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VALIDATED STANDARDS OF THE INDUSTRY: SPIRIT™ HELICOPTER & BLACK HAWK

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1. Abstract

The BLACK HAWK and SPIRIT™ (S-76) helicopters embody the technology of the 1980's and have entered production. The major part of their development programs is behind them. Both aircraft have had their performance, reliability and operating attributes validated by Sikorsky and the SPIRIT helicopter has been certificated by U.S. and foreign governments. This paper documents the tests performed and the achievements of both aircraft against the contractual commitments. New materials were qualified for environmental effects, S-76 interiors meet fixed-wing flammability requirements, and icing has been addressed for the BLACK HAWK. The performance and unique safety features of flight critical sub-systems are reviewed to illustrate the new standards to which new helicopters must be judged.

2. BLACK HAWK Missions & Description

The UH-60A BLACK HAWK, Figure 1, is primarily a tactical transport helicopter designed to deliver the 11-man infantry squad in high threat combat conditions world-wide and under Army hot-day conditions (4000 ft., 95°F). Secondary missions include the medical evacuation of 4 to 6 patients and tactical resupply and logistics support in forward combat areas.

Figure 1

Complete details of the Army requirements for the Utility Tactical Transport Aircraft System (UTTAS) are presented in Reference (a). The unique and critical requirements include vertical climb at a rate of 450 feet-per-minute at an altitude of 4000 feet and air temperature of 95°F with full load and at 95% rated power; maximum cruise speed of 145 to

175 knots; system mean time between failure of 4.5 hours; 0.8 maintenance man-hours per flight hour in the field; air transportability in the C-141 and C-5A.

The UH-60A BLACK HAWK has a single 4-bladed articulated main rotor 53.67 feet in diameter and a four-bladed counter-torque tail rotor 11 feet in diameter and canted 20 degrees. The helicopter is powered by two General Electric T-700 turbine engines each rated at 1560 shp. An aft tail wheel provides protection in hard landings at large flare angles. Main and tail rotor blades are folded manually. The rotor head is lowered and the tail pylon is folded to fit within the C-141 cabin. A three-view of the BLACK HAWK is shown in Figure 2.

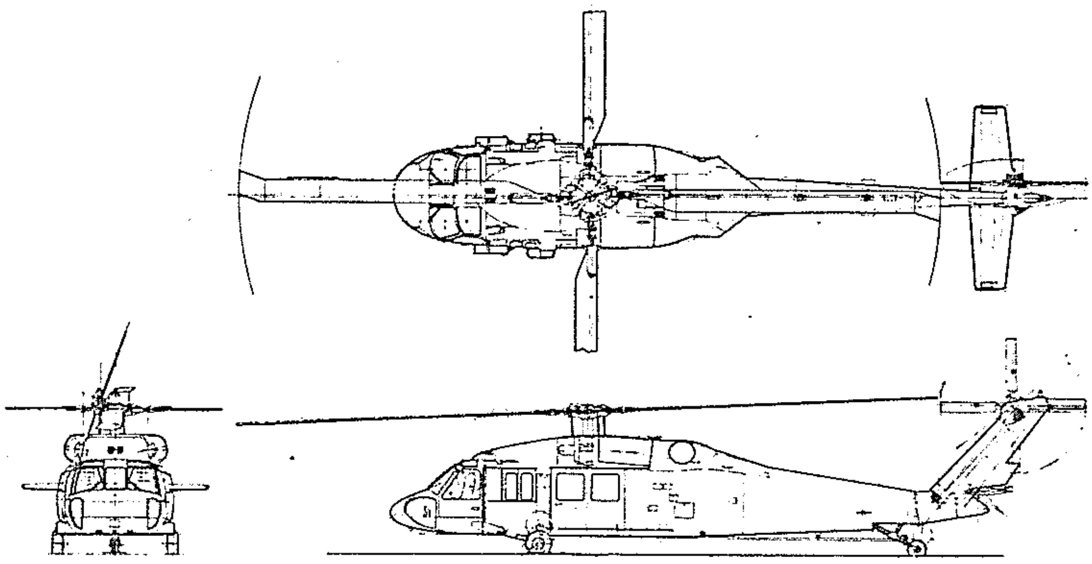

Figure 2

A detailed discussion of the advanced technology used in BLACK HAWK to achieve the goals established by the U.S. Army is presented in Reference (b). The main rotor system uses pairs of spherical and cylindrical elastomeric bearings to provide all angular motions of each blade without requiring lubrication. The hub is a high strength titanium forging. The main rotor blade has a titanium spar with unlimited life, a Nomex honeycomb core aft structure and fiberglass outer covering, and is corrosion free. An improved rotor-mounted bifilar vibration absorber with cycloidal bushings contributes to the low vibration levels achieved. The tail rotor is bearingless and is constructed entirely of non-metallic materials. Spars are laminated graphite epoxy and are continuous from one blade tip to the opposite tip. The combination of an automatically programmed and controlled active stabilator and an advanced digital automatic flight control system provide uncoupled aircraft response and excellent handling qualities and optimum aerodynamic efficiency in forward flight. The main transmission is modular in construction and can operate for over 30 minutes after loss of oil. The cockpit canopy is a single piece molded fiberglass structure. The BLACK HAWK airframe structure is 17% non-metallic.

3. BLACK HAWK Development History

From the inception of the BLACK HAWK program the U.S. Army planned an extensive testing and development program to achieve a high degree of readiness for production. As a result of carrying out this plan, the BLACK HAWK is the most thoroughly tested and developed helicopter in the experience of Sikorsky Aircraft and has set new standards for the validation of helicopters.

Sikorsky was awarded a basic engineering development (BED) contract for the YUH-60A in August 1972 for fabrication of three prototypes, a static test article and a ground test vehicle. Upon completion of the development testing the three prototypes were delivered to the U.S. Army for seven months of government competitive testing (GCT) which began in March 1976. Competitive testing was completed in October 1976 and led to award of a production contract to Sikorsky Aircraft in December 1976.

The final development effort on the BLACK HAWK was the maturity phase which began in January 1977 and is scheduled to be completed in 1980. This program involves ground and flight qualification of the production aircraft configuration, design and development of mission flexibility kits such as medical evacuation, blade de-icing, etc., North Continental United States (North Conus) testing and Army verification of the production aircraft.

4. Flight Test Highlights

The YUH-60A was first flown on October 17, 1974. A total of 622 hours were flown during Basic Engineering Development, which was completed at the beginning of the second quarter of 1976. During the Government Competitive Test and Maturity Phase an additional 1695 hours were flown on the development aircraft and 120 hours were flown on the production aircraft so that by March 6, 1979 a total of 2437 hours were flown, Figure 3.

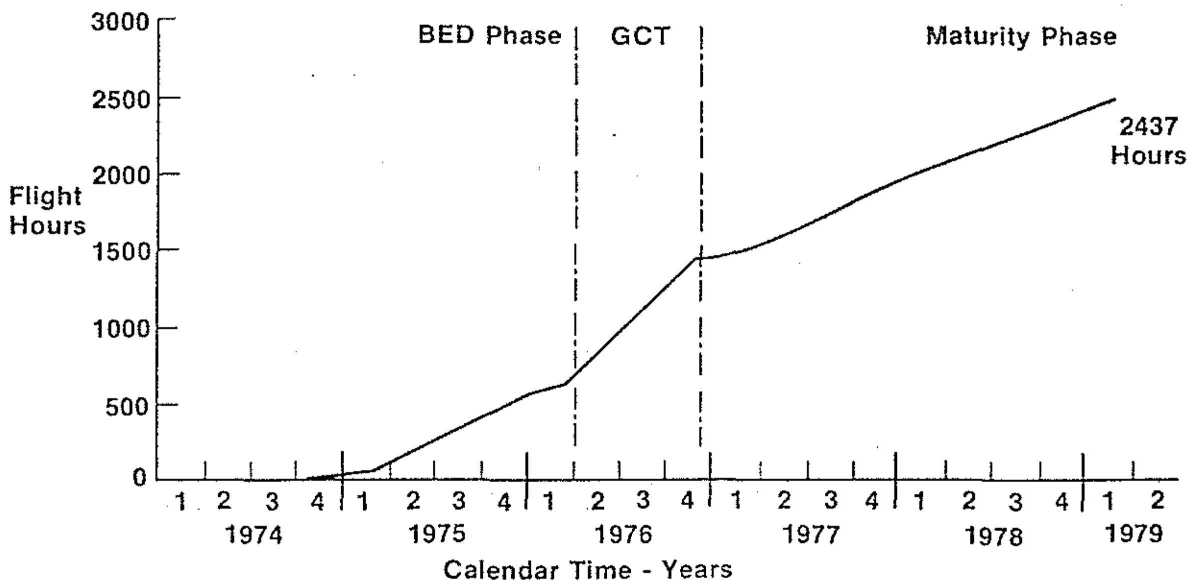

Figure 3 - FLIGHT HOURS

The BED phase provided the opportunity to wring-out the aircraft, to establish its overall performance, to qualify its components and sub-systems and to fine-tune the aircraft in preparation for the Government Competitive Test. Some of the major flight test accomplishments are summarized in Figure 4.

- VERTICAL & FORWARD FLIGHT PERFORMANCE
- HANDLING QUALITIES & AFCS DEVELOPMENT; QUALIFICATION WITH EXTREME AFT C.G
- VIBRATION SURVEY & DEVELOPMENT
- PROPULSION SYSTEM TESTS; IR SUPPRESSION DEVELOPMENT
- STRUCTURAL DEMONSTRATION, FLIGHT LOADS SURVEY
- AVIONICS QUALIFICATION
- EXTENDED RANGE KIT QUALIFICATION
- WINTERIZATION KIT QUALIFICATION
- RADAR REFLECTIVITY

Figure 4 - UH-60A BLACK HAWK - FLIGHT TEST ACCOMPLISHMENTS

During this period main rotor blade vibratory loadings, caused by upwash over the nose, were reduced by raising the rotor 15 inches; maneuvering performance at cruise speed was increased by adding a modified camber airfoil over the center portion of the blade; handling qualities were improved by going to a programmed incidence and automatically controlled stabilator. The flight controls are discussed in Reference (c).

Several important operational tests were performed. These included tests in Alaska and in the Northern Continental U.S. (Ft. Drum, N.Y.). In these tests the YUH-60A was flown in moderate icing for the full duration of its endurance and with up to 3 inches of ice accumulated on non-heated areas with no significant increase in structural loads or vibration. The aircraft also completed 90 hours of NORTH CONUS flying with cold soaking.

Another important operational test was the demonstration of the ability of the YUH-60A to operate from a 6-degree nose down slope, 15-degree nose-up slope and on a 15-degree side-hill slope.

The development program included qualification of a range extension kit. With the fuel capacity increased from 2350 pounds to 7407 pounds the UH-60A demonstrated a non-stop 880 nautical mile flight lasting 6.9 hours. With this range the BLACK HAWK can be self-deployed to Europe.

During the Government testing the air transportability of the YUH-60A was confirmed. The BLACK HAWK was successfully loaded in a C-141 within the times indicated in Figure 5.

	YUH-60A	Spec.
Preparation	1.4	1.5
Loading	.5	.5
Unloading	.3	.5
Preparation	1.8	2.0

Figure 5 - AIR TRANSPORTABILITY DEMO - HOURS

5. Ground Test Highlights

An extremely thorough ground test program was carried out using a ground test vehicle, transmission test facilities, main and tail rotor whirl stands, hub and shaft test facility, a variety of component fatigue test facilities, and electrical and hydraulic system test facilities.

The ground test vehicle which included the total helicopter dynamic system accumulated 2044 hours of testing to date, Figure 6.

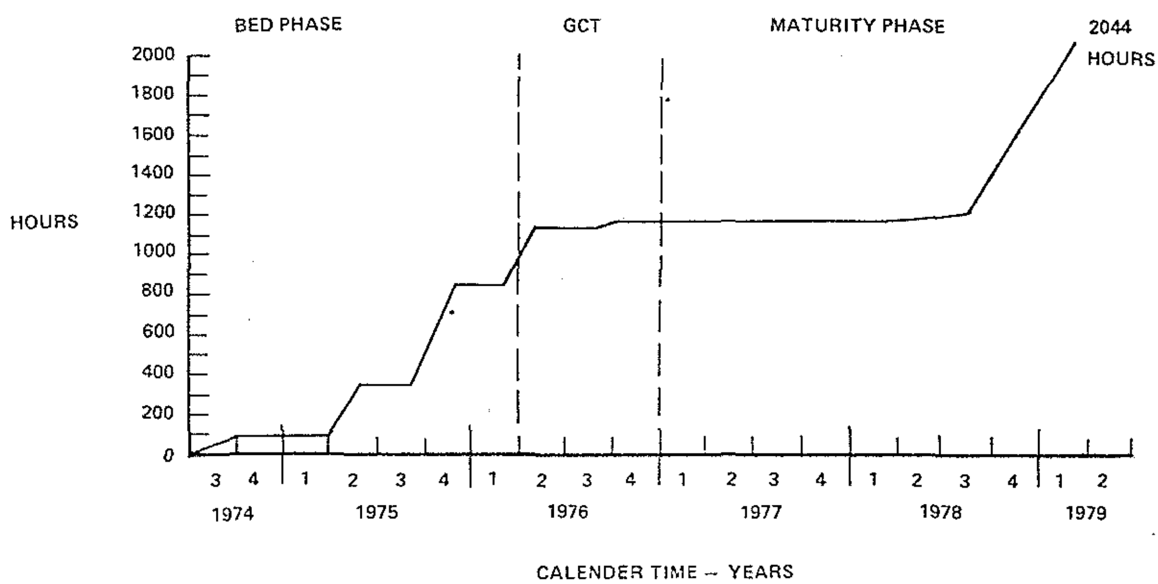

Figure 6 - YUH-60A GROUND TEST VEHICLE ACCUMULATED HOURS

The main gearbox accumulated a total of 6812 hours through GTV, bench and aircraft tests, Figure 7. During these tests the main transmission developed 3600 horsepower (128% overtorque). The two inputs achieved a rating of 2828 hp. The gearbox was operated for 60 minutes without oil and a single input rating of 1560 hp was demonstrated.

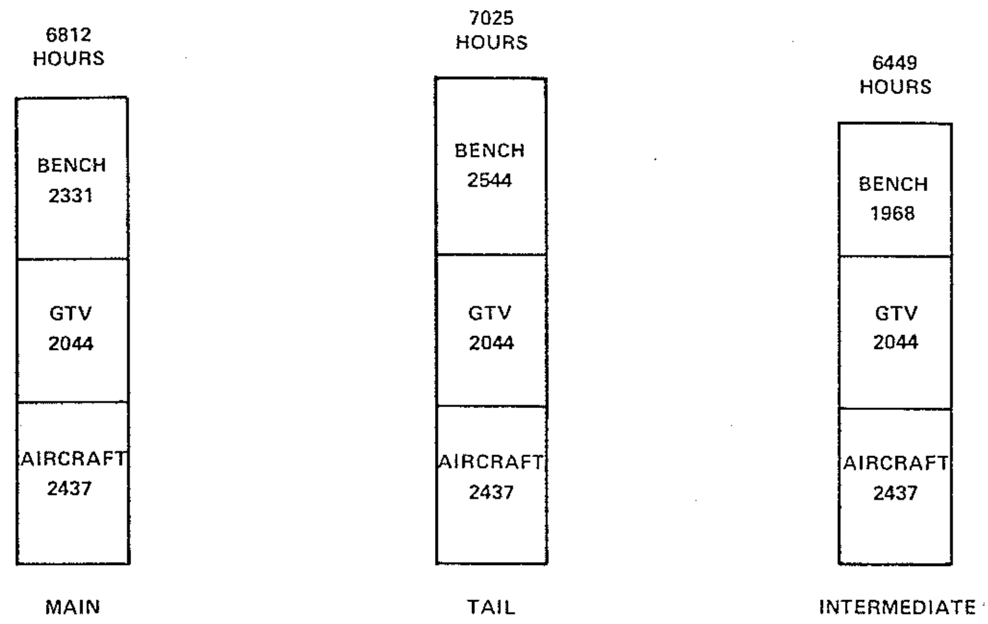

Figure 7 - UH-60A TRANSMISSION TEST

In further tests to qualify the main gearbox for the SH-60B SEAHAWK the rating was increased to 3000 hp as a result of 75 hours of overstress tests. The single input rating was increased from 1560 hp to 1700 hp. Only minor changes were necessary. These tests confirmed that there are no life-limited components in the main gearbox and validated "on-condition" maintenance. The condition of the gearbox is monitored using five fuzz-burnoff chip detectors and oil pressure and temperature indication. The bearings were designed for a B-10 life approximately three times that in prior aircraft thus contributing substantially to the gearbox reliability.

In qualifying the production transmission, the gearbox was run more than twice as long as required at the various power levels, Figure 8.

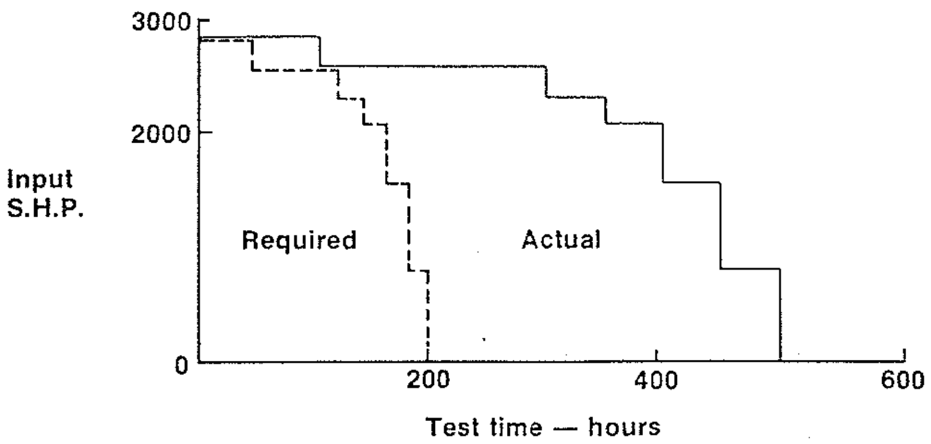

Figure 8 - PRODUCTION TRANSMISSION QUALIFICATION

The tail gearbox accumulated a total of 7025 hours of bench, GTV and aircraft test time, and the intermediate gearbox accumulated 6449 hours of bench, GTV and aircraft time, Figure 7. These tests established a rating of 424 horsepower and demonstrated 750 peak horsepower. Both gearboxes were operated for 60 minutes without oil. These tests demonstrated that both gearboxes can be overhauled on condition using fuzz burnoff chip detectors and monitoring of oil temperature.

The main rotor was tested for 597 hours on the whirl stand and in addition accumulated 2044 hours on the GTV and 2437 hours on the aircraft for a total of 5078 hours, Figure 9. During the whirl tests the rotor figure-of-merit of 0.75 was confirmed and the rotor was tested over a range of speeds from 90% of design rpm to 125 percent.

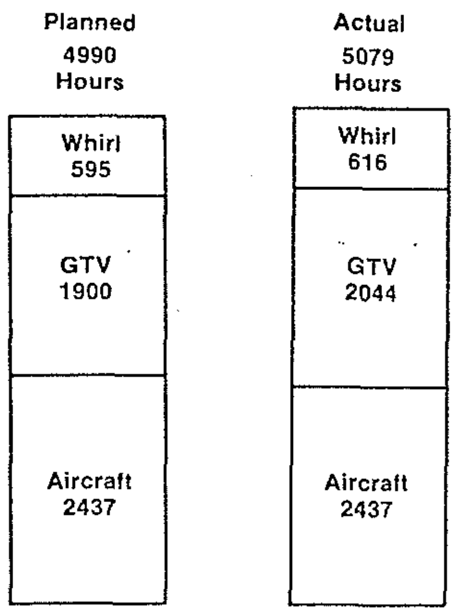

Figure 9 - MAIN ROTOR THOROUGHLY TESTED

This endurance testing established the reliability of the rotor hub, elastomeric bearings, blade spindle assembly and root end, dampers and damper bearings and control rod-end bearings. The tests were successful in revealing problems whose solution brought the rotor system to its current excellent reliability. Early in the test program cracking of the elastomeric bearing shims was experienced. This was resolved through use of higher strength steel. Tests on the GTV and in flight revealed a need to improve the load distribution in the rubber plies through design modifications in order to prevent separation of the rubber layers and to improve the manufacturing process controls. It was also found necessary to abandon the use of Molalloy® in the rod-end bearings in favor of Teflon®.

Further demonstration of the rotor system reliability was achieved using a unique hub and shaft test facility in which the rotor hub, shaft and blade retention bearings are subjected to overload centrifugal force and extreme flapping until failure is caused. This provides important information on the relative strengths and the failure modes of primary rotor system components. In this facility the rotating components can be taken safely to failure. In addition to these tests the elastomeric bearings were qualified in a facility which properly reproduces the loadings and flexures of the bearings. This was a vital step in validating the structural performance of the elastomeric bearings in the environments of hydraulic fluids, engine fuels, water, sand, ozone and fungus. These tests showed that the materials selected were essentially unaffected by these environments. Elastomeric bearing tests established a service life of greater than 2500 hours. To date performance has been outstanding.

Succesful operation of components under the temperature extremes of -65°F to +125°F was accomplished by testing the GTV in the Eglin climatic laboratory. In all cases the aircraft was cold-soaked for 24 hours when testing at a constant temperature and for 48 hours when a change in test temperature was made. Success was also achieved in tests of the starting system, hydraulic and electrical systems, windshield anti-ice system and cabin and cockpit heat distribution.

The main and tail rotor and flight control systems components which experience fatigue loadings were tested in the reliability laboratory. By July 1979 approximately 85 percent of the components, which number 76, met or exceeded requirements. Eight items which have less than 5000 hours fatigue life are undergoing continued development. Figure 10 shows the high level of component reliability achieved to date — 75 percent have no replacement time and 20 percent have a life between 5000 and 20,000 hours.

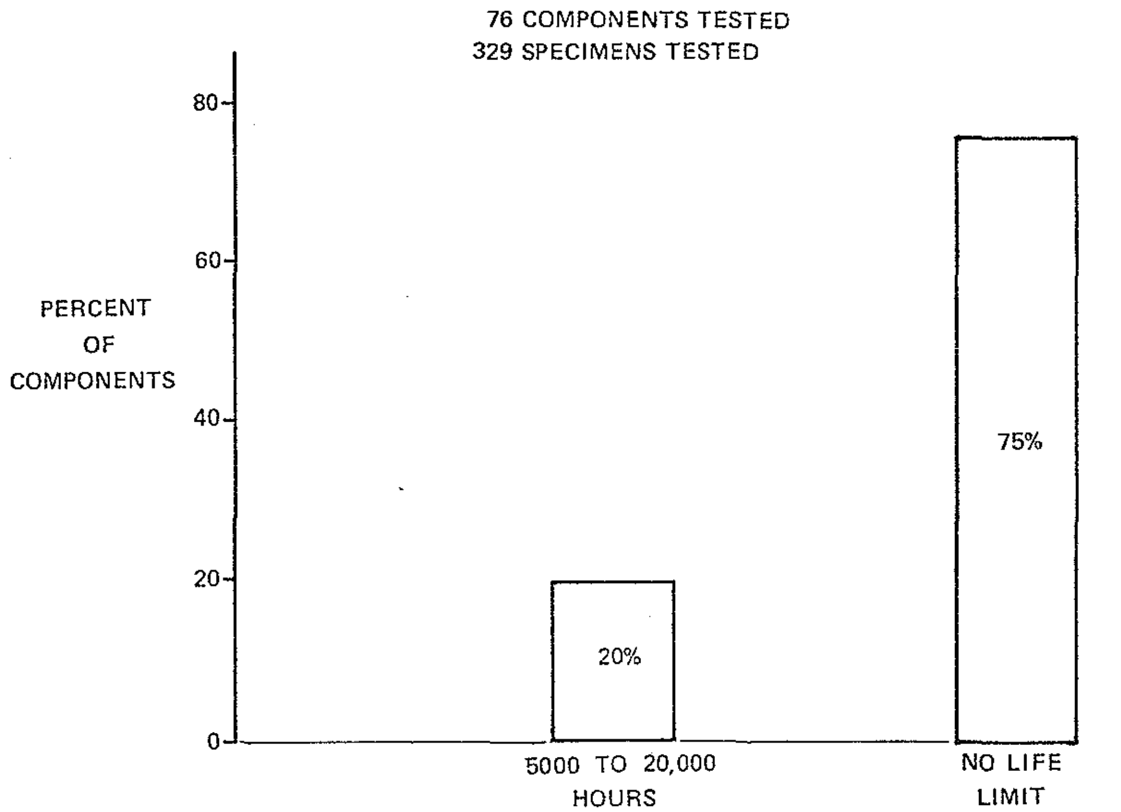

Figure 10 - BLACK HAWK COMPONENT FATIGUE LIVES

The tail rotor was tested over a wide range of pitch angles and at rotational speeds of 90% to 125%. Precession rates were established to induce tail rotor blade bending. A total of 616 hours was accumulated in whirl tests, 2044 hours on the GTV and 2437 hours on the aircraft, giving a total of 5097 test hours.

The major accomplishments were the verification of tail rotor performance and, after severe excitation of the elastic modes, demonstration of tail rotor aeroelastic stability. Several problems were surfaced the solutions of which contributed to the high reliability of the production tail rotor system. These solutions included an improved tail rotor torque rib assembly, use of nylon shims in the spar to hub attachment, improved tail rotor boot and improved bonding jumper attachments.

The extensive flight and ground tests completed make the BLACK HAWK the most tested helicopter to enter the Army inventory.

6. Weight and Performance

The UH-60A attributes as determined by Sikorsky Aircraft meet or exceed the specification requirements, see Figure 11. Through meticulous weight control the production aircraft weighs 536 pounds under the specification value. This reduction in empty weight yields 18 percent more payload, Figure 12.

	Requirement	Demonstrated
Vertical rate of climb, feet/minute	473	760
Hover ceiling, feet	4770	5380
Maximum cruise speed, knots	145	145-146*

*Estimated

Figure 11 - PERFORMANCE

PAYLOAD = GROSS WEIGHT - (OPERATING WEIGHT & FUEL)

REQUIREMENT 2640 = 16,450 - 13810

ACTUAL 3113 = 16,450 - 13337

18% INCREASE IN PAYLOAD

Figure 12 - BLACK HAWK PAYLOAD EXCEEDS REQUIREMENT

The BLACK HAWK payload-range performance under Army hot-day conditions is shown in Figure 13. Also shown is the range achieved with the extended range kit which, as discussed earlier permits self-deployment from the U.S. to Europe.

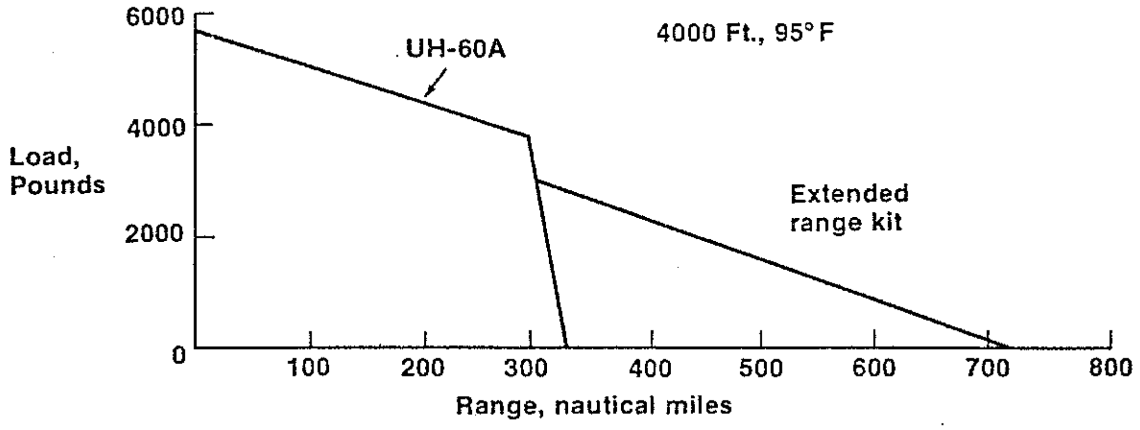

Figure 13 - PAYLOAD RANGE

The requirement to achieve a vertical rate of climb of 450 ft./min. at 4000 feet and 95°F at 95% intermediate power resulted in a concentrated effort to achieve a hover efficiency at least 10% higher than prior practice. For this reason a high overall twist of -19° was selected. Whirl tests demonstrated that the goal had been achieved with an unprecedented single rotor figure-of-merit value of M = 0.75. With this high efficiency the hot-day hover ceiling exceeded the design point, Figure 14.

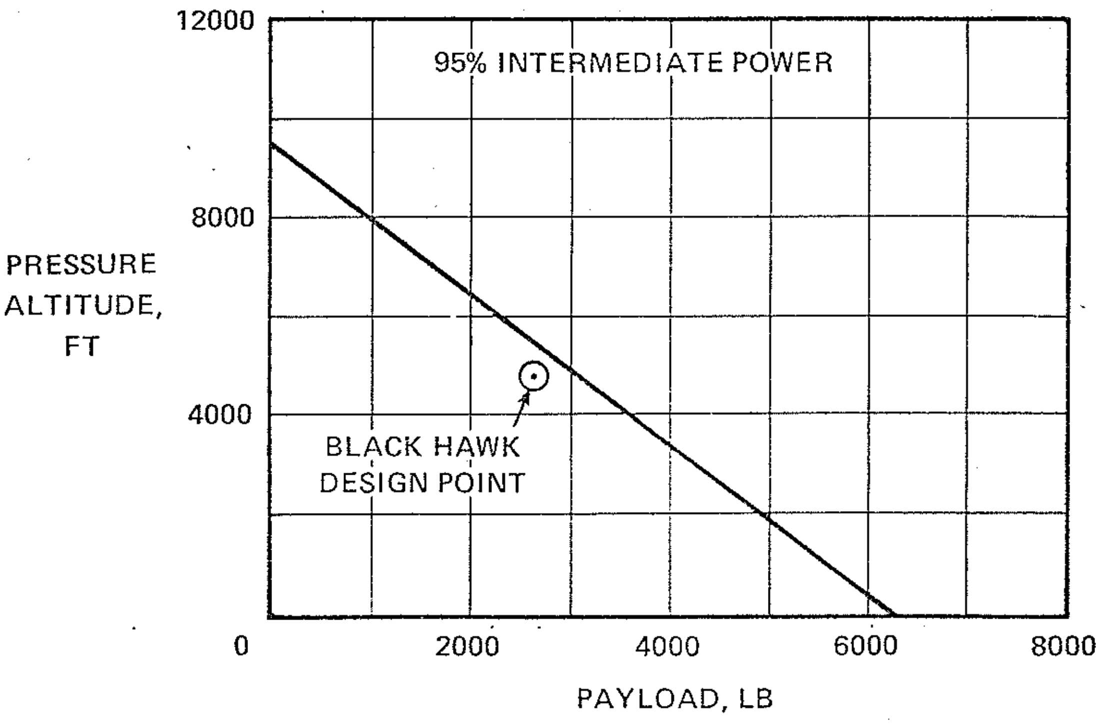

Figure 14 - UH-60A OGE HOVER CEILING - 95°F DAY

The high twist rotor and the titanium spar made it possible to meet both the hover and high speed performance requirements.

At this writing the U.S. Army is in the process of evaluating the reliability, maintainability and performance of the production aircraft.

7. Structural Demonstration, Vibration, Handling Qualities

The development testing demonstrated an outstanding maneuvering capability without encountering structural limits or oscillatory phenomena. Figure 15 shows the demonstrated maneuver envelope. A load factor of 3.1 g was achieved at 155 knots, 2.8 g at 190 knots and a maximum 1 g flight speed of 190 knots was demonstrated. During these tests an advancing tip Mach No. of 1.01 was experienced without any adverse effects. This results from the use of tip sweep. Maneuvering pitch and roll rates of 80 degrees per second were also demonstrated. The advanced Sikorsky airfoil and the swept tip contributed to this excellent maneuvering performance.

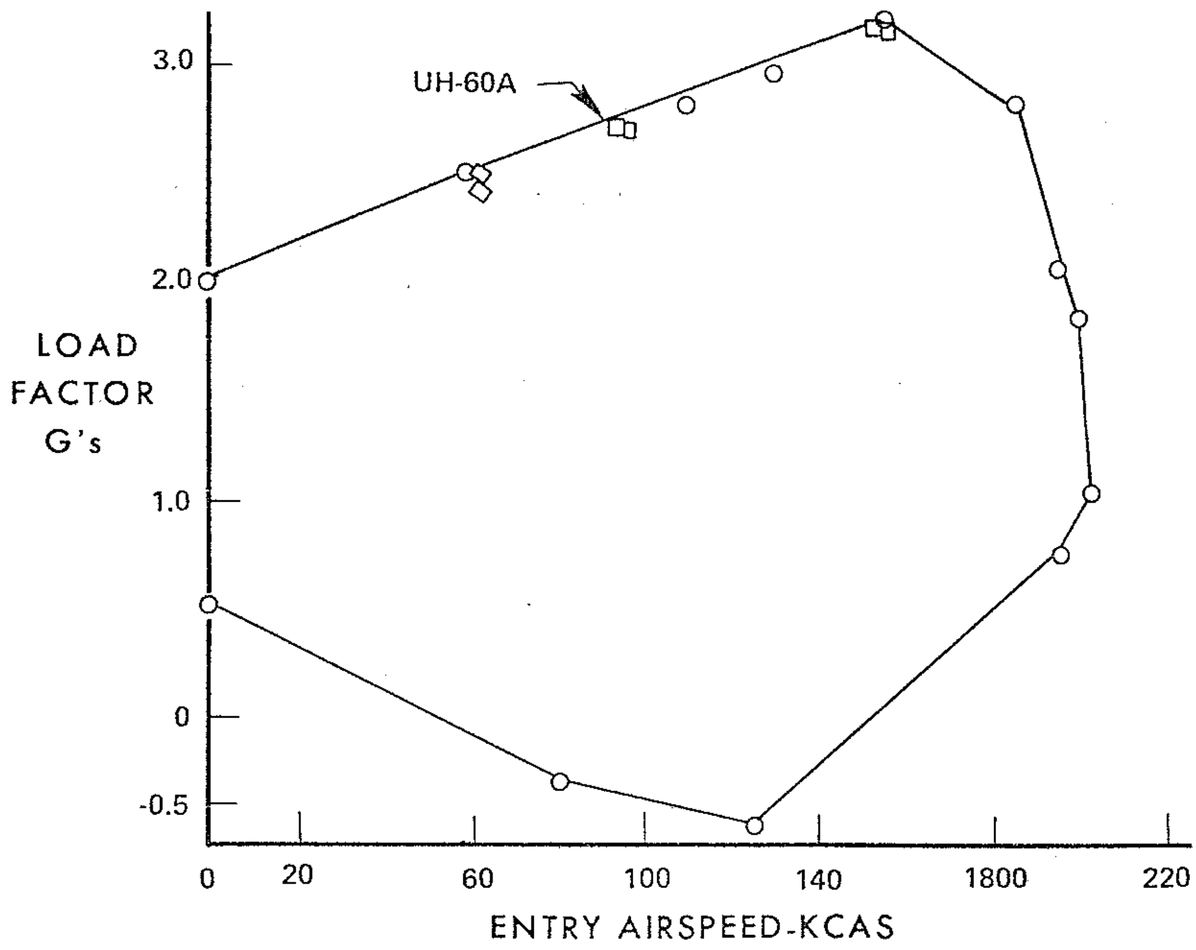

Figure 15 - DEMONSTRATED MANEUVERING ENVELOPE

The UH-60A was designed with a tail wheel to protect the airframe in high flare landings. The BLACK HAWK successfully demonstrated a landing at 11.5 fps at design gross weight exceeding the requirement of 10.0 fps, and demonstrated a landing at 7.0 fps at alternate gross weight exceeding the requirement of 6.0 fps.

From the outset a major objective was to achieve higher reliability by reducing aircraft vibration. Improvements in the aircraft tuning, bifilar absorber geometry and cabin absorbers were made to achieve the low level of cockpit vibration of less than 0.1 g, Figure 16. Low cabin 4-per-rev vertical vibration was achieved at gross weights of 16,450 and 20,250 pounds. These levels of vibration equal or better the specification requirement of 0.12 g in the cabin.

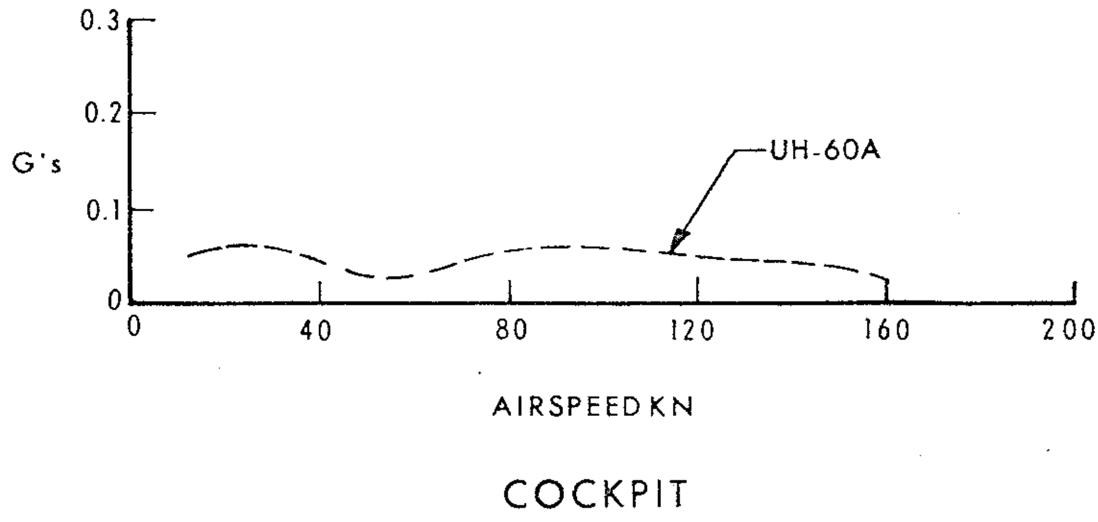

Figure 16 - VIBRATION LEVELS

Reference (c) discusses the UH-60A mechanical and automatic flight control systems in detail as well as the aircraft stability, control and handling qualities. A few highlights are repeated here briefly.

The UH-60A has a canted tail and a stabilator both of which receive unique treatment in meeting the handling qualities requirements. The stabilizer incidence is automatically varied as a function of airspeed and collective pitch to provide a favorable variation of pitch attitude with airspeed.

Pitching moments induced by collective pitch change of the tail rotor are nullified by a mixing of tail rotor pitch to longitudinal cyclic pitch. Pitching moments caused by gust generated sideslip are nullified by stabilator incidence changes in proportion to lateral acceleration sensed at the aircraft nose. These control features contributed significantly to the excellent aircraft flying qualities and enabled flight demonstration of the large sideslip angles shown in Figure 17. Longitudinal and lateral stability and control requirements were met as a result of the thorough flight testing performed and the ability to readily adjust mechanical and electronic control system parameters to provide best flying qualities. (See Reference (c).)

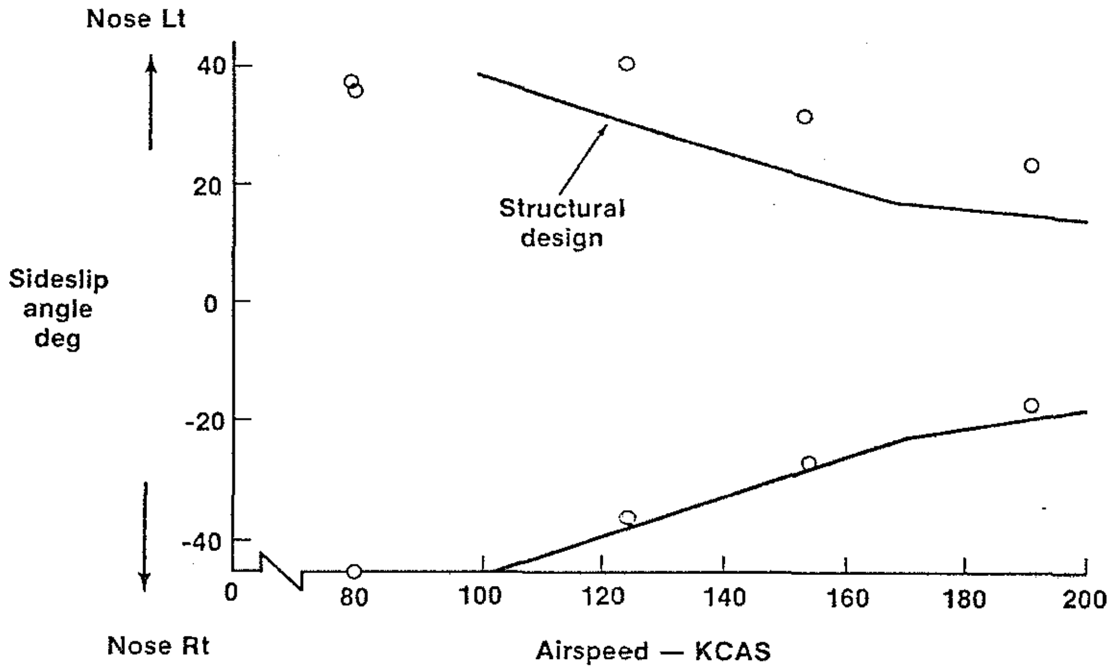

Figure 17 - SIDESLIP ENVELOPE

8. Reliability & Maintainability

A value of mean time between failure of 4.5 flight hours was established as the system requirement to be achieved at the time of delivery of the 200th aircraft. The term "failures" here includes even such small items as light bulb failures. During development testing the system reliability has been monitored to expose hardware requiring correction in order to progress toward achieving this goal. The computed MTBF is currently above 3.5. A concentrated effort will continue to achieve the required value.

An independent evaluation and projection of the MTBF of early production aircraft was made by the U.S. Army Materiel Systems Analysis Activity. Based on 457 hours of flight testing during the maturity phase and based on corrective actions to failures experienced during maturity testing it was estimated that an MTBF of 3.9 hours would be experienced by early production aircraft. At this time it appears certain that the value of 4.5 hours will be reached. The U.S. Army is currently in the process of evaluating reliability and maintainability of the production aircraft.

The maintainability of the UH-60A BLACK HAWK far exceeds that of prior helicopters and establishes a new and challenging standard for the industry. The value of 0.79 maintenance man-hours per flight hour achieved by the BLACK HAWK represents a *reduction to one-fifth* of the *maintenance required* by *prior operational* helicopters. This level of maintenance is achieved by the elimination of scheduled removal intervals (TBO) and replacing components "on condition." In addition, the gearbox, hydraulic units and control elements are built in modules permitting rapid replacement in the operating environment and many components are interchangeable from left to right.

9. Ice Protection System

The elements of the UH-60A ice protection system are illustrated in Figure 18. The blade de-icing elements are contained entirely within the blade contour and have no impact on leading-edge erosion protection. The capability of flight into moderate icing conditions has been demonstrated by a test program which consisted of the following successful tests:

- Icing tunnel tests of the engine air inlet conducted in the summer of 1975.
- Prototype YUH-60A flight testing in Alaska behind the Army spray tanker in the fall of 1976.
- UH-60A icing tanker flight tests in Minnesota in the Spring of 1979.

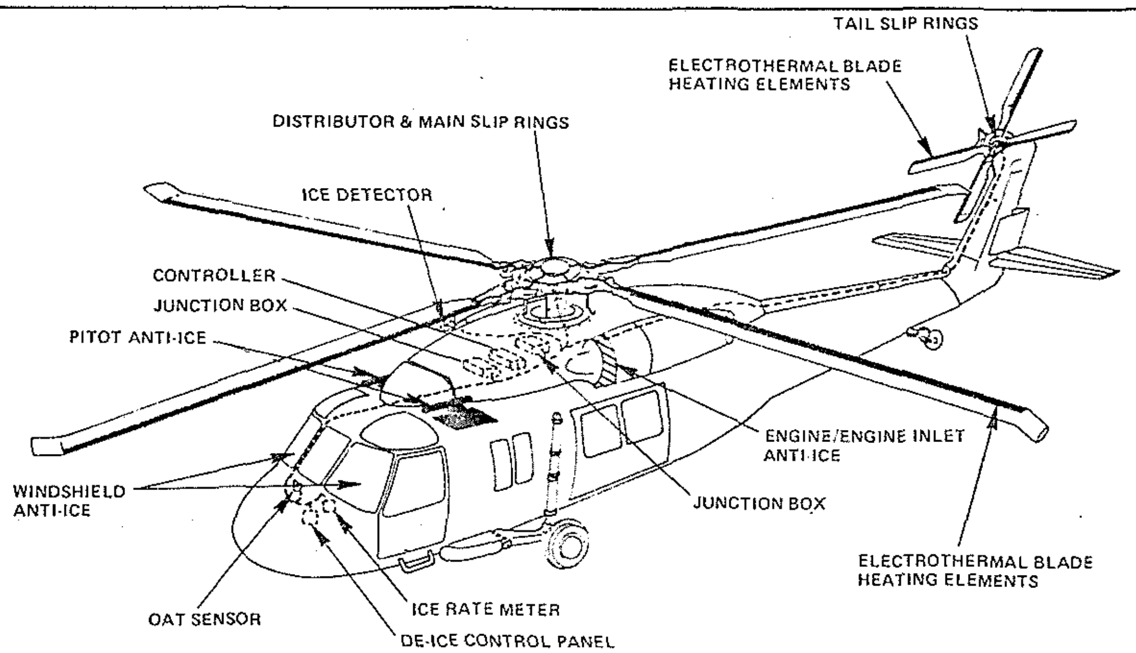

Figure 18 - BLACK HAWK ICE PROTECTION SYSTEM

Icing tunnel tests in the NASA Icing Research Tunnel included icing conditions as severe as 1.0 gm/m³ at -4°F, 15 micron droplet diameter and 2 gm/m³ at +23°F, 25 microns. These tests demonstrated the capability of the bleed air heated engine air inlet duct to operate throughout its required environment. The Alaska icing tests included operation of the total YUH-60A for the duration of the spray tanker water supply. Test conditions ranged from .25 gm/m³ at -15°C to .5 gm/m³ at -5°C. Total icing immersion time was 3.5 hours.

The Minnesota icing tests also included UH-60A flight tests for the duration of the spray tanker water supply. Test conditions ranged from .5 gm/m³ at -10°C to .75 gm/m³ at -5°C. Total icing immersion time was 2 hours.

These tests are especially severe since the spray rig produces larger droplets than natural icing.

10. Interior and External Acoustics

The interior acoustic goal for the BLACK HAWK was to achieve a 91 dB speech interference level in the cabin. To achieve the noise requirement without an exhorbitant weight of acoustic treatment initial development was pursued to reduce the noise radiated by the gearbox housing and the airframe structure. A reduction of 6 —10 dB at the radiating frequencies was achieved with application of damping materials to the airframe. The interior acoustic treatment is made in rigid panels to provide good maintenance and serviceability features. The panels are isolated from the airframe structure to minimize interior noise. The acoustic materials used are insensitive to hydraulic fluids and engine oil, are abrasion resistant and meet flammability requirements.

The external noise of the BLACK HAWK is substantially lower than that of current utility helicopters. This results from the swept tip and improved aerodynamics of the rotor blades, and the unloading of the tail rotor in forward flight by means of camber on the fin.

11. SPIRIT Helicopter Mission and Description

The SPIRIT helicopter was specifically designed to support long range offshore oil operations and the corporate market. The offshore oil support design goal was to transport 12 passengers with two crew members with a still air range of 400 nautical miles with one-half hour reserve, one-engine-inoperative flight at maximum gross weight at 1000 feet altitude and 90°F temperature and with a normal cruise speed of 145 knots. From the outset it was established that the helicopter would make use of advanced technology to achieve greatly reduced direct operating cost and a high measure of reliability. The technology applied to the SPIRIT helicopter is discussed in References (b) and (f).

The SPIRIT helicopter is shown in flight in Figure 19 and a three-view is presented in Figure 20. The aircraft is certificated to 10,000 lbs. gross weight. It is powered by two Allison 250-C30 turbo-shaft engines with a take-off rating of 650 hp and maximum cruise power of 557 hp.

Figure 19

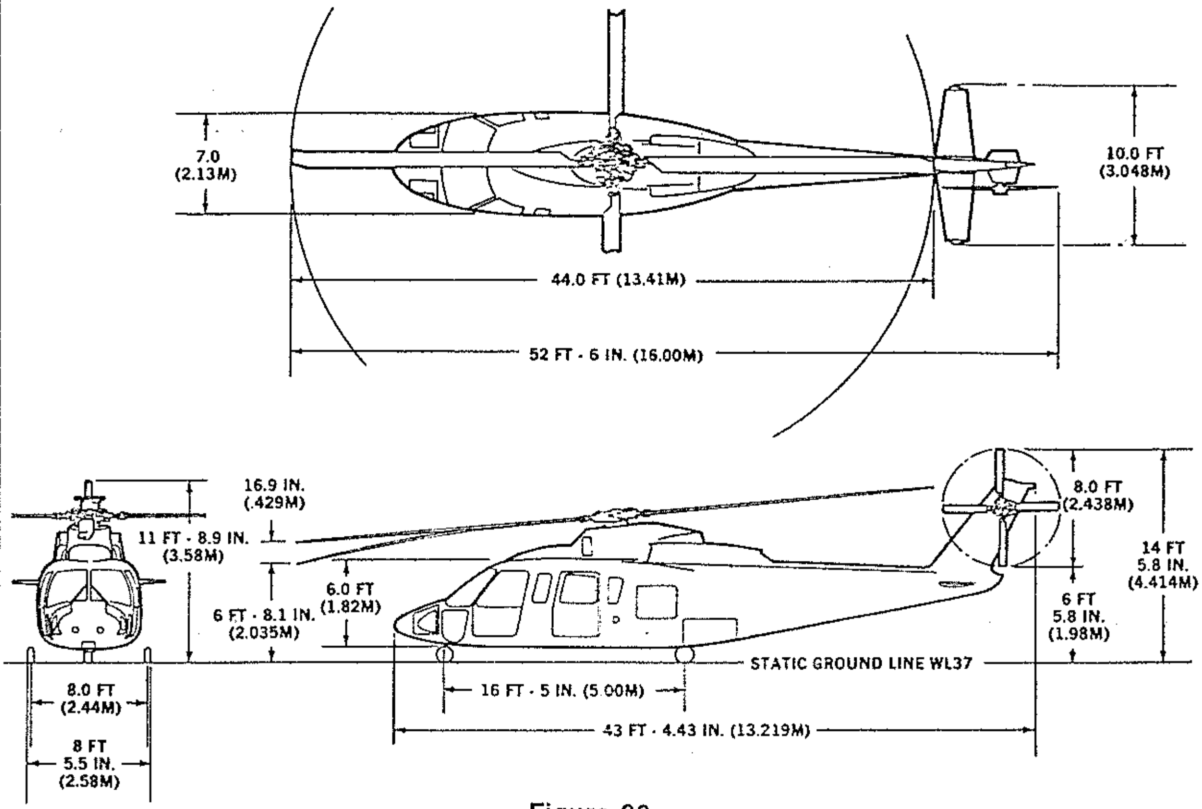

Figure 20

12. Development and Certification

The SPIRIT helicopter received its initial FAA type certification in November 1978. In addition, foreign certifications in Canada, Australia, Netherlands and United Kingdom have been achieved.

A total of 1238 flight hours have been accumulated for development testing, FAA and CAA certification, functional and reliability testing and ferry and check flights. Flight tests also included high altitude and cold weather tests in Alaska and Colorado and tests of the external load system for a 4300 pound load.

13. Ground Test Program

A thorough ground test development program was completed and included dynamic component structural substantiation, rotor drive system qualification, sub-system qualification and component qualification.

A total of 444 hours of tie-down tests was accumulated on the rotor drive system. Adding these hours to the transmission bench test hours gives 1564 hours of main transmission tests, 1394 hours of intermediate transmission tests, and 1444 hours of tail transmission tests. To meet CAA requirements 267 hours of additional transmission spectrum tests over and above FAA test requirements were run, up to a torque rating of 140% of rated torque. This spectrum is shown in Figure 21.

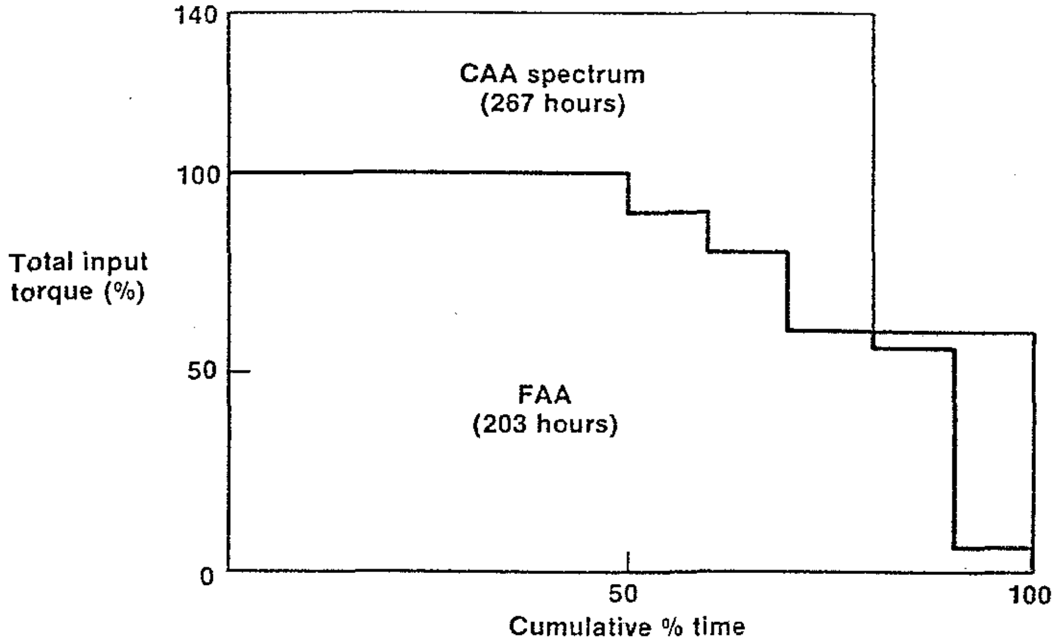

Figure 21 - MAIN TRANSMISSION TEST SPECTRUM

The S-76 engine air inlet has been successfully tested in the NASA Icing Research Tunnel. Without inlet heating, the S-76 plenum inlet system prevents ingestion of damaging quantities of ice by the engine. The S-76 meets the icing requirements of FAR 29, 1093 (b).

14. Reliability and Maintainability

High standards of reliability and maintainability were established at the outset in order to contribute to high levels of operator profitability. A reliability program was established to achieve the desired goals within 12 to 24 months after initial aircraft delivery. This program includes nearly 1000 hours of reliability tracking and design corrective actions during the development period and planned data collection for a field usage period of 6000 hours. Results to date based on 390 in-service flight hours are very promising as shown in Figure 22.

	PLANNED	SERVICE EXPERIENCE
TIME BETWEEN FAILURE (MTBF) (HRS)	4.04	4.10
MEAN TIME BETWEEN ABORTS (MTBA) (HRS)	92.9	130.1
MISSION RELIABILITY (1 HR MISSION)	.9893	.9923
CORRECTIVE MAINTENANCE-MAN-HOURS PER FLIGHT-HOUR	3.00	*
PREVENTIVE MAINTENANCE (SCHEDULED INSPECTION) MAN-HOURS PER FLIGHT-HOUR	0.91	

*MAINTENANCE OF SERVICE AIRCRAFT NOT CURRENTLY TRACKED

Figure 22 - SPIRIT HELICOPTER IS EXCEEDING R&M GOALS @ 2500 HOURS IN SERVICE

15. Aerodynamics

The performance commitments constituted a major challenge to the aerodynamicist to meet hover performance, cruise speed and range and the particularly critical one-engine-inoperative Category A climbout requirement. High aerodynamic efficiency was required and care had to be exercized in the sizing of the rotor, selection of blade airfoils, tip shape and twist and in achieving a low level of parasite drag. The steps taken to achieve the established specifications are presented in detail in Reference (e).

The selection of the rotor geometry to achieve a high ratio of lift-to-power at the climbout speed with one engine inoperative was based on tests of a CH-53A helicopter with -6 degree twist blades, with -14 degree twist blades and with both 6 blades and with 3 blades to establish experimental values of power loading at minimum power over a wide range of blade loading and disk loading. It was necessary however to compromise the blade loading to meet the high cruise efficiency requirements. As a result the blade loading was changed during design as the analysis progressed. The final value of blade loading is sufficiently low so that control load limits are not reached in cruise flight.

The rotor blade uses two airfoil sections selected to provide high forward flight efficiency. Flight tests and two-dimensional airfoil tests were used to confirm the advantages of the SC-1095 airfoil for use at the blade tip and the drooped nose airfoil for the portion of the blade inboard of the 80 percent radius.

The superior performance of the tapered and swept tip was demonstrated in full-scale rotor tests in the Ames 40 × 80 foot wind-tunnel. These tests also confirmed that the selection of -10 degrees of twist provided the expected rotor performance.

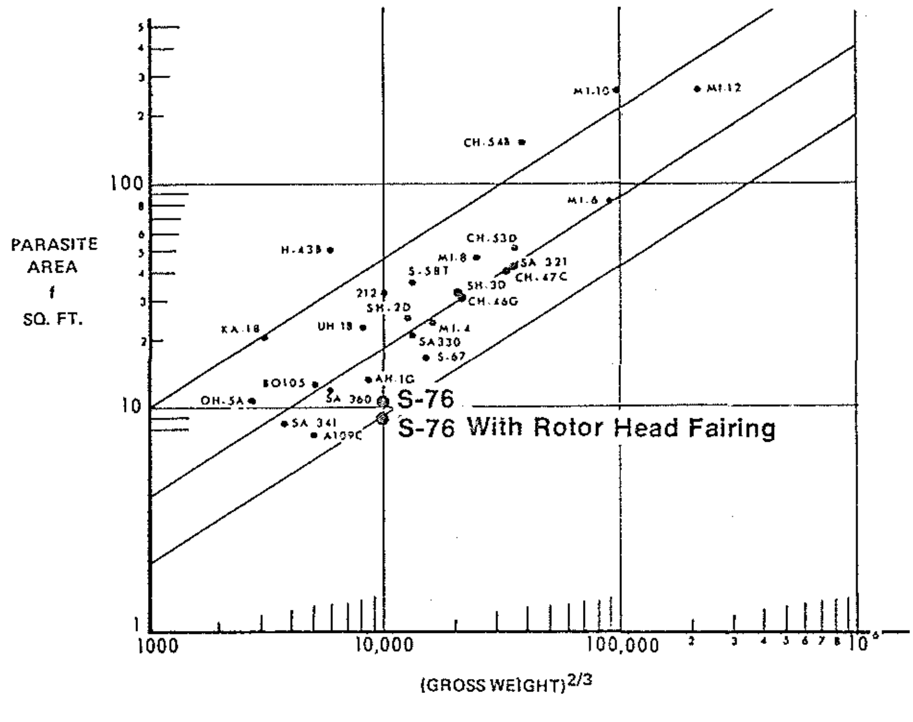

Figure 23 - S-76 HAS LOW PARASITE DRAG

Reduction of parasite drag to levels considerably lower than prior helicopter drag values was critical to meeting the required range. The low parasite drag achieved in the S-76 SPIRIT helicopter is shown in Figure 23. The specific features that contributed to this low value are: a fully retractable landing gear, flush covers, doors and access panels, flush windshield and glass areas; rigid honeycomb sandwich fuselage skins with butt joints and flush riveting; reduced frontal area and cleaner rotor hub; and cambered fin. In addition particular attention was given to the detail design of all air inlets and outlets and in particular the engine airflow system, see Reference (e).

When compared to an S-61 helicopter scaled down to the S-76 gross weight, the S-76 has one-half the drag. This is indeed a new standard of cleanness.

16. Structures and Materials

A major effort was mounted in the design of the SPIRIT helicopter to achieve low weight. A large amount (over 250 lbs.) of Kevlar 49/epoxy is used in the airframe, Figure 24. Composite structure accounts for 23 percent of the airframe weight. Since we were pioneering in the use of composites as primary structure a large R&D program was undertaken to establish the allowable design strengths of the materials under environmental exposure and to show compliance with FAA certification requirements. A test program was carried out to establish design allowables and demonstrate producibility of selected material systems. The program included establishment of moisture absorbtion criteria, materials selection for both properties and producibility, coupon static and fatigue tests to establish design allowables with environmental factors applied, subcomponent tests to verify design allowables and establishment of material and process specifications. A study of relative humidity — temperature data for a variety of world-wide stations was used to establish moisture absorbtion criteria. As a result computations were made of the time for various thicknesses of Kevlar/epoxy to reach saturation at 87% relative humidity. Based on analysis of black surface solar exposure a temperature of 190°F was established for elevated temperature tests.

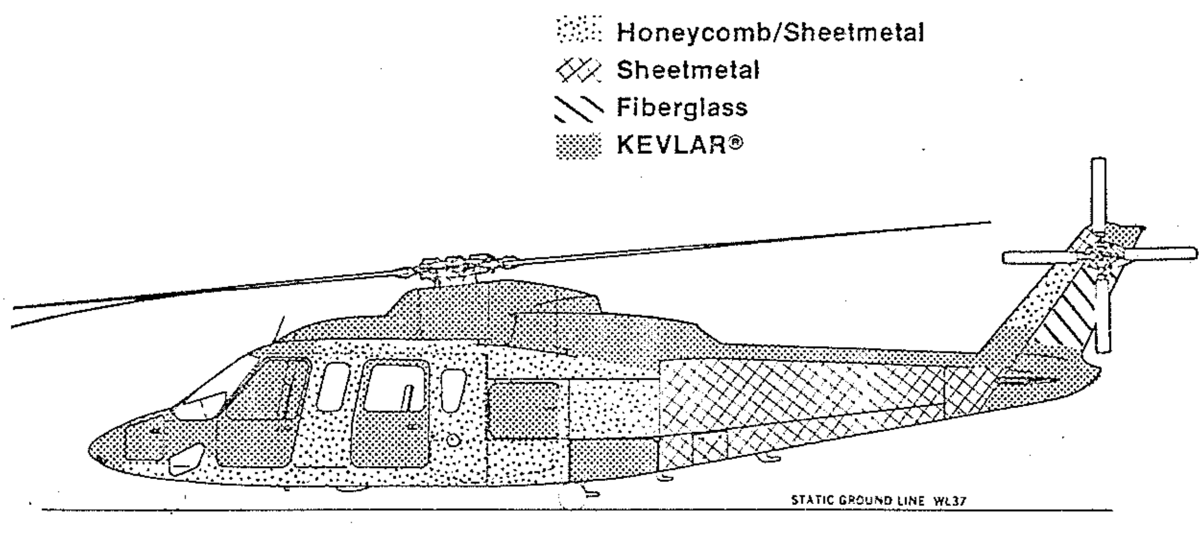

Figure 24 - AIRCRAFT CONSTRUCTION

Material screening tests were performed to evaluate a variety of prepreg systems with Kevlar fabric, typical results of which are presented in Figure 25, showing the superiority of the 350°F cure systems.

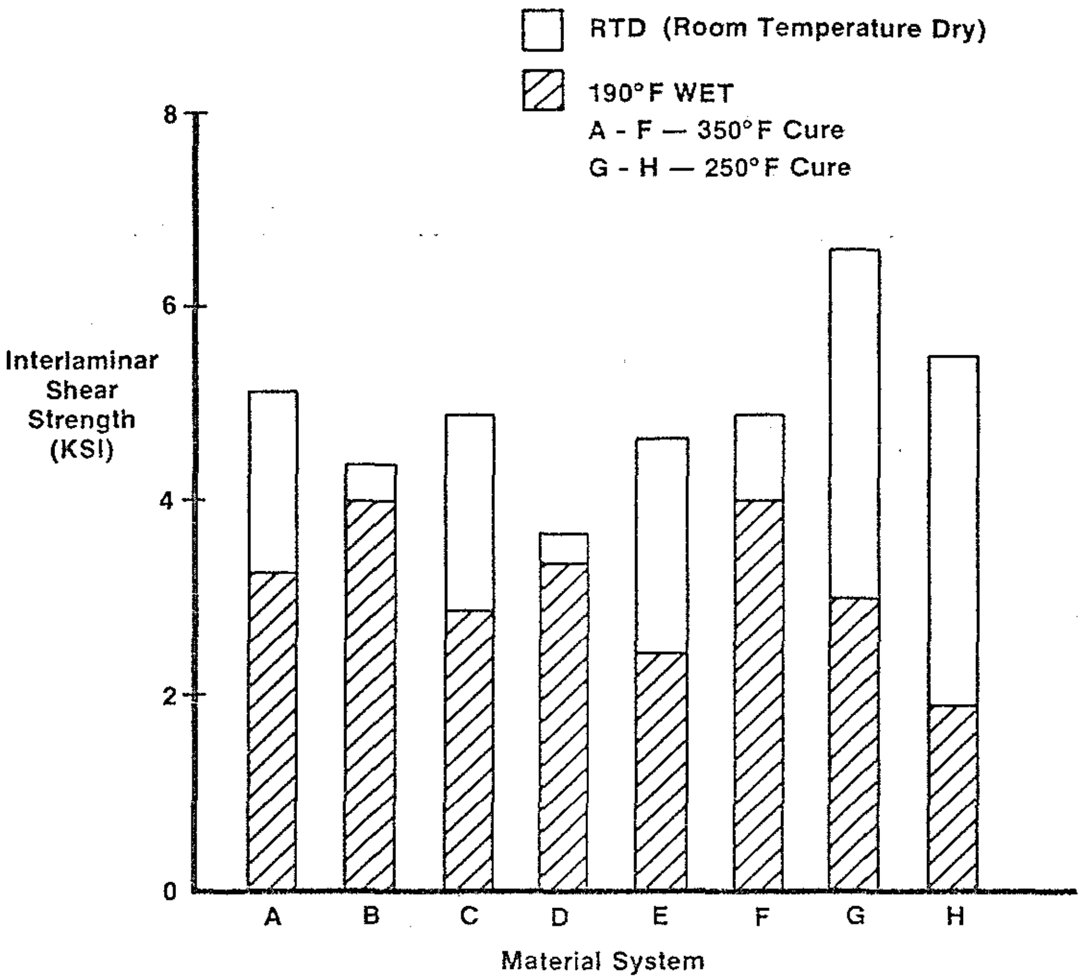

Figure 25 - KEVLAR/EPOXY MATERIALS SCREENING TEST RESULTS

Design allowables coupon tests established all principal mechanical properties under room temperature and elevated temperature (190°F) and dry and saturated conditions.

Fatigue tests were performed for similar environmental conditions. A typical result for 0.90° laminates is illustrated in Figure 26.

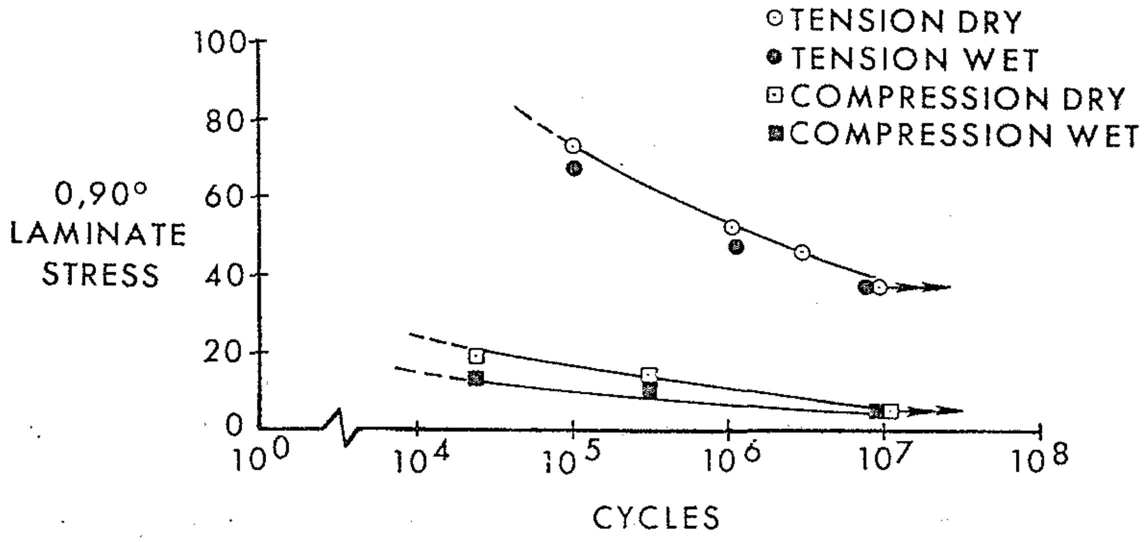

Figure 26 - 0,90° LAMINATE FATIGUE BEHAVIOR

Following the coupon tests a subcomponent fatigue test was performed to establish an experimental environmental knock-down factor. The resulting apparent factor was considerably higher than that shown by the coupon tests thus demonstrating the conservative nature of the current design allowables.

The Kevlar/epoxy components have been flying for over two years at the Development Center in Florida and have not experienced any major malfunctions. Because of the newness of the composite structures used on the SPIRIT helicopter, research on environmental effects will continue by exposing several structures to hot and humid environments on roof tops and by examining components returned from service periodically to determine the amount of moisture absorbed and their structural properties.

17. Materials Flammability

Sikorsky Aircraft elected to meet the fixed-wing standard, FAR 25.853, for materials. This standard requires interior materials to be self-extinguishing within 15 seconds after ignition. Over 50 different types of materials were tested, involving close to 1500 specimens. FAA approval was obtained for all interior materials used in the SPIRIT helicopter.

18. Internal and External Noise

Low levels of interior noise have been achieved in the SPIRIT helicopter by reducing the source noise and by careful interior acoustic treatment. A 10 dB SIL (speech interference level) reduction in source noise was achieved by careful grinding of gears and by main gearbox and skin damping. Acoustic treatment of the utility interior achieved 78 dB SIL in hover and 82 dB SIL in cruise. The VIP interior has noise levels of 76 dB SIL in hover and 78 dB SIL in cruise.

The external noise levels are better than projected FAA EPNL standards by an average of 2EPNdB. No blade slap noise occurs in either cruise or landing. Hover noise at 500 feet distance averages 87 PNdB. Measured noise exposure contours showed a maximum 75 dBA footprint of 2400 feet along the take-off path and 4500 feet along the landing path. The relation of the S-76 external noise level to the ICAO standard is shown in Figure 27.

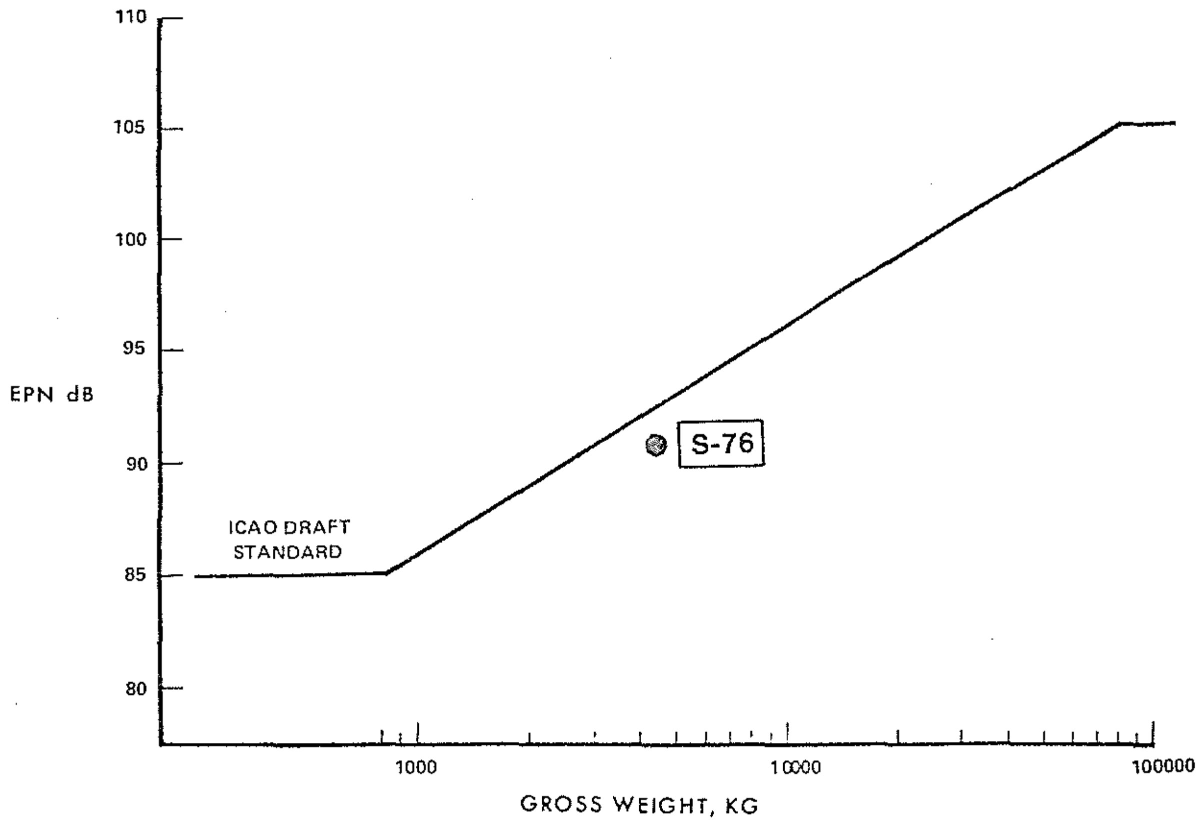

Figure 27 - NOISE LEVEL/STANDARDS COMPARISON TAKE OFF

19. Handling Qualities

On the basis of experience with the first groups of customer pilots trained in the SPIRIT helicopter, it seems certain that new standards of aircraft handling qualities have been achieved. This was accomplished by thorough analysis, wind-tunnel testing, simulation and flight development. The fixed, low horizontal stabilizer, main rotor pitch-flap coupling, pitch bias actuator, mechanical control couplings and stability augmentation provide levels of gust suppression, ride comfort, general handling qualities and stability that far exceed the properties of prior production helicopters. A detailed discussion of the development activities is presented in Reference (h).

Controllability with adequate control margins in 35 knot winds from any direction has been demonstrated. Sideflight speeds of 50 knots to the left and right have been demonstrated.

VFR certification to 155 knots without stability augmentation and IFR certification to the same speed with a single channel (non-redundant) 3-axis stability augmentation system (SAS) has been achieved. Further actions toward single pilot IFR capability are currently underway.

20. Transport Efficiency

The overall transport efficiency of the SPIRIT helicopter far exceeds that of its predecessor which was built with technology of the 1950's. The S-76 saves more than 5 gals of fuel per passenger per 100 miles flown, Figure 28. On this basis a fleet of 100 SPIRIT helicopters flying 200 miles/day, 300 days per year would save several million gallons of fuel per year.

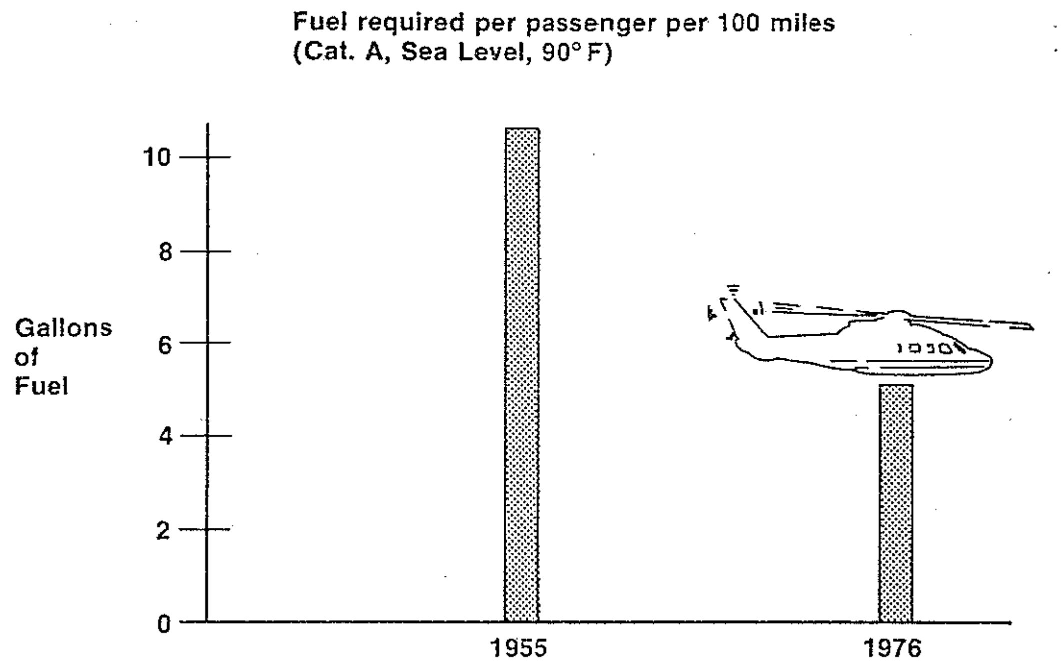

Figure 28 - LOWER FUEL CONSUMPTION

The excellent efficiency and R&M of the SPIRIT helicopter provide a 2:1 reduction in seat mile costs compared to 1950's technology helicopters, Figure 29.

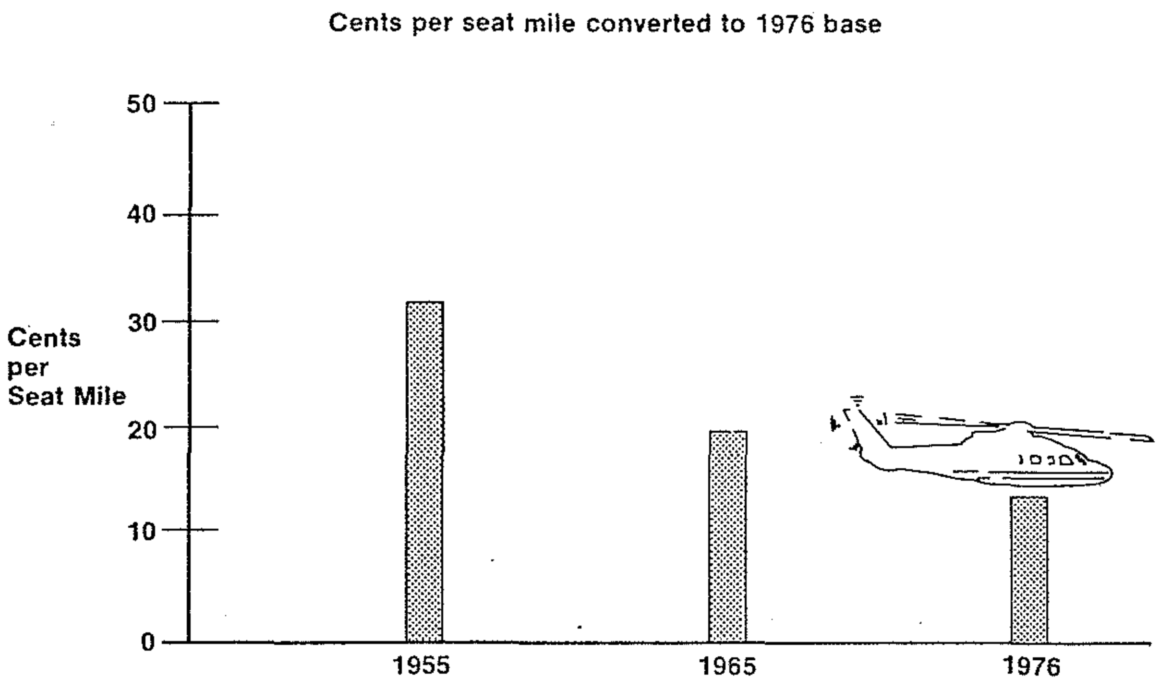

Figure 29 - LOWER PASSENGER SEAT MILE COSTS

21. Conclusions

The UH-60A BLACK HAWK was designed to provide a greater level of safety than heretofore possible. Much of the new technology applied to improve reliability, condition monitoring, environmental compatibility, redundancy, benign failure modes and crashworthiness has contributed to establishment of new standards of safety. As discussed in the previous pages new standards of performance, reliability and maintainability have been validated through a most thorough U.S. Army development program.

As in the case of BLACK HAWK, the new technology used in the SPIRIT helicopter has resulted in new standards of performance, reliability, maintainability and safety. New materials have been pioneered and have been validated for environmental effects through thorough testing. Interior materials have been selected to meet high flammability standards. The rotor system and drive train have successfully undergone over 1400 hours of ground testing. A new standard for aerodynamic cleanness and system efficiency has been achieved. Interior and exterior noise levels are low and better FAA and ICAO standards. Excellent handling qualities have been demonstrated.

The SPIRIT helicopter has been validated for U.S. and foreign commercial missions in a configuration that has established a new standard for transport efficiency.

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