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DESIGN AND DEVELOPMENT OF THE ADVANCED LIGHT HELICOPTER (ALH) - AN OVERVIEW

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The Advanced Light Helicopter (ALH) designed and developed at Hindustan Aeronautics Limited, India, is a unique multi - role, multi-mission helicopter in the 5 tonne weight category, meeting a broad spectrum of military and commercial requirements.

The ALH incorporates a number of advanced technology features such as hingeless main rotor and bearingless tail rotor, Integrated Dynamic System (IDS), 6 degree of freedom Anti Resonant Isolation System (ARIS), crashworthiness features and extensive use of composites.

This paper highlights the advanced design features adopted, configuration of systems, testing aspects and the status of development programme of ALH.

1. INTRODUCTION

The ALH (Figure 1) incorporates state-of-the-art technology and is designed as a cost effective, multi-role, multi-mission twin engine helicopter in the 5 tonne weight category. State-of-the-art technology enables operation in hot & high conditions, cold weather and in saline atmosphere. The Army/Airforce Version has a skid undercarriage while the Naval Version features retractable wheeled tricycle undercarriage. Significantly , it is well sized for civil applications too. The cabin is spacious with seating upto 14 passengers in high density format.

Three view drawing of the ALH is shown in Figure 2.

Fig. 1 : ALH in Flight

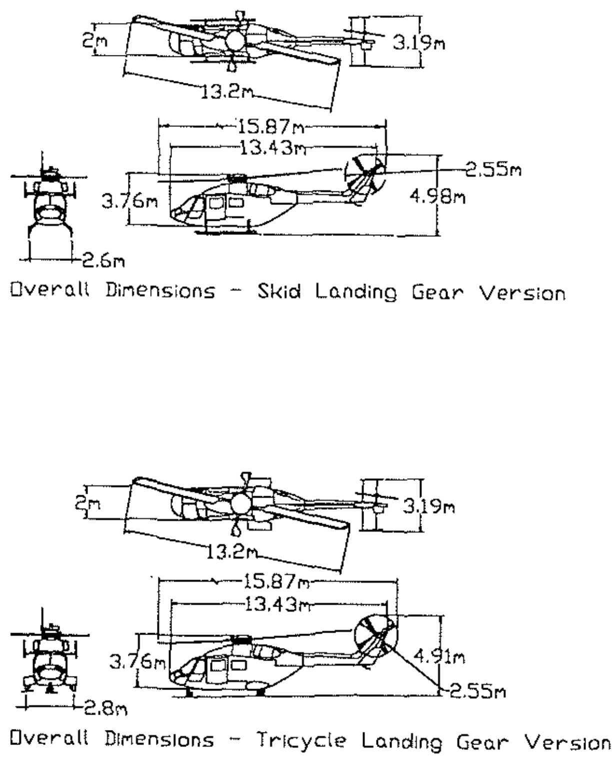

Fig. 2 : Three View Drawing of the ALH

Main characteristics of ALH are listed in Table 1. The helicopter can fulfil the roles as indicated in Table 2.

TABLE 1 : Main Characteristics of the ALH

1	**WEIGHT DATA**	
	Empty Weight	2450 kg.
	Design Gross Weight	4500 kg.
	Max. Take off Weight	5500 kg.
	Underslung load	1500 kg.
	Fuel capacity	1040 kg.
2	**ACCOMMODATION**	
	Cabin Volume	7.33 Cu.m.
	Cargo Volume	2.16 Cu.m.
	Seating Capacity	2 Crew+12 Passengers (Normal) 2 Crew+14 Passengers (High Density)
3	**GENERAL PERFORMANCE DATA** (SL, ISA + 15°C)	**4500 kg.**
	Cruise Speed	245 km/h
	Max. Continuous Speed	290 km/h
	Never Exceed Speed	330 km/h
	Max. Rate of Climb	13 m/s
	Range (20 min. reserve)	750 km
	Endurance (20 min. reserve)	4 hr.

TABLE 2 : Roles of ALH Variants

CIVIL ROLES	UNARMED ROLES	ARMED ROLES
VIP Travel	Heliborne Assault	Anti-tank
Commuter	Logistic Support	Close air Support
Search and Rescue	Reconnaissance	Anti-submarine Warfare
Emergency medical Service	Air Observation Post	Anti-Surface vessel warfare
Underslung Load	Casualty evacuation	
Offshore operation	Training	

Figure 3 shows an overview of the advanced technology features incorporated in ALH.

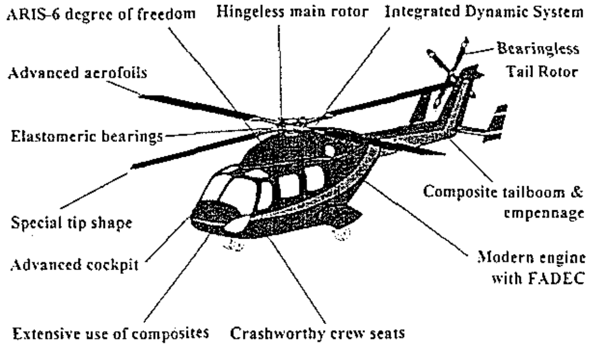

Fig. 3 : Advanced Technology Features in ALH

2. DESIGN GOALS & OBJECTIVES

The major design objectives are :

- Maximum Take Off weight upto 5500 kg.
- High flexibility of operations in multi-role Versions (Armed, Unarmed and Civil)
- 2 + 12 seats (normal configuration) or 2 + 14 seats (high density configuration)
- Good hot and high performance capability; also under OEI condition.
- High speed and long range/endurance
- Good handling qualities and high agility.
- Optimum Empty to All Up Weight ratio
- Option of Skid and Wheeled Undercarriage
- Low noise and vibration
- High reliability, low maintenance and low vulnerability
- Crashworthiness capability
- Good cockpit ergonomics with good allround vision.

The above requirements are met by :

- Four-bladed hingeless main rotor with composite hub and blades and elastomeric bearings, resulting in high agility, high controllability, improved performance, fewer components, low maintenance and elimination of lubrication.
- Four - bladed bearingless tail rotor designed for operation at high altitudes, severe manoeuvring and wind conditions and naval operations.
- Integrated Dynamic System which houses main drive system and Upper Control System, providing increased efficiency, improved

reliability, reduced vulnerability and improved ballistic tolerance.

- Twin engine configuration with a choice of two state-of-the-art engines with FADEC.
- 4-axis Automatic Flight Control System incorporated in collective, pitch, roll and yaw channels to reduce work load on the pilots and for accurate execution of mission tasks.
- Six-axes Anti Resonant Vibration Isolation System installed between the main gear box and fuselage to reduce vibrations and dynamic loads on the fixed system components.
- Well balanced metal / composite structure with crashworthiness capabilities.

3. DESIGN / TECHNOLOGY FEATURES

3.1 DYNAMIC SYSTEM

The Integrated Dynamic System (IDS) is a new concept (Ref.1) successfully proven on the ALH.

The IDS (Figure 4) comprises of Main Rotor Blades, Rotor Head, Main Transmission, Upper Controls and Main Rotor Hydraulic Flight Control Actuators. The integration and modular construction renders a compact design with the advantages of low vulnerability, increased safety and reliability, reduced weight and reduced maintenance cost.

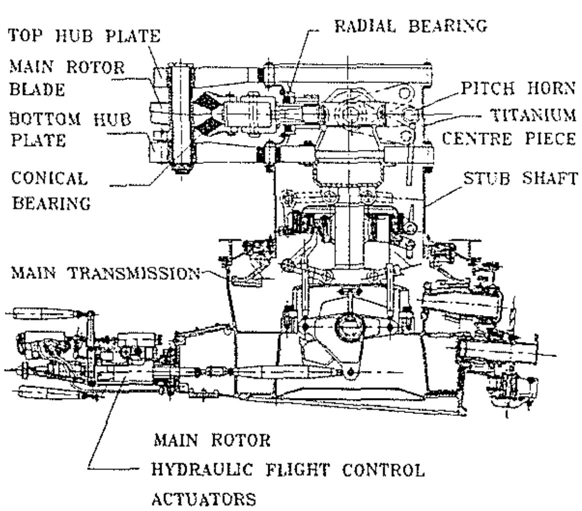

Fig. 4 : Integrated Dynamic System

3.1.1 Main Rotor System

The Main Rotor System is hingeless, soft-in-plane configuration with flexible composite Main Rotor Blades, attached to the composite rotor hub through elastomeric bearings. Hingeless rotor system provides the advantages such as superior Nap Of the Earth (NOE) flight, good flying qualities, high control moment capability, fast control response and freedom from mechanical instabilities.

The Selection of overall dimensions and specific aerodynamic parameters of Main Rotor Blades was largely governed by high altitude hover capability and high forward speed requirement. High performance aerofoils have been selected. The blades have an optimised parabolic tip shape for low rotor noise and improved lifting at high speed. Selection of inplane stiffness and frequency was based on mechanical and aeroelastic stability and dynamic loads. The blades are made of glass carbon composite with a metallic leading edge protection.

The Main Rotor Hub consists of carbon composite upper and lower plates, titanium centre piece and elastomeric bearings. The rotor controls are entirely housed within the centre piece resulting in reduced number of parts, elimination of need for lubrication, reduced vulnerability and improved ballistic tolerance.

The Upper Control System comprises of mixing unit assembly, swash plate mast, swash plate, rotating control rods, rotating and non rotating scissors and tracking unit assembly.

3.1.2 Tail Rotor System

The Tail Rotor is a four bladed, bearingless, stiff in-plane pusher type incorporating the flex beam concept. The blades are made in pairs with a flex beam running from one blade to the other. (Figure 5.)

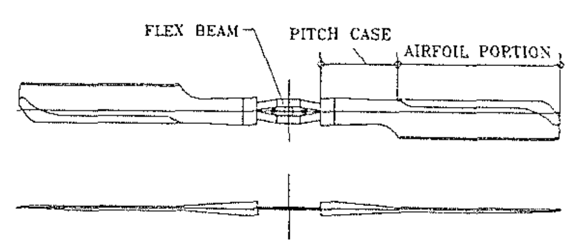

Fig. 5 : Tail Rotor Blade Pair

The tail rotor system comprises of the Tail Rotor Hub, Tail Rotor Shaft, Blade pair assembly and Tail Rotor Upper Controls (Figure 6).

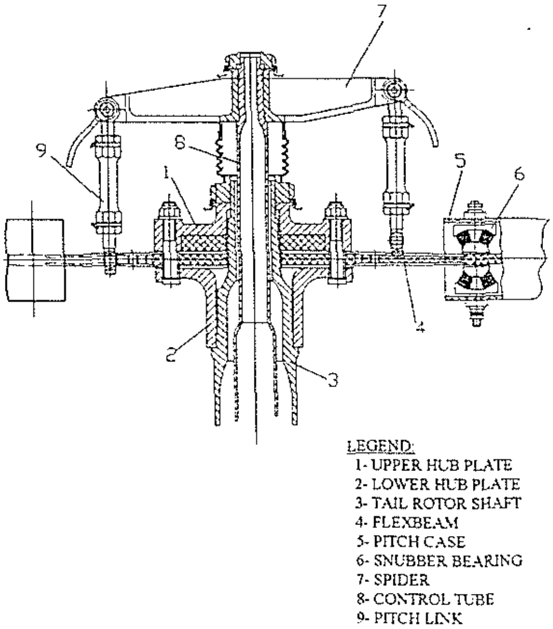

Fig. 6 : Tail Rotor System

3.1.3 Transmission System and Drive Train

The Transmission System consists of Main Gear Box, Auxiliary Gear Box, Intermediate Gear Box, Tail Gear Box, Tail Rotor Drive Shaft and the Rotor Brake. Main Gear Box combines the power of the two engines and also transmits power to the tail rotor via flexibly coupled shafts.

The Main Gear Box is a 2-stage transmission with a high reduction ratio spiral bevel collector stage. The collector gear is directly attached to the Main Rotor Hub through a stub shaft and is mounted on a common duplex ball bearing for rotor and collector gear (Figure. 4). The inner diameter of the collector gear is large enough for the location of the upper control system inside the gear box and rotor hub.

3.2 VIBRATION CONTROL

Design goal of a highly manoeuverable helicopter leads to higher rotor dynamic loads. These loads have to be reduced to ensure crew/passenger comfort, structural integrity and functional adequacy of equipment on board the helicopter.

Anti Resonant Isolation System (ARIS), effective in all 6 degrees of freedom, has been developed for ALH to isolate the fuselage from the dominant 4/rev rotor dynamic loads. Four ARIS units are installed between the main gear box and the fuselage in 45° position to fuselage centre line. An ARIS unit in principle is a spring mass system(Figure 7). Each unit consists of a carbon/glass spring, diaphragm for articulation, pendulum with adjustable mass for tuning, elastomeric bearings, spring housing and supporting tube for attachment to the fuselage. Each ARIS unit is tuned on a functional test set-up to obtain maximum reduction in force transmissibility.

In addition, vibration isolators are provided between the engines and the supporting structure on the fuselage to isolate the engines from dominant rotor excitation.

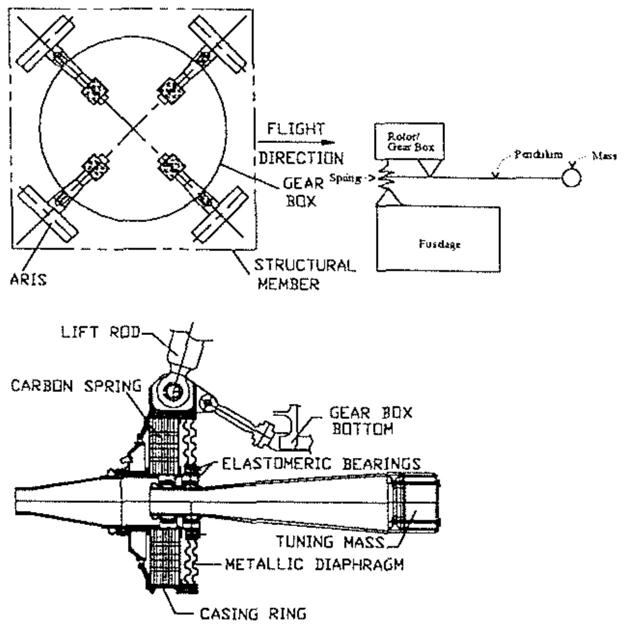

Fig. 7 : Anti Resonant Vibration Isolation System

3.3 POWER PLANT SYSTEM

The first three prototypes of ALH are powered by Turbomeca TM333-2B1 engines while the fourth prototype is powered by LHTEC CTS 800-4P engines. These engines have modular design leading to simple installation and easy accessibility.

A Full Authority Digital Electronic Control (FADEC) provides for governing of the free turbine, power turbine overspeed, automatic starting, load sharing, self test and failure indication.

The engine mounting is through two front mounts (with vibration isolators), one side mount and one rear mount. The mounts are designed to withstand transient torque and crash load conditions. The rear mount has an adjustable feature for aligning the engine output shaft with Main Gear Box.

The fuel tanks are flexible crashworthy type. In addition supply tanks are provided with self sealing protection.

3.4 AIRFRAME STRUCTURE

ALH Airframe design is based on Strength and stiffness criteria , Fatigue and damage tolerance , and controlled deformation with respect to crashworthiness.

The cockpit is ergonomically designed to provide good allround visibility, easy accessibility of controls, minimum reflections of illuminated instruments at night and adjustable crash protected crew seats. Flight controls and equipments are installed in such a way that ample space is available for normal / emergency crew entry and exit.

Notable features of the Airframe are :

- Cabin volume of 7.33 cu. metres with comfortable head room.
- Two hinged doors one on each side of the cockpit.
- Large sliding cabin doors permitting easy ingress and egress.
- Large rear clamshell doors permitting loading of bulk stores
- Crash energy absorbing features
- Jettisionable windows in the cabin
- Extensive use of composites.

3.5 EMPENNAGE CONFIGURATION

For the horizontal stabiliser an inverted cambered profile has been used to provide good handling during climb and autorotative descent. Vertical stabilisation is augmented by the side fins at the ends of the horizontal stabiliser.

3.6 UNDERCARRIAGE

ALH is fitted with a tricycle nose wheel type of landing gear capable of operating from small ships and oil rigs / platforms or alternately with skid type of landing gear.

3.7 FLIGHT CONTROL SYSTEM

The Flight control system provides dual controls in the cockpit using conventional cyclic stick, collective lever and pedals. Push pull rods are used to transmit pilot input to the hydraulic control actuators.

3.8 AUTOMATIC FLIGHT CONTROL SYSTEM

The ALH is equipped with a state-of-the-art 4 axes digital Automatic Flight Control System (AFCS). The system is designed for both stability augmentation to provide basic stabilisation for the entire flight envelope, reducing the pilot workload during turbulence and control augmentation for optimising the helicopter handling qualities. The system consists of duplex lanes in pitch, roll and collective and simplex lane in the yaw axis. The software tuning of the system makes it easily adaptable for specific ALH requirements.

The system interfaces with other helicopter systems like avionics and sensors enabling various autopilot modes.

3.9 ELECTRICAL SYSTEM

The electrical system consists of both the AC and the DC generating systems. The AC generation system has two independent sub-systems, each consisting of an alternator (5/10 KVA), Alternator control power unit and a master box. The AC generation system is configured to provide adequate safeguards in case of alternator failure. The DC generation system also has two independent subsystems, each consisting of a starter generator (6 kW) and associated control and protection system, with battery backup for 15 minutes for emergency conditions.

3.10 INSTRUMENTS AND AVIONICS

The ALH is equipped with a standard instrument and communication/navigation package, which meets the BCAR definition of minimum IFR kit. This includes V/UHF communication , UHF (standby), Intercom, ADF (Radio Compass), Gyromagnetic compass with RMI, Radio altimeter, IFF, Flight and Navigation instruments, ASI, VSI, Barometric altimeter, Indicators for engine, fuel, hydraulics, transmission and electrical system, Centralised Warning Panel, control panels for various systems and AFCS. Depending upon the mission, additional avionics like weather radar, VHF (FM), HF(SSB), V/UHF Homing, Doppler navigation system, radar warning receiver, sighting system, FLIR, NVG etc., can be provided on the helicopter.

3.11 HYDRAULIC SYSTEM

The hydraulic system comprises of system I, system II and system III. Systems I and II supply power to duplex (tandem) main rotor and tail rotor flight control actuators. System III supplies power to the landing gear, wheel brake system, deck lock harpoon and optional utility hydraulic equipments and services. The hydraulic system operates on a system pressure of 206 bars.

3.12 EMERGENCY FLOATATION GEAR

For the Naval version of the ALH design features are incorporated to prevent water entry through joints, openings, access cutouts in airframe and fuel tank bay. The Navalised ALH is capable of ditching and floating in the sea upto sea states 5/6. The system comprises four floats with supply of compressed nitrogen gas.

4. TESTING

Extensive testing has been carried out to verify the design. The testing covers model tests in wind tunnel, floatation tests, ground testing of components / systems, Ground Test Vehicle (GTV) testing, airframe shake tests and flight testing.

4.1 WIND TUNNEL TESTING

Wind tunnel tests (Fig. 8) were carried out for pressure / force measurements at the HAL wind tunnel having a closed test section of 6 ft x 9 ft. The testing aided modifications for fuselage shape optimisation and for obtaining aerodynamic data.

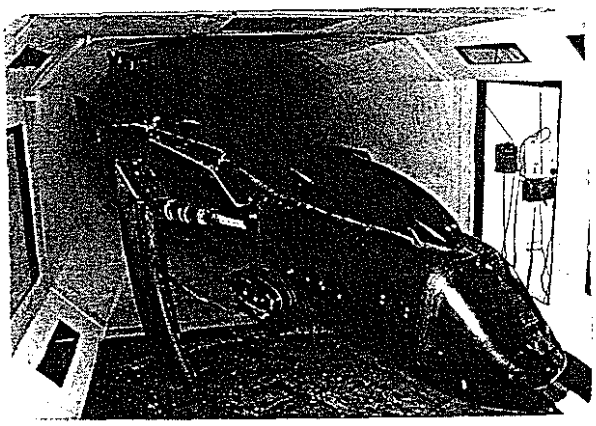

Fig. 8 : 1:5 Scale Pressure Model of ALH

4.2 FLOATATION TESTS

Floatation and ditching tests were carried out on a 1:10 Froude scaled model (Figure 9) in a water channel with simulated sea conditions. Testing has demonstrated satisfactory floatation characteristics.

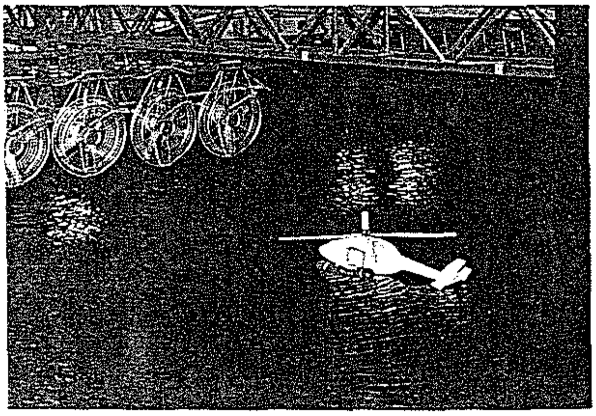

Fig. 9 : Floatation Test

4.3 GROUND TESTING OF COMPONENTS / SYSTEMS

Ground tests were carried out to validate the design, to establish design allowables, to establish TBOs of various systems and to meet the certification requirements. The ground test programme involved material tests, structural element tests, strength and fatigue test on components, endurance tests on gear boxes and system tests. Specific test rigs and test facilities are Main and Tail Rotor Whirl Tower for Rotor Testing, Tail Boom and empennage testing in environment chamber, Static and drop test of landing gear, Breakaway Fuselage testing, Gear Box testing, hydraulic and flight control system testing and ARIS tuning.

4.3.1 Whirl Tower Testing

Both the Main and Tail Rotors have been tested on Whirl Tower (Figures 10, 11) to establish their dynamic and aerodynamic characteristics.

The main rotor blades were tested on the whirl tower to identify the rotor modes, damping, static and dynamic loads in addition to the performance characteristics for different rotor speeds, collective and cyclic pitch angles. The frequencies obtained from whirl tower are in good agreement with analysis.

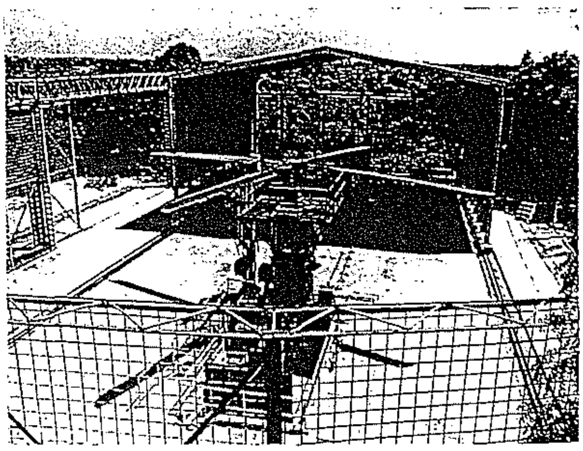

Fig. 10 : Main Rotor Whirl Tower

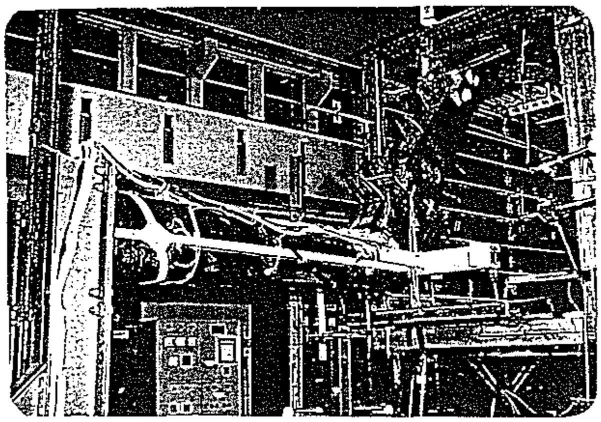

Fig. 12 : Tail Boom Testing in Environment Chamber

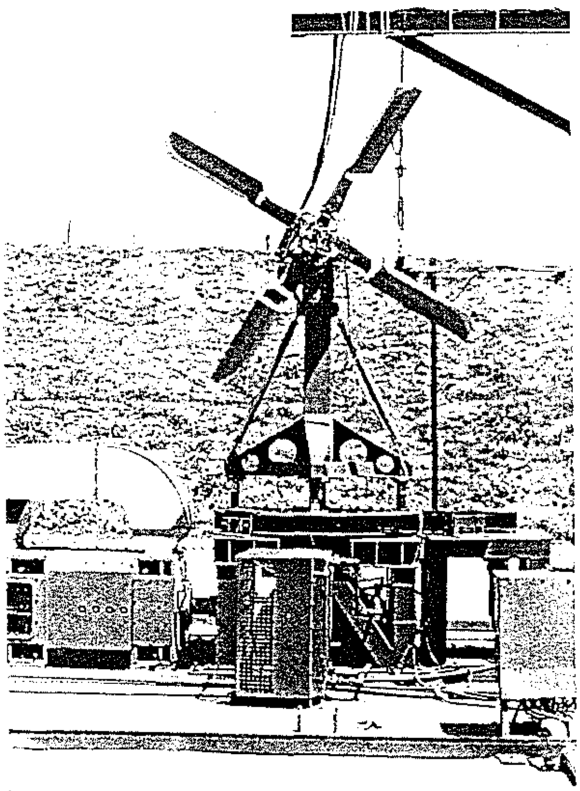

Fig. 11 : Tail Rotor Whirl Tower

4.3.2 Tail Boom and Empennage Testing

Static strength tests were conducted on the composite tail boom and the vertical fin at room temperature and at elevated temperature of 80° C (Figure 12). Tests on horizontal stabiliser were carried out separately.

4.3.3 Static and Drop Test of Landing Gear

The skids have been tested for the landing loads including the crashworthiness requirements by conducting static and simulated drop tests. (Figure 13).

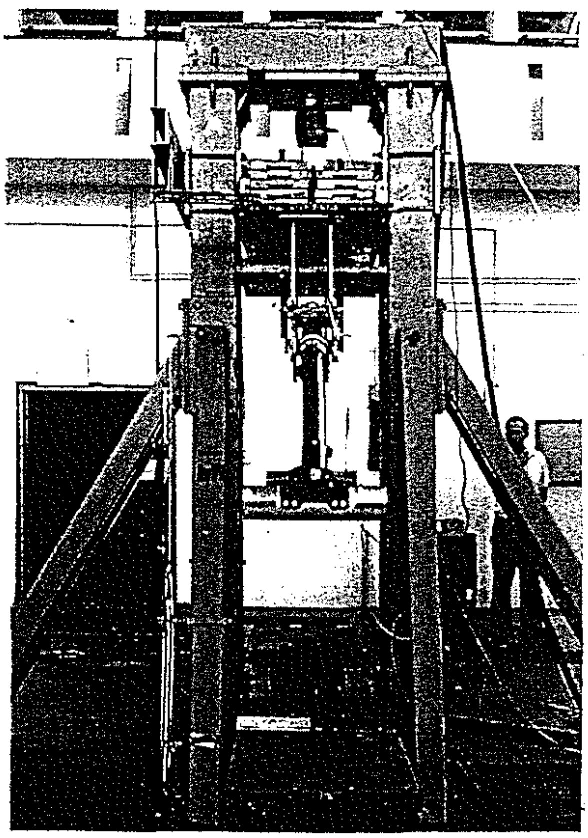

Fig. 13 : Skid Drop Test

Figure 14 shows the test set-up for drop test of wheeled landing gear.

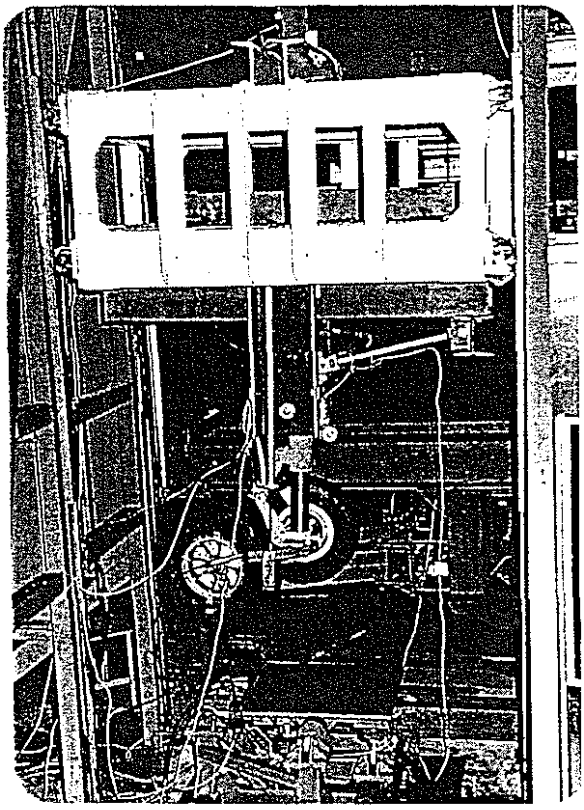

Fig. 14 : Drop Test of Wheeled Landing Gear

4.3.4 Breakaway Fuselage Testing

Breakaway fuselage (BAF) test (Figure 15) is a specific test carried out upto limit loads on the complete Airframe specimen consisting of all the primary structural components but without any functional systems.

A drop load test of the full airframe is planned to prove the crashworthiness requirements of the ALH.

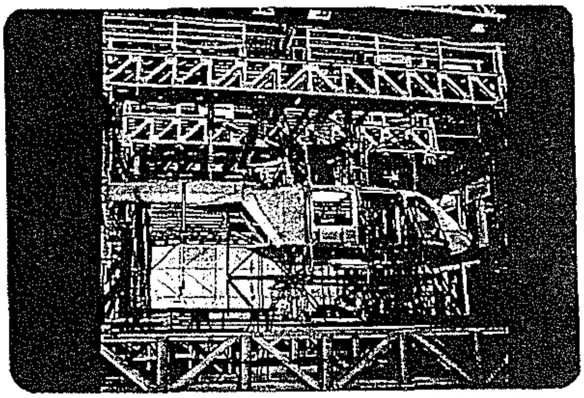

Fig. 15 : Breakaway Fuselage Testing

4.3.5 Gear Box Testing

Figure 16 shows the Main Gear Box under testing. The test rig is a closed loop, four square system comprising of a rig gear box, Main Gear Box specimen and a top gear box.

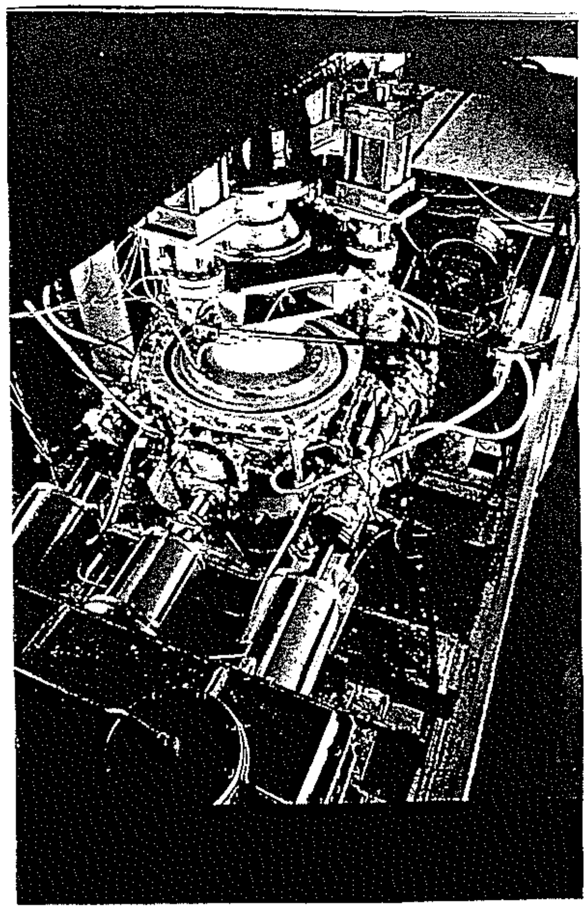

Fig. 16 : Main Gear Box Testing

4.4 GROUND TEST VEHICLE (GTV) TESTING

The Ground Test Vehicle (GTV) is a non flying helicopter firmly anchored to the ground (Figure-17). The GTV is totally representative of the airframe in order to provide the correct dynamic environment of the drive system. The GTV essentially contains all the helicopter systems like engines, flight controls, rotors, hydraulics etc., and is used basically to prove the endurance of the drive system. The feedback from GTV runs is the backbone of information for the prototype flights.

Fig. 17 : Ground Test Vehicle

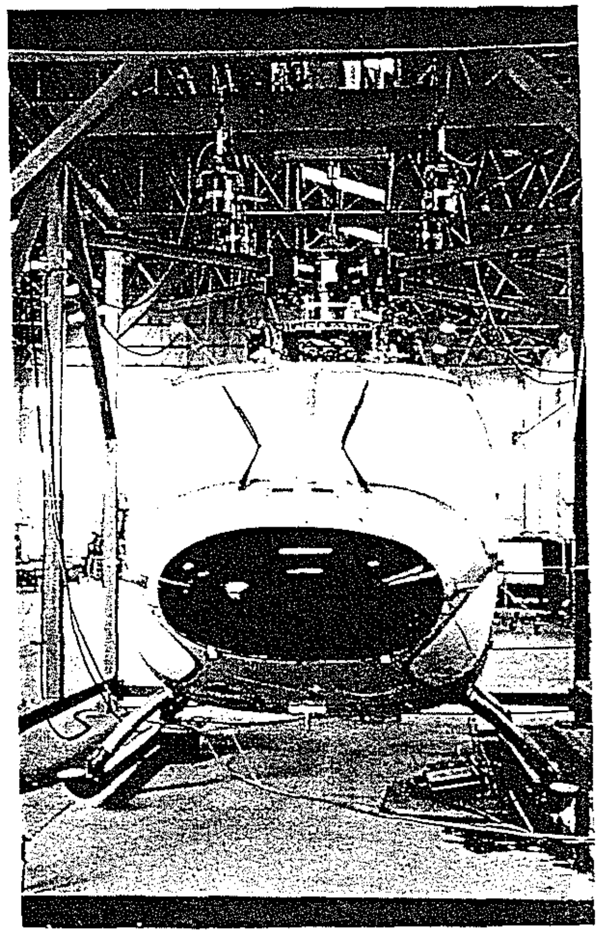

Fig. 18 : Shake Test

4.5 AIRFRAME SHAKE TEST

The shake test (Figure 18) was conducted for different configurations of skid and wheeled variants of the helicopter to identify the frequencies, mode shapes, modal damping, generalized masses and responses both on ground and under free-free condition. For conducting the free-free condition vibration/response tests, the helicopter was suspended by a very soft air spring having a natural frequency around 1 Hz. The fundamental frequencies and damping obtained were used for validating ground resonance analyses. Generally good correlation was observed between tests and analysis as shown in Figure 19.

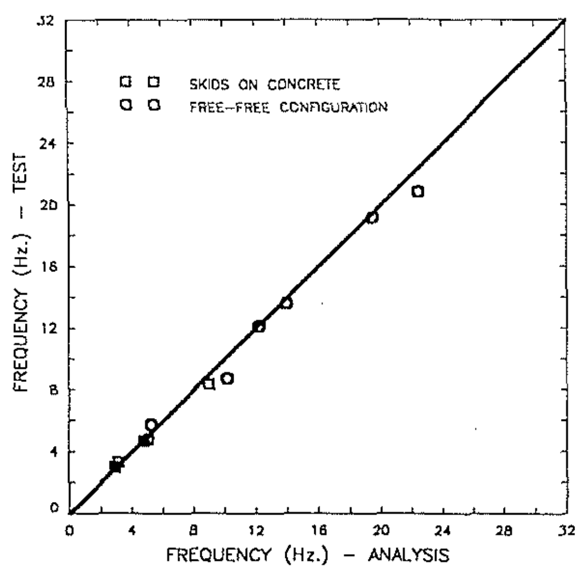

Fig. 19 : Airframe Shake Test - Modal Survey

4.6 FLIGHT TESTS

The flight test programme is distributed on four prototypes which are flying and one civil prototype which is to fly shortly. The complete altitude and speed envelope as well as weight and CG envelope have been covered and tests to meet certification requirements are in advanced stage of completion.

4.6.1 Ground and Air Resonance Tests

Ground resonance tests of prototypes with skids and wheel landing gear have been carried out on concrete and turf for various All-Up-Weights (AUW) at different collective pitches.

The results obtained from ground resonance tests were compared with those of the whirl tower tests for estimating the effects of couplings. Ground resonance characteristics on snow have also been checked and it is found that there is no tendency of the ALH to get into ground resonance.

Air resonance tests were carried out by periodic rotor excitation through cyclic stick. Test results show satisfactory damping, indicating that ALH is free from air resonance over the complete flight envelope.

4.6.2 Handling Qualities

The handling qualities of ALH have been verified through the entire flight envelope.

4.6.2.1 Manoeuvres Close to Ground

The ALH has been flown sideward to both sides to speeds upto 50 kmph and rearward to speeds upto 30 kmph. This has been carried out for AUW upto 5.5 tonne under various C.G conditions.

Turn on spot for different AUW under various C.G conditions have been demonstrated to a maximum yaw rate of 60 deg / sec on either side (sustained).

Landings and take offs from slopes of upto 10 deg with combinations of wind direction and helicopter attitude were carried out.

No pitch ups have been observed during transition to forward flight.

4.6.2.2 Dynamic Stability

The dynamic stability tests have indicated that with the current ALH empennage configuration, the long period longitudinal mode characteristics are better than predicted and have also been established after removal of end plates. ALH has been flown without the horizontal stabilizer upto a forward speed of 270 kmph as part of the empennage optimisation study.

The Dutch-Roll mode damping is positive throughout the flight envelope.

4.6.2.3 Control Characteristics

Since the ALH rotor is of hingeless type, the rotor dominates the flying qualities. Control response has been assessed in the longitudinal and lateral axes. The handling has been assessed by the pilots as good under all conditions tested. Flight test results indicate that the controls have sufficient margins.

4.6.3 Performance

4.6.3.1 Hover performance

Hover tests have been conducted to establish the HOGE and the HIGE performance at low and high temperatures.

4.6.3.2 Level flight performance

The level flight data obtained from different flights of ALH prototypes for a particular AUW has been analysed and compared with theoretical estimate. The results show good agreement with theoretical estimate (Figure 20).

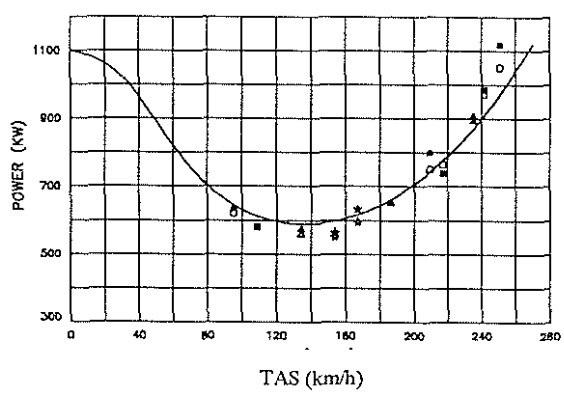

Fig. 20 : Level Performance ALH

4.6.3.3 Climb Performance

Tests were conducted to assess climb performance for vertical and oblique rate of climb. The vertical rate of climb with different AUW shows good agreement with theoretical estimate. (Figure 21) Test results for oblique rate of climb also matched with theoretical estimate.

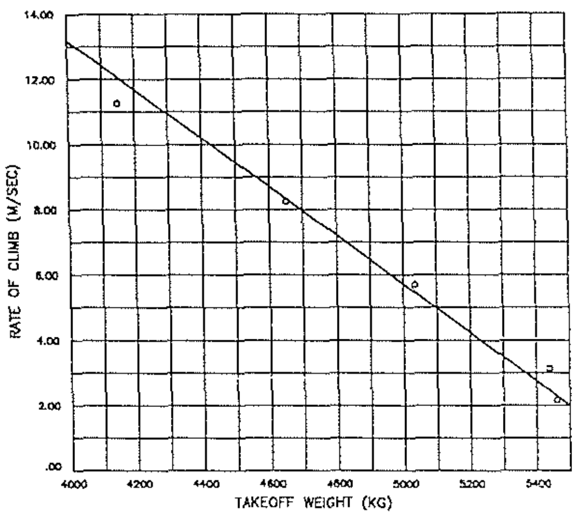

Fig. 21 : Vertical Rate of Climb Vs Take off Weight

4.6.4 Vibration and Noise

Vibration levels at various locations of helicopter were assessed with and without ARIS installed. With ARIS installed, the helicopter shows highly satisfactory vibration levels over the entire flight envelope. The 4/rev vibration levels at pilot/co-pilot seat in all axes are shown in Figure 22.

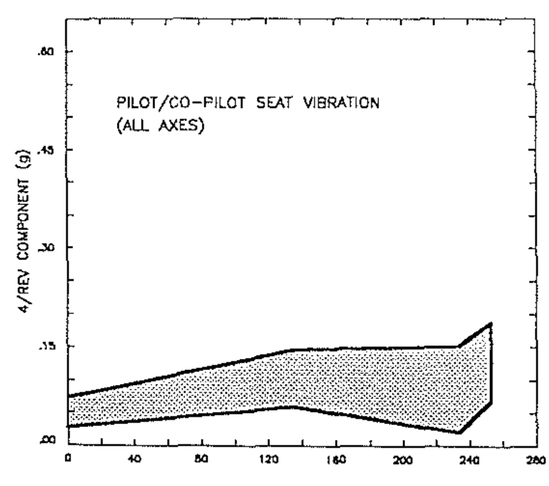

Fig. 22 : Seat Vibration with Forward Speed

External noise measurements indicate that noise levels are within acceptable limits.

4.6.5 Field Trials

Most of the flight tests were carried out at Bangalore which is at a pressure altitude of 900 m. For performance and handling at Sea Level, two series of Sea-level trials have been conducted. During these trials, both the skid and wheeled version of ALH have performed satisfactorily.

Flight test programme was successfully carried out in order to prove the performance and handling characteristics of the helicopter at high altitude and difficult terrain and at extreme cold weather conditions (Figure 23).

Ship Deck Trials were carried out to prove the performance and handling characteristics of the helicopter (Figure 24).

Performance and system capabilities of the ALH have been validated during Hot Weather Trials also.

In all the above trials, the performance parameters were fully met. Handling qualities of the prototypes were satisfactory. Enough control margins were available during low speed envelope expansion and while establishing Ship - Helicopter Operating Limits (SHOL) diagram.

Fig. 23 : High Altitude Cold Weather Trials

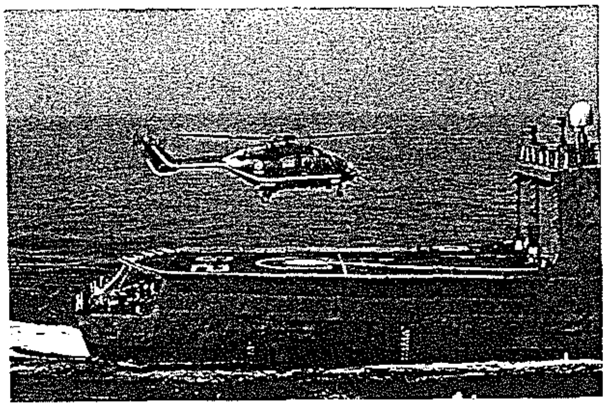

Fig. 24 : Ship Deck Trials

5. PROGRAMME STATUS

Presently four prototypes (3 prototypes in skid and 1 prototype in wheeled configuration) are under flight testing to meet certification requirements. Fifth prototype (Civil Version) is scheduled to make its maiden flight shortly. Ground testing of critical components to meet certification requirements is nearing completion. While provisional certification is expected to be obtained this year, final certification is expected next year.

Flight test results have demonstrated the capability of ALH in meeting, and in some cases even exceeding , the stipulated performance requirements.

Based on the favourable characteristics exhibited by the flying prototypes, production has been launched.

6. SUMMARY

Advanced technology features of ALH contributed significantly to realise a modern state-of-the art agile and highly manoeuverable helicopter , with high lift and speed capability, fine hot & high performance, low noise & vibration levels and good empty to all-up weight ratio. Extensive development flights backed by analysis and ground testing was a significant factor in successfully achieving the desired goals.

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