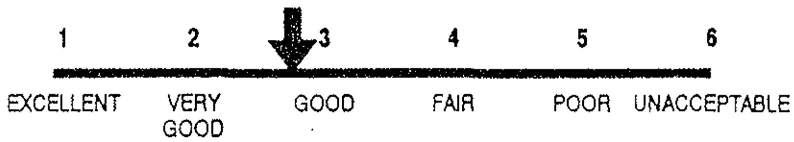


Figure 4. Tactical Situation Display

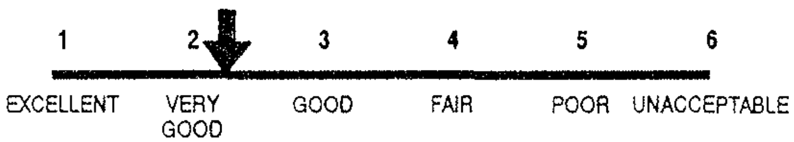
Table VI. Controls and Displays Demo Results

Night Ground and Flight Evaluations	Responses to whether the systems were adequate for night operations	
	#1 Test Subject	#2 Test Subject
Evaluation of crewstation interior lighting subsystems	Yes	Yes
Evaluation of the MFD, UFD, KU, ORT, IHADSS displays	Yes	Yes
Evaluation of crewstation NVIS compatibility	Yes	Yes
Effect of lighted components on IHADSS readability	Yes	Yes

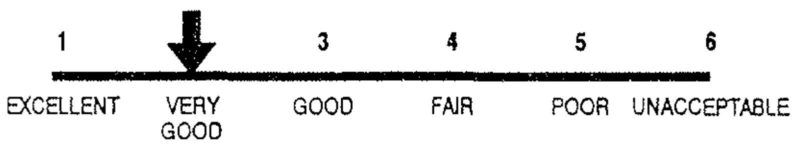
INTERIOR LIGHTING SUBSYSTEMS



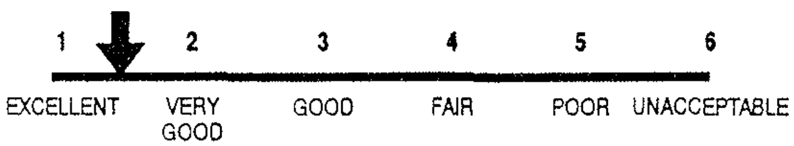
MFD, UFD, KU, ORT, IHADSS DISPLAYS



NVIS COMPATIBILITY



IHADSS READABILITY



Sights Subsystem. The sights subsystem provides the capability to detect, locate, recognize, designate, and track targets in adverse weather either day or night and provides accurate target line-of-sight (LOS) and range information to the aircraft's processing centers. Video is provided to the crew for nap-of-the-earth (NOE) flight at night or in adverse weather conditions. The sights subsystem consists of the IHADSS, TADS, and the Longbow fire control radar. In addition to the above sights, the subsystem also includes the pilot night vision sensor (PNVS) which provides infrared video for piloting the aircraft at night.

Innovative integration was used to "link" the existing TADS sensor with the new fire control RADAR. When the fire control RADAR locates and prioritizes targets, the TADS is automatically positioned to the highest priority target for visual verification. This "link" capability allows the crew to quickly verify and engage multiple targets. As the crew launches a missile against the selected target, the TADS is automatically repositioned to the next target.

Key performance requirements of the TADS and fire control RADAR are classified and cannot be discussed in this paper. However, performance of the TADS system was tested as part of the Armament Survey which is discussed in the following Weapons Subsystem section. The fire control RADAR is currently undergoing its mode performance demonstrations.

Weapons Subsystem. The weapons subsystem monitors, initializes, and controls the preparation and firing of the Hellfire modular missile system (HMMS), folding fin aerial rockets (FFAR), and 30mm area weapon system (AWS). The missile interfaces are designed to accommodate the future addition of an air-to-air missile. The weapons subsystem provides all launch, firing electronics, and safety monitoring devices required to prepare and launch missiles and rockets and for firing the 30mm gun. Mode control, fire control computations, steering cues, weapon constraints, and firing inhibits are also provided by the subsystem. The weapons subsystem consists of the HMMS (four MIL-STD-1760 launchers, with up to 16 missiles), FFARs and launchers (four launchers, with up to 76 FFARs), AWS (30mm gun, 1200 rounds maximum, turret control box, gun control box, and magazine controller), and four articulating pylons each containing a pylon interface unit.

The weapons subsystem uses a new Kalman-based seven-state target state estimator for precise ballistic fire control solutions. This estimator is augmented by a laser range validator filter which rejects secondary LASER returns and provides accurate target range and range rate information. Both the target state estimator and the LASER range validator filter were both designed by McDonnell Douglas Helicopter Systems and tailored for the Longbow Apache.

The armament survey was used to demonstrate the overall performance of the Longbow Apache as a total weapon system. Area weapon and Hellfire performance requirements are classified but the pass/fail test results are given in tables VII and VIII. Aerial rocket impacts are required to have an accuracy of 23 milliradians in azimuth and 19 milliradians in elevation. Rocket test results summarized in table IX show that the Longbow Apache was able to meet its required performance specifications for rocket accuracy.

Area weapons firing results show that the Longbow Apache was able to pass all of the required firing points. In fact, the Longbow Apache shot so well that the test range crews had trouble keeping the targets repaired. After scoring direct hits from 3 kilometers away, one test pilot exclaimed that he had waited 14 years to shoot that well.

LASER Hellfire missiles were successfully fired against their targets with the aircraft in a hover and with the aircraft flying at 90 knots. The RF missile is currently undergoing tests but, as shown in table X, there has been eight out of eight successful launches from a Longbow Apache. One of the launches used the TADS to locate the target demonstrating that an aircraft without a fire control RADAR can still utilize the RF missile. Future tests will demonstrate that, using the improved data modem, a fire control RADAR equipped aircraft will be able to hand a target directly to a missile on another aircraft without the second aircraft acquiring the target. This feature has already been demonstrated in ground tests.

Table VII. 30mm Gun Firing Results

Test Point	Aspect (deg)	Range (km)	A/C Airspeed	A/C Maneuver	Target Type	Pass/Fail
1	0	1.0	0 kn	Hover	Vertical	Pass
2	-45	1.0	0 kn	Hover	Vertical	Pass
3	-90	1.0	0 kn	Hover	Vertical	Pass
4	+45	1.0	0 kn	Hover	Vertical	Pass
5	+90	1.0	0 kn	Hover	Vertical	Pass
6	0	2.0	0 kn	Hover	Horizontal	Pass
7	0	3.0	0 kn	Hover	Horizontal	Pass
8	N/A	1.0	80 kn	Left Veer	Vertical	Pass
9	N/A	1.0	80 kn	Right Veer	Vertical	Pass
10	N/A	2.0	80 kn	Left Veer	Horizontal	Pass
11	N/A	2.0	80 kn	Right Veer	Horizontal	Pass
12	0	1.0	0 kn	Hover	Moving	Pass
13	0	1.0	80 kn	Forward	Moving	Pass

Table VIII. Laser/Hellfire Live Fire Results

Event	Missile Type	Range	Target Type	A/C Maneuver	Mode	Pass/Fail
1	SAL	4 km	Stationary	Hover	LOBL	Pass
2	SAL	6 km	Stationary	90 kn fwd flight	LOBL	Pass

Table IX. Rocket Fire Test Results

Test Point	Rocket Type	Range (km)	A/C Airspeed	A/C Maneuver	Target Type	Pass/Fail	
						AZ	EL
1	6PD	1.0	0 kn	Hover	Vertical	Pass	Pass
2	6PD	2.0	0 kn	Hover	Vertical	Pass	Pass
3	6PD	3.0	0 kn	Hover	Vertical	Pass	Pass
4	6PD	3.5	0 kn	Hover	Vertical	Pass	Pass
5	6PD	1.0	90 kn	Forward	Vertical	Pass	Pass
6	6PD	1.4	90 kn	Forward	Horizontal	Pass	Pass

Table X. LBHMMS Missile Firing Test Results

Launch Dynamics	Clutter Level	LOBL/LOAL	Target Characteristics		Pass/Fail
			Speed	Type	
A01	Medium	LOBL	Fast	T72	Pass
A02	High	LOAL	Stationary	T72	Pass
A03	Medium	LOAL	Fast	T72	Pass
A04	High	LOBL	Fast	T72	Pass
A09	Medium	LOAL	Fast	T72	Pass
A10	High	LOAL	Slow	T72	Pass
A13	Low	LOBL	Fast	BMP	Pass
A20	Low	LOBL	Fast	T72	Pass

Data Management Subsystem (DMS). The DMS performs system tests and provides system status monitoring, system status displays, data recording, and data transfer. The major components of the DMS are the system processors and the data transfer unit. Built-in-test functions are embedded in each of the individual avionics equipment.

The data management subsystem is required to provide on-aircraft detection of 95 percent of all mission-essential and flight-critical failures and 95 percent unambiguous fault isolation of detected faults for all new or existing contractor-furnished equipment.

The Longbow Apache is currently undergoing its Built-in-Test Demonstration for new contractor-furnished equipment. Preliminary results indicate that the subsystem will meet its required detection/isolation rates.

Aircraft Survivability Equipment (ASE) Subsystem. The ASE subsystem provides automatic detection, identification, and warning of various types of radar and laser threat emitters. The subsystem also provides radar and infrared (IR) emitter countermeasures. Detection, identification, and warning with respect to threat emitters is performed by the radar warning receiver, laser warning receiver, and radar frequency interferometer. Countermeasures are provided by the radar jammer, infrared jammer, and chaff dispenser.

All of the components of the ASE subsystem are existing Government-furnished equipment with individual control and display panels. The Longbow Apache was required to eliminate these separate panels and integrate the control and display functions using the multifunction displays without degrading threat response times. The aircraft survivability equipment survey was used to evaluate the integration. Test results shows that control and display system demonstrated reliable performance with negligible impact to threat response. The survey also sited several "enhancing characteristics" such as automatic paging to ASE display pages when a threat is detected, and cockpit control of chaff program firing modes.

Flight Control Subsystem (FCS). The FCS consists of a hydromechanical system that is augmented by a flight management computer (FMC). The FMC provides stability and command augmentation, turn coordination, attitude hold, heading hold, altitude hold, three-dimensional hover/velocity hold, stabilator control, and backup control.

Although not required, the flight control subsystem was successfully tested, under night time conditions, against ADS-33 which is the aircraft handling qualities specification for new airframes such as the Comanche. The Longbow Apache is the first U.S. Army helicopter to meet the requirements of ADS-33 under night flying conditions.

In conclusion, the Longbow Apache avionics subsystems have consistently demonstrated that they meet or exceed their performance requirements. It is the successful integration and performance of these subsystems that makes the Longbow Apache a Total Weapons System for the modern battlefield.