# HELICOPTER VIBRATIONS: A MAJOR COMFORT IMPROVEMENT THROUGH SEAT SARIB® IMPLEMENTATION

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**Abstract**
In response to current vibration regulations and driven by the wish to further improve the comfort on helicopter seats, Airbus Helicopters and its partner Dynalya have seized the opportunity to develop a mechanical anti-vibration device called "Seat SARIB®". This passive device is fitted at the interface between the floor and the seat and is dedicated to the vertical b/rev vibration filtering on the entire nominal frequency range of a rotorcraft and it is independent of the passenger weight. The system offers a vibration attenuation of more than 10dB while only adding only 2-3kg of weight per seat. The development, tuning and testing of this system are detailed in this article, as well as the certification methodology deployed in order for our customer to benefit from this new comfort improvement. The Seat SARIB® has been certified by the European Aviation Safety Agency (EASA) in October 2017 for the cockpit seats of the Airbus H145 rotorcraft.

## NOTATIONS

*AVCS :* Active Vibration Control System
*b/rev (Hz) :* Frequency defined by multiplying b the number of blades of the main rotor by the main rotor rotation rate in Hz.
*SARIB*: Anti-vibration System with Resonators Integrated in the [MGB] Bars
*X :* longitudinal axis
*Y :* lateral axis
*Z :* vertical axis
*K :* Stiffness
$\lambda$ : Amplification factor

## 1. OBJECTIVES AND CHALLENGES

### 1.1. Introduction

Nowadays, customers are more and more sensitive to vibrations. One influencing factor are several regulations and directives such as the EU Directive [1] which aims at ensuring that workers are exposed to reasonable vibration levels and which can be quite challenging for helicopters certified in the last decades.

Today the common answer for helicopter manufacturers to improve the vibration comfort is the AVCS (Active Vibration Control System). This system generates at the helicopter floor level a vibrations field opposite to the primary structural vibrations field induced by the main rotor, and therefore attenuates the vibration levels transmitted from the floor.

The AVCS is optimized to reduce vibrations for the whole cabin to a good to very good level. The backsides are high integration efforts, power consumption, maintenance efforts and significant weight addition. In addition to this global solution and in the aim of creating a brand new standard for vibration comfort on helicopters – and if possible to reach a "plane type" feeling locally – Airbus Helicopters, through a part of the French national research project named "CAMELIA" has chosen to act at a more local level, meaning at the interface between the floor and the seat.

### 1.2. Objectives

The objectives of the development of this local floor/seat interface system are therefore to decrease locally and significantly the vibrations transmitted to the passengers through the seat. In addition, the cost, weight, maintenance needs, electrical consumption, ease of integration and retrofit of such an anti-vibration device will have to coherent with the constraints of our customer's everyday missions.



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### 1.3. Elastomeric bearings seat suspension solution analysis

The classic solution for solving vibration problems on seats is to put flexibility between the seat and the floor as on seats for truck drivers.

Unfortunately, this solution is not applicable in the case of the helicopter for several reasons:

First of all, in order to be effective in a frequency range from 15 to 30Hz the suspension has to have a resonance frequency lower than 8Hz which requires extremely soft springs and large static strokes in order to cover passenger mass variations and a load factor of 2g.

For example a suspension with a resonance frequency set at 8Hz for a 50kg passenger will require a total travel of 190mm for a 120kg passenger which is incompatible with the height of a helicopter cabin. Therefore, an active load compensation system is required to keep the seat always in the same position whatever the passenger and flight conditions.

Secondly, there is an important scattering to consider among passenger's morphology. For an anti-vibration device for which the b/rev frequency is expected to be filtered (priority on most of the helicopters), the tuning of the system is modified based on the various inertial characteristics of the passengers, depending on the chosen concept. Therefore the performance will strongly vary in this case.

Finally, each movement of the passenger on its seat or flight turbulence excites the suspension mode, risks to make come in end stop the suspension and to create a shock. A soft guidance, and globally a classical suspension are therefore not adapted to the helicopter seats.

### 1.4. Semi-active and active solutions

To be able to cover the variability of morphology and nominal regime imposed to a seat suspension, the use of more complex solutions such as semi-active or active solution could seem adapted. This opportunity has been considered and analysed in the light of their maturity on rotorcraft, the additional weight impact, their impact on the ergonomics, their potential impact on the electrical consumption of the aircraft, their safety aspects, their potential impact on inertial loads and their development lead-time.

As a result, regarding our special development objectives presented in §1.2, the semi-active and active solutions have not been favoured as prime solution, but have been kept as a second option.

### 1.5. Tuned mass dampers

Another option in the search for simplicity would be to add a resonator (spring and mass) tuned on the b/rev to absorb the vibration levels. However most of Airbus Helicopters aircrafts have today a wide nominal regime law (up to 4Hz variation on the b/rev) and thus would not be compatible with a basic resonator whose effective resonance frequency range is less than 1Hz wide.

### 1.6. Inertial resonators

The inertial resonator consists of a spring mounted in parallel of a mass whose movement is amplified by a lever arm (Figure 1).

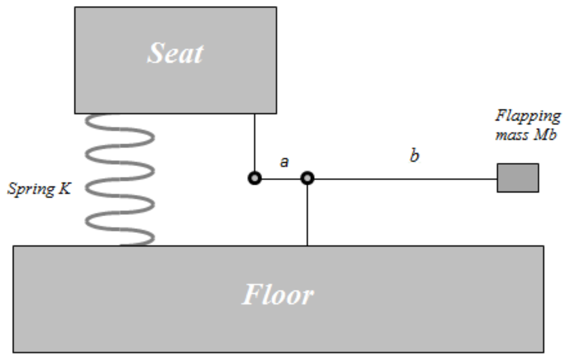


*Figure 1: Seat SARIB® schematical functioning*

At the upper and lower joints of the assembly, the forces of the spring and the mass are added in phase opposition. The spring force is frequency-independent while the force of the amplified mass varies with the square of the frequency.



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So at a particular frequency ω (see equation (1)) called anti-resonance the forces cancel each other out creating a total dynamic decoupling.

$$(1)\quad \omega = \sqrt{\frac{K}{M_b \lambda(\lambda - 1)}} \text{ where } \lambda = \frac{b}{a}$$

This anti-resonance has very interesting characteristics for a seat suspension. On the one hand, it is totally independent of the masses and the dynamic responses of the assemblies it links; in particular of the seat and passenger masses, which is a very interesting property in the case of this study. On the other hand, it is characterized only by the stiffness of the spring, the amplification of the lever arm and the oscillating mass, so very stiff springs can be used to limit static deformation.

That is the reason why the inertial resonator solution called SARIB® has seemed more appropriate to the seat challenges.

### 1.7. Choice of the SARIB® solution

The properties of the inertial resonators and in particular of the SARIB® are fully coherent with the objectives and the challenges of the system described in the previous paragraphs.

Airbus Helicopters has a huge background using inertial resonator with the device called SARIB® used for many years on Tiger and NH90, and recently in new applications see Reference [6]. The challenge was to adapt and miniaturize the SARIB® concept to the specific constraints of a seat. These constraints are mainly a low height and short static travel to maintain an acceptable clearance between the top of the head and the cabin roof, a high pitch and roll stiffness to avoid unwanted modes and to prevent the seat from tipping over (when a passenger grabs into the cabin, for example) and last but not least to withstand crash loads as well as the seat alone. These architectures have been patented through Reference [8] and Reference [9].

## 2. FROM A CONCEPT TO A FLYABLE PROTOTYPE

### 2.1. Proof of concept development

#### 2.1.1. Description of the first prototype

A first prototype was made to check the behavior of the seat SARIB®.

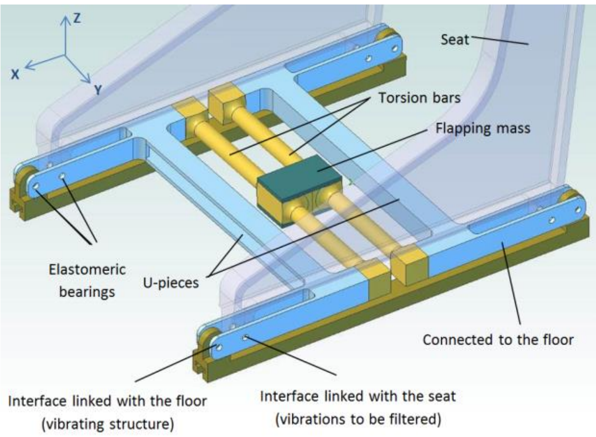


*Figure 2: First prototype design*

It consists of 2 symmetrical U-pieces with hinge bearings at the end of the U-arms. The first bearing is connected to the vibrating structure and the other bearing is connected to the structure whose vibrations have to be filtered.

The central part of these U-shaped parts represents the SARIB®'s flapping mass and the arms the amplification lever. 2 torsion bars connected together by their center represent the stiffness K. This is therefore an illustration of the classic architecture of a SARIB® in a particular configuration that combines both the filtering function and vertical guidance and that permits to use the springs as a part of the tuning mass.

On the one hand, under the effect of a vertical movement the torsion moments of the bars are balanced and create anti-resonance by combining with the dynamic forces of the mass.

On the other hand, the suspension has a very high stiffness around the X and Y axes in order to avoid tilting.

Around X this stiffness is ensured by the important bending and torsion inertia of the central part of the U and around Y it is ensured by the bending stiffness of the torsion bars amplified by the lever arms.



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### 2.1.2. First loaded test

The first tests were carried out on a shaker with simple centered masses in order to verify the attenuation performance in Z with a rigid structure.

*Figure 3: First protype of seat sarib with mass on shaker*

As shown by Figure 4, this test confirms that attenuation performances are mass independent. Moreover, a very wide bandwidth for attenuation (here above 20Hz the system attenuates) is observed, which validates the simulation results and corroborates the interest of the SARIB® in the frame of a variable nominal regime.

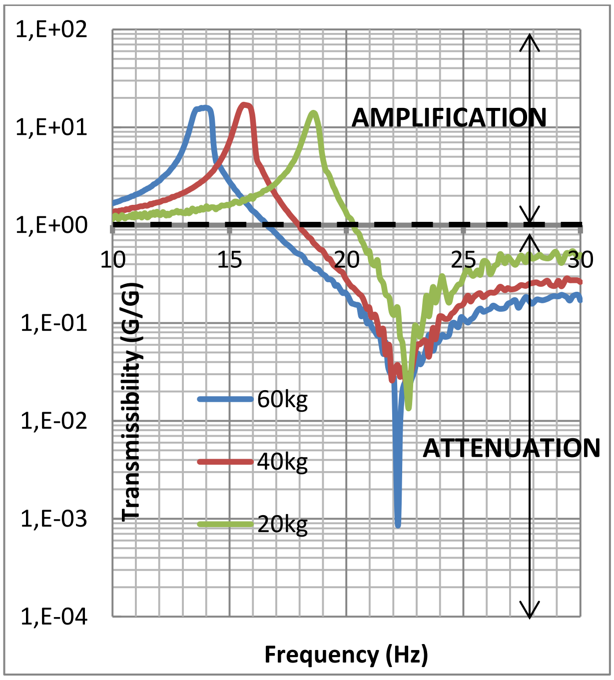


*Figure 4: Transmissibility between shaker and mass for different masses*

The testing of an off-centered mass on the seat shows that the behavior illustrated Figure 4 is not impacted, proving that the Z-guide works correctly.

### 2.1.3. Test with B/E aerospace H160 seat

Tests continued with a real helicopter seat equipped with ballast in order to check the behavior under real conditions introducing the free play and stiffness of the foams and the seat structure.

*Figure 5: First prototype of seat sarib with Fisher H160 seat and ballasts*

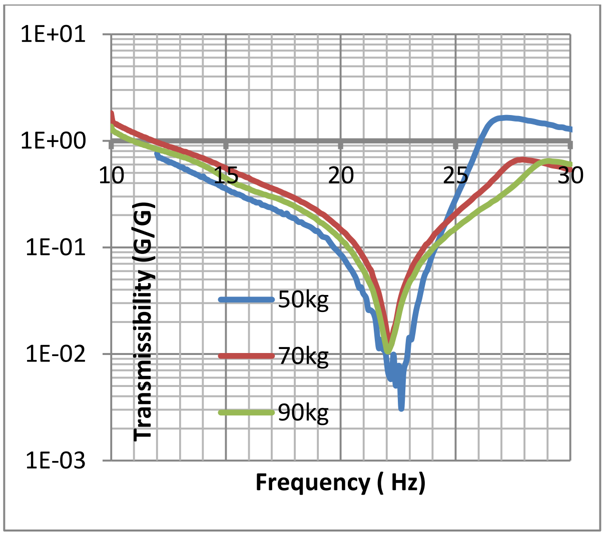


*Figure 6: Transmissibility between shaker and seat cushion for different weight of ballast*

The behavior is similar to the one measured with a rigid mass and it shows that the SARIB seat is insensitive to the dynamic response of the seat. However, a mode around 28Hz appears on the curves on Figure 6. A detailed analysis shows it is a rotational movement around Y due to the flexibility of the elastomer bearings.



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### 2.1.4. Conclusion of the test campaign on the first prototype

These initial tests have showed the impressive performance reached with a seat SARIB® not yet optimized and the potential for evolution of this system.

Furthermore, these tests permitted to identify two ways of improving the design:

- Implementation of cylindrical torsion bars complicates a lot the design and the assembly,
- The elastomer bearings used are too flexible radially which creates parasitic modes and reduces the efficiency of the amplification lever arm.

## 2.2. Flyable prototype

Following the very promising results of the first prototype, the next step has been to design a flyable version in order to check the behavior in flight, and thus add the influence of a real helicopter structure.

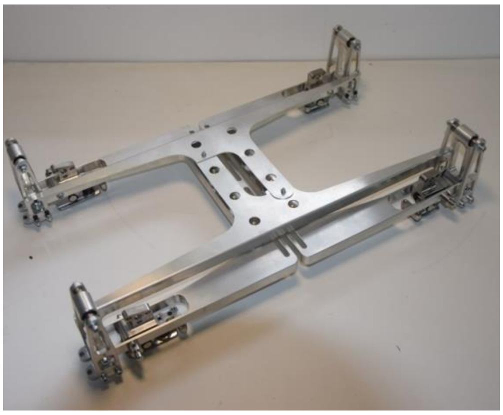

*Figure 7: XYZ flyable seat suspension*

The major improvements are the following ones:

### 2.2.1. New elastomeric bearing

The elastomer bearings have been replaced by Paulstra industrial bearings. These bearings, produced in very large quantities, offer perfectly matching properties and are an efficient low cost solution.

The chosen bearing has a radial stiffness higher than 20000N/mm guaranteeing a high frequency mode around Y.

An interesting point is that the particular arrangement of the torsion springs of the seat SARIB® induces that, at the anti-resonance, the dynamic forces of the springs and masses cancel each other out in the central part of the SARIB®. In this way, the bearings do not see any radial dynamic force which substantially increases their estimated life time.

### 2.2.2. One piece mass spring assembly

The design of the central part has been considerably simplified by replacing the U and torsion bars by a one-piece part in aluminum 7175 T851 integrating all functions.

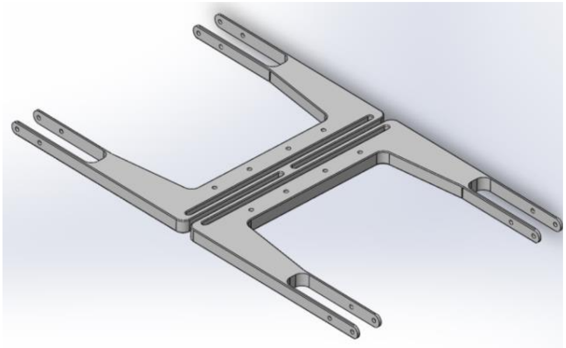

*Figure 8: Mass spring one piece assembly*

The cylindrical torsion bars are now aluminum blades that also work in torsion. The use of aluminum to make springs is unconventional but calculations in fatigue shows that they are largely oversized in the case of seat SARIB®.

### 2.2.3. Coplanar suspension

In order to achieve a suspension totally isolating the passenger from the vibratory environment, a suspension to filter the coplanar vibrations X and Y has been added to the seat SARIB®.

It is a pendulum suspension patented by Airbus Helicopters (see Reference [7]) which suspends each direction of the seat feet thanks to a link with a ball joint at each tip, here made of elastomer bearings. The advantage of using this pendulum suspension is that it is totally independent of the mass of the passenger, that it allows to obtain attenuation at very low frequency in a reduced space and that it is automatically centered.



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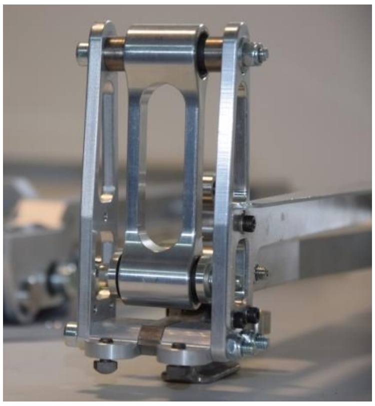

*Figure 9: Coplanar suspension link*

### 2.2.4. Anti-crash stops

In order to be able to certify this suspension, anti-crash stops have been added.

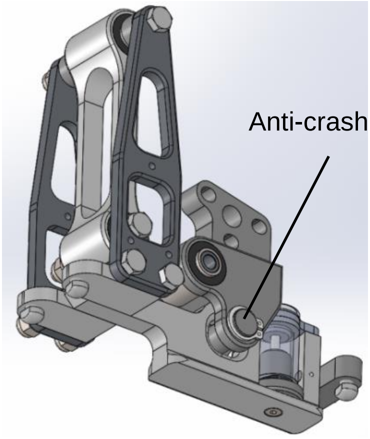


*Figure 10: Position of crash pins on suspension foot*

It is made of 17-4Ph stainless steel pins passing through an elongated hole located in the foot of the suspension and allowing the vertical displacement of the suspension for a 120kg person under a load factor of 2g before the mechanical stop is reached.

They can withstand a 10° rotation around the longitudinal axis in order to pass the floor deformation simulation required by the certification tests.

They are installed directly below the current seat feet in order to have the most direct possible load path and to avoid the introduction of a bending moment in the suspension.

### 2.2.5. Prototype Vibration Bench tests

The suspension and a B/E Aerospace seat H160 have been submitted at bench to frequency sweepings with people of different height, weight and morphology.

The following recorded curves illustrates that the vibrations at the level of the seat cushion are strongly attenuated at the anti-resonance (25Hz) with a bandwidth of several hertz whatever the passenger with only a little less efficiency for the light weight people.

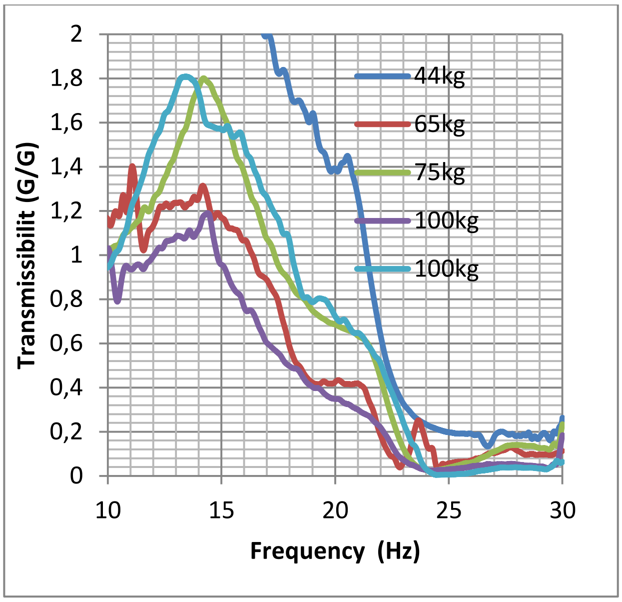


*Figure 11: Transmissibility between floor and seat cushion for several physionomy of passengers*

### 2.2.6. Prototype Vibration flight tests

After the demonstration performed at bench, the decision was made to test the prototype seat SARIB® in flight on an AH aircraft. The vertical vibration levels measured are presented Figure 12.

The seat equipped with SARIB® shows particularly low b/rev levels among the vertical (Z) axis whatever the flight phases. The vibrations are reduced by 70 to 80% on all the flight phases and sometimes more, to achieve a nearly constant level on the seat whatever the floor level.

These data have been correlated with the feedback from the crew, who rated as exceptional the level of comfort achieved on a SARIB®-equipped helicopter seat. They demonstrate that the performance expected after bench tests is still observed in flight.



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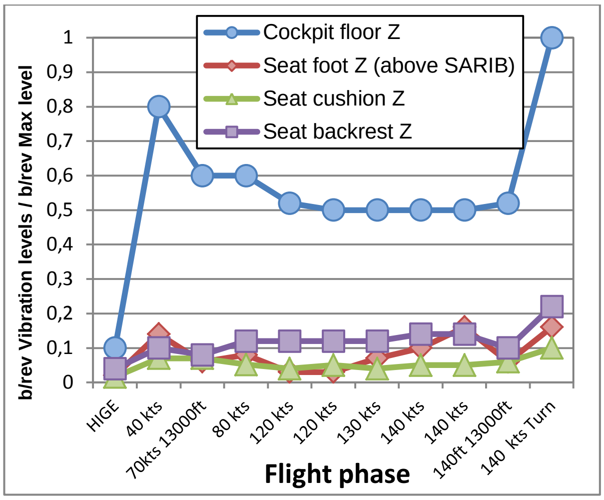


*Figure 12: Flight tests results – prototype version*

The opportunity has been grasped to test the prototype SARIB® on several other aircrafts of the Airbus Helicopters range. Similar quantitative and qualitative results have been reached on the b/rev at the same time from the measurements and the crew.

## 3. H145 SERIAL DESIGN

Given the success of the first flying prototypes, the opportunity has arisen to serialize this comfort-improving concept and to certify it for the first time on AH range on the cockpit seats of the H145. The challenge here is to keep the performance of the SARIB® while permitting a nearly transparent integration on the H145 cockpit.

### 3.1. Project requirements

The seat change (B/E Aerospace H140 seat for the H145 versus B/E Aerospace H160 for the prototypes) has been the base of the global modifications brought to the design.

The most important constraint for the design is the height limitation in the H145s cockpit. The usability for large pilots with helmets must not be altered compared to the original configuration. Any restriction of the seats longitudinal adjustment range and any interference with optional equipment have to be avoided. Furthermore, a retrofit has to be possible for each customer without difficulties.

The certification is based on the requirements applicable for the H145 helicopter, the CS29 [2] and the H140 seat requirements according to ETSO C127 [3].

### 3.2. The Function Breakdown

Based on the principal dimensions of the SARIB® a detailed functional breakdown was performed. For a highly integrated system as described here, several design iterations were required to reach a feasible solution which fulfils all requirements and constraints.

Two basic functions can be distinguished: the anti-vibration function and the load path in non-normal flight conditions.

The following sections will go into the details for each category.

#### 3.2.1. Anti-Vibration System and integration

The required height limitation is the design driver of the SARIB® in this case.

The central “H-shaped” part has been compacted between the feet, in front of the feet and at the rear part of the foot, while removing the sliding parts of the seat. This is fully adapted to B/E Aerospace H140 architecture. Moreover, associated with the abandonment of the longitudinal axis filtering which is not pertinent on the H145, it brings the height offset due to the seat SARIB® integration to an insignificant level of 3mm instead of 30mm with the previous configuration.

In parallel, the decision has been made to limit as much as possible the impact of the SARIB® integration on the seat. This reduces the risks of modifying an unknown structure and enables an easy retrofit.

In parallel the shapes of the SARIB® feet have been adapted to allow the longitudinal translation, reproducing the sliding part in the rail and the locking mechanism (longitudinal locking system). The length of the sliding part has been reduced to be adapted to the H145 rails length on all the permitted range and to avoid any interference with H145s optional equipment.

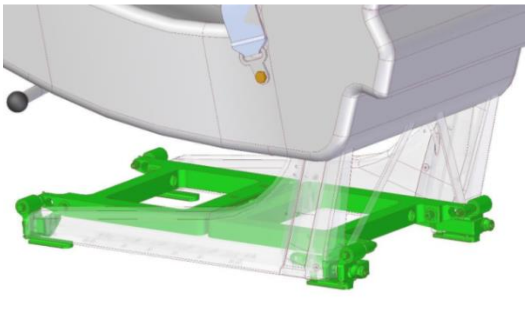

*Figure 13: Seat SARIB® on a Fisher H140 seat*



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#### 3.2.2. Load Path for non-normal flight conditions

The Anti-Vibration system is bypassed in the event of high loads in non-normal flight conditions. This includes both high-g-manoeuvres and crash conditions as required by the regulation.

In normal flight conditions the seat and occupant are supported by the H-shaped part and in this case the SARIB® is reducing vibrations as intended. The necessary movement between floor and seat is possible due to an elongated hole in the foot. If the loads reach a higher level, approximately at 2g vertical acceleration, the so called crash pin reaches its end stop in the elongated hole and the original direct load path is restored. The main dimensions of the load path are unchanged compared to the original seat foot design.

This design offers several advantages, the SARIB® is not load carrying in high load conditions, the crash pin is isolated from oscillating loads and the original seat dimensions have not been modified.

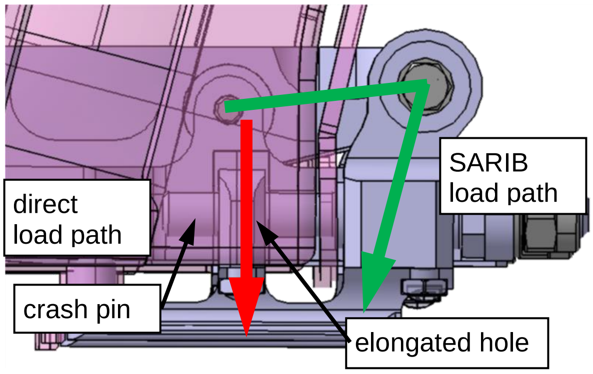


*Figure 14: Load paths in the rear foot assembly*

The forward foot design is different from the rearward foot design, because the original foot attachment did not allow a design as shown in Figure 14. In high load conditions only compression loads can be transferred. As a consequence, the H140 seat equipped with SARIB® lost its backward facing installation option available for the unmodified seat.

### 3.3. Stress and design

The actual design of the modification was driven by the high number of interfaces toward the seat and the SARIB® parts itself. The compact design furthermore required complex parts whose manufacturing details have to be considered, too. This additional constraints and some late design modifications after testing were challenging, but within the normal scope of a serialisation of a new concept.

Although testing was foreseen, a detailed stress analysis was performed in advance to validate the design choices, supporting and driving design iterations. The analysis focused on the direct load path, because the H-part is not loaded in relevant stress conditions. This eased the calculation efforts significantly, although the effort due to the many moving interfaces was high. Further similar designs will benefit from the experience gained in this project.

The materials used are aluminium for low loaded parts like the components of the SARIB®, while the crash pin and the feet are made of steel.

## 4. CERTIFICATION

The design must be compliant with all relevant airworthiness paragraphs. Because the SARIB® is a new development, no perfectly fitting reference existed. Therefore no analytical certification approach was applicable and testing was mandatory.

Current modifications to seat designs are either rigid adapters or swivel units. They can be integral part of the seat or are mounted between seat feet and seat track on the helicopter floor. Depending on this, the parts can be considered part of floor or seat.

A floor has only to comply with CS29.561 [2], for with compliance can be shown by analysis, if sufficient experience can be shown towards the authorities.
In addition modified seats also need to fulfil CS29.562 [2], which requires dynamic testing including floor warpage.

The design in this case is highly integrated into the seat, to save precious height. Therefore, the SARIB® replaces the original seat foot. Because of this; the ETSO certification of the seat is not valid anymore.

An affected area assessment leads to the conclusion that both paragraphs are applicable and have to be shown by test whereas other requirements of the applicable ETSO C127 [3] remain unaffected and no dedicated efforts were required. This approach was agreed with the authorities in advance.

This not only meant significant test efforts, but also added the requirement, that the whole SARIB® device must be able to follow the floor



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deformation without excessive force, as stated in the Advisory Circular [4].

### 4.1. Requirements

All seats installed in helicopters must be tested with a floor deformation according to Figure 15. In short one seat track has to be rolled 10° while simultaneously the other side has to be pitched 10°. The combination of movements has to be the most critical one. Because the seat without SARIB® had been already certified; the deformation was selected as in the original certification.

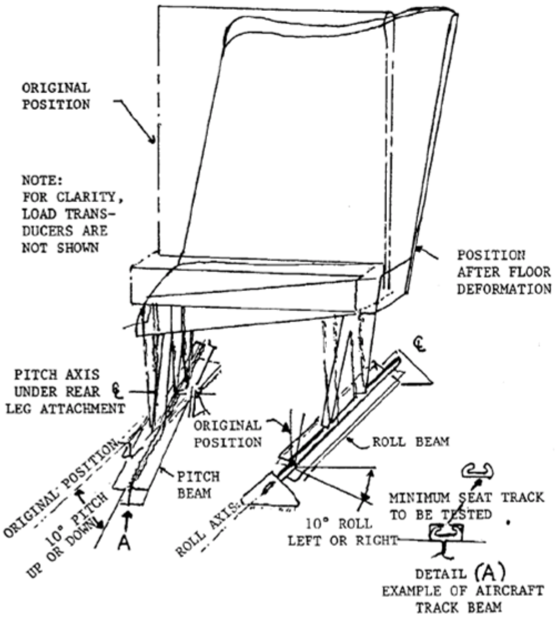
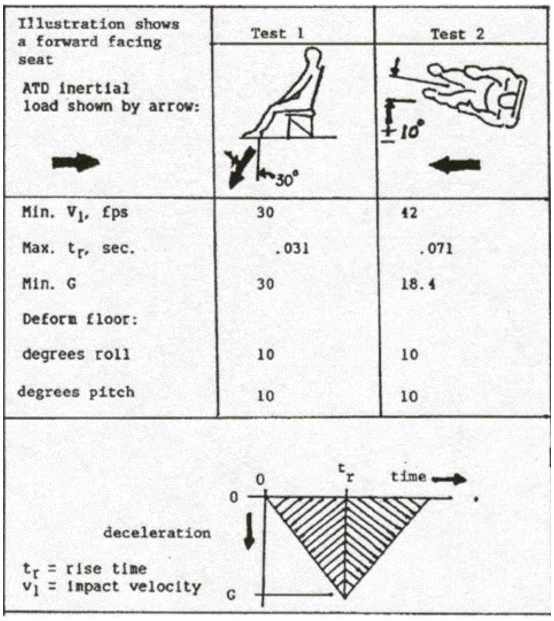



*Figure 15: Schematic Floor Deformation Fixture; Seat Legs Attached at Floor Level [AC 29.562]*

The static tests required by CS29.561 b(3) (Reference [2]) are ultimate loads and must show the following load factors:

- (i) Upward – 4 g
- (ii) Forward – 16 g
- (iii) Sideward – 8 g
- (iv) Downward – 20g, after the intended displacement of the seat device
- (v) Rearward – 1.5 g.

CS29.562 b(1) and b(2) [2] require two tests as shown in Figure 16.
The goal of test 1 is mainly focusing on the "…impact load component along the spinal column of the occupant…"
Test 2 focuses on "…the protection provided in an impact where the predominant impact load component is in the longitudinal direction in combination with a lateral component..." This test is most demanding for structural strength point of view, because loads on the feet are significantly higher under the required conditions. Of particular interest in this test is also if any changes are recorded with respect to the head travel curve.



| Illustration shows a forward facing seat<br>ATD inertial load shown by arrow: | Test 1 | Test 2 |
|---|---|---|
| Min. $V_1$, fps | 30 | 42 |
| Max. $t_r$, sec. | .031 | .071 |
| Min. G | 30 | 18.4 |
| Deform floor: | | |
| degrees roll | 10 | 10 |
| degrees pitch | 10 | 10 |



*Figure 16: Seat Restraint System Dynamic Test [AC 29.562]*

### 4.2. Static Testing

During the preparation of the static tests the floor deformation was applied the first time. In contrast to the expectations the elastomeric bearings had an unexpected advantage, by absorbing the floor deformation and thus effectively decoupling the anti-vibration parts form the main load path.
Predetermined breaking points in the H-part could be removed for the serial configuration (see Figure 17).

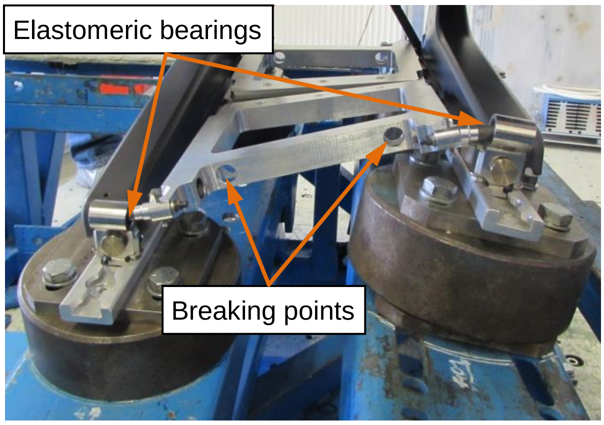



*Figure 17: Floor deformation with H140 seat and SARIB®*



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The load application was without any issues and the tests were passed with no deviations from the seats original testing. The design of the SARIB® with the two load paths worked as expected.

### 4.3. Dynamic Testing

Dynamic tests are well known for causing certification issues by the unavoidable scatter between the tests. This scatter is due to the large number of possible small variations and to certain extends chaotic movement of the dummy.

The 18.4g forward dynamic test (see Figure 18) proved the strength of the seat design was not altered with the SARIB, but the head travel curve had to slightly adjusted. If this is due to the scatter of a systematic change could not be clarified.

The 30g downward test (see Figure 19) showed only a minor deviation in the lumbar load, which is probably due to the scatter as well.

As a conclusion both static and dynamic tests were conducted without any difficulties and required no design changes.

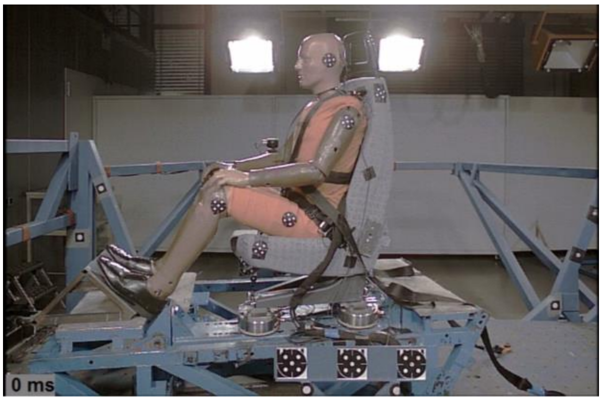


*Figure 18: Dynamic Testing 18.4g forward*

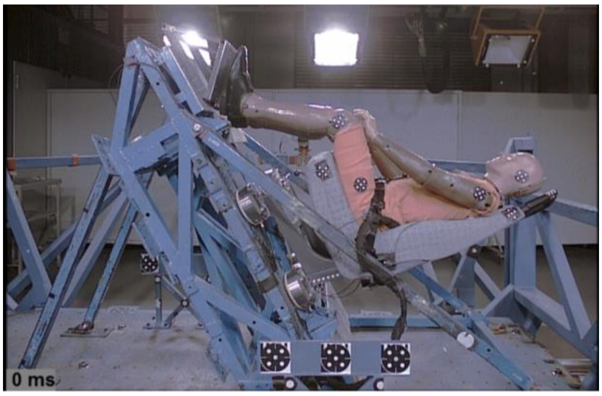


*Figure 19: Dynamic Testing 30g downward*

### 4.4. Vibration Bench testing

Once all the constraints taken into account on an ergonomic (see §3.1) and stress (see §3.3) point of view, some vibration bench tests have been performed to tune the system for an optimal functioning on the H145 b/rev range and check its performance.

The bench tests mostly consisted in vertical frequency sweepings between 10 and 35Hz aiming at identifying the SARIB® transfer functions in various configurations (loads, longitudinal tuning). An accelerometer has been put on the bench for input level measurement and an accelerometer has been put on the foot of the seat (circled in red Figure 20).

*Figure 20: Bench test instrumentation*

The transfer functions obtained are presented Figure 21. They confirm the expected behavior and remarkable performance of the seat SARIB® observed during the prototype phase: from -6,5dB to -16dB achieved on the seat compared to the floor on the whole operational b/rev range whatever the occupant.




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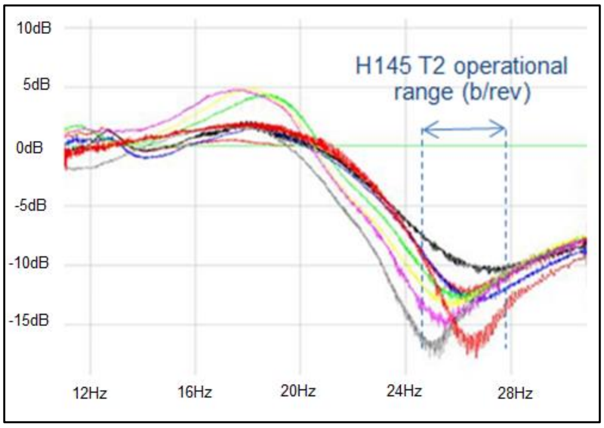


*Figure 21: Attenuation versus Frequenc for several morphologies (57kg, 80kg and 100kg) and longitudinal positions*

## 4.5. Vibration Flight testing

To confirm the bench tests conclusions in the real H145 environment and bring certification data to the vibration substantiation to FAR 29.251 and 29.1301-d [5], flight tests have been performed on cockpit seats equipped with seat SARIB®. Measurements of the floor level through classical accelerometers and of the cushion through seat pad accelerometers have been plotted Figure 22.

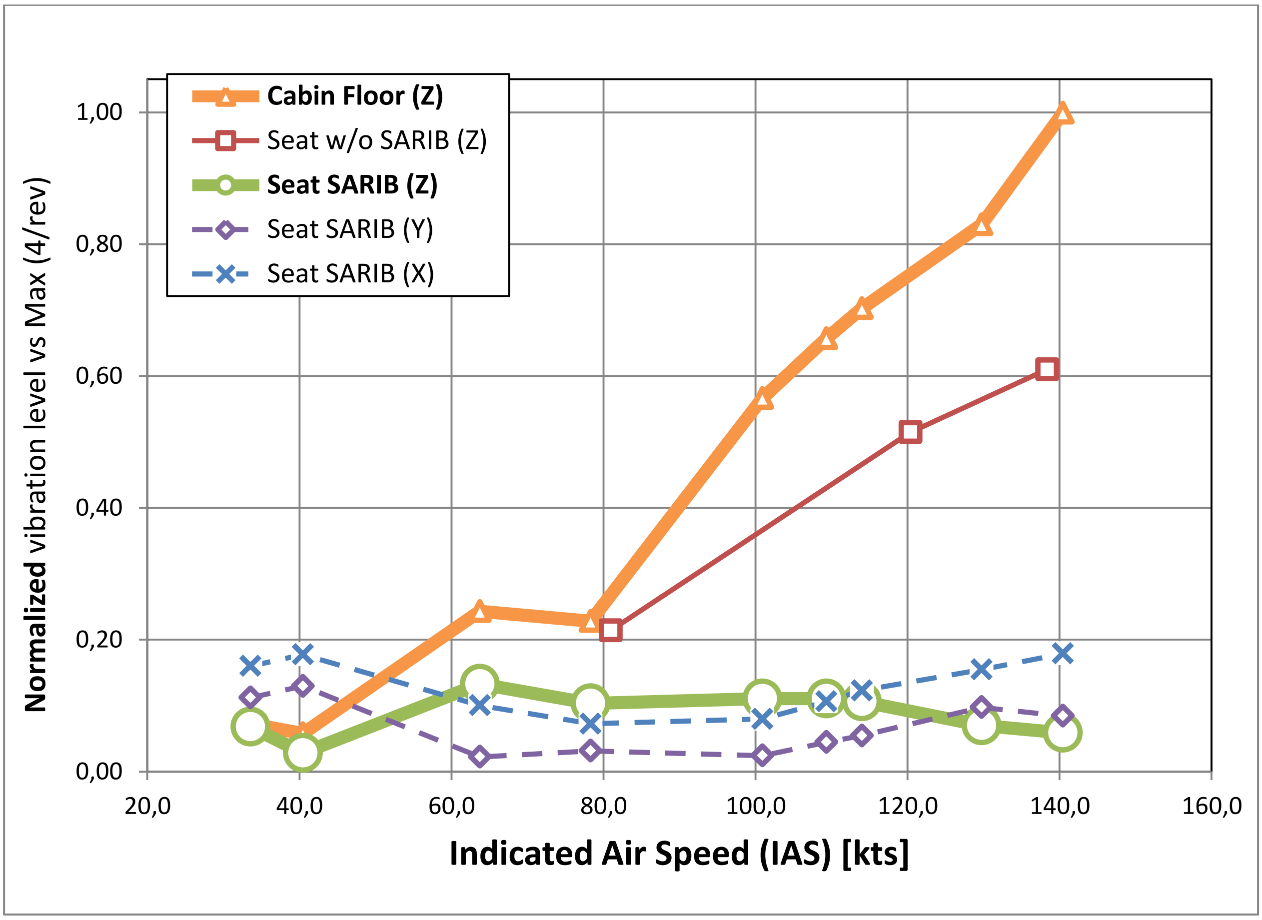


*Figure 22: Flight test results – b/rev levels versus IAS*

They show a reduction by up to 90% of the floor level among the vertical axis (Z) and a level mostly constant on the seat whatever the speed, whatever the floor level. This makes the compliance to the European directive 2002/44 on workers exposition a formality. Moreover, the levels measured among the longitudinal axis (X) and lateral axis (Y) are the same order of magnitude of the vertical axis and low. It attests that no unexpected behavior is generated by the SARIB® on other axes, which is a major point to check. It guarantees neither coupled effect nor side effects through the SARIB® integration.

The same kind of results has been observed with various flying crew morphologies and in the entire



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flight domain even in the most loaded phases. This confirms that the passive seat SARIB® solution is a perfect answer to the main vibration challenges imposed by helicopter seat integration which are robustness to nominal regime variations (96% to 107% on the H145) and robustness to occupant's weight variations.

These results have been fully confirmed by the test crews through the whole campaign, testifying that the seat SARIB® device offers a level of comfort never reached before on an AH helicopter.

## 5. CONCLUSION

The seat SARIB® is a perfectly effective mean to improve locally passenger or crew comfort with minimum impact (mass, cost, electrical consumption, integration) on the overall performance of the helicopter.

Future designs of the SARIB® will be mounted below the seat in order to minimize testing efforts, especially the dynamic testing that is expensive. But it has to be shown towards the authorities, that the SARIB® does not negatively affect the performance of the seat regarding this dynamic testing. Further improvements in the simulation and prediction of complex mechanical systems and dynamic test are a prerequisite to do so.

## 6. REFERENCES

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