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INTERIOR ACOUSTIC DESIGN OF THE HELICOPTER

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Abstract: Helicopters customers are demanding higher comfort level on board especially in the VIP market. People are generally used to fly on civil and executive jets where vibratory and acoustic environment is more comfortable than on the helicopter due to the different nature and location of the noise sources.

Helicopter interior noise is generated by main and tail rotors, engines, main gearbox and aerodynamic turbulence. The tonal and broadband noise due to all these sources is very high and needs to be reduced. Conventional passive system (soundproofing) is still the main way to control the acoustic of the cabin whereas active systems (active vibration and noise control) are not completely reliable or applicable.

The design of the soundproofing can be supported by simulation using the statistical energy analysis (SEA in short) approach. This way allows to select among different trim configurations optimizing the process and saving time and costs related to the soundproofing test and prototyping phases.

The capability to perform interior noise prediction focuses on two points. The first is the preparation of a confident vibro-acoustic model able to reproduce the interior noise levels in “green” (bare) configuration. The second is related to the collection of the acoustic material parameters necessary for the trim modeling.

This approach has been successfully used for the AW139 trim design evaluating acoustic performances versus weight and costs. Finally three different acoustic packages have been defined depending on the helicopter configuration and mission profile. Soundproofed SEA models are then definitely validated using sound pressure levels measured in the helicopter during flight.

1 INTRODUCTION

The AgustaWestland AW139 helicopter aims to become the leader helicopter in the six tons weight class in the civil market. Nowadays civil operators demand helicopters with increased levels of comfort, especially in the VIP and Corporate segment of market (fig. 1-2).
Increased comfort means cabin quieter, therefore the acoustic design of the interior is becoming more and more important. To achieve good results in term of noise reduction with the possibility to start studying the problem before the first flight of the helicopter it is necessary to use some analytical tools. One of the more recent analytical tools used in AgustaWestland is the Statistical Energy Analysis (SEA). This paper presents the use of AutoSEA2 [4], a commercially available SEA software package under the license of ESI Group, to study the vibro-acoustic behavior of AW139 and to develop an adequate soundproofing configuration in order to reach a low interior noise level in the cabin.

Figure 1: AW139

Figure 2: AW139 VIP interior

2 GREEN HELICOPTER VIBRO-ACOUSTIC MODEL

The first phase of SEA modelling concerns the green configuration of the helicopter AW139. Green configuration is the helicopter without interior liner and soundproofing, with only the bare structure.
To obtain information from Statistic Energy Analysis useful to design the soundproofing treatments the analysis is divided into three steps:

- analysis of sound pressure levels in the passenger compartment and other interior cavities;
- detection of the main energy paths from sources to passenger compartment;
- ranking of sources effect on interior noise.

In the preliminary phase, due to the lack of flight data available, SEA calculation is made using loads of unitary amplitude. Successively the same analysis is repeated modelling the input using data measured in operating conditions.

2.1 Vibro-acoustic model description

The construction of SEA model starts from the geometry imported by finite element model and CATIA model for parts not modeled in FEM.

The minimum size of SEA elements is chosen in order to have a sufficient number of modes in band to obtain statistically valid results in the frequency bands of interest (typically from 250 Hz to 6300 Hz).

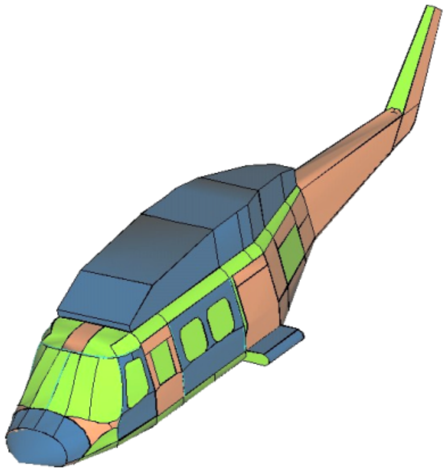

Figure 3: SEA model, structural subsystems

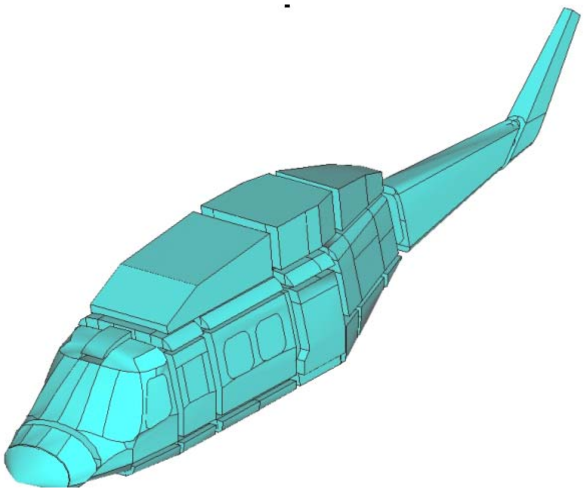

Figure 4: SEA model, acoustic cavities

Elements	**Number of elements**	**Number of SEA subsystems**
Panels	327	981
Beams	14	56
Acoustic Cavity	31	31
Total	372	1068

Material properties in terms of composition, thickness and mechanical characteristics are imported from FE model. Acoustic properties of structural materials, like damping loss factor, are measured on test samples.
The main cavity (passenger compartment) absorption is expressed in term of damping loss factor related to the reverberation time measured inside the helicopter.

2.2 First analysis phase: unitary loads

In the first phase of modelling there is a lack of experimental data concerning the input of the model, therefore analysis results are obtained introducing loads of unitary intensity.
The typology of load used is a power input with spectrum constant and equal to 1 W in the range of interesting frequencies: from 250 to 10000 Hz, in third of octave bands.
The model analyses different load cases to put in evidence some meaningful points.

Load case "gearbox", in which the following inputs are applied:
- an incoming power in each of the four struts connecting the main gearbox (MGB) to the helicopter roof (1 W – longitudinal modes);
- an incoming power in the antitorque-plate, (1 W – flexional modes);
- an acoustic source in the cavity of the upper deck (the cavity surrounding the MGB) (1 W).
The following results are computed:
- contributions of the different sources to the sound pressure level in the sequent subsystems: main passengers cabin (fig. 5), forward passengers cabin, cockpit and central fuel tank;
- the sound pressure levels in the same cavities (fig. 6);

- the detection of subsystems mostly responsible of energy transfer respectively toward the main passenger compartment (fig. 7), forward passenger compartment and main luggage van.

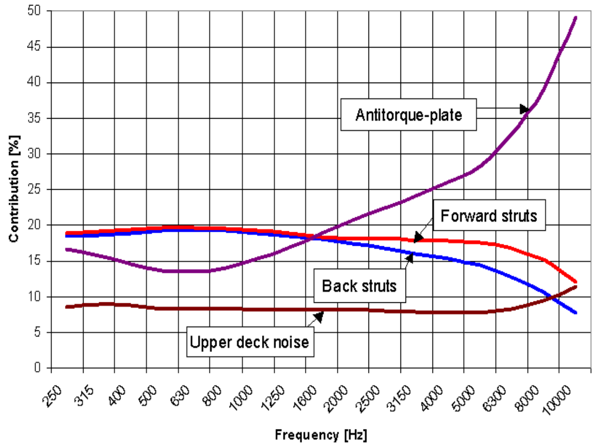

Figure 5: Source contribution to cabin SPL

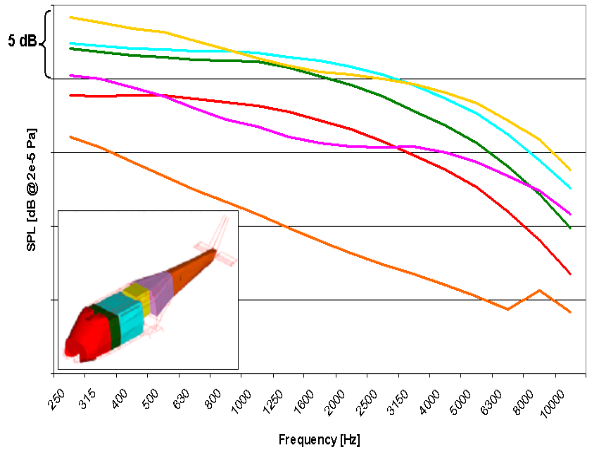

Figure 6: SPL in main acoustic cavities

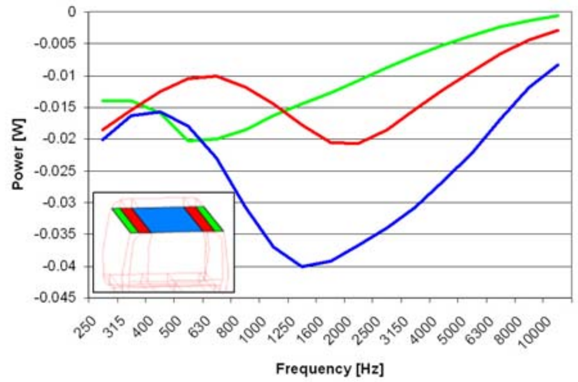

Figure 7: Power transfer from roof to cabin

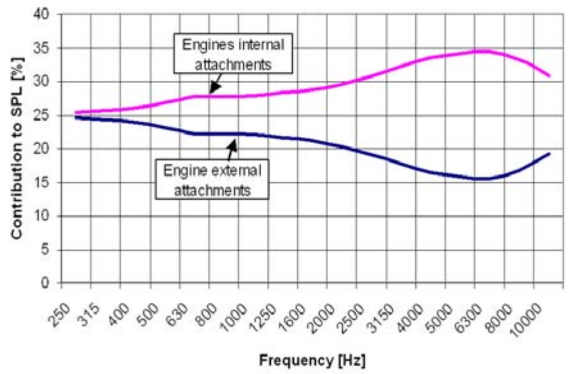

Figure 8: Engines contribution to cabin SPL

Load case "engines", in which the following inputs are applied:
- an incoming power in the back attachments of both engines (1 W – longitudinal modes);

It is computed the contribution of the load to the sound pressure level in the passenger compartment (fig. 8).

Load case for the analysis of transmission paths. This analysis allows identifying, frequency by frequency, the subsystems mainly responsible of the energy transmission from the source to the receiving subsystem (the passenger compartment).
Paths considered are:
- from forward struts to cabin;
- from rearward struts to cabin (fig. 9-10);
- from antitorque plate to cabin;
- from upper deck cavity (around the gearbox) to cabin;
- from external attachment of the engines to cabin;
- from internal attachment of the engines to cabin.

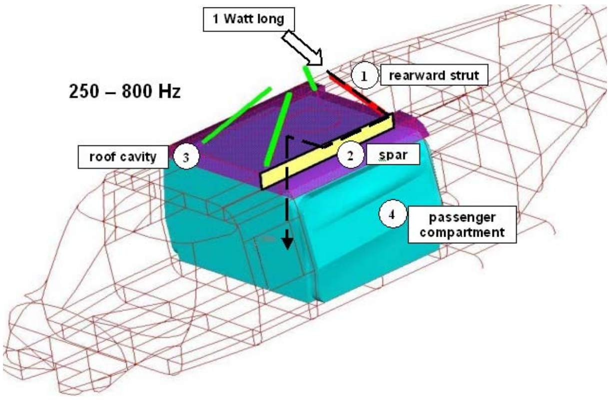

Figure 9: Rearward strut transmission path

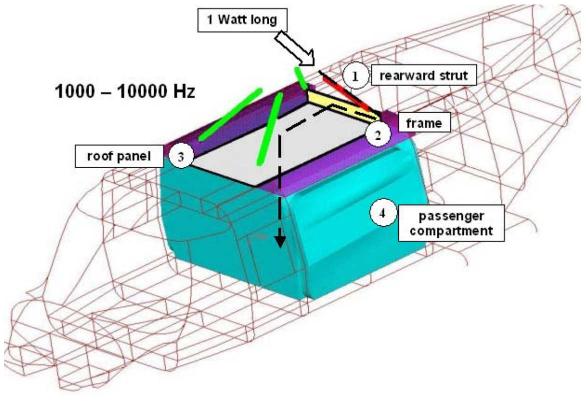

Figure 10: Rearward strut transmission path

In this first phase the statistical energy analysis allows to gain a better understanding in the vibrational and pressure energy propagation from sources to the cabin.
The contribution of the antitorque-plate to the interior noise in the cabin is, evaluating an equal power input, decidedly superior to the contribution coming from the struts. This means that the acoustic transfer function from the antitorque-plate mechanical attachments to the passenger compartment cavity is higher than the transfer functions relate to the struts. This behaviour is particularly evident for frequencies higher than 2000 Hz.
The cabin roof results the principal path of transmission of noise, both for structural and air-borne noise.
The airborne noise coming from the main gearbox (frequencies higher than 5000 Hz) and from the engines mainly arrives in the cabin propagating across the acoustic cavity over the auxiliary tank. This fact suggests installing a soundproofing treated panel to separate the cabin compartment from the empty space over the tank.

2.3 Loads measurement and modelling

The vibroacoustic model aims to reproduce the real operating conditions of the helicopter; to reach this objective, some experimental data concerning the inputs (noise sources) are measured during flight at different stationary conditions: typically at levelled flight at different cruise speeds (from 40 kts to 160 kts) plus the particular condition of hovering in ground effect (HIGE).

The main source of structureborne noise is the main gearbox, bound to the structure of the helicopter through four struts and an antitorque-plate (fig. 11). To represent this source in the model the followings data are acquired:
- vibratory level of the junction points between the struts and the roof, measured using four monoaxial accelerometers placed in the direction of struts longitudinal axis;
- vibratory level of the antitorque-plate in proximity of the junctions with the roof using two triaxial accelerometers.

In the model the vibration level of the antitorque-plate is imposed as a constraint in term of velocity calculated from the acceleration values measured. The energy is then transferred to the helicopter structure across the four punctual junctions corresponding to the four bolts.
The same method is used to introduce the vibration coming from the four struts: the velocity of the ending part of each strut is constrained to match the values measured during the flight.

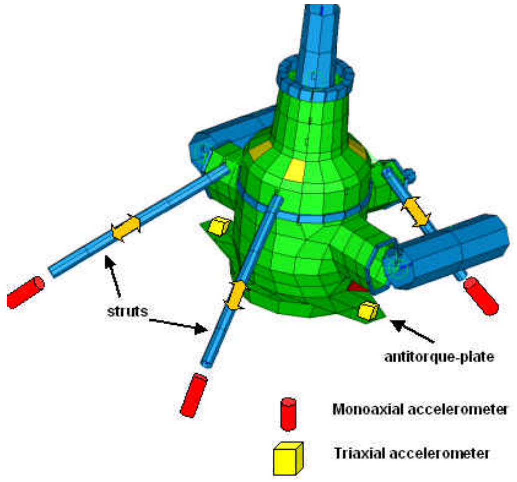

Figure 11: Gearbox and attachments

The main sources of airborne noise are:
- noise radiated by the main gearbox in the surrounding cavity of the upper deck;
- aerodynamic noise due to the interaction of the fuselage with the surrounding fluid;
- noise produced by the rotors;
- noise produced by the engines.

During the experimental campaign the level of acoustic pressure has been acquired inside the cavity of the upper deck. The aerodynamic noise and the one produced by the rotors are not really interesting because they give contribution to the noise especially in a low frequency range while we are focused on mid-high frequency problem. The measure of noise produced by the engines introduces excessive difficulties for sensors positioning (available space, high temperatures), therefore is not stored.
The airborne sources are introduced in the model imposing directly the sound pressure level measured in the cavity of the upper deck. Due to the proximity of engines cavity (where it is not possible to place microphones) the same pressure level is also imposed there.

2.4 Validation of the vibro-acoustic model

The comparison between experimental and analytical results is very satisfactory, even if we consider the fact that has not been possible to measure all the acting load inputs (engines and aerodynamical ones are undetermined).
Passenger compartment comparisons (fig. 12):
- the values of analytical and experimental SIL are almost coincident (maximum discards of the order of 1 dB, next to the error of measure);
- the shape of the analytical curve reproduces with good approximation the experimental one; only in the range from 5000 to 6300 Hz values calculated by SEA are slightly lower than experimental ones. This could be due to the missed possibility to measure all the inputs.

Luggage compartment (fig. 13):
- the values of analytical and experimental SIL differ for less than 2 dB;
- the analytical curve follows with good approximation experimental data; some points exceed the interval of confidence probably because results in this cavity are more influenced by the uncertainties we have about engines generation of noise.

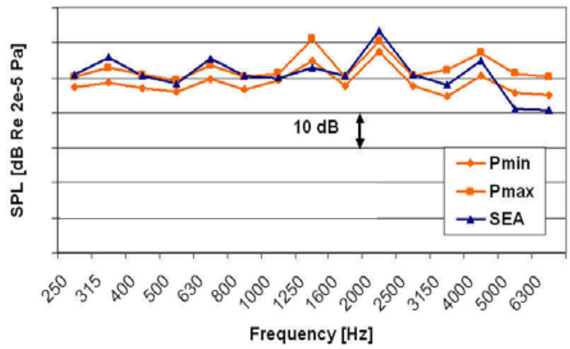

Figure 12: Passenger cabin SPL

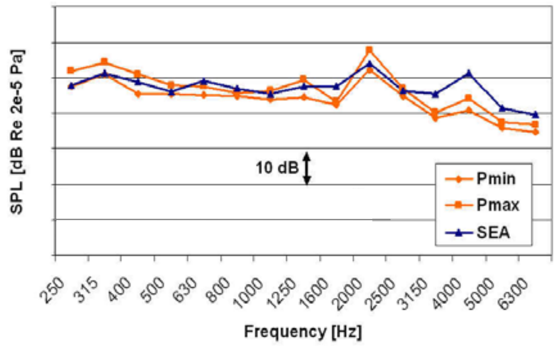

Figure 13: Main luggage compartment SPL

The contribution analysis allows to establish which source is the dominant in determining the sound pressure level in the passenger compartment.
Contribution analysis results are reported for two conditions of flight in fig. 14 and 15.
HIGE: extensional vibrations in the plane of antitorque-plate represent the dominant contribution to the SPL up to 4000 Hz. At higher frequencies the principal contribution is given by the airborne noise coming from the MGB surrounding cavity.
140 kts: vibrations in the plane of antitorque-plate always give the main contribution to SPL. In particular in the 2000 Hz third octave band antitorque-plate contribute overcomes abundantly 90%.

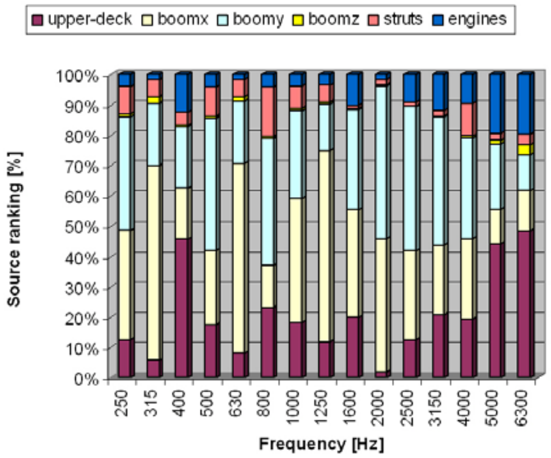

Figure 14: HIGE source ranking

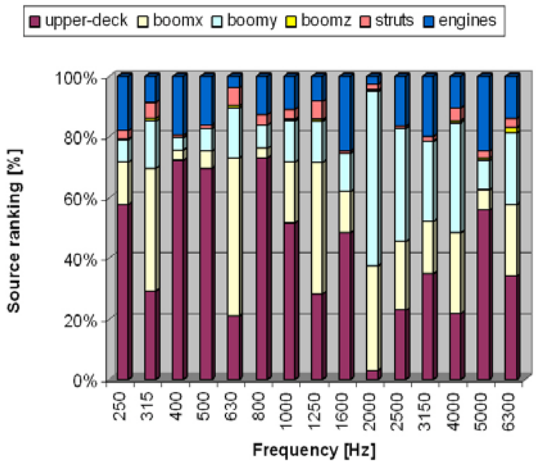

Figure 15: 140 kts source ranking

In the condition of flight at 140 Kts the analysis of energy flows shows that the maximum transfer of energy pass through the roof (fig. 16).
From calculations results that about the 50% of the whole incoming power in the passenger compartment is contained in the 2000 Hz band. Possible soundproofing interventions in the helicopter should therefore have the aim to reduce the band at 2000 Hz, due to the meshing frequency of the gleason in the main gearbox.

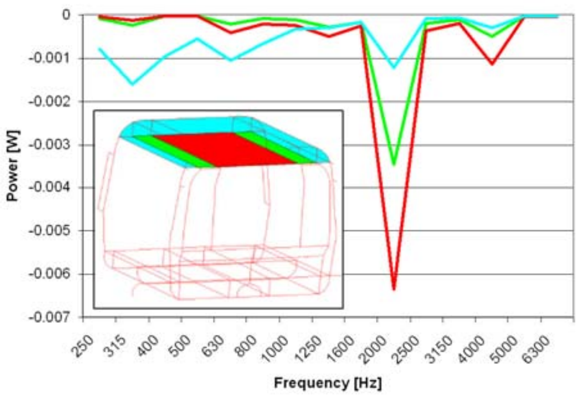

Figure 16: 140 kts, power flow from the roof

3 DESIGN OF TRIM CONFIGURATIONS BY SEA

Completed the phase of validation of SEA model of green helicopter and gained confidence in the trim packet modelling, it is possible to use statistical energy analysis in the optimization of soundproofing treatments. SEA models allow to test, in a preliminary study, different materials and different designs of the soundproofing, without the necessity to install the treatment in the helicopter and measure the result during a flight, saving therefore time and money.
In this phase we consider materials produced by two different suppliers referenced here as “mat 1” and “mat 2”. To be able to do a comparative analysis, for each supplier we define two treatment packages having similar weight per surface unity: light treatment and heavy treatment. Then we apply, in the model, the two typologies of treatments in different zones of the helicopter in three configurations A, B and C (fig. 17, 18, 19).

The light acoustic treatment is applied in the zones of the helicopter canopy not really critic concerning the transmission of noise in the passenger compartment, while the heavy treatment is used to cover the zones mostly responsible of the transmission of noise in the cabin, like the roof and/or the backward panels depending on the configuration examined. Both the treatments are made of different layers of porous and viscoelastic materials packed together resulting in the following densities: about 5 kg/m^2 the light type and 7 kg/m^2 the heavy one.
To introduce the trim packages in the model, the following parameters have been measured:
- transmission loss of the main structural panel (roof);
- transmission loss of the structural panel with the different treatments applied;
- coefficients of absorption and flow resistivity of the foams used in the treatments;
- damping loss factor of the structural panel bare and treated.

The configurations A, B, C are introduced in increasing order of performances and weight.
Configuration A: making reference to fig. 17, green zones are treated with light trim; the panel that divides the passenger compartment from the light-brown zone among the two fuel tanks is also treated with the light trim. The red zones, acoustically critic, are treated with heavy trim.
Configuration B: it differs from the configuration A because of the light treatment applied on the floor and along the cockpit rib (fig. 18).
Configuration C: comparing to B setup, the cockpit switch box is soundproofed with light treatment; light treatments of the rear panels are replaced by heavy trim; between the cockpit

and the passenger compartment is inserted a panel of plexiglas to simulate a limo-window often installed in VIP interior (fig. 19).

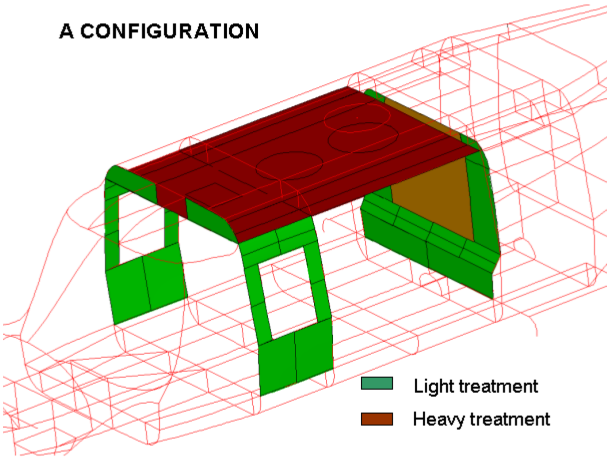

Figure 17: SEA model, A configuration treatment

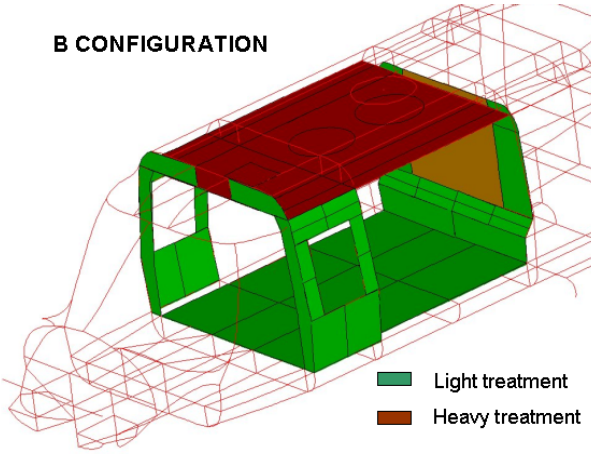

Figure 18: SEA model, B configuration treatment

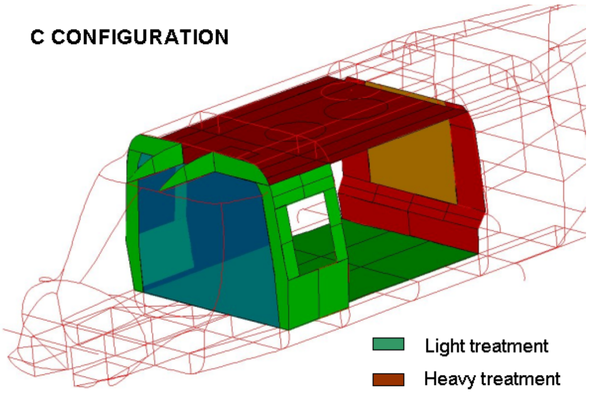

Figure 19: SEA model, C configuration treatment

Fig. 20 summarizes the values of dB-SIL calculated for the helicopter green and the configurations A, B and C, at the condition of cruise flight at 140 Kts. The treatments of the “mat 1” supplier show slightly better results in the conditions A and B. Examining the configuration C, the “mat 1” soundproofing is decidedly best (2 dB of SIL reduction) in comparison to the “mat 2” one.

Fig. 21 and 22 report the spectrum of the sound pressure level in the passenger compartment, in third of octave bands, calculated applying the soundproofing different configurations, based on the materials of the two suppliers. Obviously, the effect of the soundproofing is higher increasing the frequency, working better in the zone between 1000 and 6300 Hz. The principal peak is contained in the 2000 Hz band and SEA model predicts the ability to reduce it of about 15 dB, passing from green configuration to A, and to reduce it of 10 dB more with the C soundproofing. This additional gain, in term of sound pressure level, could justify the weight increment relate to C configuration. Moreover if we look at the peak in the 2000 Hz band we observe that “mat 1” in C configuration is more than 2 dB lower than the peak of “mat 2” curve.

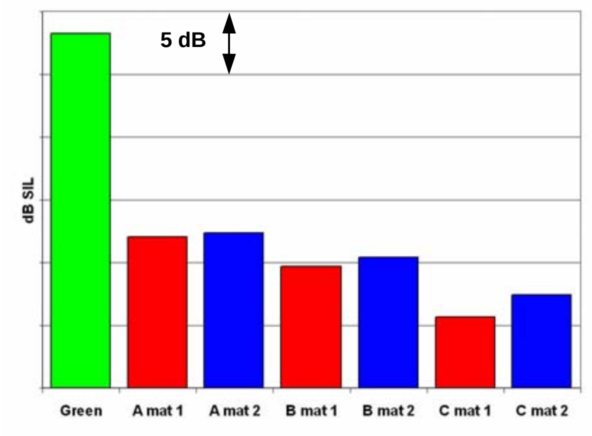

Figure 20: SEA model, SIL values at 140 kts

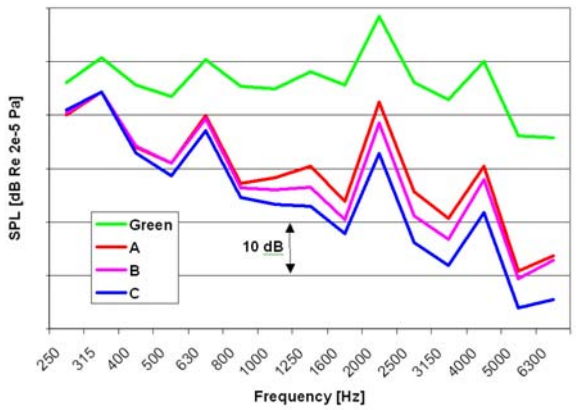

Figure 21: SPL obtained with "mat 1" treatments

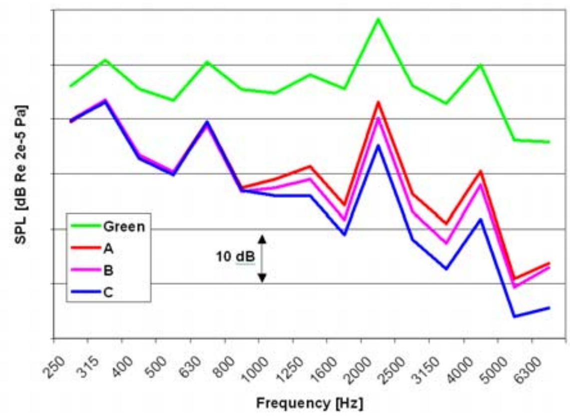

Figure 22: SPL obtained with "mat 2" treatments

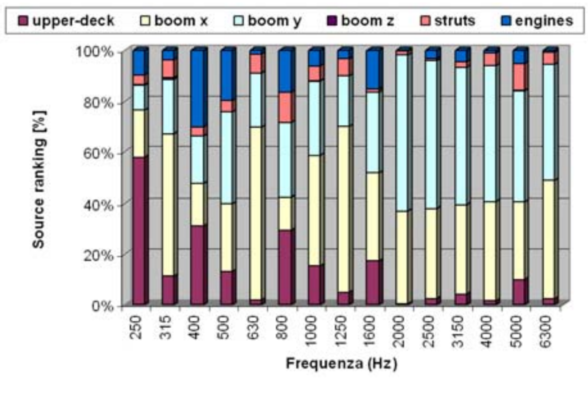

Figure 23: source ranking at 140 kts with "mat 1"

Fig. 23 shows the analysis of sources contribution to the interior noise in the passenger compartment, calculated for configuration C using material from supplier "mat 1", with the input deriving from measurements made at the speed of 140 kts. Other source ranking calculations have underlined a substantial independence from the type of soundproofing configuration, therefore the result showed could be considered representative of all the proposed configurations.

The contribution of the in-plane vibration components (boom x and boom y) of the anti-torque-plate is dominant for frequencies higher than 2000 Hz, while the component out of plane (boom z) is always negligible. At lower frequencies the airborne contribution coming

from the noise surrounding the gearbox (upper-deck) and the engines results meaningful. Struts vibrations have little importance in generating noise inside the cabin.
These results suggest that possible interventions on the sources for the reduction of the loads transmitted to the helicopter must be concentrated on the antitorque-plate.

4 CONCLUSIONS

The Statistical Energy Analysis theory applied in modeling the whole helicopter using AutoSEA2 software has demonstrated to be a powerful tool in soundproofing design.
After the construction of the model, even before the availability of experimental data about loads, it is possible to obtain some information on the acoustic behavior of the structure modeled.
Then, with real loads data, it is possible to validate the model of green helicopter, predicting the effect of source on sound pressure level in the cabin.
To conclude, SEA model of soundproofed helicopter is very useful in choosing among different treatment configurations and possible suppliers, without (in a preliminary phase) the need to install the trim on the helicopter and verify its acoustic performance during flight.

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