EH101 - DEVELOPMENT STATUS REPORT

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Abstract

This note provides a status report on the development of the EH101 basic vehicle. It concentrates on the configuration changes introduced to improve basic attributes such as handling, vibration or performance. Avionic development is covered in a paper presented by Mr. K. G. Bannister in Session 1.3.1.

Four main topics are discussed and the development route through to a production standard is explored. These attributes are:

- high frequency vibration (5 per revolution),
- low speed 'pitch-up',
- high speed lateral buffetting (shuffle),
- tail rotor performance/strength trade-off.

HIGH FREQUENCY VIBRATION

The high frequency (5 per revolution, 17.5 Hz) vibration, as measured on cockpit and cabin floor on the EH101 is excessive and unacceptable as a production standard. The target values are 0.15g as an average value in cockpit and cabin in the military aircraft, but a lower target of 0.05g has been set for civil applications.

In order to understand the mechanisms inducing vibration, it is necesary to have a sound knowledge of the 5R force generators on the aircraft, and to have reliable information on the responsiveness of the airframe to those forces. Analytical models of rotor blade forcing, and Nastran dynamic models of fuselage response have to be correlated to flight results. Subsequent changes can then be assessed for their contribution to reducing measured vibration.

The investigation has therefore been a structured approach illustrated in Fig. 1. which has separately examined the rotor forcing loads, and the structural response to those loads. Modifications have been introduced into the models, and where shown beneficial, to the aircraft to reduce vibration to the desired level.

Rotor Loads

Prediction of rotor loads at blade passing frequency is a notoriously difficult task. Both Companies have applied their own methods for predicting the rotor forcing, and have substantiated these results from direct flight measurements on blades and by loads seen by the rotor shaft. Acceptable agreement has been reached.

A comparison of the EH101 rotor with other rotors, with respect to contributing rotating blade centre-line loads has been made. Suitable scaling has been applied and the resulting 5R vertical velocity components calculated using EH101 fuselage transfer functions (Fig. 2). The results indicate that the 4R lag shear vibration response is the only one scaling excessively.

For this reason a further look at the 4R lag shear was taken. This showed that the major contributor to lag shear is inertial load originating from the second lag mode frequency proximity to 4R. An experiment was therefore configured to evaluate the effects of increasing the second lag mode frequency by increasing the chordwise stiffness of the blade. This was achieved by adding uni-directional carbon strips to the upper and lower surfaces of the trailing edge, sufficient to increase the mode frequency by approx. 12%.

The in-flight results (Fig. 3) show that the measured vibration is only marginally affected by the change.

If the main rotor forcing loads are therefore considered reasonable, the high fuselage transfer functions are seen to be the cause of the excessive measured response.

Structural Tuning

In parallel with the above a programme to refine the dynamic modelling and to correlate the results with ground shake testing and with in-flight mode measurements has been carried out.

Three dominant modes in flight have been isolated:

- Gearbox pitching mode - 15.33 Hz,
- Gearbox vertical bounce mode - 17.87 Hz,
- Fuselage lozenging mode - 19.52 Hz.

The modelling was then used to determine the effect of structural changes on the above modes. A series of practical experiments were defined and carried out including:

- rear cabin bulkhead stiffening,
- main lift frame stiffening,
- cabin door bracing,
- rear fuselage stiffening,
- softer gearbox struts.

In general these changes had some effect locally, but failed to influence vibration in the cockpit or extremities of the cabin. Although disappointing, this result is perhaps not surprising, particularly with a large, and therefore comparatively soft, structure under the influence of at least 3 dominant modes of vibration.

This work is however, still continuing since it is evident that a true understanding of baseline vibration behaviour is essential before application of other vibration control mechanisms can be applied, and also because baseline vibration must be minimised in the event of failure of further specific vibration controls.

Main Rotor Head Absorber

The gearbox pitching mode and the fuselage lozenging modes of vibration both result in significant in-plane motion of the rotor head.

A rotor head vibration absorber tuned to respond at 5R and sized to produce the necessary countering forces was adapted from two W30 spring absorbers.

This works very well and reduces cockpit floor vertical vibration at 150 kts to 0.25 g (Fig. 4).

It increases the height of the aircraft unacceptably and is heavy (approximately 200 kg installed mass).

It is possible to re-package a head absorber, perhaps by moving to a bi-filar design with the arms between the blades. If nothing better was available then a refinement of a head-absorber would remain likely.

Cabin Absorbers

Various combinations of cabin mounted absorbers (adapted from Black Hawk) have been assessed, both in conjunction with the head absorber and without it.

The objective was to determine whether these absorbers could be used to cancel the remaining vertical force effects when used with the head absorber which is effective in absorbing in-plane forcing. Additionally the mass absorbers could have potential for absorbing all modes without a head absorber being fitted.

Installations were available at both port and starboard sides in the rear cabin, on the forward lift frame and outboard of the co-pilot's seat.

Adding two absorbers in the rear cabin, while using a head absorber, further reduced vibration levels. The effect was in general however localised, with more reduction in the vicinity of the absorbers. This configuration could have been viewed as a possible conventional solution.

On their own, however, the mass of the absorbers would have to be significantly increased to become effective.

The conclusion therefore was that a complete solution using cabin absorbers in a vehicle of this size was unlikely, and would in any event be exceedingly heavy.

Active Control of Structural Response

An active control technique had commenced development on W30 being demonstrated in flight in early 1987. The application to EH101 was therefore expedited in 1988 culminating in flight trials on PP3 in Spring 1990.

A full paper on ACSR is being presented later (paper 111.6.1) by Alan Staple. A brief description will be given here to whet the appetite.

The basis of ACSR is that computer-controlled forces are applied to the structure to induce cancelling vibrations at distinct frequencies so as to produce minimum total vibration response at those frequencies. The key elements are the force-generating actuators, sensors to provide vibration information, and a computer control unit to process the vibration data and calculate the required cancelling forces (Fig. 5).

The mechanical actuation on the EH101 is provided through the main gearbox support struts (Fig. 6).

The system is adaptive to changes of flight condition, aircraft weight, centre-of-gravity and rotor speed and operates on a cyclic basis with a refresh rate of approximately 0.5 seconds.

The measured results are shown in Fig. 7 where a reduction in average vibration in cockpit and cabin of up to 85% has been achieved. The co-pilot seat position, in particular, was reduced at 140 kts by 92% to a level approaching 0.05g.

The system is also designed to control harmonics of 5R, and reductions of 50% in 10R were recorded.

Conclusions

The evaluation of ACSR on PP3 has been very successful. A comparison with the best passive solution (head absorber) shows ACSR to be superior in terms of vibration reduction (average 55% for head absorber to 85% for ACSR) and weight penalty (target 150 kg for head absorber and 100 kg for ACSR).

Furthermore, ACSR alone will bring the EH101 within the DEF STAN 00-970 level of 0.15g at all speeds.

Future development activity will concentrate on developing reliability, maintainability and safety aspects of ACSR, exploring the health monitoring potential and productionising the installation.

Having explored all avenues of vibration reduction, ACSR is confirmed as the control mechanism common to all variants and to be viewed as basic equipment.

LOW SPEED PITCH-UP

The EH101 was initially configured with a symmetrical low-set tailplane. It soon became evident that excessive pitch-up occurred in transition to forward flight and in spot turn recovery into wind. The input-up is produced by the main rotor wake moving aft and striking the tailplane as a flat-plate area with maximum effect at approximately 15-20 kts (Fig. 8).

This is not a unique phenomenon and some degree of pitch-up was perhaps expected. Nonetheless it was considered worthy trying the aircraft initially with a tailplane that provided the easiest path through the trade-offs of weight, minimum impact on vertical fin, easy folding etc.

As it happened the combination of tailplane area, moment arm, main rotor hub control power etc. was such that the effect is unacceptable (Fig. 9).

Three potential solutions were explored:

- Pivot the tailplane in low speed flight regimes (à la Sikorsky Black Hawk).
- Move the tailplane to a traditional high set position opposite the tail rotor.
- Optimise the low set tailplane area aspect ratio so as to minimise pitch-up but maintain high-speed trim and stability.

The first solution was rejected since the very large tail rotor on the EH101 makes it difficult to find a tailplane position which is compatible with tail fold whilst keeping the tailplane clear of the ground - although a pivoting asymmetrical (one-sided) tailplane could have been produced!

The second solution has been tried and is a definite cure to pitch-up whilst providing high speed trim and stability with no other high speed ill-effects. However, in order to fold the tail-unit the tailplane must first be itself folded down beside the fin. The changed load distribution in the fin, tailcone and rear fuselage also requires significant rework with potential programme implications.

Major effort has therefore been expended in exploring a low-set tailplane configuration which may produce an acceptable compromise. The final assessment was made using a one-sided high-aspect ratio tailplane of significantly reduced total area (to the benefit of pitch-up) but with better high speed efficiency so producing the required trimming forces.

Since this is by definition a compromise solution it has been necessary to acquire sufficient confidence that the compromise is a satisfactory one in the critical flight regimes of:

- Approach to, and landing on, the decks of small ships.
- Landing on North Sea oil rigs, particularly rejected take-off manoevures following an engine failure.

Accordingly, an assessment of the pilot workload increment due to this handling characteristic has been gained from flight trials using PP2 in the vicinity of a ship at sea.

All concerned are confident that this compromise is acceptable and therefore the definitive tailplane is confirmed as being this asymmetric low-set configuration - common to all variants.

SHUFFLE

A lateral buffetting has been evident on EH101. The cause is wake shedding from main rotor head and cowlings behind the rotor and striking the vertical fin and tail rotor (Fig. 10).

This again is not an unusual characteristic and has been improved on other aircraft by detailed aerodynamic attention.

Many experiments have been configured on EH101 and explored either in the wind-tunnel and/or on the aircraft. The aim was to control the airflow without causing excessive drag penalties on the aircraft.

The final choice of changes consists of:

- Main rotor head beanie,
- 'Horsecollar' on the No. 2 engine cowling,
- Tension link fairings,
- Blade root fairings,

The first two devices essentially distort the airflow downwards to avoid the fin, and therefore are drag producers. The latter changes are reducing drag of the rotating hub and rotor to the benefit of power and performance. The overall result is to reduce the lateral vibration (Fig. 11) to an acceptable level, with minimal increase in D_{100} of the aircraft.

The final confirmation that the configuration is acceptable has come from assessing an aircraft (PP3) with both the shuffle modifications, and with ACSR fitted, (benefiting 5R vibrations).

TAIL ROTOR

The initial tail rotor configuration is shown in Fig. 12. This possesses a semi-rigid rotor hub with a pair of composite straps allowing flapping flexibility. The blades are attached via elastomeric bearings (two to provide flap and lag moment restraint whilst allowing pitching freedom, and one to react to centrifugal loads).

Early difficulties were experienced in developing the bending strength at the effective hinge to permit the required safe endurance flapping motion (approx. 4°) and to allow the resulting motion arising from the limit design manoeuvre (full pedal at V_{NE} and approximately 12°).

This tail rotor hub has been through several iterations, progressively improving the strength/life balance whilst maintaining satisfactory dynamic properties.

It has however been recognised that final compliance will be extremely difficult.

This, together with recognition that a change of design could reduce parts count and benefit reliability and maintainability prompted a review of tail rotor design.

The outcome, endorsed by both Companies is shownn in Fig. 13.

This tail rotor utilises a flexi-torsion beam extending to blade half-span which absorbs by twisting the blade collective pitching motion. The blade to hub attachment is therefore bearingless.

The beams are attached via 45° skew hinges to the tail rotor mast. This hinge provides a direct δ_3 coupling and removes vibratory moments from the mast and therefore allows the tail rotor to operate with the appropriate flapping motions without inducing larger fatigue loads into the tail gearbox and supporting structure than were originally catered for.

The total number of bearings in the assembly is reduced from 12 to 4 with obvious benefits.

The new tail rotor design is well established with lead-in interim standard rotors incorporating the teetering hinges, but with present blades and attachments, now flying on development aircraft.

SUMMARY

Development of the basic vehicle has resulted in changes, the most significant briefly discussed above, so that the platform from which total system development can build is now well established.

The aircraft is well-liked by all who fly her and we have every confidence that this early development provides the spring-board to a long and successful commercial venture.

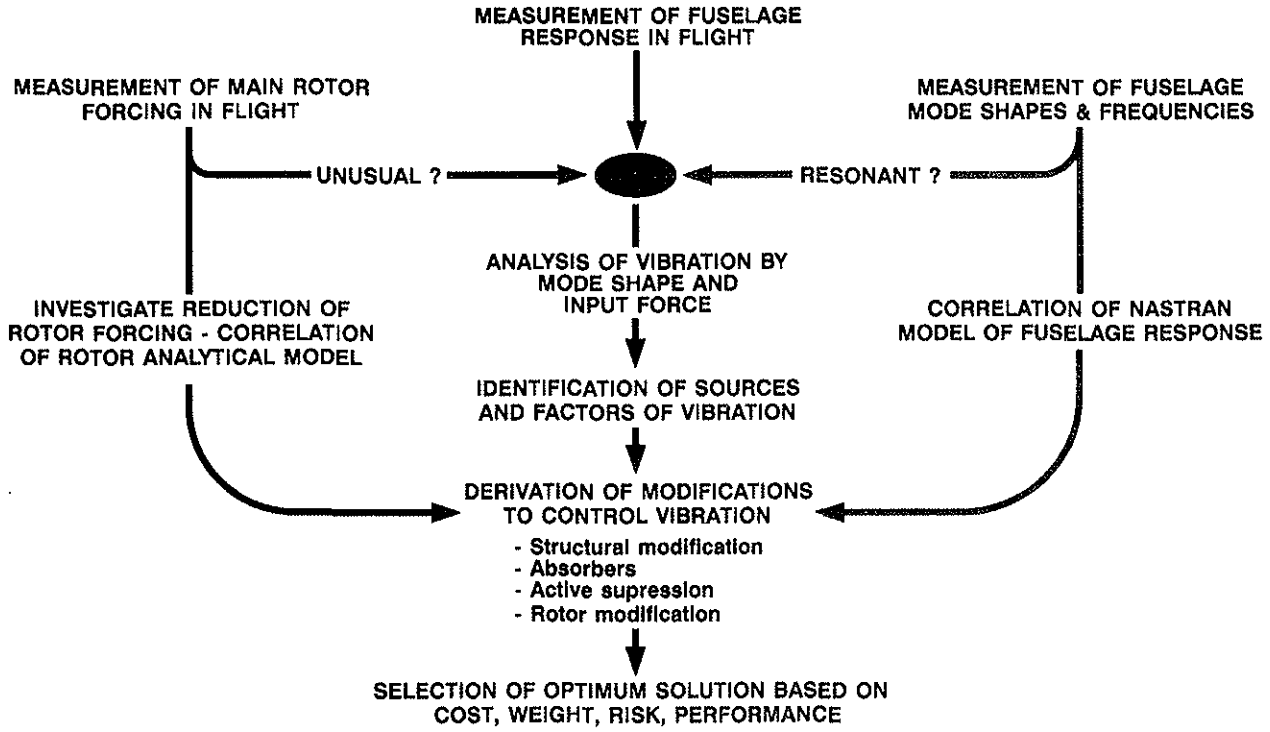


Figure 1
EH101 VIBRATION CONTROL ACTIVITIES SUMMARY

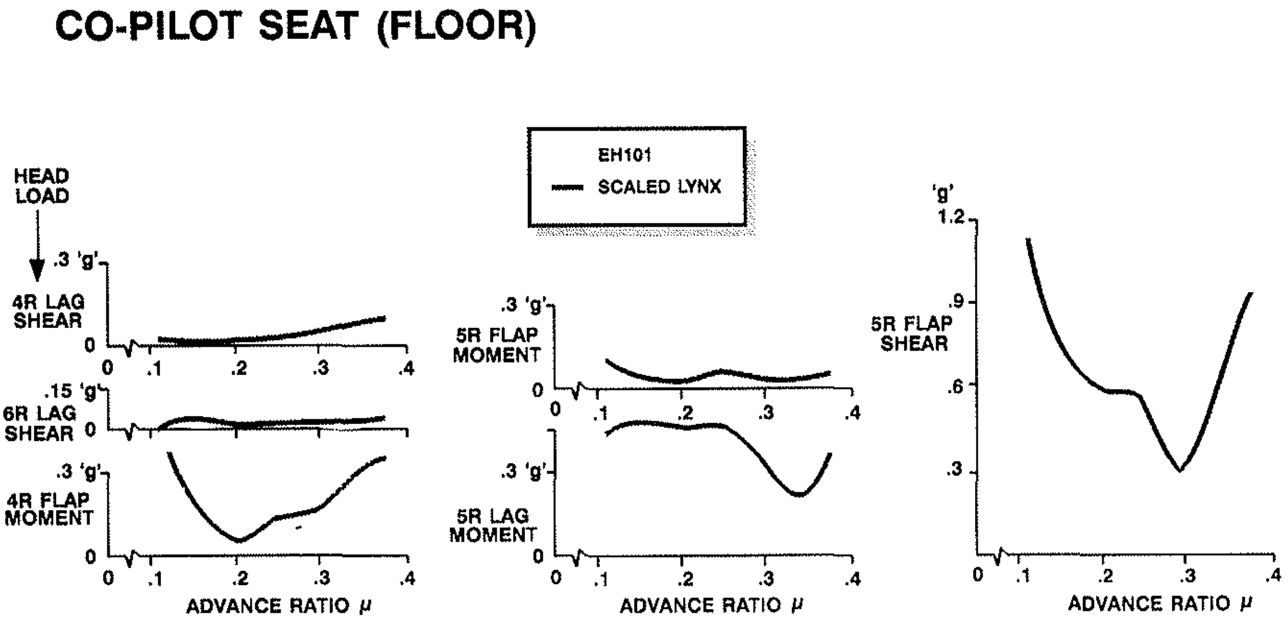


Figure 2
5R VERTICAL VIBRATION - LYNX & EH101

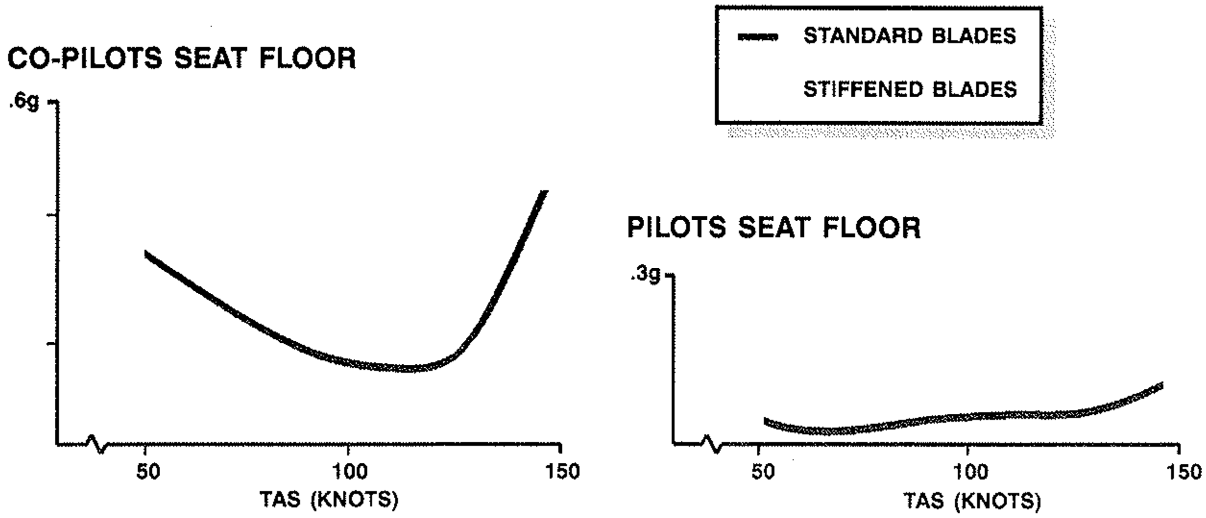


Figure 3
STIFFENED BLADES COMPARISON

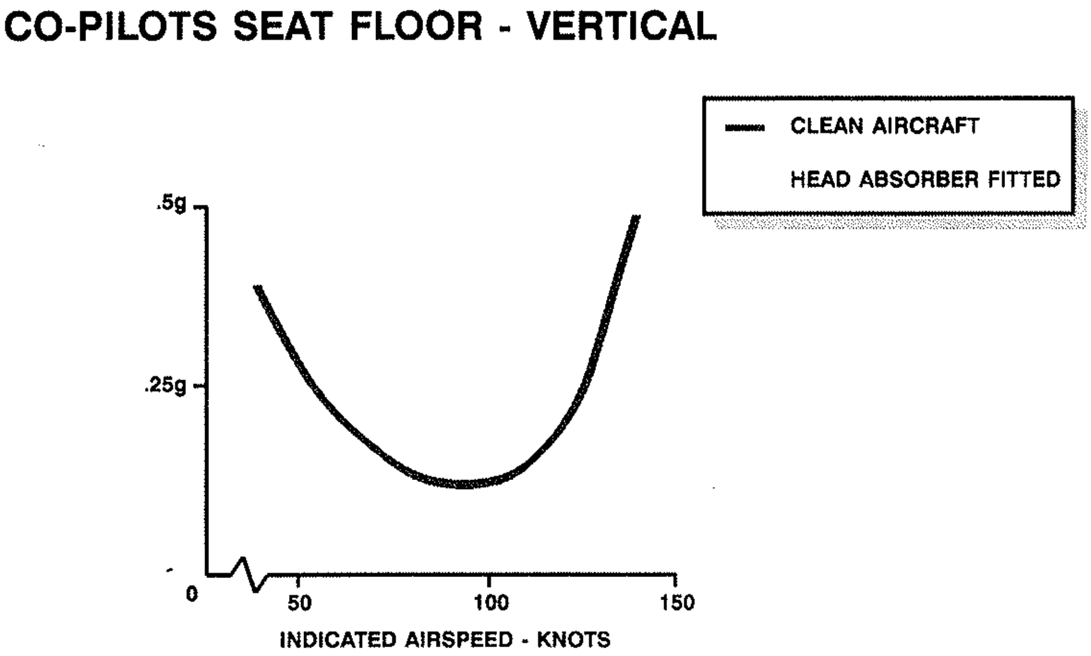


Figure 4
HEAD ABSORBER RESULT

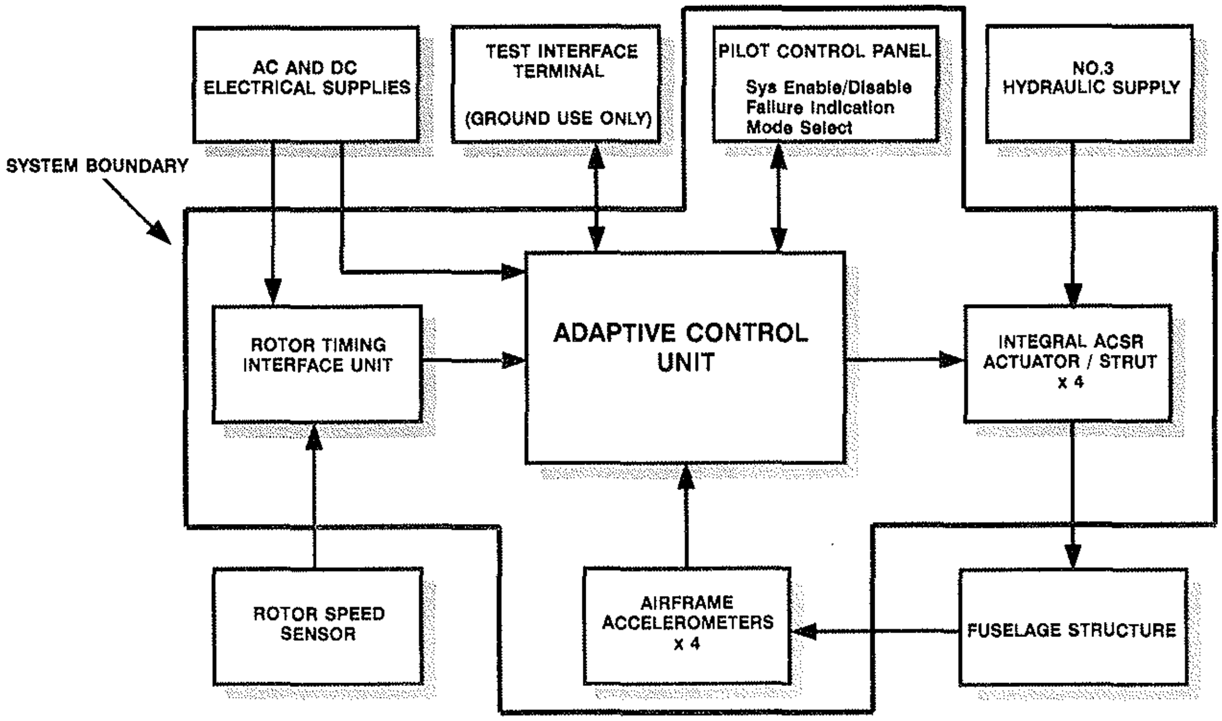


Figure 5
ACSR SYSTEM SCHEMATIC

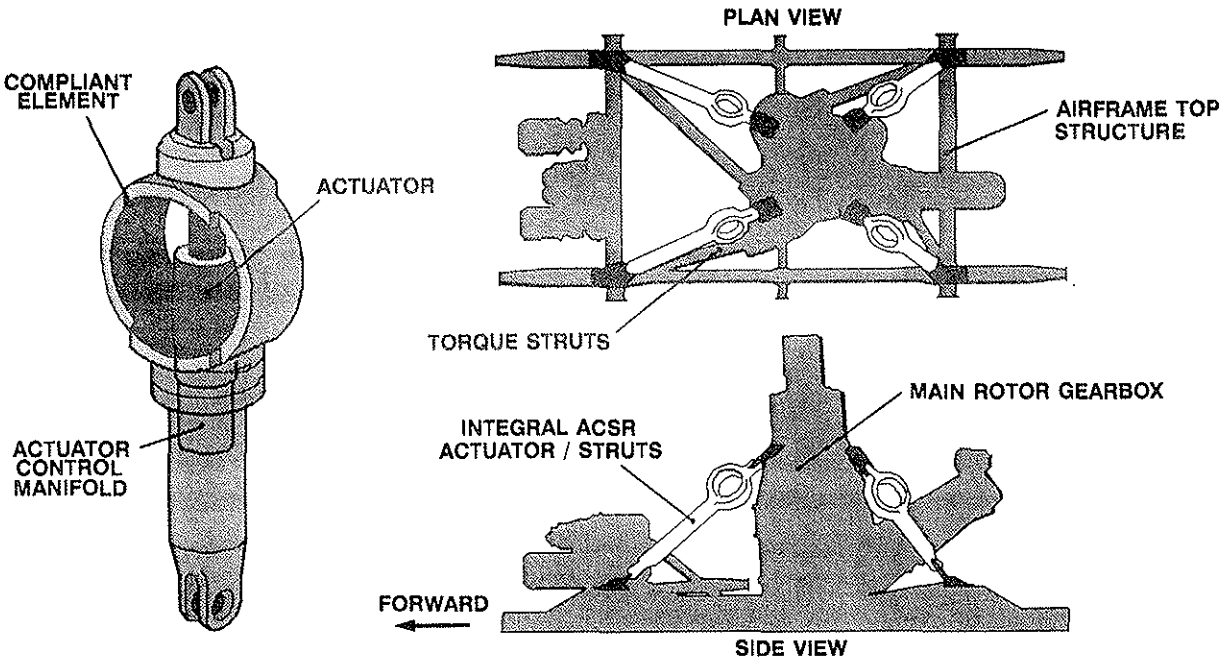


Figure 6
ACSR ACTUATOR INSTALLATION FOR EH101

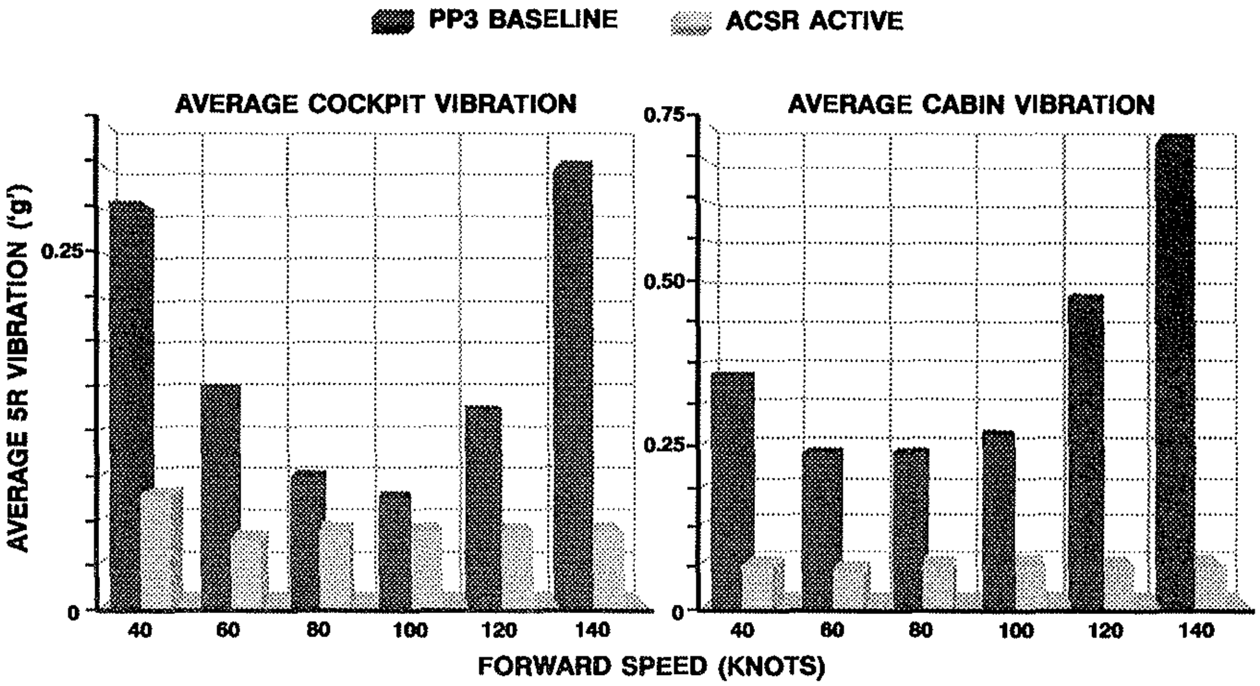


Figure 7
EH101 PP3 ACSR FLIGHT TEST RESULTS

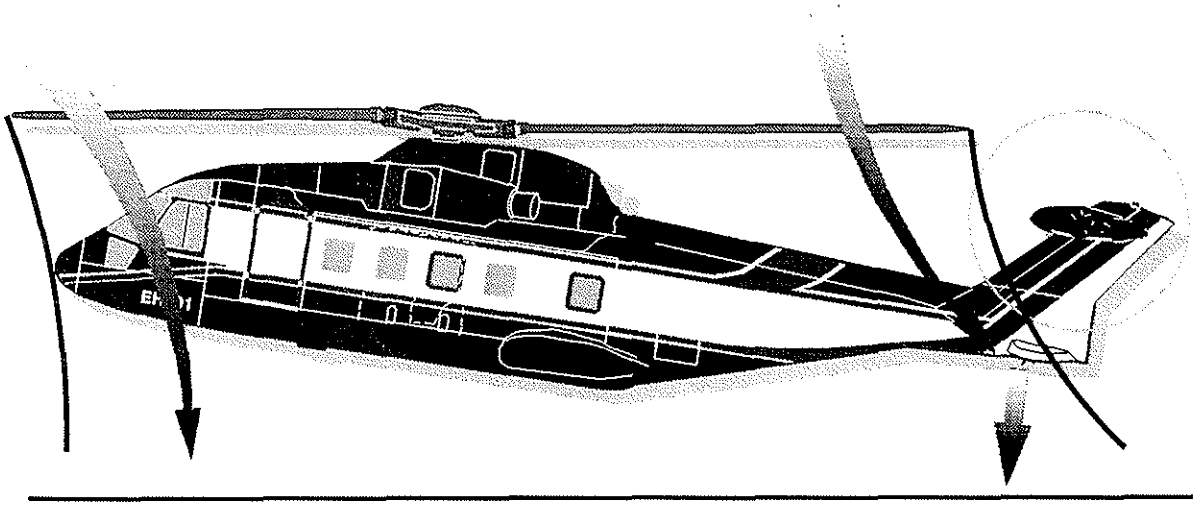


Figure 8
'PITCHUP' IN TRANSITION FLIGHT

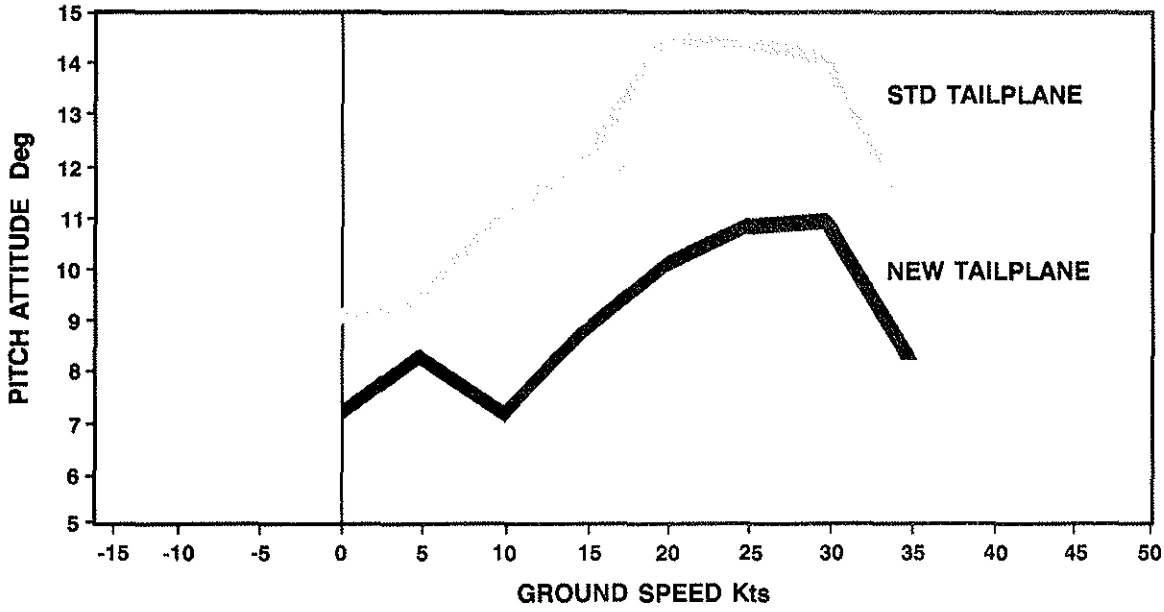
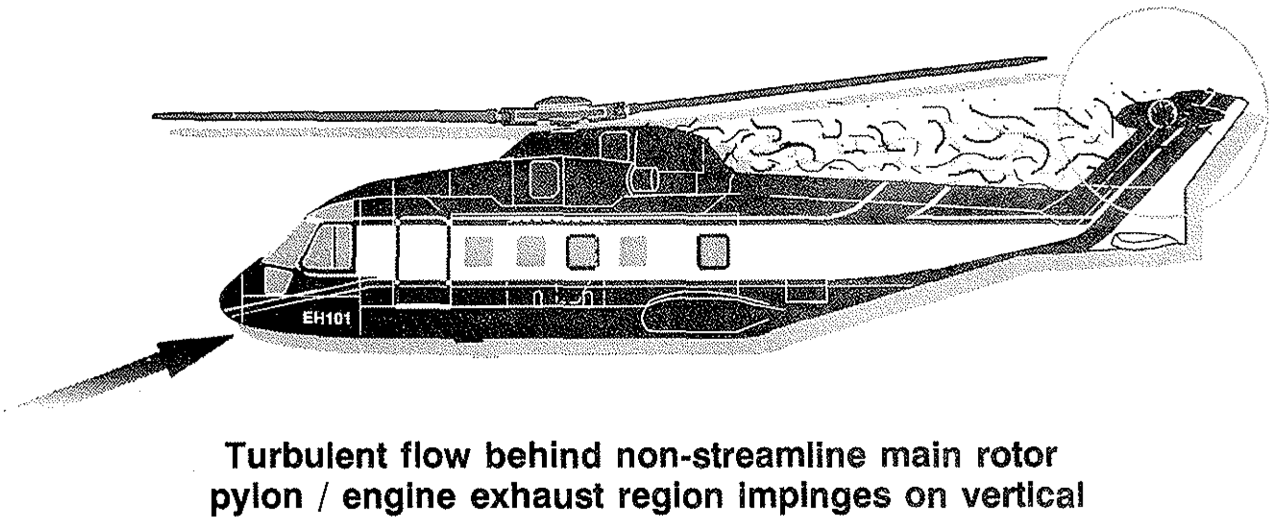


Figure 9
PITCH-UP RESULTS



Turbulent flow behind non-streamline main rotor pylon / engine exhaust region impinges on vertical fin and tail rotor

Figure 10
ORIGIN OF TAIL BUFFET IN PART-POWER DESCENT - 'SHUFFLE'

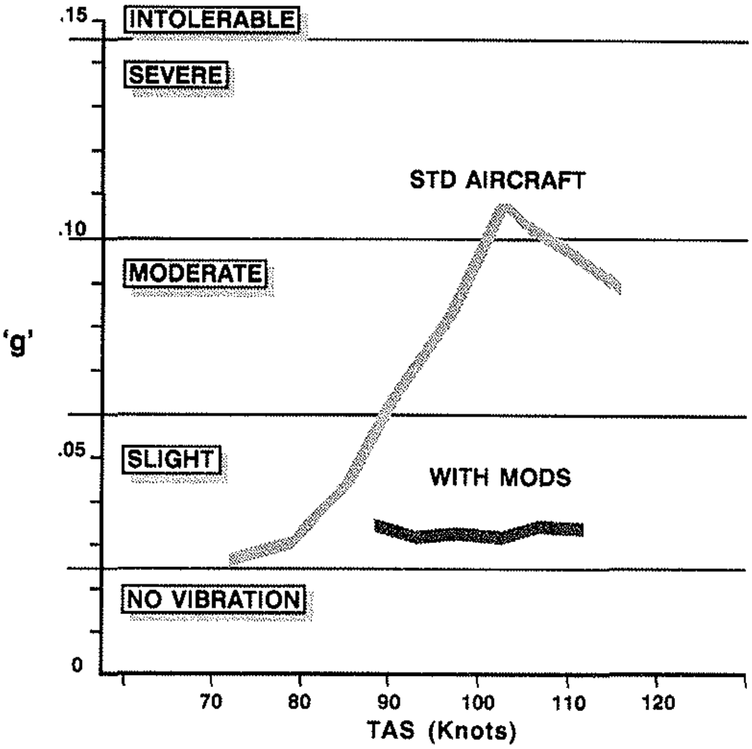


Figure 11
SHUFFLE RESULTS

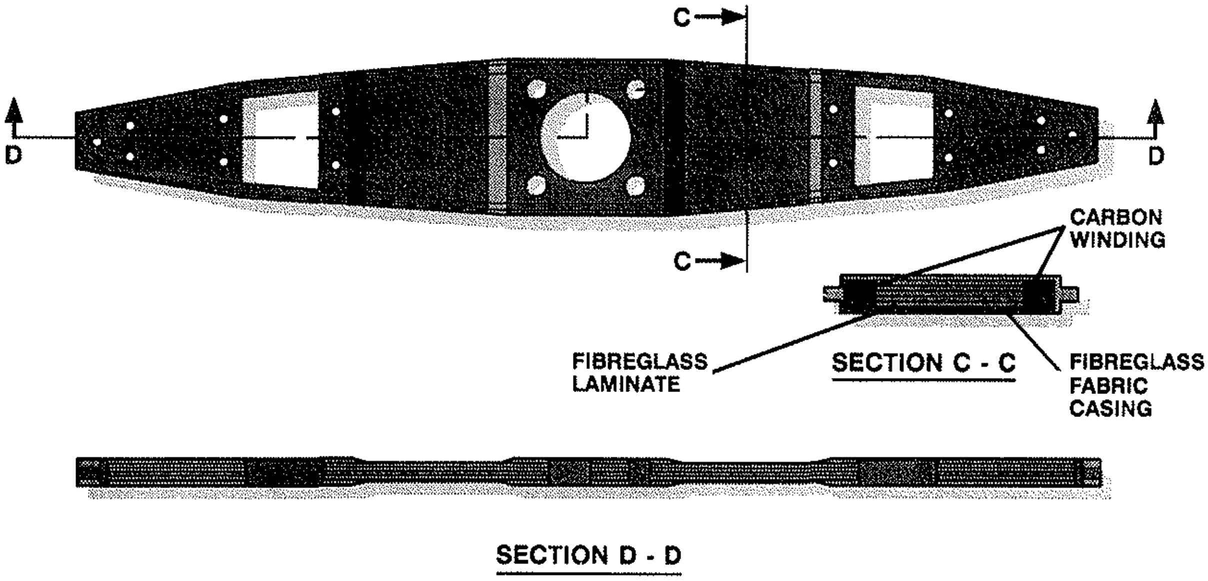


Figure 12
COMPOSITE TAIL ROTOR HUB

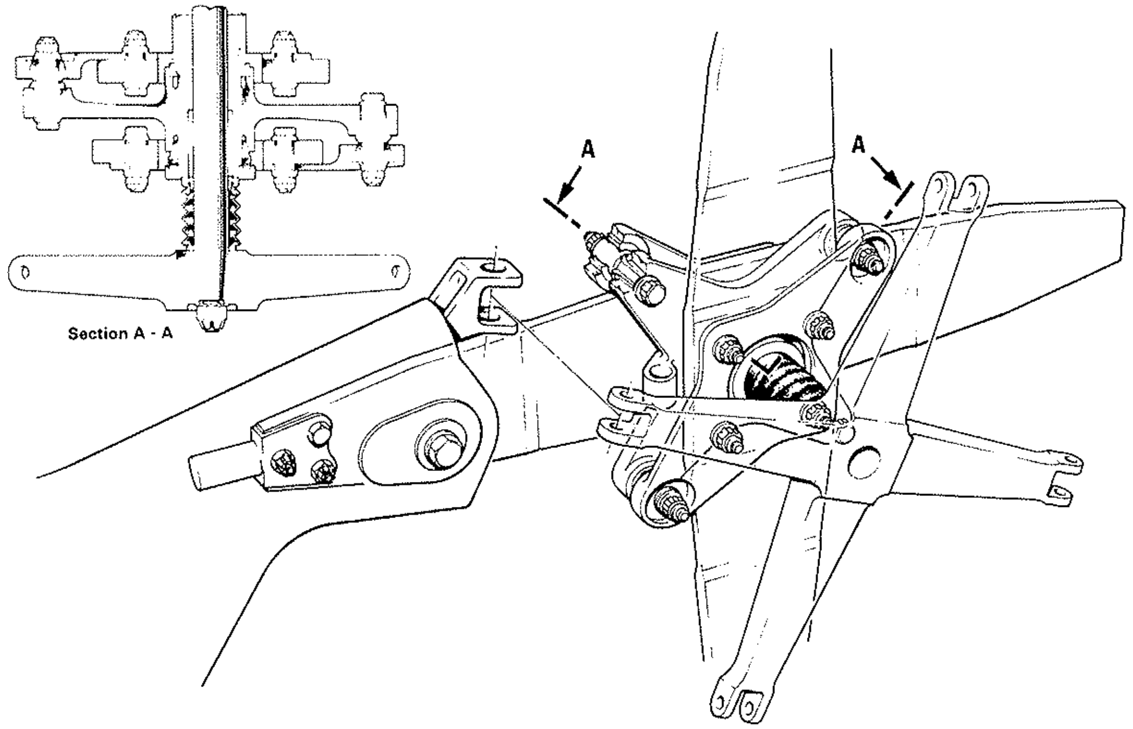


Figure 13
TEETERING TAIL ROTOR HUB