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DESIGN, DEVELOPMENT AND VALIDATION OF AN ANTI RESONANT ISOLATION SYSTEM FOR ADVANCED LIGHT HELICOPTER

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A passive vibration isolation method, namely, ANTI RESONANT ISOLATION SYSTEM (ARIS) has been adopted for the Advanced Light Helicopter(ALH). The four ARIS units, which are interposed between rotor and fuselage, isolate vibratory loads pertaining to 3 forces and 3 moments arising from the rotor, thus catering to a six-degree freedom isolation. Adequate fatigue testing of all the ARIS components have been carried out followed by the Functional Model (FUMO) test for assessing the performance of the unit. Shake test on the complete Helicopter equipped with ARIS has been done before undertaking the developmental flights. This paper broadly outlines the design, development and validation efforts made in realising ARIS.

1.0 INTRODUCTION

The ADVANCED LIGHT HELICOPTER (ALH) designed and developed by HINDUSTAN AERONAUTICS LIMITED, is a multi-role and multi-mission helicopter in the 5 tonne class which incorporates state-of-the-art technology in terms of rotor, transmission and airframe systems. With the adoption of advanced rotor systems such as hingeless and bearingless type, there is a transfer of high dynamic loads from the rotating to fixed system manifesting as vibrations in the fuselage.

Even though extensive care is taken in the aerodynamic and dynamic design of optimum rotor system in reducing the vibratory loads as much as possible at the source, with the stringent vibration criteria set for the crew/passenger comfort, vibration isolation system becomes important for the success of the helicopter.

The ALH has a passive vibration isolation system called ANTI RESONANT ISOLATION SYSTEM (ARIS). The ARIS units, each of 2 degree of freedom, which are interposed between rotor and fuselage system, isolate vibratory loads pertaining to 3 forces and 3 moments arising from the rotor and hence ARIS is effective in all 6 degree of freedom.

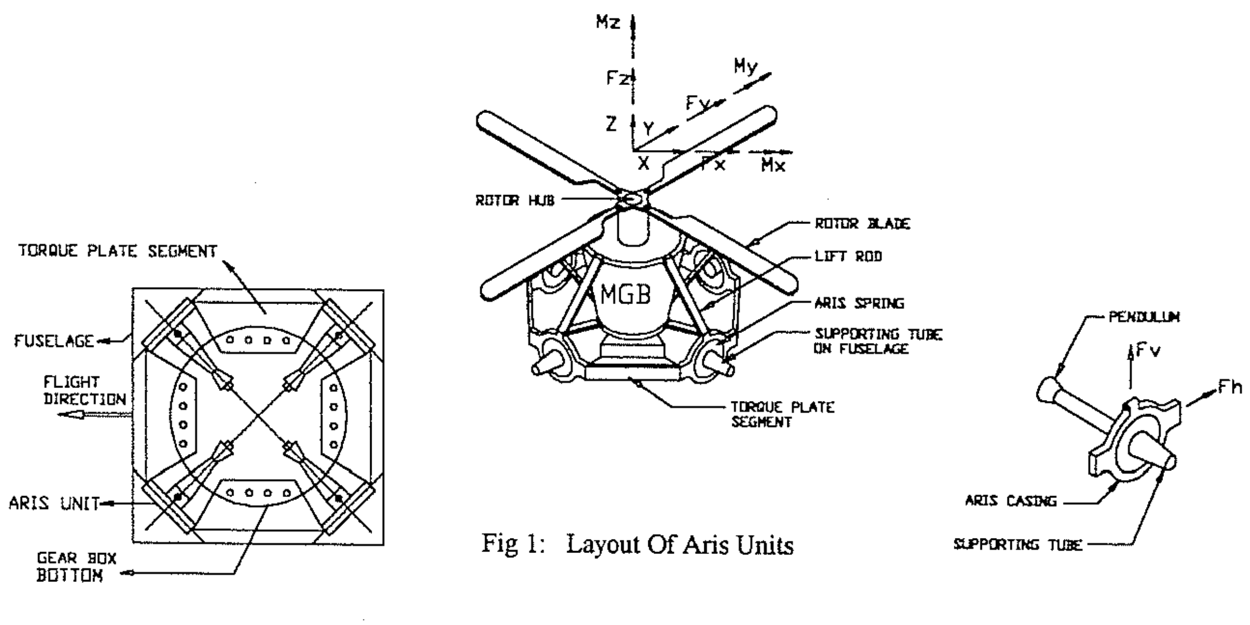

Fig 1: Layout Of Aris Units

2.0 DYNAMIC LAYOUT OF ARIS

The most significant main rotor induced cabin vibrations will have the frequency 4 / rev (21 Hz) as the ALH has 4 bladed main rotor. In order to reduce these vibrations 4 ARIS units have been installed between the main gear box (MGB) and the fuselage, see Fig.1.

A single ARIS unit consists, in principle, a spring mass system (see Fig.2) which when excited through dynamic loads results in angular displacement of the pendulum. At the desired frequency of 4/rev for which the ARIS unit is tuned, the induced inertia forces at the pendulum mass will cancel out with the dynamic force of the spring resulting in no dynamic force transmitted to fuselage, Fig.3.

The simplified model, Fig. 2, is useful in making a parametric study of various parameters like, spring stiffness(Kr), pivot distance (e), pendulum mass (mp), and amplification ratio (Rp/e) to arrive at an optimum values for easy realisable hardware which would 'FIT, FORM, and FUNCTION' effectively.

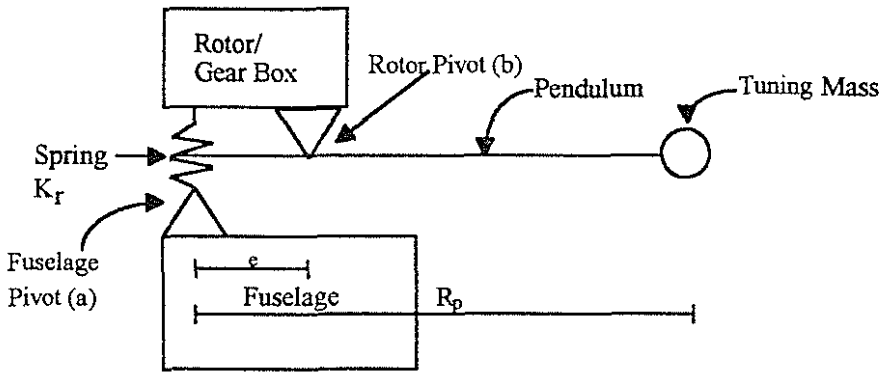

Fig 2 : Idealization Of ARIS Unit

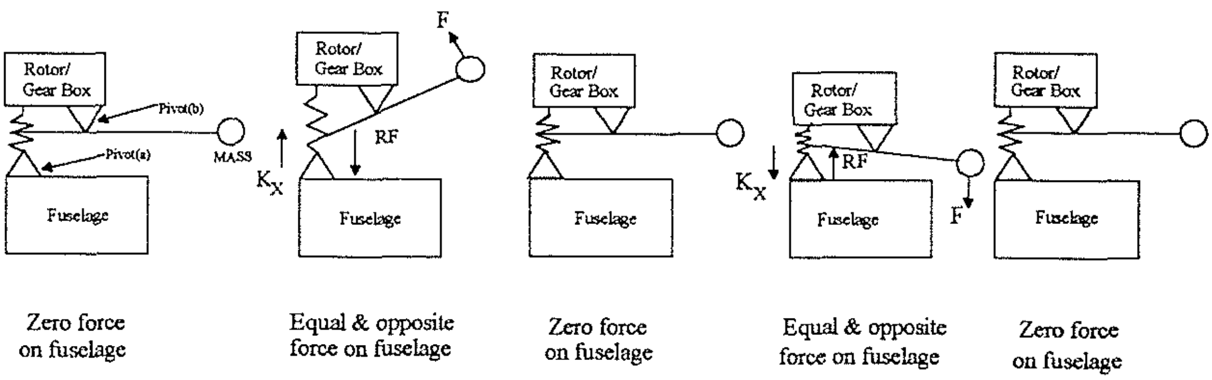

Fig 3 : Functioning of ARIS Unit

A typical variation of transmissibility in vertical direction derived from simplified model for different spring stiffness is shown in Fig. 4. As can be seen, with higher stiffness of spring, the gap between resonant frequency and anti resonant frequency reduces indicating increase in sensitivity. Based on the analysis and space available for functioning of ARIS, the key parameters like spring stiffness(Kr), pivot distance (c) and amplification ratio were fixed at 5500N/mm, 35 mm, and 11 respectively, which defined the dynamic layout.

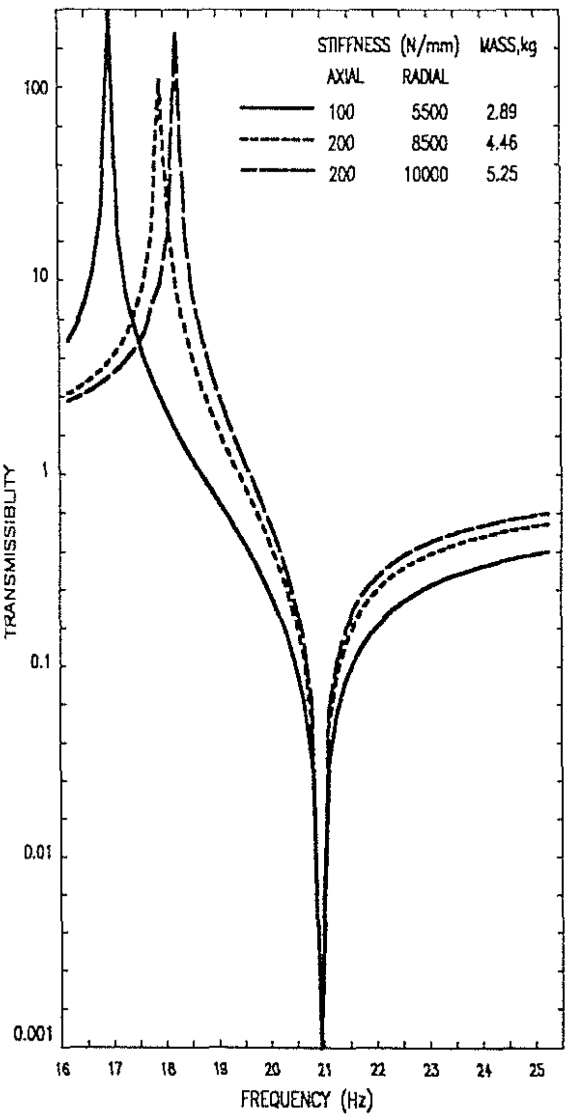

Fig 4: Transmissibility For Different Spring Stiffness

3.0 HARDWARE REALISATION

After optimising the dynamic layout, it is important to realise the hardware which would fulfil the dynamic requirement and at the same time to have sufficient static and fatigue strength for the estimated load spectrum.

The hardware of ARIS, Fig. 5, mainly consists of casing ring, support tube, carbon spring, corrugated metallic diaphragm, composite pendulum and the elastomeric bearings.

The function of the spring is to provide required stiffness in radial direction while diaphragm has to transfer the motion of the spring to pendulum which vibrates and generates required inertia force to balance the exciting force from the rotor. The purpose of the elastomeric bearings is to provide support for the pendulum and to transfer the inertia forces to pivot points. Casing ring and support tube provide the necessary interfaces to introduce loads from rotor and to react at the fuselage points through ARIS elements.

Limit stopper is provided on ARIS unit in order to avoid over-loading and to provide a path for transfering the load in case of spring failure, thus ensuring flight safety.

4.0 ANALYSIS OF ARIS

Using finite element method (FEM), two types of analysis have been carried out. The first analysis considers Airframe as rigid (lumped mass) with detail modelling of ARIS units and MGB housing as shown in Fig. 6.

From this analysis, it is possible to understand the load paths and motions over the frequency domain. The model also helps in making sensitivity analysis with respect to various parameters of ARIS. Typical plots of transmissibility and lift rod force are shown in Fig. 7(a-b).

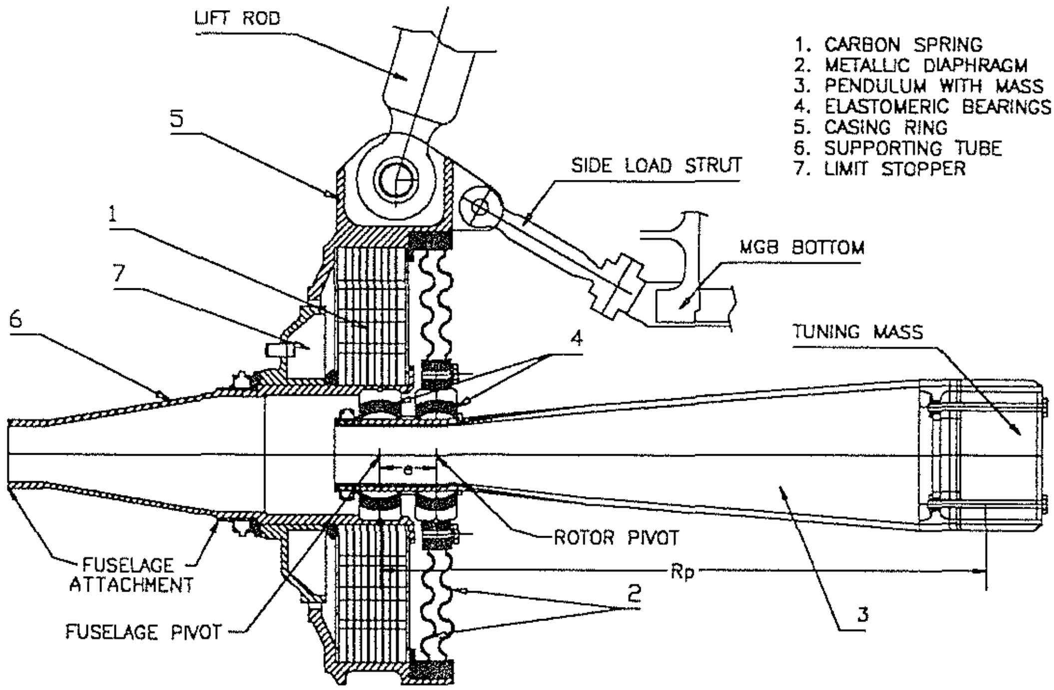

Fig. 5 : SECTIONAL VIEW OF ARIS UNIT

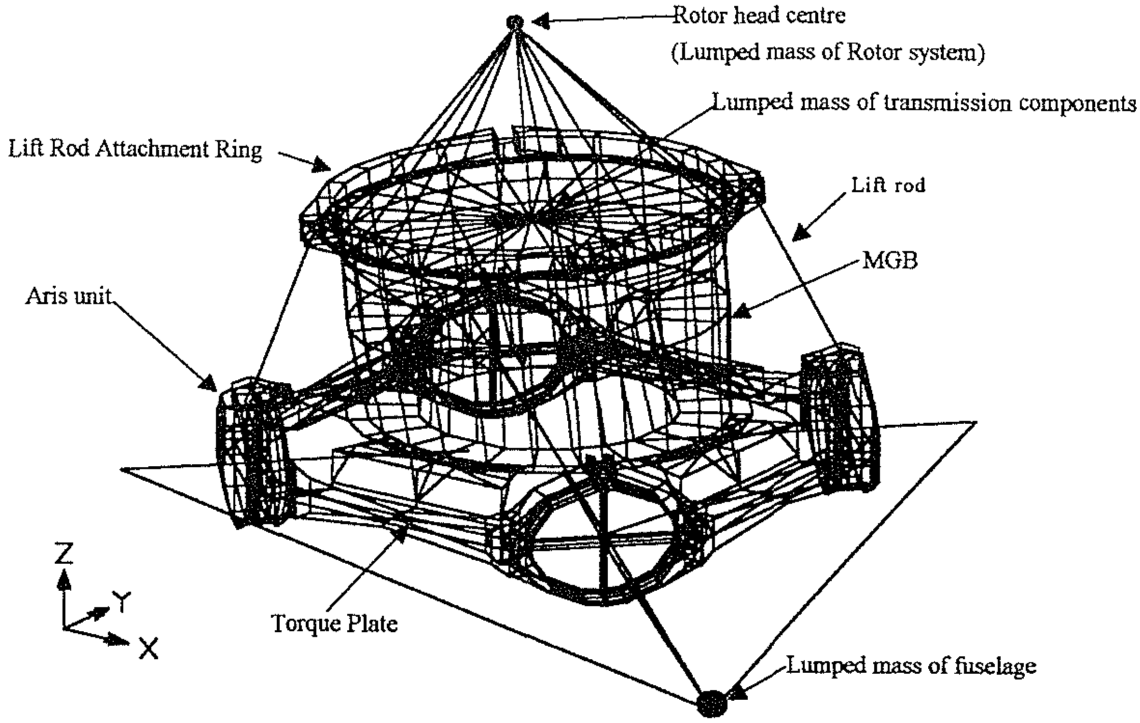

Fig.6 : FE IDEALISATION OF MGB ASSEMBLY WITH ARIS UNITS

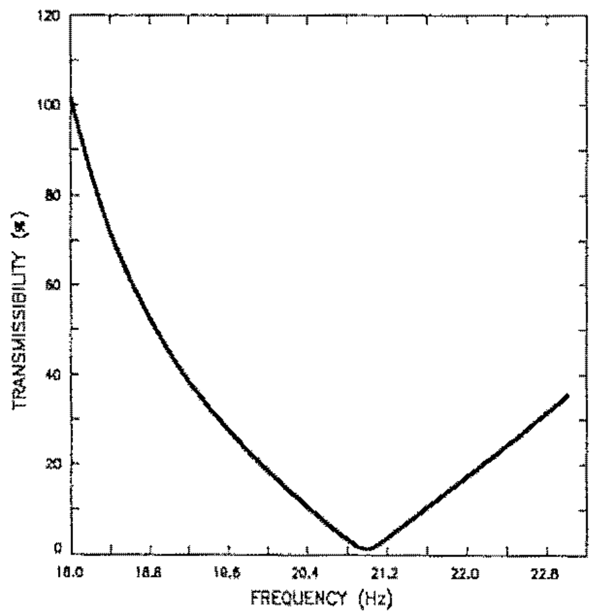

Fig. 7a : Transmissibility

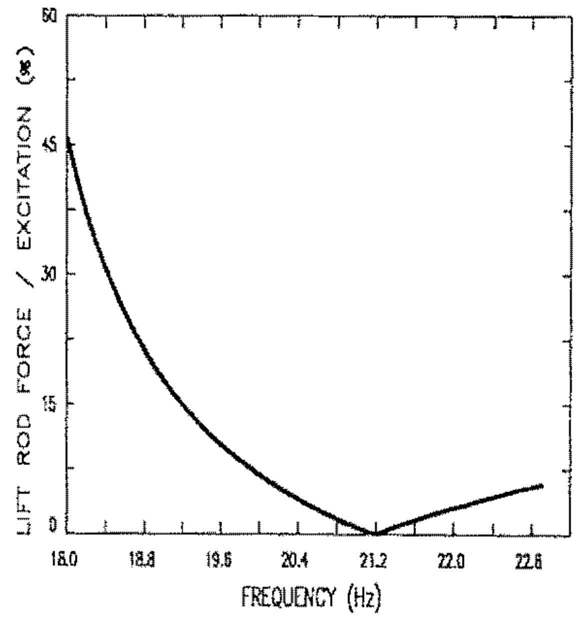

Fig. 7b : Lift Rod Loads

In the second type of FEM analysis (Fig.8), the complete air frame is modelled in detail while the ARIS units are considered as spring - mass system connecting fuselage and rotor head centre.

The aim of the analysis is to establish the transmissibility and displacement at various location of fuselage like pilot and co-pilot seat attachment points, interface of gear box with engines and Tail power take off.

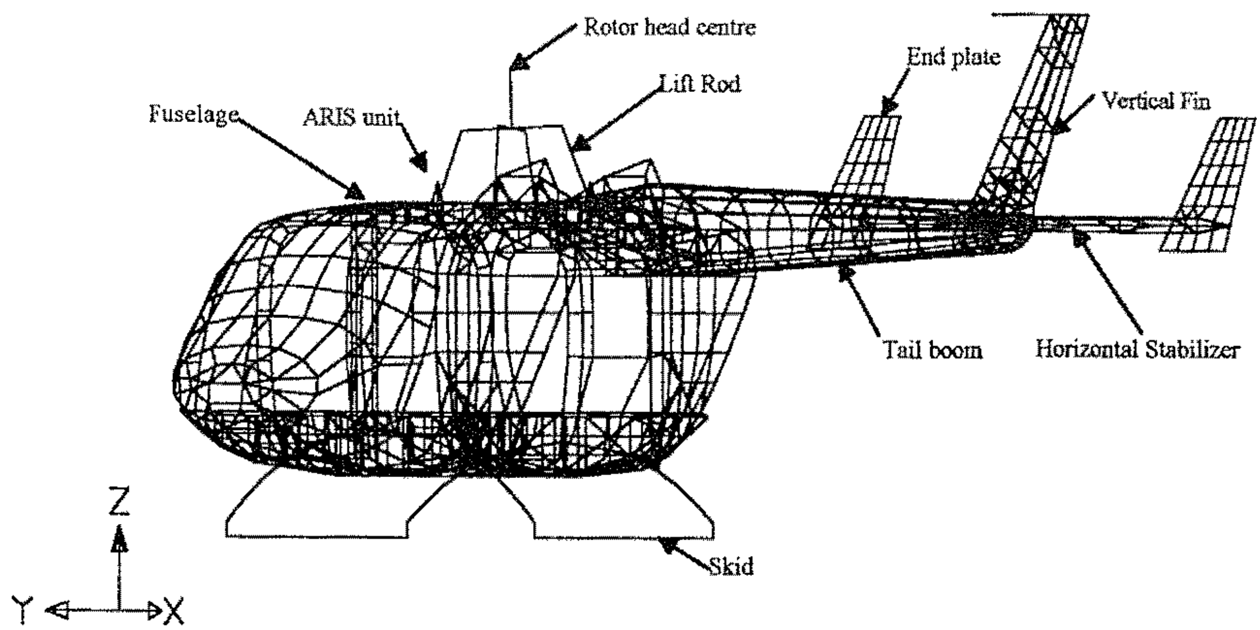

Fig. 8 : FE Idealisation of Airframe With ARIS Units

Also, this model helps in calculating the static and dynamic displacements which would help in defining axial and angular misalignment of various shaft interfaces. A typical plot of response in vertical direction at pilot seat attachment point is shown in Fig. 9.

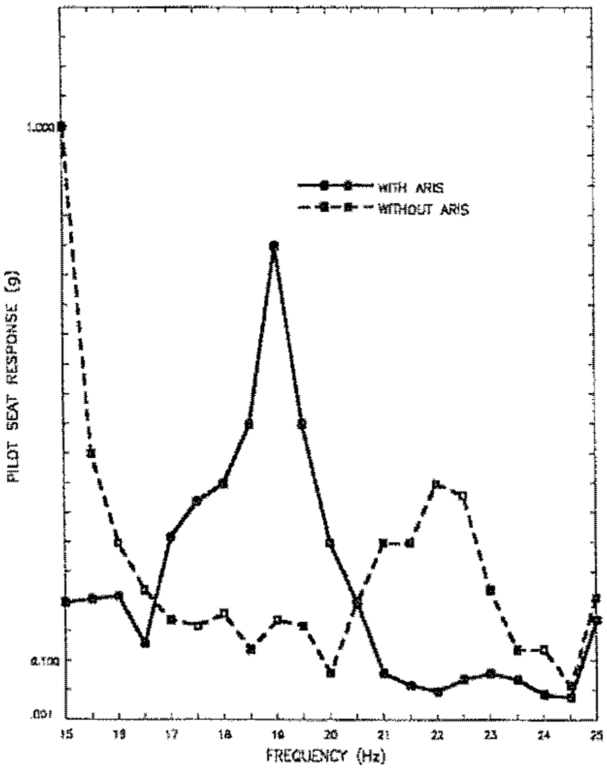

Fig. 9 : Pilot Seat Response with and without ARIS

5.0 GROUND TEST ON ARIS ELEMENTS

All the elements of the ARIS have been subjected to static and fatigue tests to establish their capabilities before taking up the assembly for functional tests. The tests carried out on the elements are briefly given below.

5.1 CARBON SPRING

The carbon spring, Fig. 10, has 9 individual spring elements bonded together to get the desired radial stiffness. The individual spring elements have predominantly 4 unidirectional carbon prepregs in the spiral form assembled and hot cured.

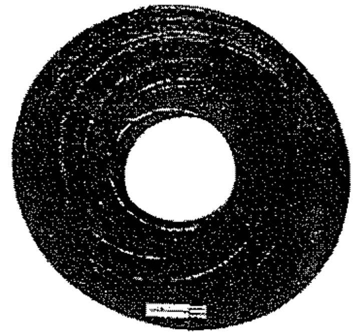

Fig. 10 : ARIS Spring

The following tests have been conducted to assess the spring capability on the test rig, Fig. 11.

- Radial stiffness measurement at different azimuth positions (0^0 to 90^0) to establish radial symmetry.
- Axial stiffness measurement
- Static test simulating limit and ultimate loads
- Fatigue test with displacement input (radial & axial) to assess the endurance capability.

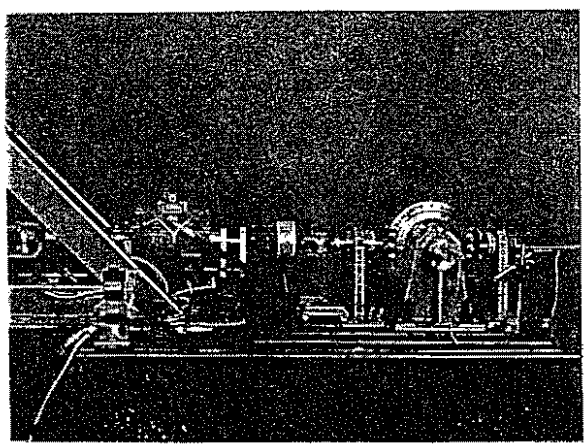

Fig. 11 : ARIS Spring Test Rig

5.2 DIAPHRAGM

The metallic diaphragm, Fig.12, which has corrugation to improve the buckling capability, is cold formed from steel sheet. The requirement is that radial stiffness should be high (50 Kr) and axial stiffness low (similar to spring). The high radial stiffness is required for effectively transferring the displacement to the pendulum. The type of test carried out is similar to the one mentioned for the spring.

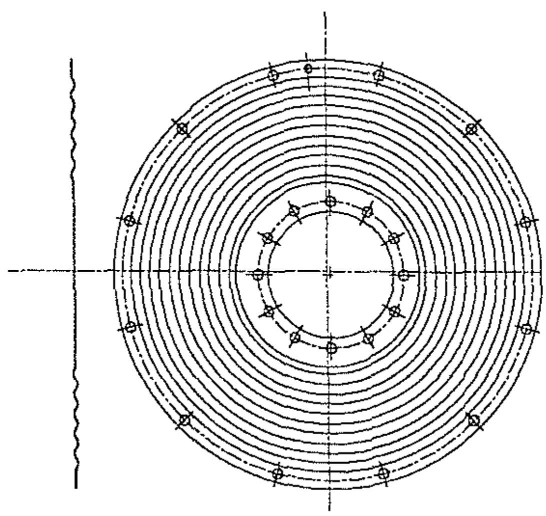

Fig 12. Diaphragm

5.3 ELASTOMERIC BEARING

The elastomeric bearings, Fig.5, act as pivot points for transferring the motion and to react the inertia loads form the pendulum mass to the fuselage and rotor points. In order to meet the above requirement, the elastomeric bearings must have specific stiffness requirement in radial, axial and cocking directions along with sufficient fatigue capability.

The following tests have been carried out to assess the bearing characteristics.

- Stiffness check in Radial, Axial and cocking directions.
- Fatigue tests simulating cocking motions, Axial and radial loads.

5.4 CASING RING AND SUPPORT TUBE

Static and Fatigue tests have been conducted on the casing ring and support tube assembly simulating loads arising out of rotor forces and moments.

6.0 FUNCTIONAL MODAL TEST (FUMO)

In order to assess the functional efficacy of the ARIS UNIT, the unit is tested on Fumo test rig , Fig.13, and tuned to the required frequency of 21Hz.

The FUMO test rig has rotor and fuselage inertia simulated with respect to ARIS Unit . The rotor point is excited through an electro-mechanical device whose frequency can be varied. Accelerometers are provided at the input and output point to assess the transmissibility which is defined as the ratio of transmitted force to the excitation force.

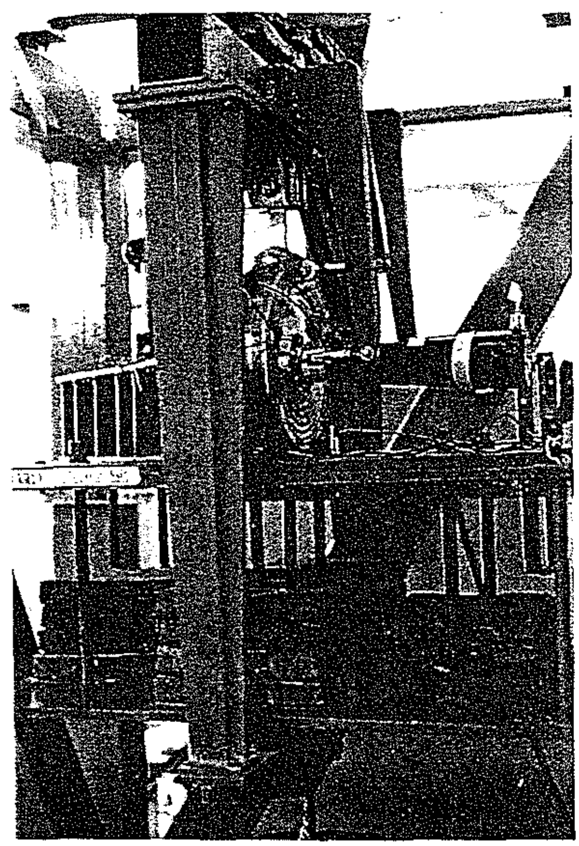

Fig. 13 : FUMO Test Rig

A Typical transmissibility variation with respect to excitation frequency is shown in Fig.14. The tuning is done by adjusting the mass position to have minimum transmissibility at 21 Hz.

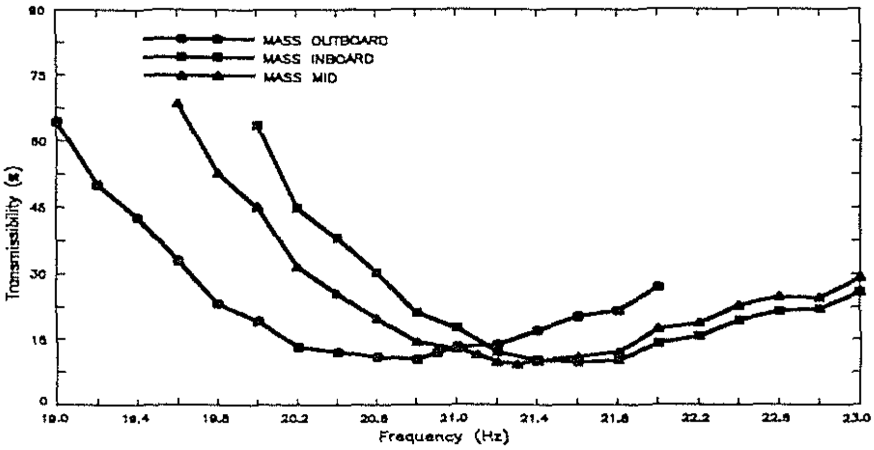

Fig.14 Transmissibility with different Tuning Mass position

7.0 SHAKE TESTS

Before taking up the development flights, shake tests were conducted on the prototype with ARIS installed to determine the frequencies, mode shapes and response characteristics and to correlate with the analysis. In this regard, test was done with helicopter on ground to assess the ground resonance related characteristics like body frequency and damping. For assessing the response charaterstics, the helicopter was suspended by an air spring and excitations done through electro-mechanical exciters at the rotor hub points simulating vertical forces, pitch and roll moments individually. Comparison of test results with analysis is shown in Fig.15 for the vertical excitation. Similar trend was observed for other excitations.

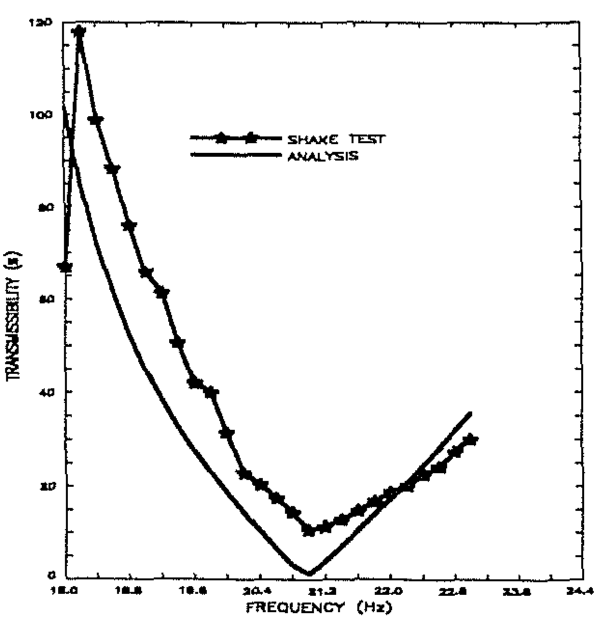

Fig.15 : Transmissibility

8.0 DEVELOPMENT FLIGHTS WITH ARIS

Initial development flights on the prototype were carried out without ARIS to establish the baseline data with respect to vibration and load levels. In order to cover the intended flight envelope, development flights were continued with pendulum absorber tuned to 3/rev frequency. The data acquired during the above flights helped in evaluating ARIS performance.

The four ARIS units were tuned in FUMO test rig and installed on the second prototype (PT2) for functional assessments and measurement of displacement and loads. In this regard, ARIS units were instrumented to measure the loads and displacements in both vertical and horizontal directions.

Development flights demostrated the functional adequacy of ARIS with CHR rating 1 to 3 with regard to vibration level over the speed range. During the above flights, there were failures of the diaphragm and spring. The reason for these failures was established as due to higher dynamic spring displacement compared to design specification values. Also, correlation of spring and diaphragm fatigue capability with measured displacements indicated failure in low cycle region resulting in short life.

In order to carry on with further development flights, ARIS units with reinforced diaphragm were installed. In addition, pendulum absorbers were mounted on the rotor blades for reducing the dynamic spring displacements, thus enhancing the fatigue life. The data from the above flights were also useful in review of the ARIS design.

The flight test results pertaining to 4/rev vertical components of lift rod force, vibration level at pilot and co-pilot seat bottom, spring displacement and pendulum root bending moment for different configurations are presented in Figs. 16 to 20 respectively. The data shows the effectiveness of the ARIS supporting the qualitative assessment of pilots.

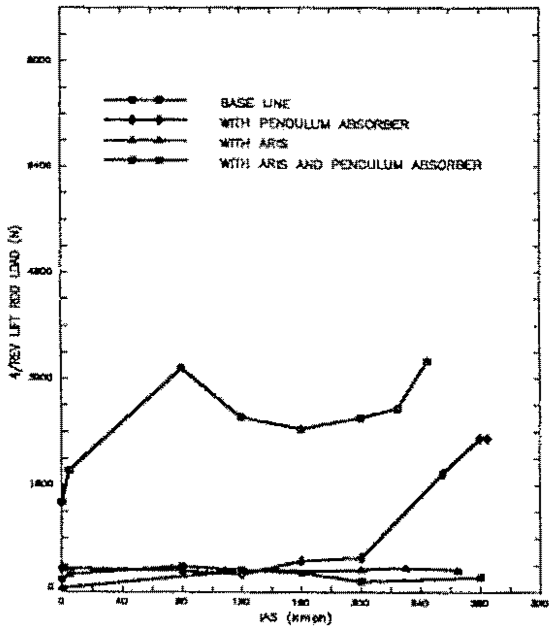

Fig. 16 : Lift Rod Dynamic

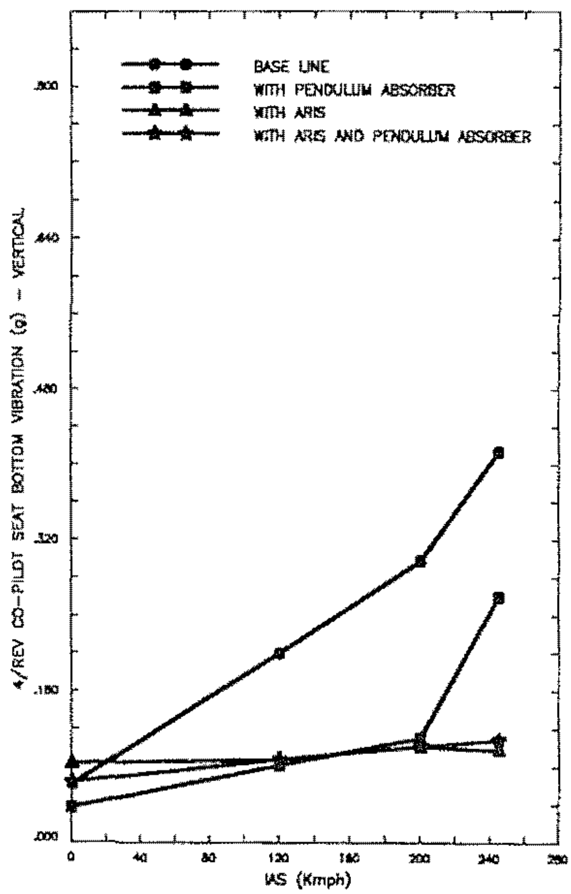

Fig 18 : Co-Pilot Seat Vibration Level

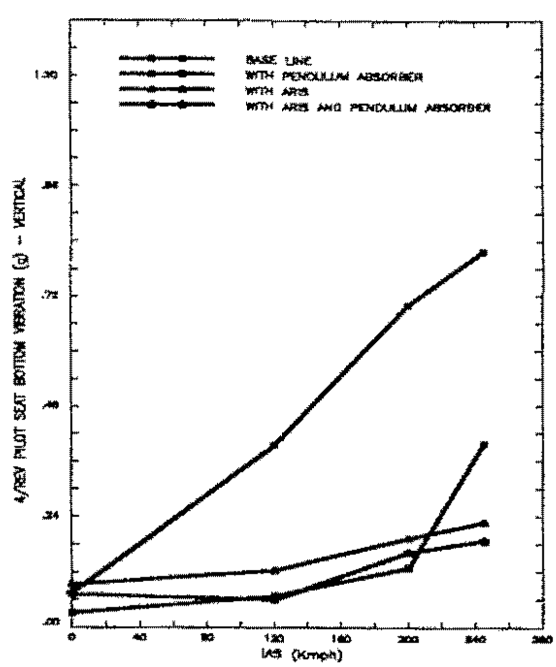

Fig. 17 : Pilot Seat Vibration Level

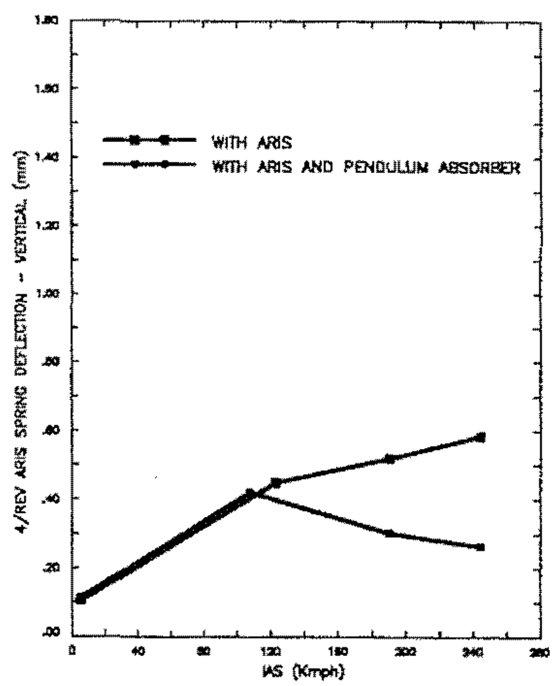

Fig. 19 : Spring Displacement With Forward Speed

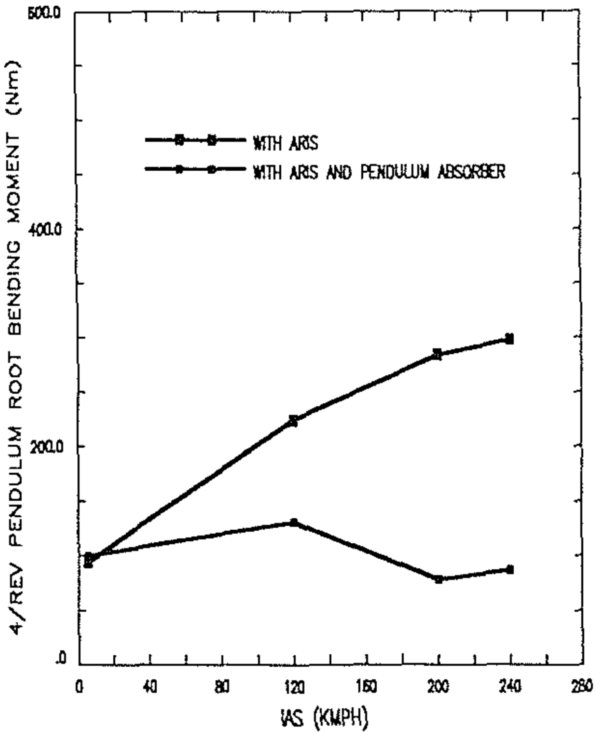

Fig. 20 : Pendulum Root Bending Moment

9.0 CONCLUSION

The ARIS concept with regard to its function has been successfully realised through hardware and effectively integrated on the prototype.

The spring and the diaphragm had limitation with regard to fatigue life due to higher measured dynamic displacement on the spring compared to design values.

Based on the data, the design has been reviewed to have improved life on the spring and the diaphragm.

Flight test will continue to assess the performance of modified ARIS in terms of function and endurance capability.