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LIGHT HELICOPTER TECHNOLOGY FOR THE YEAR 2000

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The next generation of light helicopters entering the market will face a highly competitive environment. To be successful in that environment, the next generation of light helicopters must offer distinct improvements in cost, payload, noise, reliability, maintainability, and crew station (Figure 1). All of these must be incorporated into an optimized, integrated design. Fortunately, over the last several years, the technology has been maturing and will provide significant advancements in those areas.

Over the course of the 1970's and 1980's, there has been a broad industrial investment in research to update rotary wing technology. This technology advancement has included not only the small individual projects and interactions, but also the use of these projects as building blocks to be combined and integrated into current future operational aircraft (Figure 2). At McDonnell Douglas Helicopter Company, these programs have included a wide range of technology demonstrators, including advanced rotors and hubs, advanced directional control systems, simulation, and analysis development. These technology programs were then integrated into the current operational aircraft at McDonnell Douglas to provide wind tunnel tests beds to further flight development. This technology has produced advancements in several major areas: Configurations, Structures, and Systems.

The research work in advanced configurations has produced designs and improved the current generation of helicopters along the lines of noise, safety, and vibration control. Typical of the advanced configurations, is the No Tail Rotor concept (NOTAR) which replaces the conventional tail rotor with a combination of a circulation control tailboom and a direct jet thruster. In the NOTAR concept, the tailboom now generates force using circulation control principals (Figure 3). A thin stream of air emitted out of the side of the tailboom influences the main rotor downwash to flow around the tailboom to produce an anti-torque force in much the same manner as the circulation control airfoils on the X-Wing. In hover, under high downwash conditions, the circulation control tailboom generates the majority of the trim anti-torque force. For the additional trim anti-torque force and for maneuvering, or when the circulation control tailboom is ineffective, a direct jet thruster at the aft end of the aircraft provides the required force.

The direct jet thruster is a cone within a cone. The inner cone has fixed exit areas, right and left. The outer cone rotates around the inner cone to modulate the amount and direction of the thruster force. The air for both the circulation control tailboom and the direct jet thruster is provided by a variable pitch fan mounted at the forward end of the aircraft. The pressures and flow velocities within the NOTAR concept are relatively low for circulation control, being about half a pound per square inch, producing slot and thruster velocities on the order of 250 feet per second.

The thruster and the pitch of the variable pitch fan are controlled from the pilot's directional control inputs in the same manner as it is in conventional helicopters (Figure 4). For pedals neutral type position, there is a moderate fan pitch and the thruster is open to the primary left turn direction. To initiate a pedal turn either right or left, blade pitch is increased, and the thruster is rotated to provide force to initiate the turn in the desired direction. In this illustration, pedals are used, but a side-arm controller could also be used.

The NOTAR concept has been under development for over 10 years and is currently reaching fruition to be used in upcoming configurations (Figure 5). The NOTAR concept started out as a basic research concept under a full scale rotor on the MDHC whirl tower. Once a base data was acquired, the power efficiency of the circulation control tailboom and its potential for integration to a total directional control device became apparent. That circulation control tailboom concept was then carried into flight evaluation sponsored by Aviation Applied Technology Directorate. From the results of that program, NOTAR grew into a demonstrator aircraft which integrated the circulation control tailboom, direct jet thruster and variable pitch fan. The integrated aircraft was then flown to demonstrate response and handling qualities and validate the total concept. The results were very encouraging. However, more technology development was indicated. McDonnell Douglas has carried on NOTAR concepting to evaluate an improved tailboom as well as developing an improved fan. The work has culminated in the flying of the advanced configuration tailboom.

An example of the development effort on the NOTAR program is the flow visualization studies around the circulation control tailboom.

The objective of this study was to improve the tailboom and eliminate some of the aerodynamic fences that were added during the initial flight testing. After several attempts at an analytical solution, MDHC embarked on an experimental program. A scale model NOTAR configuration was built and tested at the McDonnell Douglas Research Laboratory water tank hover test facility (Figure 6). Flow conditions seen in the base aircraft were evaluated and configurations developed.

The water tank testing provided flow visualization data using laser doppler experimentation to improve aerodynamic characteristics of the NOTAR aircraft (Figure 7). With the excellent visualization techniques, we were able to define the flow attachment around the room in its interaction with other sections of the aircraft. In the water tank, we successfully duplicated the full scale, three-dimensional flow conditions found in flight, then using that validated technique, develop an improved NOTAR configuration incorporating an additional slot.

Based on that laboratory result, the flight aircraft was modified in early 1986 under company funds and successfully flown as shown in Figure 8, completing the loop of laboratory tests and flight test validation. The improved NOTAR successfully flew over the entire flight envelope demonstrating dramatic expansions of base aircraft envelope. This aircraft has continued to fly to provide the necessary database.

STRUCTURES

To meet the challenge of weight reduction for increased payload as well as the reliability and maintainability goals, the application of advanced materials and processes will be required. The all metallic structure is rapidly being augmented with composite material structures which promise reduction in weight and cost with intended increases in fatigue life and strength. McDonnell Douglas Helicopter Company has been active in defining material properties for composite materials and exploring their application on rotorcraft. Two examples of these are the Helicopter Advanced Rotor Program (HARP) and the composite fuselage work currently being done at McDonnell Douglas Helicopter Company.

The HARP rotor (Figure 9) is an all composite rotor system that replaces all the bearings and joints of the conventional single rotor with a composite material flexture. The HARP rotor has a composite flat strap-cruciform flexbeam, composite pitch case, and composite rotor blades. The elastomeric snubber dampers on the inboard end provide in-plane damping as well as eliminate pitch flap coupling. Materials used in this experimental hub include Kevlar, fiberglass and graphite. The all composite blade was designed with advanced airfoils for improved performance features at 2:1 taper ratio over the outer 25 percent of the blade. The airfoil sections along the span of the blade are selected for optimum aerodynamic performance at that particular radial station.

After extensive laboratory and component test, the HARP rotor, a full scale flight rotor, was fabricated and tested on a 500D test bed (Figure 10). The HARP aircraft was flown over the V_N envelope of the basic 500 aircraft.

The HARP has been demonstrated over much of the model 500E envelope with speeds and load factors demonstrating exceptional performance and structural integrity (Figure 11). Of particular significance in designing the HARP rotor was the ability to tailor the rotor stability and structural characteristics to achieve low vibration (Figure 12). The HARP rotor is a four-bladed rotor with approximately twice the hinge offset of the equivalent five-bladed 500E rotor that it replaced. These characteristics would tend to drive the aircraft vibration up but by properly tailoring the structural characteristics of the all composite rotor, those vibration characteristics were essentially left untouched over the baseline aircraft. Subsequent to the development of the HARP rotor system, the flexbeam rotor concept was carried forward into a design for a 15,000-pound attack helicopter flexbeam rotor (Figure 13). Additional flexbeam work was done to increase the reliability and motion requirements of the flexbeam concept.

Another major thrust in structures in MDHC, as well as in the industry, has been the application of composite materials to helicopter fuselage structures. Advance composite materials will increase in percentage as time goes by to meet the significant weight reduction challenges presented to the next generation of light helicopter. It is envisioned that in the next generation of aircrafts, 80 to 90 percent of the fuselage weight will be those of composite materials. This has already been achieved in the 1980's as shown in Figure 14, where the total empty weight includes the weights of the fuselage, and rotor and other systems, but not of the engine(s). To meet those goals, MDHC initiated a multi-phased, internally-funded program. The phases of the program spanned initial coupon material characterizations into concept development through large scale component tests of a major airframe structural design (Figure 15). These phases were all aimed at developing a technology demonstrator that supports the upcoming programs in LHX, product improvement programs for the Apache, and an advanced light helicopter.

The initial step in the composite fuselage program was to develop the component concepts to form a database to support the total overall design (Figure 16). Typical of the type of design challenges were the stiffener shapes and intersections used in various designs. The intensive preliminary design effort concepts were presented, fabricated and then forwarded to the laboratory test phase where they could be evaluated for the strength and energy absorption characteristics. Figure 16 shows several typical bulkhead tunnel beams at different design approaches under laboratory crush tests to evaluate their strength and energy absorption characteristics.

With a database having been developed, full scale fuselage components were designed and tested to evaluate a total integrated design using our MD500 series aircraft as a technology demonstrator (Figure 17). Large components were extracted from the lower fuselage to be fabricated and tested. The large section of the belly of the MD500 series was extracted and used as a subject for a manufacturing design study to improve the tooling and producibility effects (Figure 18). A series of tests and evaluations were conducted to validate both the design and manufacturing approach. A crash impact test facility was developed to evaluate the energy absorption characteristics of the composite floor sections. In this test fixture, sections as well as the complete fuselage floor were crushed under controlled conditions to measure the strength and energy absorption capabilities (Figure 19). These tests were carried out in a sequential building block approach and proved to be highly successful. The test demonstrated a composite floor section capable of successfully absorbing its energy share in a standard impact situation.

In addition to the current thermoset initiatives in composite materials, efforts are also underway to bring to fruition potential cost savings of thermoplastic structures. Currently underway is a program to examine fiber reinforced thermoplastics. Here a difficult part containing many design contour complexities was chosen to be manufactured out of thermoplastic material, which for this particular application was chosen to be a PPS glass system (Figure 20). The manufacturing, producibility, and strength characteristics of this part were all verified using thermoplastics, indicating thermoplastics has a key role to play in future light helicopter design. To extend that, work is currently underway internally to McDonnell Douglas to use thermoplastics on a primary aircraft structure. The structure chosen for design work is the vertical stabilizer box on the Apache helicopter. Here a PEEK graphite system has been selected due to its high strength characteristics.

SYSTEMS

Advanced avionics systems will have a major impact on future helicopter design. The pace of electronic improvement will guarantee that this impact will accelerate in the future. An example of the impact of advanced avionics is crew station design. McDonnell Douglas Helicopter Company is currently pursuing systems technology required to provide an improved cockpit environment as well as minimize pilot workload. In these design efforts, advanced digital flight control computers are integrated with multi-function displays, a full authority side-arm controller provide the full improved pilot operability. An example of the impact of avionics in cockpit design is shown in the comparison of three cockpits for the 500 series aircraft (Figure 21). Current generation of 500MD cockpit with TOW shows the current approach to crew station design. With the application of advanced full digital computers and panel displays, significant improvements in cockpit visibility can be achieved. In this system, only critical information is presented to the pilot for his use during flight. As a further enhancement to that, a minimal cockpit display system was developed which provided only essential information and again greatly enhanced the field of view of the pilot. This contributed dramatically to piloting capability as well as reduced workload.

An integral part of the crew station development will be the use of artificial intelligence techniques to augment the pilot. McDonnell Douglas Helicopter Company has been active over the last several years in developing the AI technology in its application to rotorcraft problems. Under a recent contractual effort, McDonnell Douglas Helicopter Company has taken these AI techniques and applied them to maintenance diagnostics on the AH-64 helicopter (Figure 22). Under that program, McDonnell Douglas Helicopter Company developed an Intelligent Fault Locator (IFL) for four subsystems on board the Apache; fuel system, communication navigation, avionics system, mechanical flight controls, auxiliary propulsion unit, APU systems. The knowledge base was created, the AI techniques developed, and all were integrated into a portable computer to be fielded with the maintenance personnel. The IFL is now in field evaluation at the Army at Ft. Rucker, Alabama and Ft. Hood, Texas. To date, it has a 100 percent success rate for fault location for fielded Apache aircraft. In addition to its success rate, it is also demonstrated over a 10:1 reduction in maintenance manhour time required to identify and fix the various faults. The potential of this system to be integrated on with a flight data recorder has the potential to allow onboard health monitoring as well as maintenance action.

The impact of AI on off aircraft actions also is seen in Figure 23. In this case, AI techniques have been used to develop an avionics expert in the manufacturing environment. This allows the diagnosis of problems on the multiplex bus installed on board the AH-64A aircraft. In this manner when the bus is checked out in manufacturing, the AI system allows the manufacturing personnel to quickly and efficiently locate any manufacturing faults and correct them on-line. This is currently being applied on the production line at McDonnell Douglas Helicopter. Potential for application of future light helicopter aircraft will be a significant reduction in manhours in the production of the aircraft.

CONCLUSIONS

The next generation of light helicopter will incorporate significant technical advances in areas Configurations, Structures, and Systems. The application of these technologies will improve next generation light helicopter in areas of noise, capability, reliability and maintainability (Figure 24). Structural weight reductions in the order of 20 percent are envisioned due to the application of thermoplastic and thermoset materials. Concurrent with that would be a reduction in manufacturing hours driving down acquisition costs in the next generation helicopter. Reliability and ride quality will be greatly increased using new systems such as NOTAR and HARP. Maintenance actions can be reduced by more than 20 percent with the application of new configuration concepts as well as using advanced materials. All this will result in the next light helicopter having both improved capability and affordable.

- ***ACQUISITION COST/DIRECT OPERATING COST***
- ***PAYLOAD/WEIGHT FRACTION***
- ***RIDE QUALITY***
- ***NOISE***
- ***RELIABILITY/MAINTAINABILITY***
- ***USER-FRIENDLY AVIONICS***
- ***INTEGRATED DESIGN***

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Figure 1. Light Helicopter Challenges

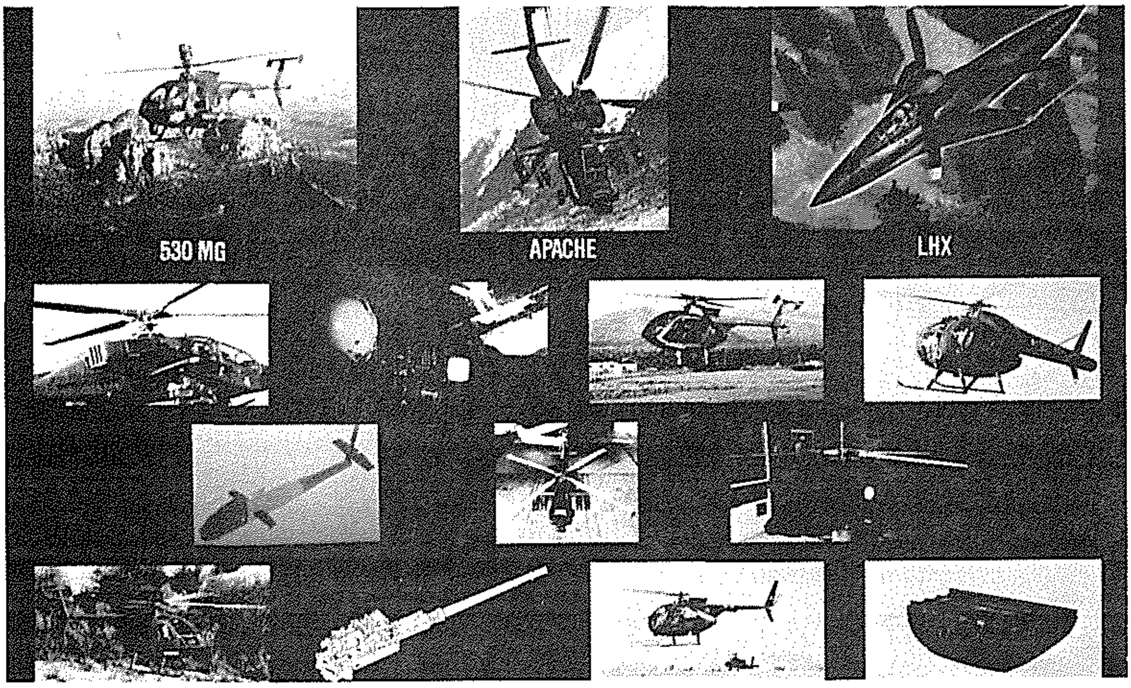

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Figure 2. Technology Advances on a Broad Front

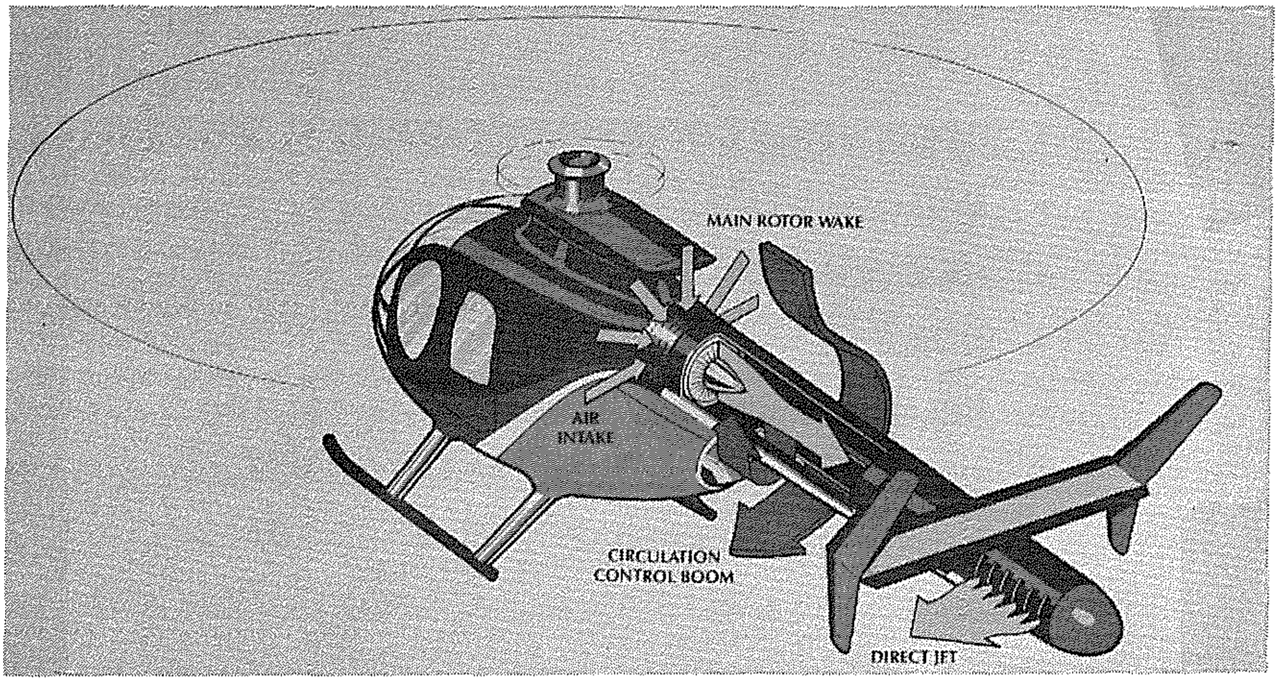

Figure 3. NOTAR (No Tail Rotor) Concept

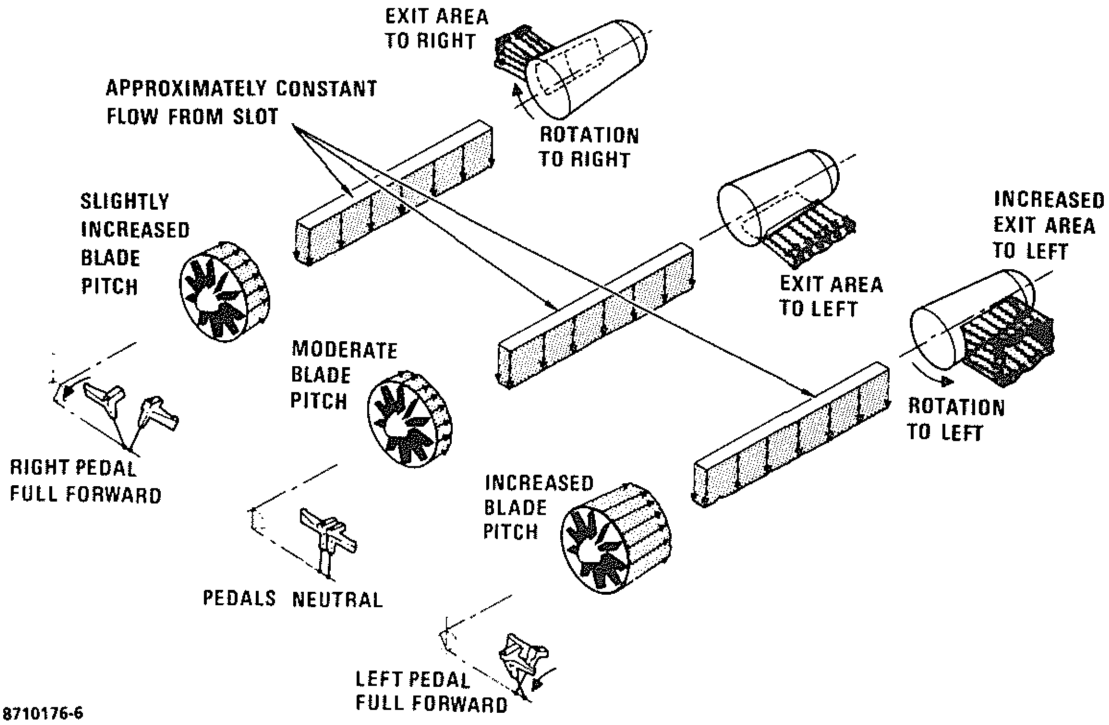

Figure 4. NOTAR System Function

AUG 1976 — BASIC DATA GENERATION — MDHC WHIRL TOWER
- DEC 1977 — FIRST CONCEPTUAL FLIGHT
- APR 1980 — NOTAR PATENT ISSUED
- SEP 1981 — GROUND TESTS — FAN/THRUSTER/THRUSTER TRANSIENT RESPONSE

DEC 1981 — FIRST TOTAL SYSTEM FLIGHT, OH-6A
- SEP 1982 — SIMULATION — FLIGHT SIMULATION ON FLIGHT SIMULATOR FOR ADVANCED AIRCRAFT AT AMES

MAY 1983 — GOVERNMENT PILOT EVALUATION
- MAY 1983 — USAAVRADCOM TECHNICAL REPORT
- DEC 1983 — AERODYNAMIC PANEL MODELS
- FEB 1984 — TIEDOWN TESTS — AIRCRAFT ON TOWER TO SIMULATE OUT OF GROUND EFFECT HOVER
- AUG 1984 — NEW FAN DESIGNED, INLET MODS
- SEP 1985 — FAN/STATOR GROUND TESTS

OCT 1985 — WATER TANK TESTING
- OCT 1985 — WIND TUNNEL TESTS
- DEC 1985 — GROUND TEST WITH NEW FAN/INLET AND MORE POWERFUL ENGINE

MAR 1986 — SECOND SLOT FLIGHT TEST

MAR 1987 — GOVERNMENT PILOT EVALUATION

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Figure 5. NOTAR Test/Analyses History

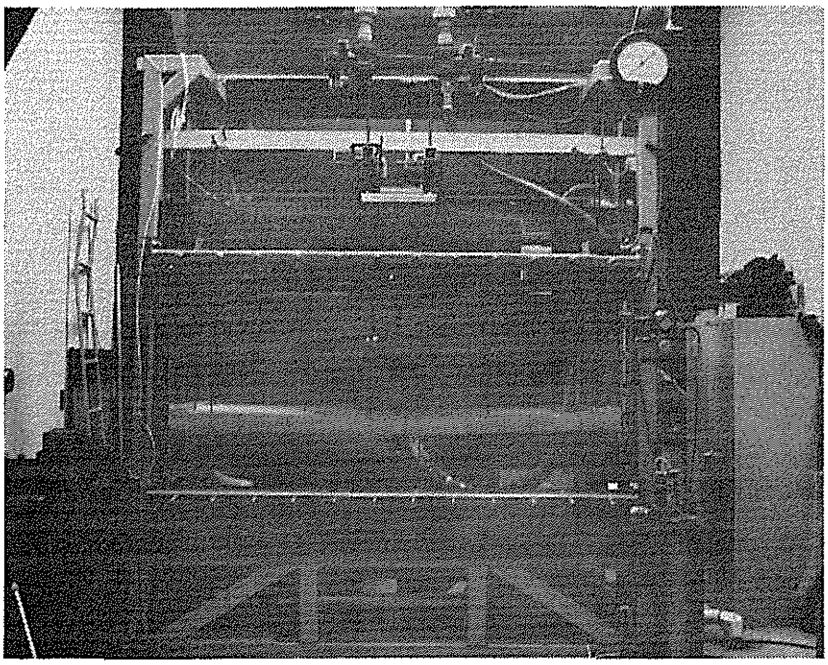

Figure 6. MDRL Hover Test Facility

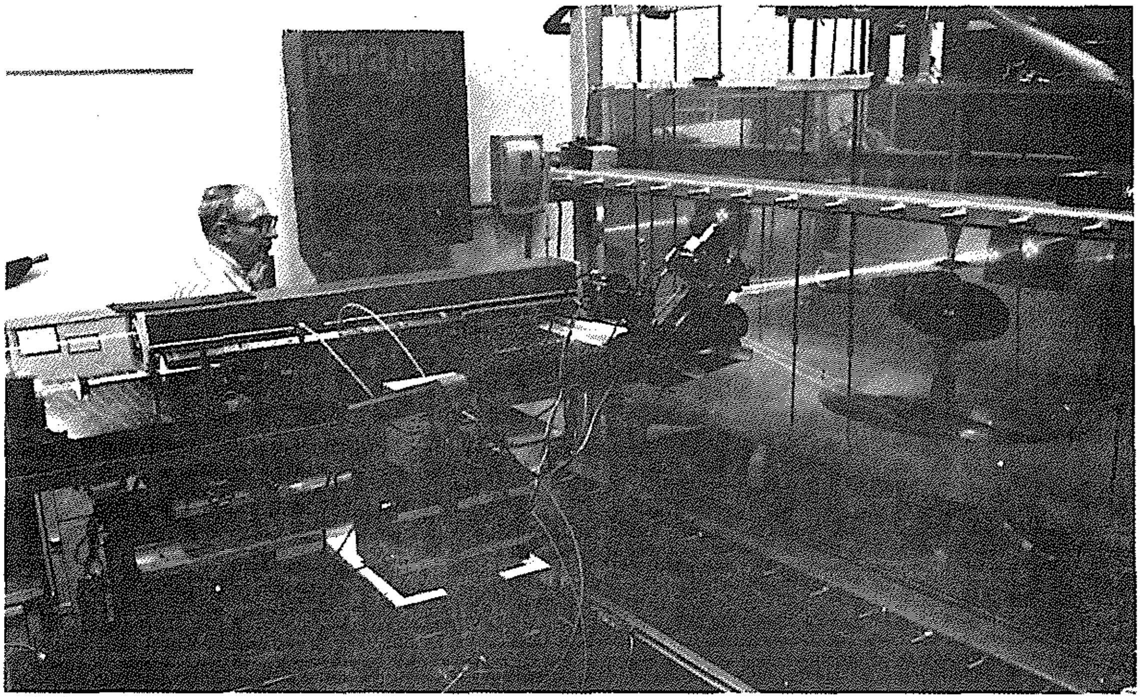
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Figure 7. Laser Doppler Velocimeter Measurements in Hover Test Facility

Figure 8. First Flight of Improved NOTAR

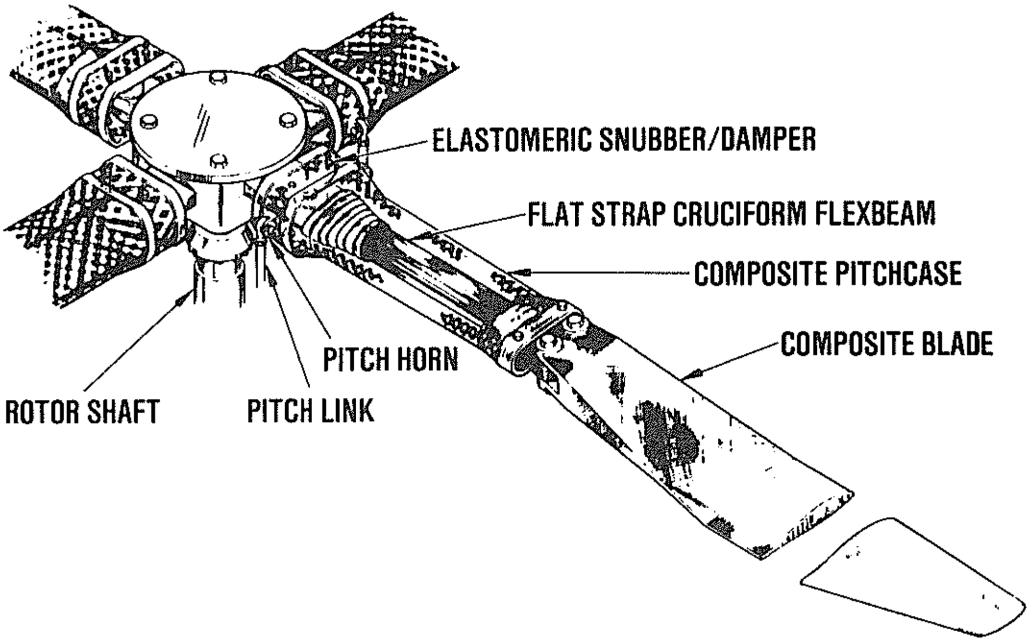

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Figure 9. MDHC Advanced Rotor (HARP)

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Figure 10. HARP First Flight

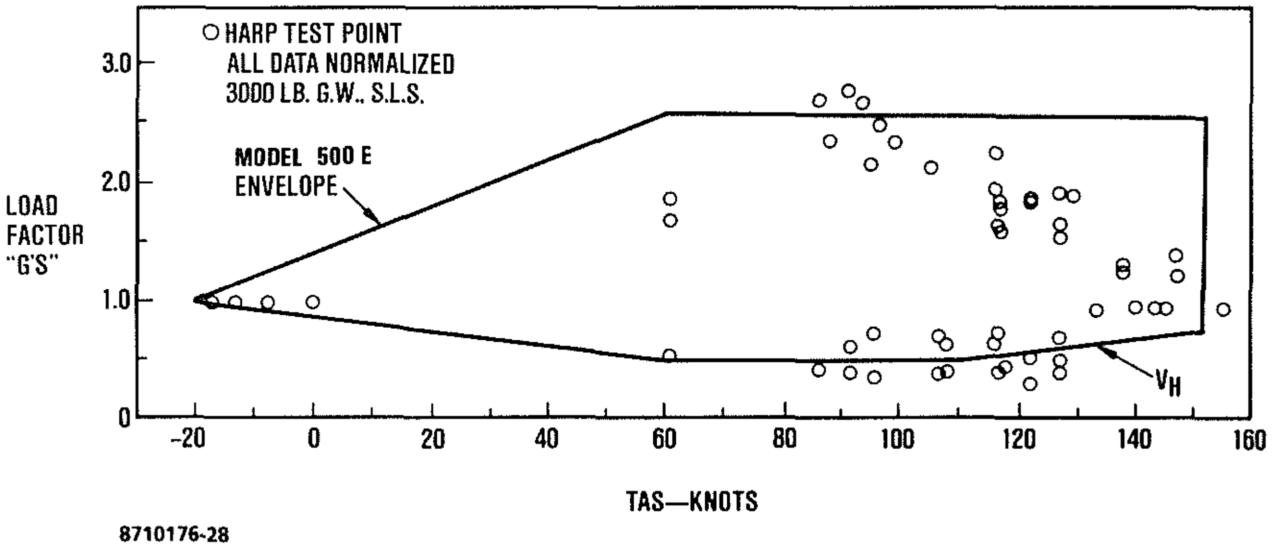

Figure 11. HARP Demonstrated V_N Envelope

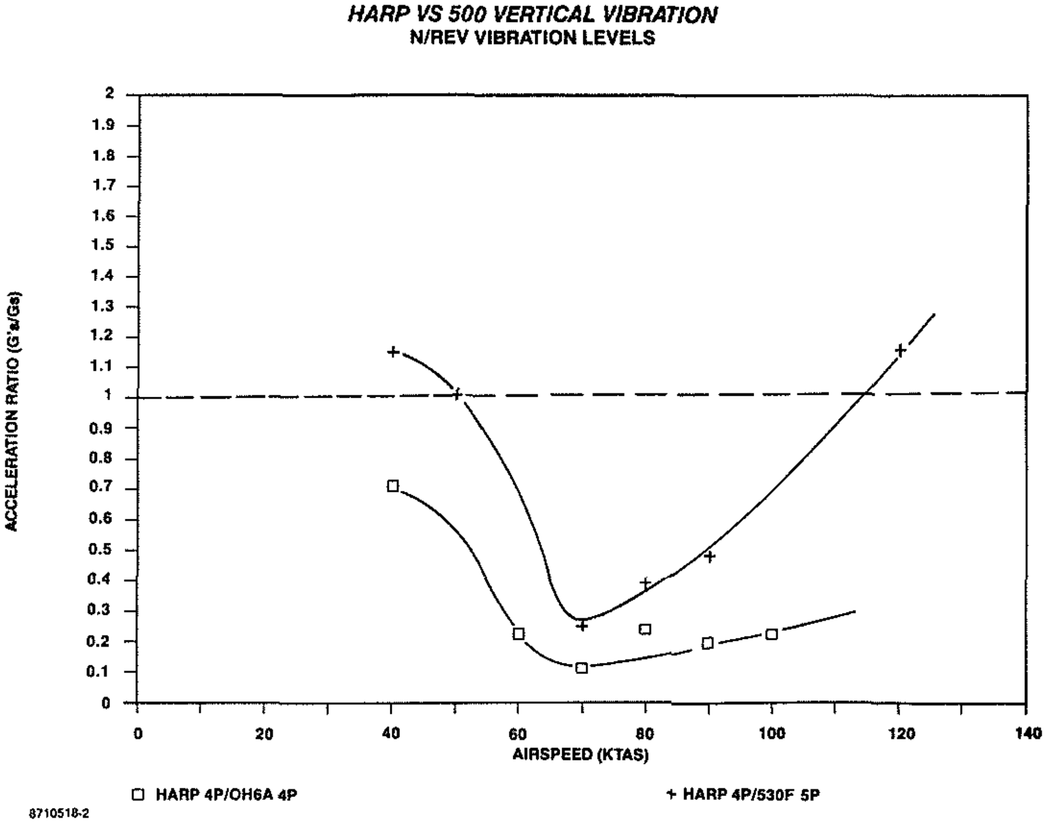

Figure 12. HARP Vibration Comparison

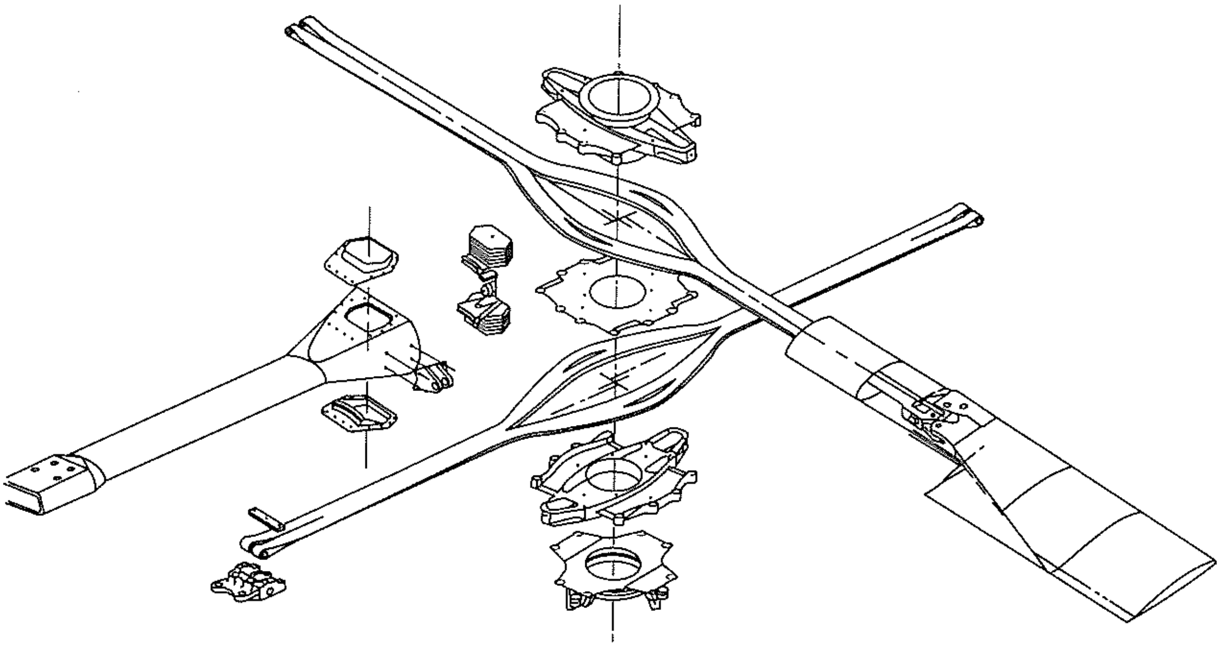

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Figure 13. AH-64 Advanced Composite Hub (ACH Prototype Hub)

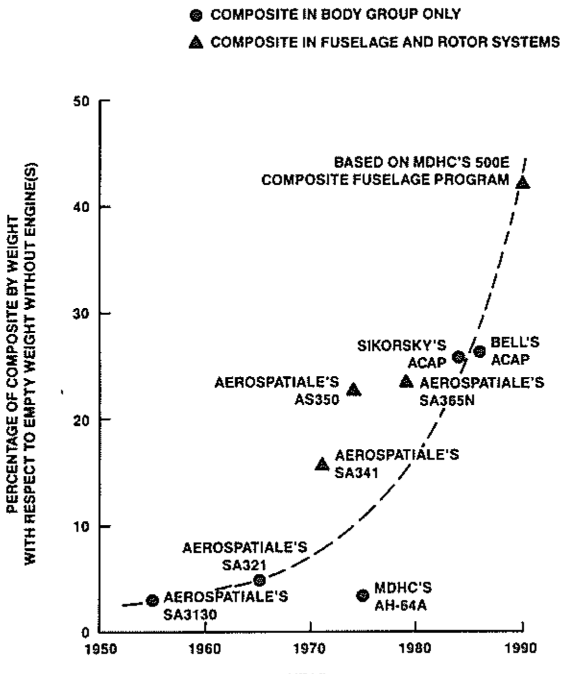

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Figure 14. Fuselage Composite Weight

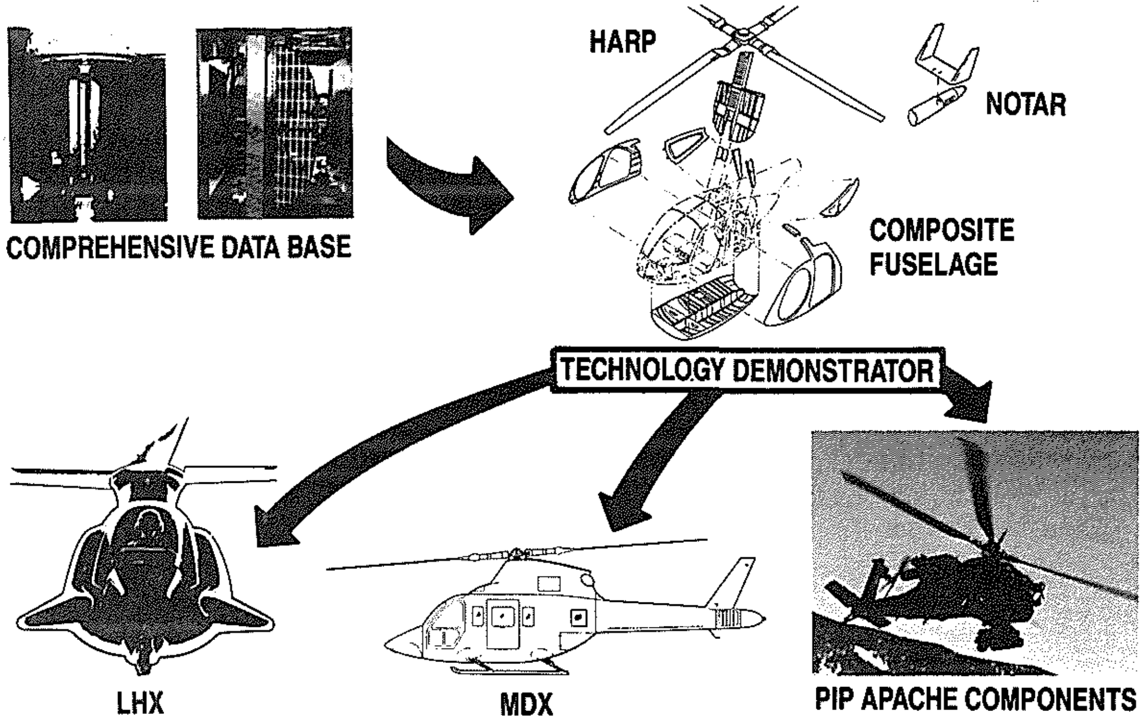

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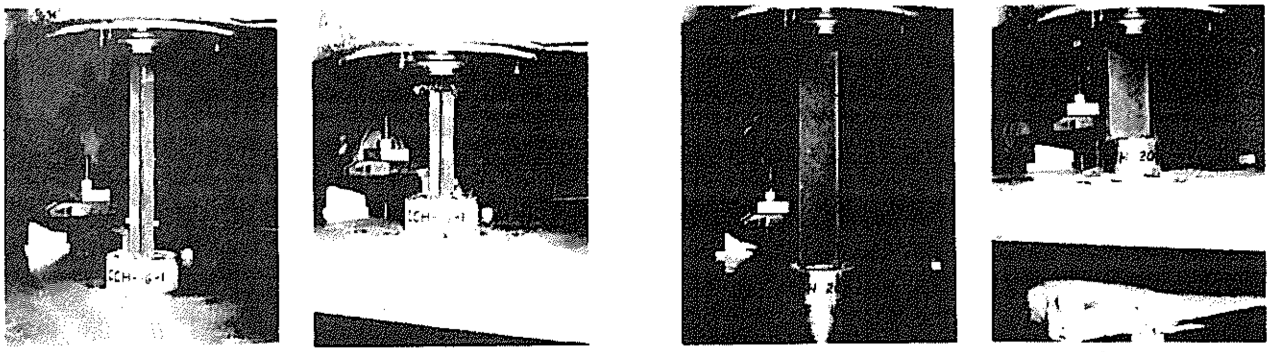
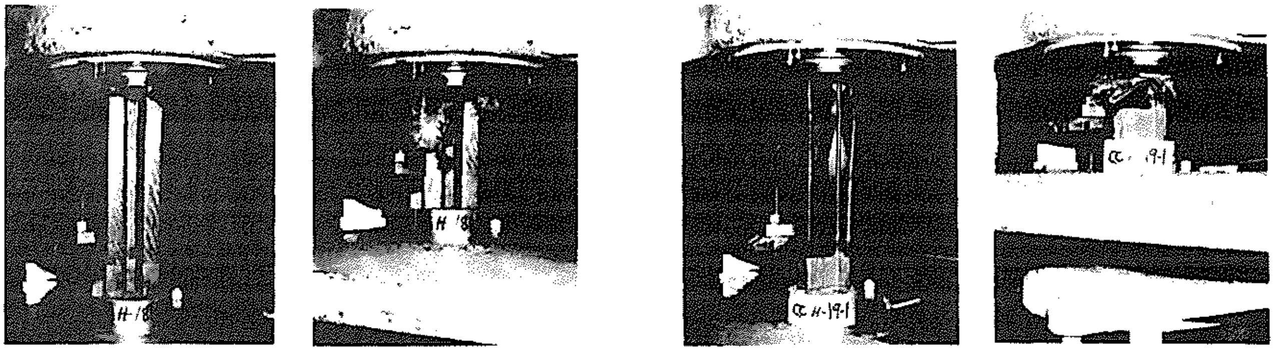
Figure 15. Flightworthy Composite Fuselage Program Concept


CRUCIFORM SECTION

CHANNEL SECTION


HAT SECTION

ZEE SECTION

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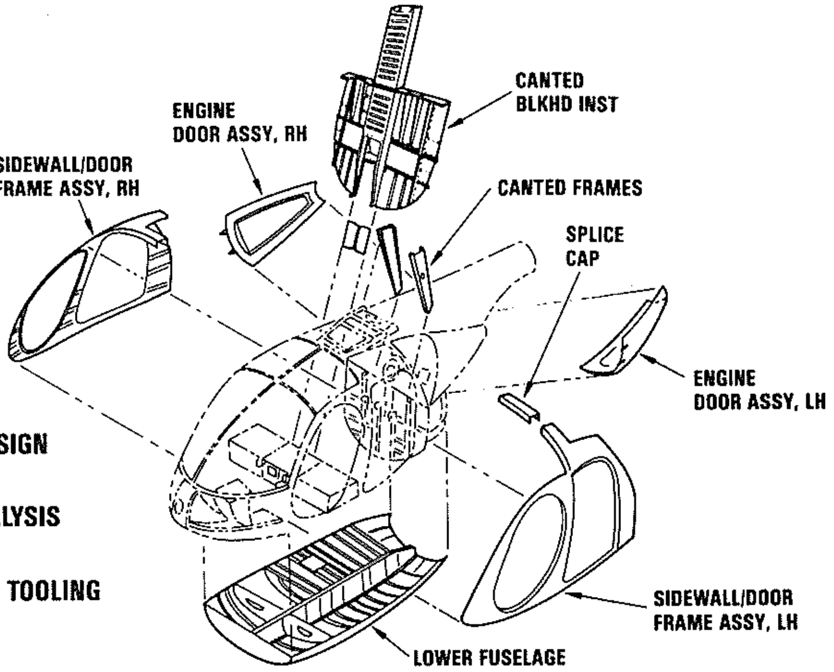
Figure 16. Bulkhead Tunnel Beams



- **PRELIMINARY DESIGN COMPLETED**
- **SENSITIVITY ANALYSIS COMPLETED**
- **FEMALE MASTER TOOLING COMPLETED**

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Figure 17. Full Fuselage Composite Design

- **PARTS COUNT REDUCED FROM 33 TO 13**
- **LABOR HOURS REDUCED 30%**

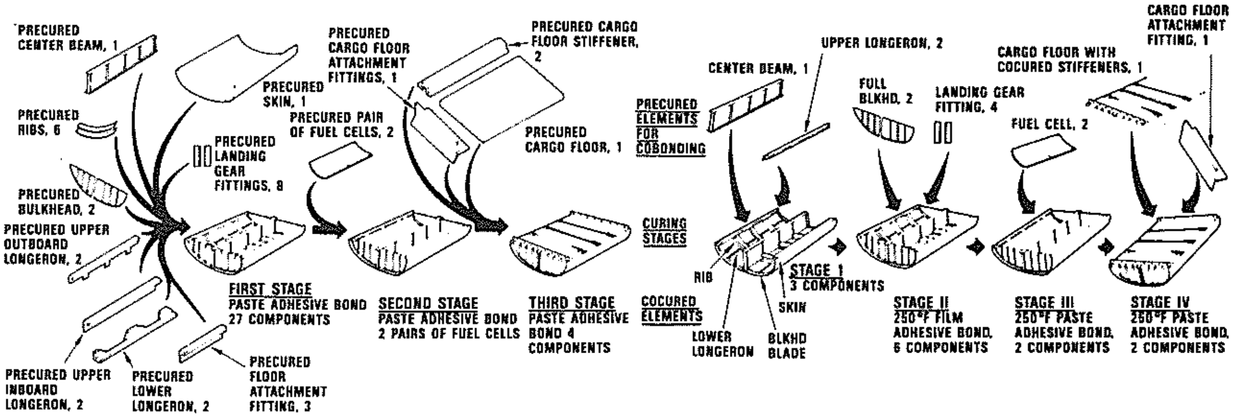

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Figure 18. Improved Tooling Approach

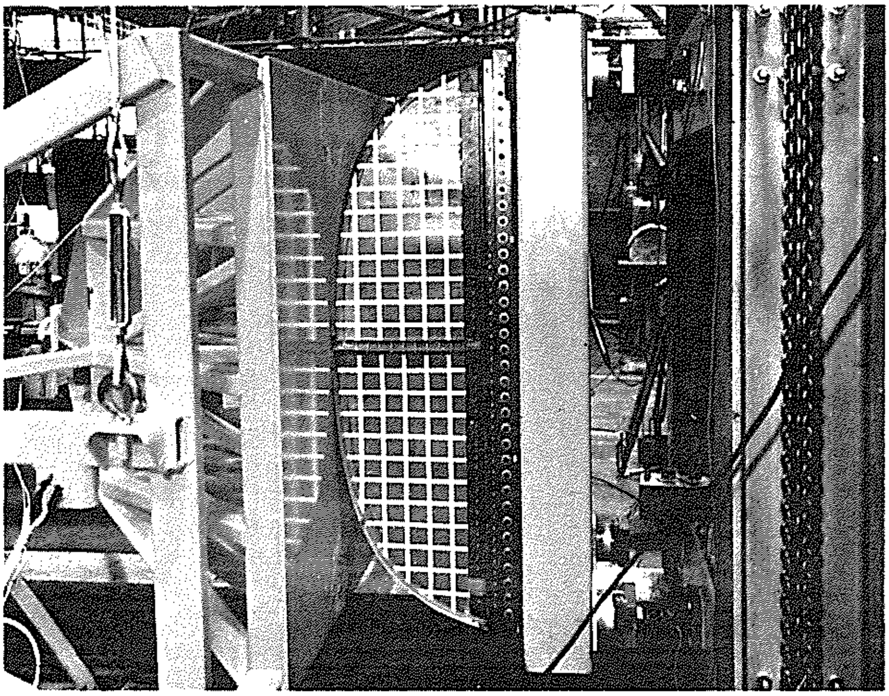


Figure 19. Third 25-Inch Subassembly Impact Test Set-Up

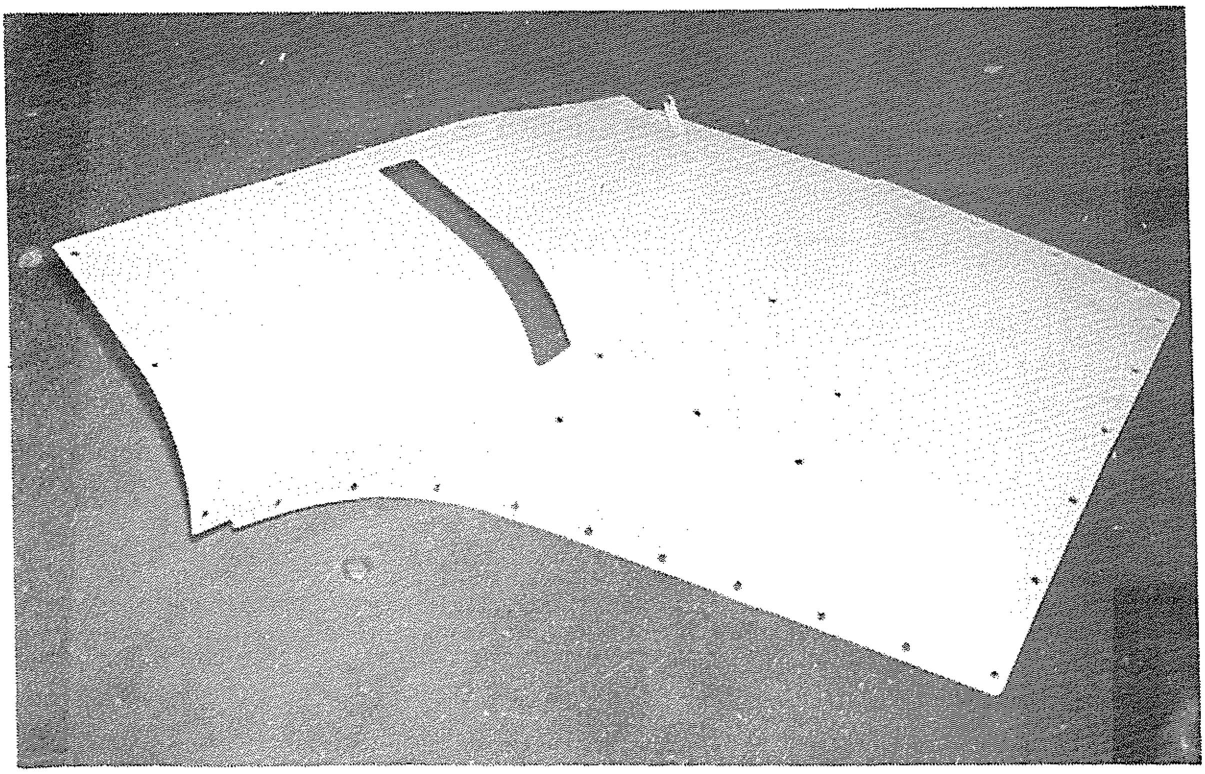
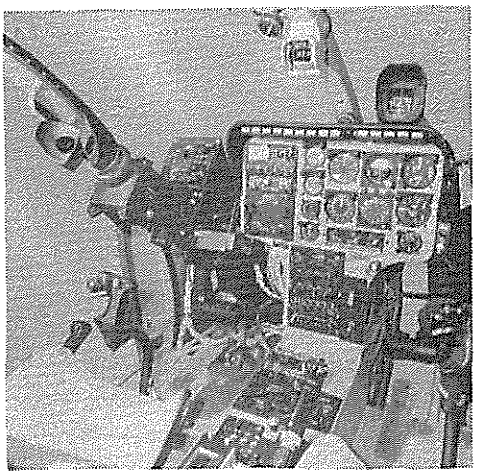
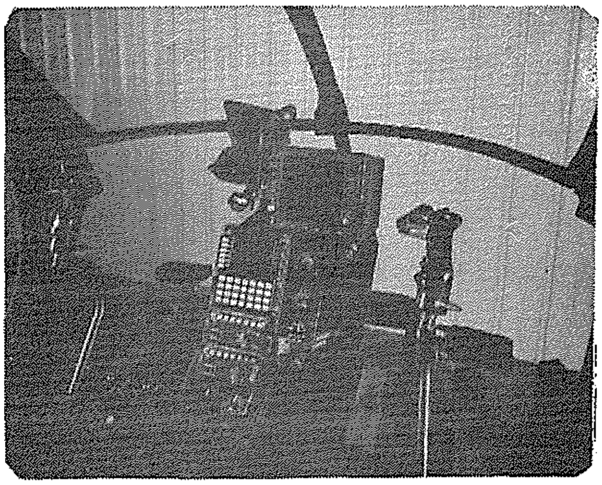


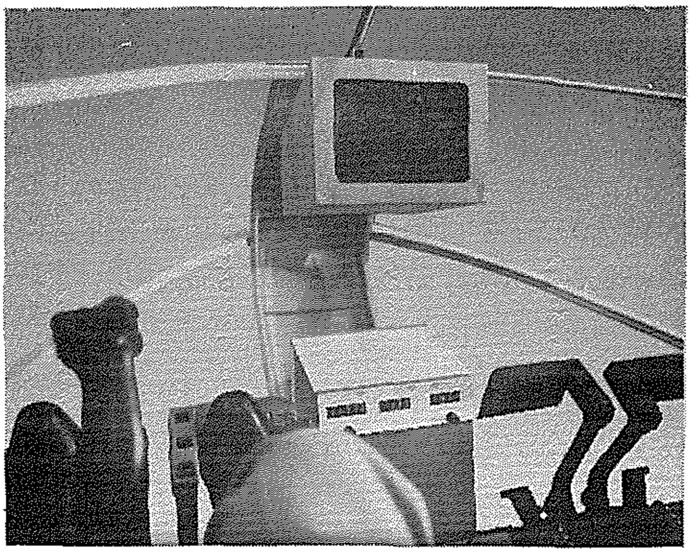
Figure 20. Thermoplastic Structure



500MD



500MG



Minimal System

Figure 21. Avionic Impact on the Cockpit

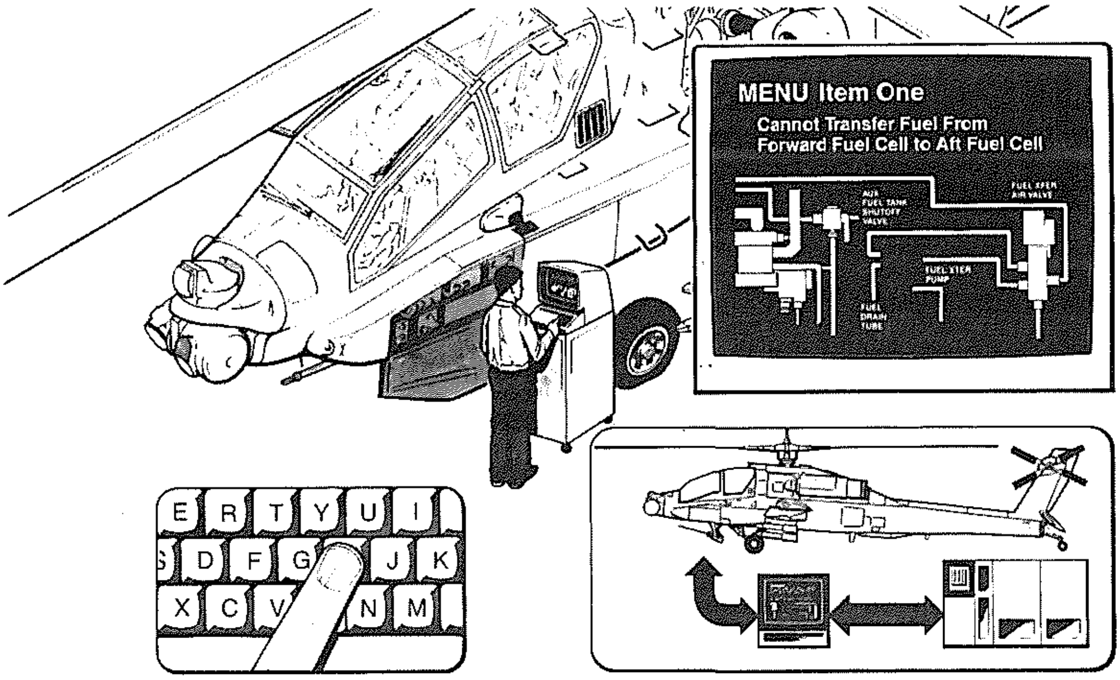
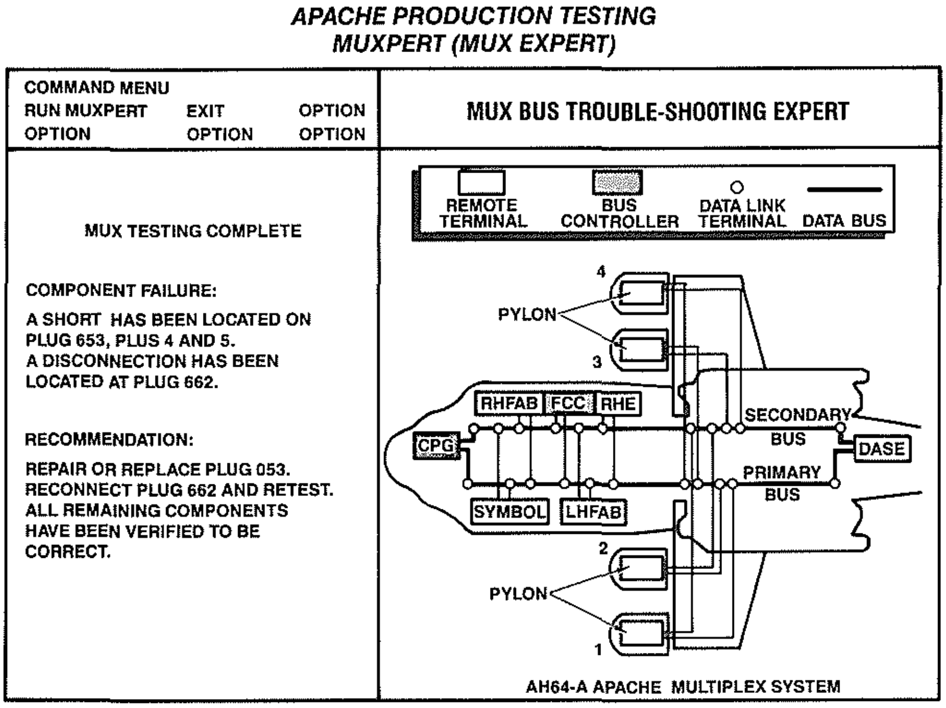


Figure 22. AI: Intelligent Fault Locator



APACHE PRODUCTION TESTING
MUXPERT (MUX EXPERT)

COMMAND MENU
RUN MUXPERT OPTION
EXIT OPTION
OPTION OPTION

MUX BUS TROUBLE-SHOOTING EXPERT

MUX TESTING COMPLETE

COMPONENT FAILURE:

A SHORT HAS BEEN LOCATED ON PLUG 653, PLUS 4 AND 5.
A DISCONNECTION HAS BEEN LOCATED AT PLUG 662.

RECOMMENDATION:

REPAIR OR REPLACE PLUG 053.
RECONNECT PLUG 662 AND RETEST.
ALL REMAINING COMPONENTS HAVE BEEN VERIFIED TO BE CORRECT.

8710518-4

Figure 23. MUXPERT Manufacturing System

Figure 24. Future Light Helicopter Concept