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THE SARIB VIBRATION ABSORBER

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ABSTRACT

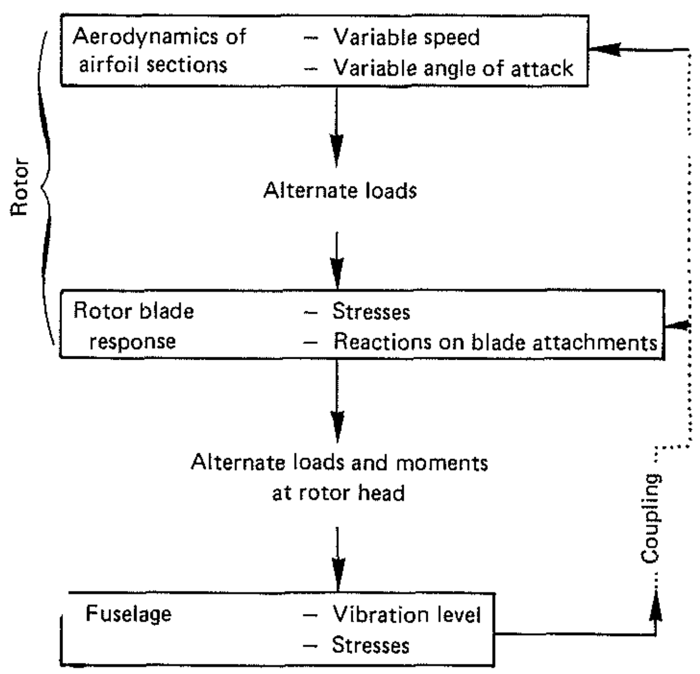
This document synthesizes the work and test results as performed on the SARIB I and II vibration absorbing systems. It first presents a review of the major vibration absorber systems under study or installed on Aerospatiale's and other various world manufacturers' aircraft and gives the results of the flight tests performed on the SARIB I and II vibration absorbers as mounted on the AS 350 Ecureuil. It is shown that the reduction in vibration level is quite significant and weight saving as well.

1 – MEANS FOR ABSORBING VIBRATIONS ON AEROSPATIALE'S AND OTHER MANUFACTURERS' HELICOPTERS

1.1 – Introduction

The problem of vibrations on a helicopter proves very special : the rotor is a powerful vibration generator which raises problems specific to this type of aircraft ; one of the major problems being that of forced vibrations. The rotor induces alternate loads throughout the aircraft and therefore fatigue and vibrations in the cabin, which is one of the principal factors in the helicopter comfort and in the life of system components.

Let us review the diagram that briefly describes the forced vibration development process throughout the aircraft :



These alternate loads are periodic ; their fundamental frequency is the rotor rotation frequency.

Depending on the rotor blade characteristics, these loads are amplified or reduced and induce stresses and reactions in rotor hub. These reactions constitute the fuselage excitation loads and moments. The response of the fuselage in turn depends on its own dynamic characteristics.

It is therefore important to select the rotor blade and fuselage dynamic properties so that their response to aerodynamic excitation be minimum. Aerospatiale thus make every effort in defining dynamically upgraded rotor blades and fuselage.

However, the efforts made to this end did not prove sufficient enough not to require additional absorbing means.

It should be noted that fuselage feedback on rotor blade dynamic condition and blade motion feedback on aerodynamic loads may complicate the forced vibration problem.

Upgrading of performance, mission duration and versatility, looking into an increased level of comfort, new technologies, normal higher rate production scattering and imperfect control of forced vibration dynamic and aerodynamic problems at design level, therefore required **the necessity for developing vibration damping and control means.**

The problem proves difficult since the vibration technology has to meet the following requirements :

- System with an unlimited service life
- Reliability (mainly for the systems mounted on rotor)
- Reduced maintenance or no maintenance
- Minimum weight, drag, power consumption and cost
- Minimum dimensions and weights.

1.2 – Classification of vibration damping and control means

The vibration damping and control means can be broken down into 3 major classes :

- At rotor head
- At rotor-to-fuselage interface (M.G.B.) via suspensions
- In fuselage.

The three charts 1, 2 and 3 list the major vibration control systems according to this classification and specify the efforts made by Aerospatiale within this field.

CHART 1

VIBRATION CONTROL AND DAMPING SYSTEMS

AT ROTOR HEAD

Legend
P : in production
T : flight tested
A : currently being designed and tested
R : research stage

	SYSTEM	HELICOPTER	PROGRESS STAGE	FIRST-TEST YEAR
PASSIVE	Pendulums :	BELL		
	– Vertical bifilar	206 L-M	T	1979
	– Coplanar bifilar	206 L-M	T	1979
	– Mercury	206 L-M	T	1979
		412	A	1981
	– Centrifugal	206	T	1979
		222	T	1979
		SIKORSKY		
	Bifilar pendulums	S61	P	around 1970
		S76	P	1977
		UH 60B	P	1976
		SH 60B	P	1979
		WESTLAND		
	Spring-mass vibration isolator	WG 13	T	?
		AEROSPATIALE		
	Pendulums :			
	– Coplanar bifilar	AS 350	T	1979
	– Centrifugal	AS 350	T	1976
	– Spring mass	AS 350	P	1977
		AS 355	P	1979
	– Ball-type resonator	AS 350	T	1974
	– Centrifugal	AS 365	T	1977
ACTIVE		BELL		
	Rotor adaptive vibration control		R	?
	Rotor adaptive vibration control	AEROSPATIALE – Tabs on blades	R	?
		– Multicyclic control	A → T	1984
		BOLKOW		
	Rotor adaptive vibration control		R	1982
	Rotor self-adaptive vibration control	HUGHES	T	1983
ZONES ACCOMMODATING THESE SYSTEMS : ROTOR HEAD,BLADES OR CONTROL SYSTEM				

CHART 2

VIBRATION CONTROL AND DAMPING SYSTEMS

VIA SUSPENSIONS

Legend
P : in production
T : flight tested
A : currently being designed
R : research stage

SYSTEM	HELICOPTER	PROGRESS STAGE	FIRST-TEST YEAR
NODAMAGIC	BELL		
Nodal suspension	206 L	P	1975
	214 B	P	1976
	214 ST	P	1981
	222	P	1979
LIVE	206 B	T	1980
MDOF	206 L-M	A	1986
	BOEING VERTOL		
IRIS (Boeing Vertol)	YUH 61A	T	1976
DAVI (Kaman)	UH 1B	T	around 1972 - 1973
	WESTLAND		
RAFT (flexible mounts or DAVI)	WG 30	T	1979
	BOLKOW		
IRIS (Boeing Vertol)	B 105	T	1976
DAVI (Kaman)	BK 117	T	1981
	AEROSPATIALE		
Unidirectional flexible mounting plate (barbecue)	SA 341	P	1968
	SA 342	P	
	SA 330	P	1965
	AS 332	P	1980
Bidirectional flexible mounting plate (barbecue)	SA 360 / 361	P	1972
	AS 365	P	1977
	AS 350	P	1974
	AS 355	P	1979
Flexible bar	SA 341	T	1968
DAVI ring-type resonator		R	1980
SARI		R	1980
SARIB	AS 350	T	1980
Slaved SARIB		R	1985
ZONES ACCOMMODATING THESE SYSTEMS : BETWEEN TRANSMISSION ASSEMBLIES (MGB) AND FUSELAGE			

CHART 3

VIBRATION CONTROL AND DAMPING SYSTEMS IN FUSELAGE

Legend
P : in production
T : flight tested
A : currently being designed
R : research stage

SYSTEM	HELICOPTER	PROGRESS STAGE	DESIGN
	BELL		
Frahm's pendulum in fuselage nose	222	P	1973
Passive lug-type horizontal stabilizer resonator	206 B and IV	P	1981
	SIKORSKY		
Resonator slaved to rotor r.p.m. (aircraft nose)	S76	P	1977
Nose lateral resonator	SH 60B	(P) T	1979
	WESTLAND		
Nose resonator	WG 13 WG 30	T	1980
	BOEING VERTOL		
Isolation of cabin floor and fuel hold via resonator	Model 234 (derived from CH 47)	T	1980
Slaved resonator (position of masses)	CH 47		around 1975
	AEROSPATIALE		
Battery resonator (aircraft nose)	SA 341	T	1968
	SA 342	T	
	SA 360	P	1972
	AS 365	T	1977
	SA 330	P	1965
	AS 332	T	1981
Leaf-type resonator	AS 365	T	1981
	AS 350	P	1974
	AS 355	P	1981
	AS 332	T	1981
	AEROSPATIALE		
Structure active control		R	1982
Active vibration control through horizontal stabilizer oscialltion		R	?
Shaker		R	1968
ZONE ACCOMMODATING THESE SYSTEMS : FUSELAGE STRUCTURE			

1.3 – Aerospatiale's position

Aerospatiale has been one of the first helicopter manufacturers to propose, on the market, a vibration absorbing system, i.e. a focal point suspension also called barbecue after the M.G.B.-to-structure flexible coupling system in the form of a mounting plate for the SA 330 Puma (see Figures 1 and 2 : focal point suspension principle). Other systems have also been designed by Aerospatiale such as :

- Rotor head resonators (bifilar, centrifugal pendular, spring-mass isolator, ball-type pendular resonator ...)
- Cabin resonators (leaf-type resonator, battery anti-vibration mounts ...)
- «Bar-actuator» hydraulic system ...

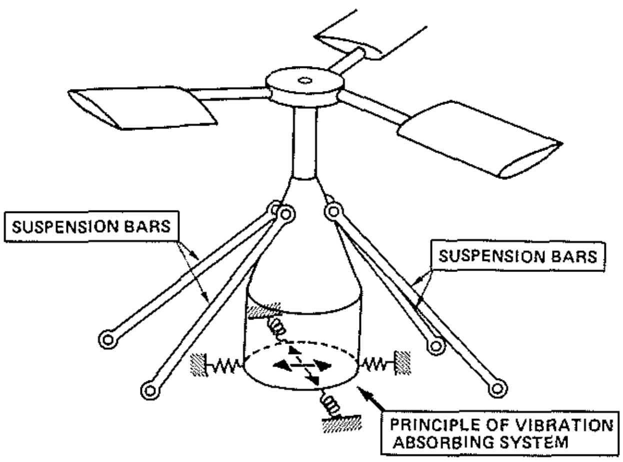


Fig. 1 : PRINCIPLE OF FOCAL POINT SUSPENSION

Moreover, the focal point damping systems have been enhanced through the introduction of a two-axis vibration isolation and simplification (use of laminated elastomer mounts and flexible composite bars).(See figure 2) .

These systems quite fill their functions and provide the Aerospatiale helicopters with high competitiveness as concerns the vibratory comfort.

In the recent years, new concepts of leaf suspensions of the SARI and SARIB types were designed and developed ; the latter type is discussed herein. Thanks to their simplicity and cost, the passive vibration damping systems quite meet the criteria previously stated. It is obvious that exploring this type of system is not ended and that some systems (ball-type pendular resonators, meshing pendulums, ring-type resonators, ...) can prove satisfactory, even if not yet industrially perfect.

Semi-active or simple active systems can also be interesting.

As far as more elaborate active techniques are concerned two fields have been explored :

- Multicyclic control vibration active damping
- Structure vibration active damping.

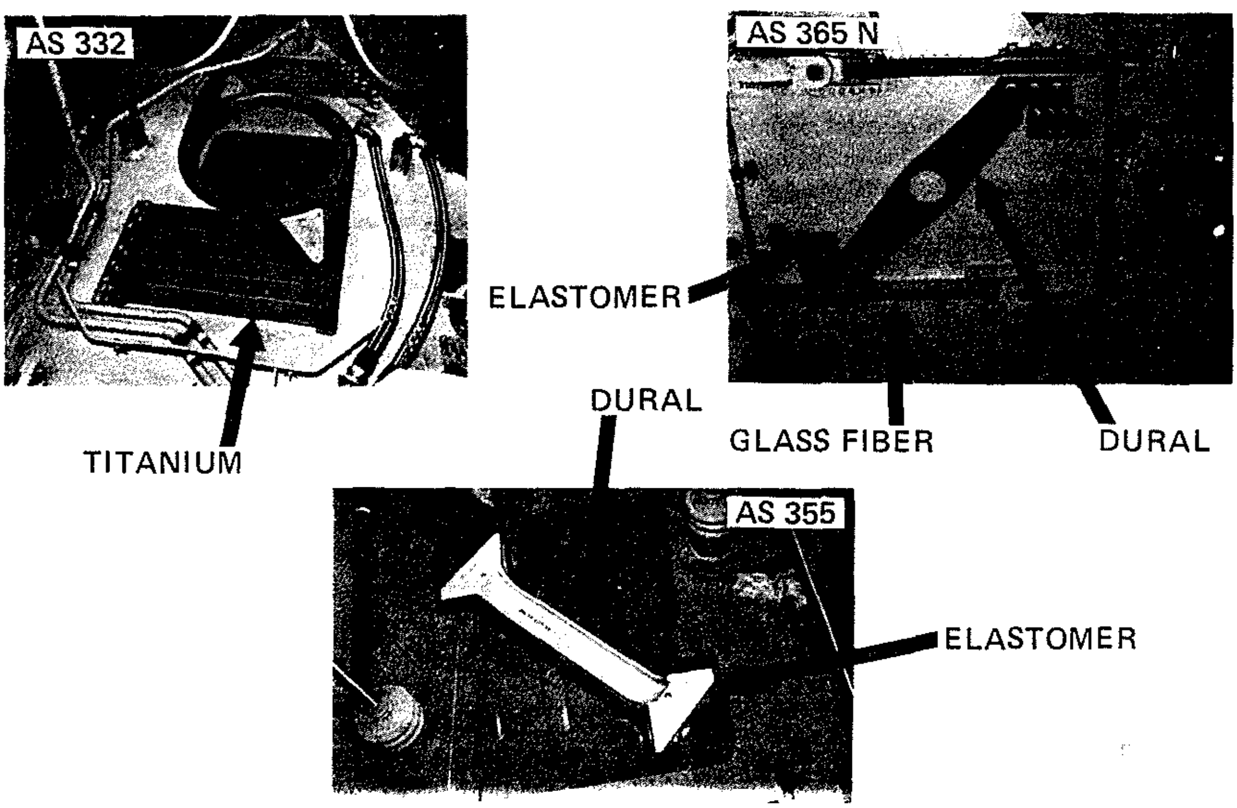


Fig. 2 : SUSPENSION TECHNOLOGIES ON OUR HELICOPTERS

However, these systems seem, nowadays reserved for rather heavy aircraft that can support the associated cost penalty. As a matter of fact, a data processing and measurement electronic sophistication is required for implementing such systems. The latest advances in the hydraulic, pneumatic (pass band) and electrical (power increase) fields have permitted exploring this way. Their development cost obviously is also higher.

On the other hand, these systems will better be suited to resolving the new constraints raised by the plurality of the missions required of a helicopter :

- Possibility of a variable rotor speed to optimize rotor performances
- Increased performance (especially for the duration of the mission).

It should also be recalled that the objectives aimed at, as far as the vibrations are concerned, are more and more stringent and that specifications on a 0.03 g vibration level in cruise flight is envisaged by 1990.

When reviewing the means to reduce the vibration level, the development of the rotor and structure upgrading methods must not be forgotten. If these methods prove more efficient in the future, they would permit enhancing the major components of the helicopter and would reduce accordingly the amount of efforts to carry out in order to improve the vibration level through auxiliary vibration absorbing systems.

2– THE SARIB-TYPE VIBRATION ABSORBING SYSTEMS

2.1 – Technical Interest

The SARIB concept is one of the concepts recently designed *and developed by Aerospatiale within the framework of de*velopment of passive vibration absorbing systems.

This concept proves worthy for several reasons :

- The SARIB makes it possible to absorb entirely or partly dynamic loads and moments Fx, Fy, Fz, Mx and My, as generated by the rotor whereas the former barbecue systems only absorb the moments and a small part of loads Fx and Fy (30 %).
- Providing few minor modifications be embodied, the SARIB system can easily be suited to the current generation aircraft which all are equipped with bars. It should be reminded that the bar-type solution provides a significant weight reduction of the M.G.B. casing.
- This concept leads to easier adjustments for more compact mechanical assemblies, especially when the distance between rotor head and M.G.B. sump is small.
- The number of parts specific to the vibration absorbing system can be reduced hence a saving, a reduction of the assembly and maintenance times and therefore a lower cost for such a system.
- Owing to its very design, this system can easily accomodate any types of resonators, especially fluid resonators.

2.2 – Description of the SARIB concept and difficulties raised

Figures 3, 4 and 5 illustrates the functional principle of such a system ; the M.G.B. is suspended by means of flexible leaves with one end attached to M.G.B. sump and other end at -tached to M.G.B. suspension bars by means of a rigid coupling permitting a flapper to move

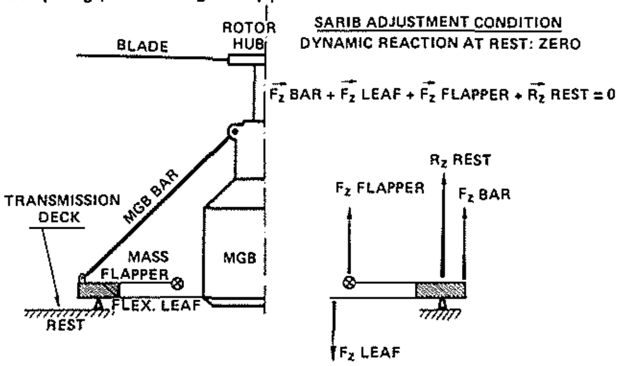


Fig. 3 : SARIB PRINCIPLE

The vertical dynamic load (Rz rest) input in the helicopter structure is the sum of 3 loads :

- Dynamic load in bar(Fz bar)
- Dynamic shear load across leaf (Fz leaf)
- Dynamic load generated by flapper (Fz flapper)

The latter load can easily be controlled through change in position or mass weight and thus, allows suspension to be adjusted with respect to the excitation frequency. The suspension is said to be adjusted when the resultant of the 3 dynamic loads is zero.

A large number of variants to this concept can be imagined since the boundary conditions such as leaf restraining, position of bar load and load in restraint pick-up points, etc ... are a lot.

Two types of SARIB suspension were studied :

- The SARIB I version where the flexible leaves are clamped at both ends and also transmit the rotor torque. Due to the high-stress rate evidenced on the leaves, this variant gave rise to time-limited flight experiments. The sufficiently encouraging results however lead to the SARIB II definition.
- The SARIB II version where the leaves are clamped on flapper end and simply rest on M.G.B. end, the rotor torque here being taken from M.G.B. sump through a flexible membrane. This variant is currently being tested in flight and offers an acceptable stress rate.

Figures 6 and 7 give an idea of the technological design adopted for both versions. The experience gained from calculations, model and aircraft tests in laboratory and flight tests show that the major difficulties to solve are :

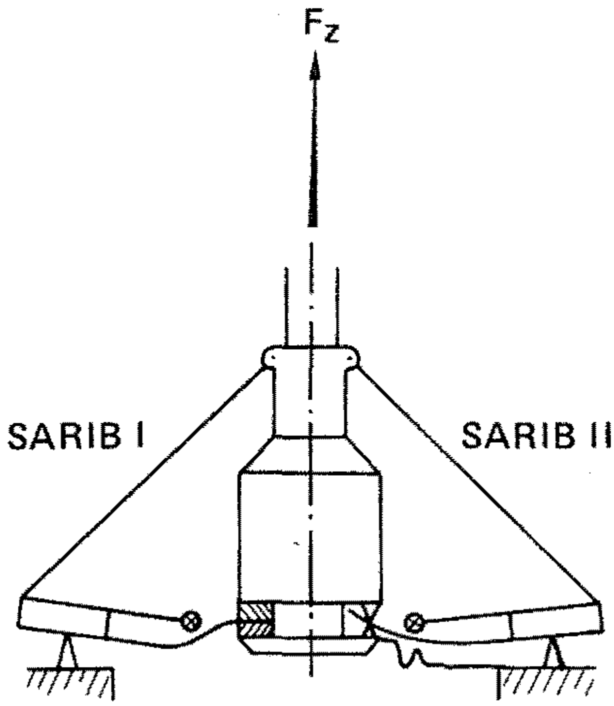


Fig. 4 : MODE SHAPE UNDER F_Z LOAD

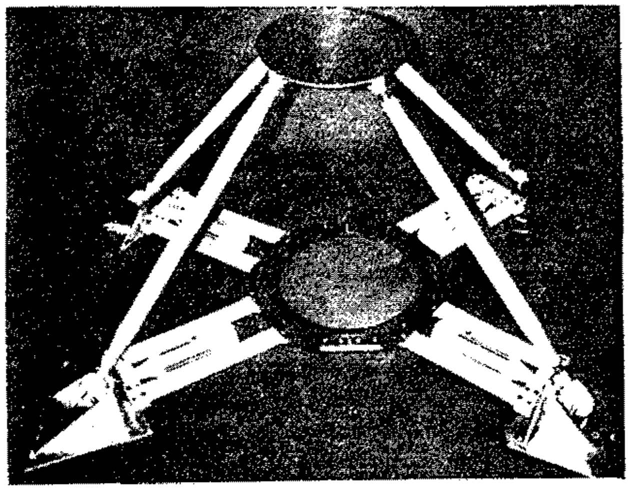


Fig. 6 : SARIB I ASSEMBLY (not mounted on MGB)

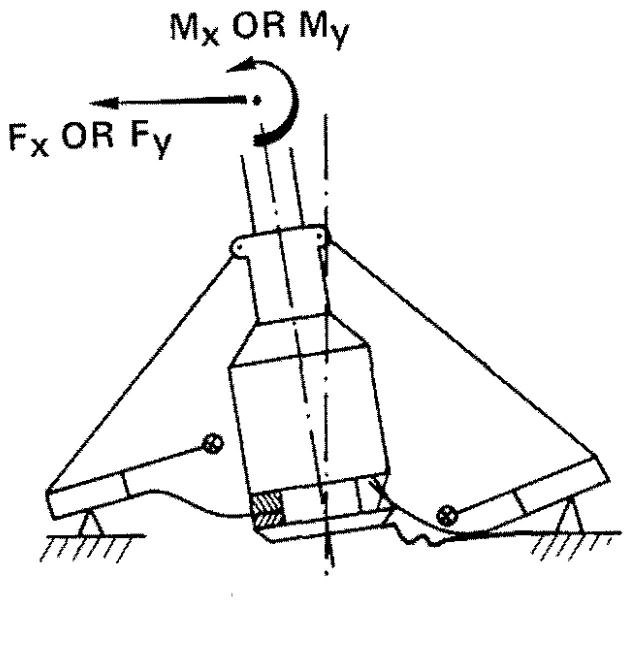


Fig. 5 : MODE SHAPE UNDER MOMENT M_Y OR M_X OR LOAD F_X OR F_Y

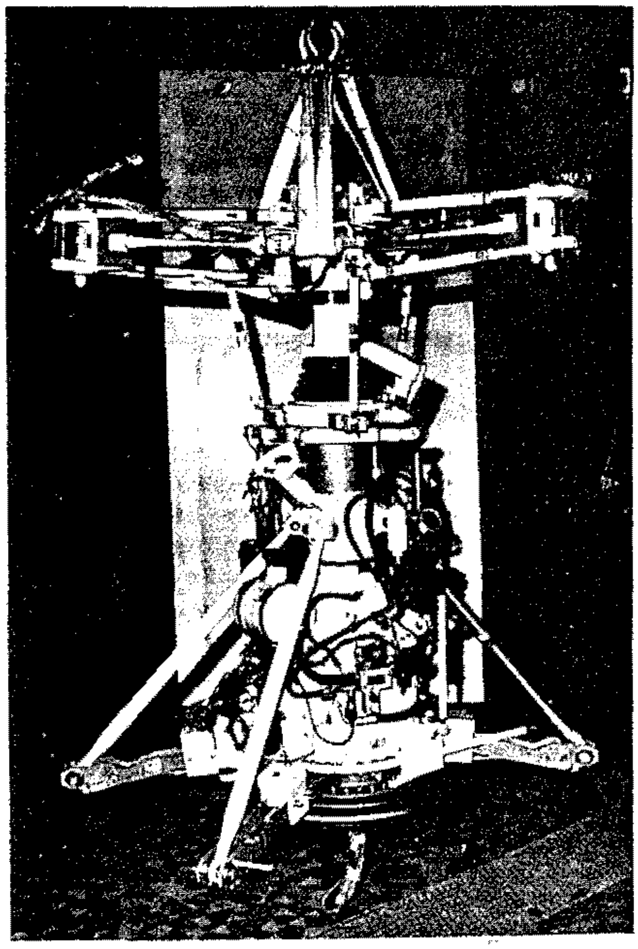


Fig. 7 : SARIB II ASSEMBLY (mounted on MGB)

- The necessity for finding a good compromise between the static stiffness of the system which has to be high enough to limit the movements of the gearbox to acceptable values, mainly at load factors, and the dynamic stiffness which must be sufficiently low to limit the effects of a rotor rpm variation on suspension adjustment ; these sensitivity effects are due to the closeness of the natural frequency of the SARIB suspension and the frequency to be damped.

- The necessity for obtaining a good adjustment criterion or compromise, since all Fz vertical loads and coplanar loads and moments (Fx, Fy, Mx, My) cannot be absorbed simultaneously. As a matter of fact, the adjustment values are lightly different. It will therefore be necessary to damp one type of load to the detriment of the other.

- The necessity for modifying the flight control linkage so as to prevent reinjection phenomena in the controls. These phenomena, originating from M.G.B. vertical movements, were encountered on first flight experiment on SARIB I and disappeared on SARIB II after embodiment of these modifications.

- The necessity for a good design of flexible leaves and of the boundary conditions to reduce the static and dynamic stresses within these leaves. This entailed transmitting the rotor torque through a flexible mounting plate below the gearbox in SARIB II version and eliminating flexible leaf restraining on M.G.B. end.

- The necessity for finding an industrial adjustment method for this absorbing system taking into account the normal manufacturing scatterings, fit tolerances and filtering sensitiveness of the system.

2.3 — Results : technical and economic advances

Further to the encouraging results from the theoretical study and feasibility study on model, the experiment of a SARIB type damping system has been conducted on a three blade AS 350 Ecureuil aircraft. It should be noted that this aircraft is currently equipped, as far as the production aircraft is concerned, with

i) a rotor head anti-vibrator,

ii) a bidirectional flexible mounting plate (BBQ) and

iii) two cabin anti-vibrators.

The objective to be attained for this experiment was to obtain a vibration level in cabin at least as good as or better than that of an aircraft equipped with these three damping systems while aiming at a significant weight saving and cost reduction of the vibration damping system installed.

At the present stage of the study and experiment, the following conclusions can be drawn :

— Laboratory tests

The laboratory tests on aircraft (Figure 8) allowed comparing tests and calculations and validating the theoretical model using finite element method developed on this occasion.

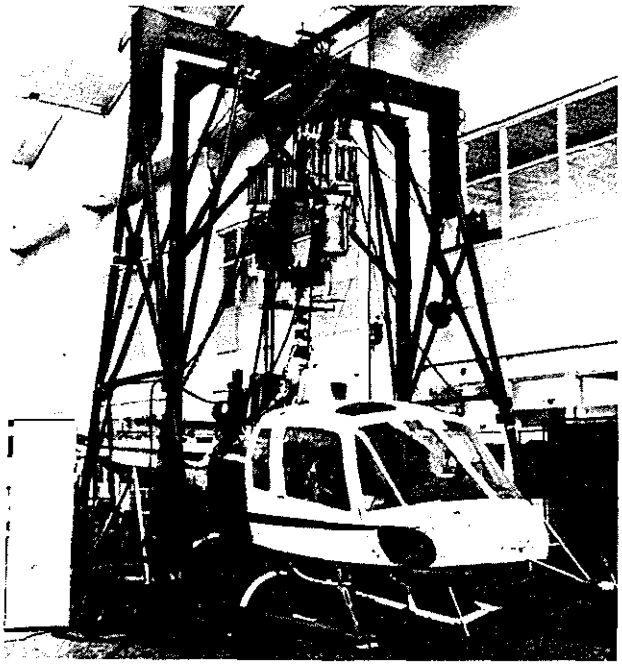


Fig. 8 : SARIB II VIBRATION ABSORBING SYSTEM LABORATORY TEST ON AS 350 AIRCRAFT 001

They were also used in determining the adjustments selected for the flight tests and in giving a more precise idea of the operating mode, sensitiveness and efficiency of such a damping system.

Figure 9 shows the acceleration levels as measured at copilot seat for two types of excitations at rotor head. It can be noted that the levels obtained with SARIB II absorbing system are better than those obtained with SARIB I. On this figure are also plotted the results obtained in a configuration where the SARIB I absorbing system was locked. It should be noted that the results are excellent for a vertical heaving excitation and they could further be improved for a torque excitation at rotor head.

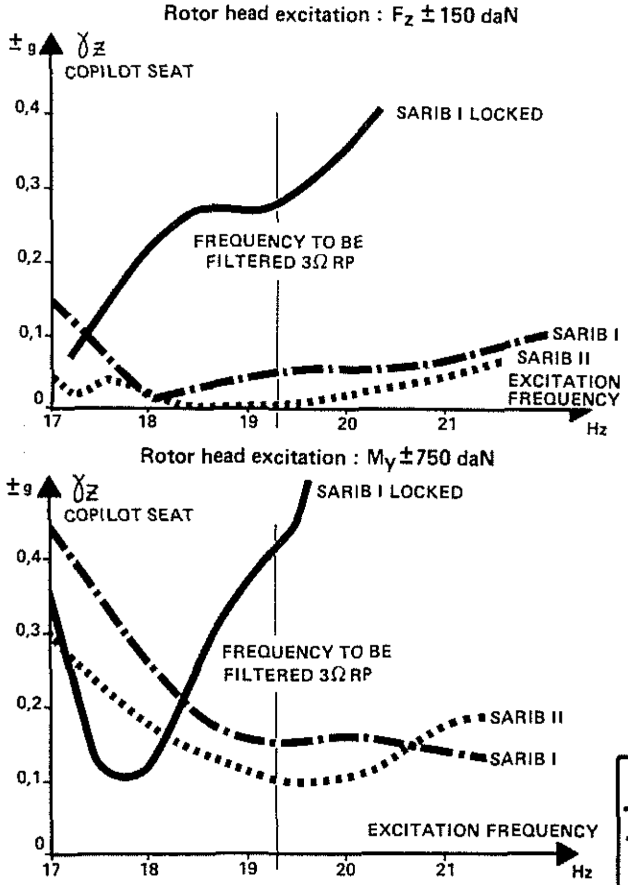


Fig. 9 : VIBRATION LABORATORY TEST ON AS 350 AIRCRAFT S/N 001

– **Flight tests** (Figures 10 and 11)

The in-flight experiment on SARIB I did not lead to any optimization process. The results obtained for the vibration level in cabin however proved interesting enough to carry on work.

The in-flight experiment on SARIB II is completed. The vibration level recorded up to maximum continuous power is as good as or better than that recorded with SARIB I and stays quite within the acceptance criterion set up for the current production aircraft.

In-flight upgrading allows the vibration level in cabin to be reduced below 0.1 g throughout the flight envelope. Therefore the first objective is already attained.

As to the stress measurements, the levels reached do not raise any problems even in the extreme centre-of-gravity location conditions.

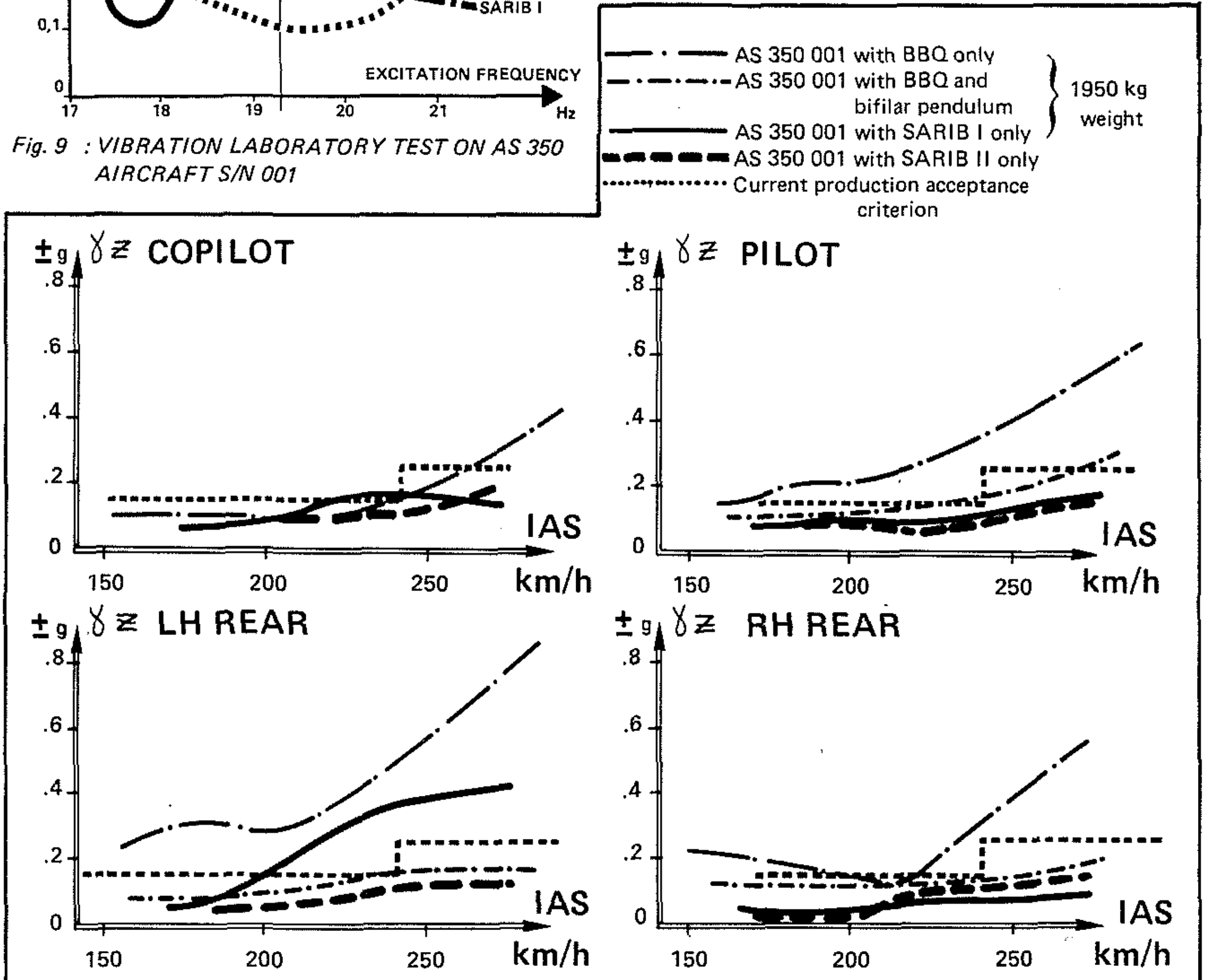


Fig. 10 : VIBRATION LEVEL IN CABIN - 3ΩRP
(AS 350 001 : LEVEL FLIGHT)

— **Weight breakdown**

The current total weight of the passive systems installed on a production AS 350 is 50.6 kg and includes the rotor head anti-vibrator, the barbecue and the two cabin anti-vibrators,

The SARIB II version experimented in flight which was not designed to the weight saving goal, weighs 48.6 kg.

A weight saving study for industrialization of the SARIB II damping system estimates this weight to 32.2 kg.

Improvements regarding the relative position of load pick-up points are under way, which would allow an additional weight saving of 2 kg approximately.

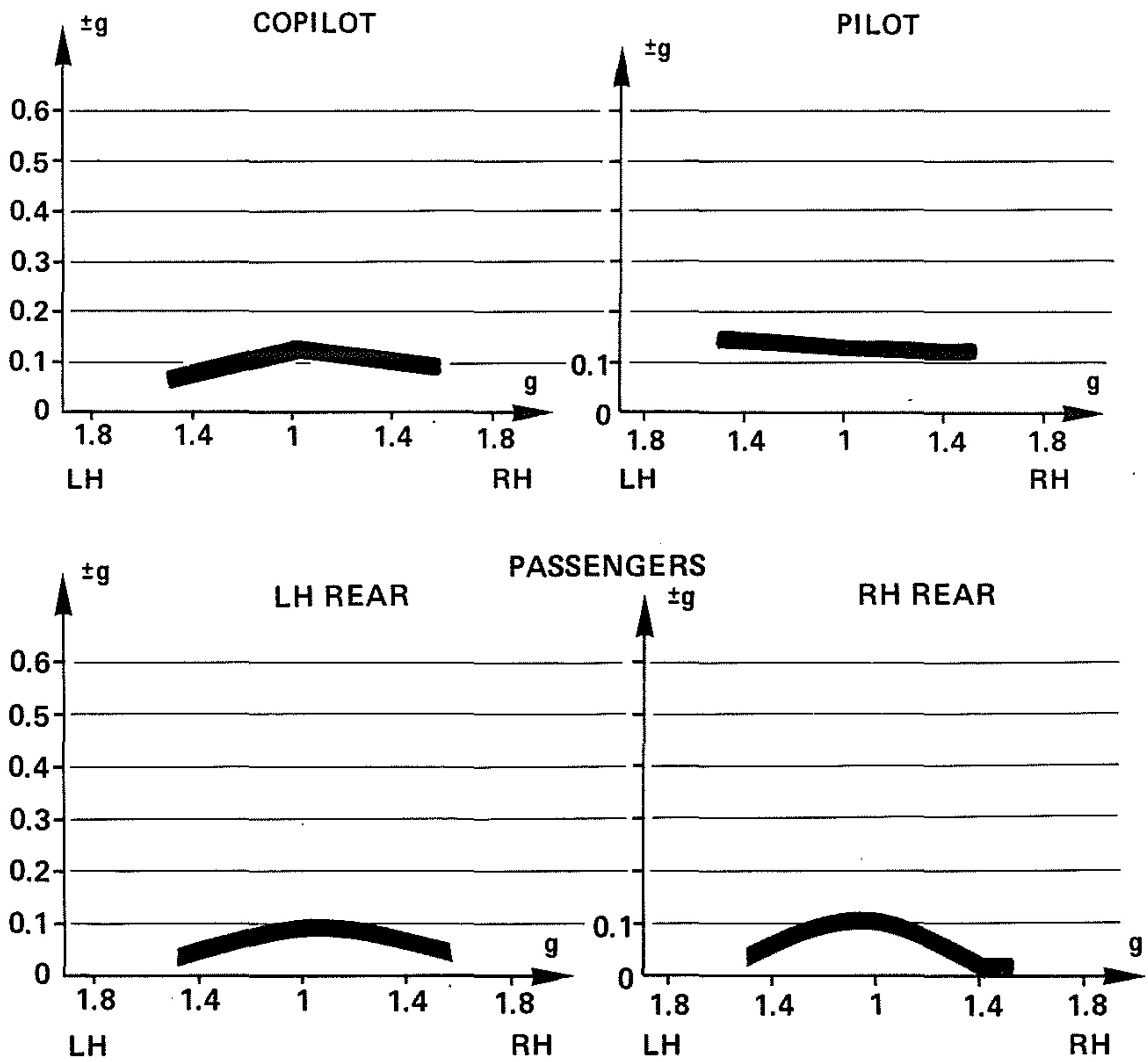


Fig. 11 : 3 VIBRATION LEVEL IN CABIN VS LOAD FACTOR (AS 350 001 - WITH SARIB II - IAS 120 kts)

	PRODUCTION AS 350 CURRENT SYSTEMS	AS 350 PROTOTYPE SARIB II	AS 350 PRODUCTION AIRCRAFT SARIB II
Weight of absorbing systems	50.6 kg	48.6 kg	32.2 kg
% of weight of absorbing systems as compared to empty weight (1045 kg)	4.8 %	4.6 %	3.1 %
Weight difference with respect to the production version		2.0 kg	18.4 kg
% of difference as compared to aircraft empty weight		0.2 %	1.8 %

A SARIB II absorbing system designed for industrialization on the AS 350 therefore allows to save 18 to 20 kg. i.e. 2 % of the empty weight approximately.

– **Cost**

A preliminary comparative study of the cost of detail parts, assembly time, installation on aircraft and adjustment time showed that the cost of a SARIB II type damping system as fitted to an AS 350 should be equivalent to that of the damping systems currently installed on this family of aircraft. A more comprehensive industrialization study shows a quite lower cost (on the order of 20 to 30 %).

2.4 – Looking to the future

Installation of SARIB system on a four-blade aircraft

The system studied herein covers a three-blade aircraft.

As for a four-blade aircraft this system becomes lighter because of the lower weight of the resonators required for vibration filtering. In fact, since the excitation frequency is higher, the resonator weight required to provide the same dynamic load is lower for a given amplitude of displacement of the resonators. This weight is conversely proportional to the frequency square.

Moreover, the dynamic stiffness of leaves must be higher, which facilitates obtaining a compromise between the static and dynamic stiffnesses.

3– CONCLUSION

Evaluating the SARIB absorbing systems raises the following remarks :

- The SARIB is an absorbing system which very efficiently absorbs the vibrations.
- The static and dynamic dimensioning compromise for a leaf-type passive system can be obtained in the difficult case of a three-blade rotor and is facilitated for rotors with four blades or more.
- The SARIB concept easily permits technological improvements of any type such as the use of new materials in leaves, activation, use of fluidic resonator, etc ...
- In its roughest version, the concept leads to a cheap, simple absorbing system, not requiring any maintenance on low-and medium-weight aircraft ($\leqslant$ 4 T) and which thus shows very attractive.
- It does not show impeding sensitiveness to scatterings such as rotor speed changes, operation with high deformation (load factor) providing the dimensioning is properly achieved.