Internal Noise Prediction within Aircraft Cabin

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ABSTRACT

For about two decades, Structural Dynamics and Coupled Systems Department of ONERA has developed, validated and applied different methods for modeling and predicting internal and external noise of complex structures in the low (LF), medium (MF) and high (HF) frequency ranges. These activities were initialized for sound radiated from submarine structures and then applied to aeronautic and space structures as helicopters, planes and launchers, for internal noise prediction.

For the LF and MF domains, these methods are based on Finite Element modeling for both structures and internal fluids and on the integral method for unbounded external fluids while for the HF domain, they are based on Statistical Energy Analysis (SEA).

- *For the LF range, the classical modal approach is used for both structures and internal fluids. The coupling is then performed on the "fluid-structure" common interface.*
- *For the MF range, a specific method called "Onera-MF method" has been developed. This method uses a direct approach for the coupling between internal fluids and structures and it was implemented initially in an "in-house" version of ADINA code. Now it is implemented around Nastran code.*
- *For the HF range, the usual SEA method has been reformulated in order to take into account the coupling of external and internal heavy fluids with a structure. A ONERA code has been developed.*

A lot of validations and applications of the methods and associated codes were performed by numerous comparisons between theory and measurements.

- *The first validations were performed by numerical methods on submarine structures and on helicopters in LF and MF domains.*
- *Now these methods (mainly SEA approach) are used to predict internal noise inside –helicopters (from mainly Eurocopter) and -Airbus passengers-cabins/cockpits in MF and HF ranges ; for different sources of excitation: Turbulent Boundary Layer extended over fuselage, Air conditioning inside cockpits for planes and Noise coming from Gearbox, coming from main rotor and coming from engines air intakes for helicopters.*

A review of the previous methods and their main validations and applications for aircraft internal noise are presented herein.

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1.0 INTRODUCTION

In this paper, we will present first a summary of the different methods used at ONERA within the framework of the prediction of internal and external noise of complex vibrating structures in the three different domains of frequency: LF, MF and HF domains. For LF range, classical modal approach is used for both structures and internal fluids. For MF range, a specific method called "*Onera-MF-method*" has been developed. This method is implemented in an "in-house" version of ADINA code. For HF range, usual SEA method has been reformulated in order to take into account strong coupling of heavy unbounded fluids with a structure. A ONERA code has also been developed. Main applications of these methods to internal noise prediction of aeronautical structures will be presented finally.

2.0 REVIEW OF METHODS USED AT ONERA FOR VIBROACOUSTIC PROBLEMS

2.1 Numerical method for LF domain

LF domain can be defined as the frequency band where spectral responses of coupled system {*external fluid*}-{*structure*}-{*internal fluids*} reveal isolated resonances, indicating the presence of an underlaying modal structure of an associated conservative system. These resonances come from the first elastoacoustic eigenmodes of coupled system {*structure*}-{*internal fluids*}. This method is fully detailled in [1, 2] and it is based on the classical modal approach which builts up the coupling of the two modal bases of first eigenmodes of both structures and internal fluids over the "fluid-structure" common interface. It is used at ONERA mainly for external vibroacoustic problems of submarine structures. For internal vibroacoustic problems, we prefer to use a MF method which can be extended in that case to LF domain.

2.2 Numerical method for MF domain

In MF domain, the main method used at ONERA is a method called "*Onera-MF method*" [3, 4]. This method has been developed specifically at DDSS Department and it can be applied to vibroacoustic systems defined by: - a continuous and complex structure which is constituted of elastic or viscoelastic materials, dissipative and unhomogeneous and which can be usually discretized by classical Finite Element method (FEM), - one or several viscous or unviscous internal fluids, compressible, gas or liquids, occupying acoustic cavities, - a compressible external unviscous fluid, gas or liquid, occupying an unbounded domain.

2.2.1 Formulations used for vibroacoustic system

Coupling between external fluid and structure is treated by method of integral equations which solves a Neumann problem linked to Helmhotz equation. Internal fluid is treated by solving a Neumann internal problem which is formulated in terms of velocity potential field for fluid. Internal fluid is discretized by Finite Element method. Linear, viscoelastic and solid structure is also treated by Finite Element method.

2.2.2 Characteristics of Medium-Frequency domain

MF domain is the frequency-domain where modal densities of systems are not constant. They can be either high or either poor when frequency is varying within the MF-band. In this domain, characteristics of materials can vary with frequency and it is not possible to find a unique conservative system associated to the analyzed system for a large range of frequencies. Moreover, Finite Element models used for the resolution in this frequency-band must be built up using a large number of nodes and consequently a large number of degrees-of-freedom (DOF) ; which leads to handle large matrices systems.

That is why standard methods of modal reduction usually used in low-frequency domain are not accurate when frequency increases. The use of such methods requires to extract a very high number of eigenmodes of the vibroacoustic system, at prohibitive cost and without assuming convergence of iterative algorithms. A direct frequency-by-frequency method is not either envisaged at a reasonable numerical cost because we have to inverse for each discrete frequency a very large linear complex matrices system having a very high number of physical D.O.F.s. That is why a specific method adapted to MF domain has been developed.

2.2.3 Onera-MF method

The method is based on the use of a time integration and Fourier transform technique which is summarized below. The MF broad band is divided in several narrower frequency sub-bands. The linear complex matrices system is then solved for each MF sub-band in three steps:

1) The short time scale which is associated to the central frequency of sub-band is analytically treated in frequency domain using a frequency shift technique.

2) The long time scale which is associated to the bandwidth is solved by an usual direct step-by-step numerical integration method in time domain (Newmark method).

3) The MF solution is reconstructed in frequency domain by Shannon theorem using only the time solution (at sampling time steps) constructed in step 2) before.

MF method has led to develop codes which allow us to calculate the vibroacoustic response of structures coupled or not to internal or external fluids. These codes were initially articulated around an "in-house" version of ADINA code. Now, MF method is implemented around MSC/Nastran code within I-DEAS environment.

2.3 SEA method for HF domain

Statistical Energy Analysis (SEA) is adapted to HF domain which can be defined as the frequency band where spectral responses of coupled system {*external fluid*}-{*structure*}-{*internal fluids*} have no resonances nor local accidents. In this domain, dynamic behaviors are very smoothed, indicating that modal density of conservative system associated to coupled problem {*structure*}-{*internal fluids*} is uniforme in frequency and is high. SEA method used at ONERA and its associated software are directly coming from a reformulation of basic SEA method [6]. This reformulation [7, 8] was performed in order:

- to avoid some restrictive hypotheses of the basic formulation of SEA (iso-energy of resonant modes of a subsystem, iso-contribution in the coupling between of a resonant mode of a subsystem to any resonant mode of another subsystem),
- to improve determination of new coupling loss factors,
- to introduce a model for estimating the envelope of SEA prediction around averaged response, due to uncertainties of SEA parameters.

3.0 VALIDATIONS AND APPLICATIONS

Validations on LF method have been performed on coupled {*structure*}-{*external heavy fluid*} [5, 11].

First validations of "*Onera-MF method*" were focused on the "own-noise" of sonar-domes excited by turbulence boundary layer [10]. More recently, other validations concern more academic systems: a cavity filled with water and coupled to a plate [18], a plate coupled to external air and excited by a mechanical force [12], a plate coupled to external air and excited by the Turbulent Boundary Layer [19], a cylinder in air and in water [13]. These three latest systems also allowed to validate SEA method for light and strong coupling between a structure and unbounded external fluid. SEA method has also been validated for a box which is representative of the structure of an helicopter cabin [16].

3.1 Applications for helicopters

Main application of MF method concerns Dauphin helicopter of Eurocopter which is excited by random forces due to Main Gearbox (MGB) emergent frequencies and applied to Transmission deck (see **Fig. 1**) by BTP struts [9]. Simplified FE model used for MF analysis is presented at **Fig. 2** and comparison between in-flight measurements and FE computation on cabin pressure levels obtained for main MGB emergent frequencies is presented at **Fig. 3**.

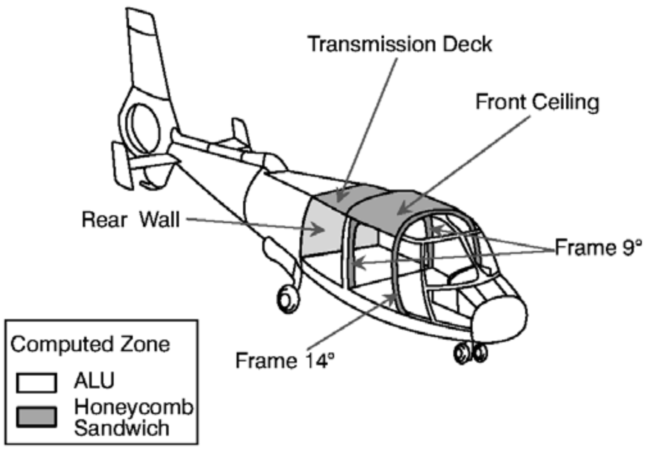

Figure 1: View of Dauphin SA 365N helicopter and selected parts for FEM analysis

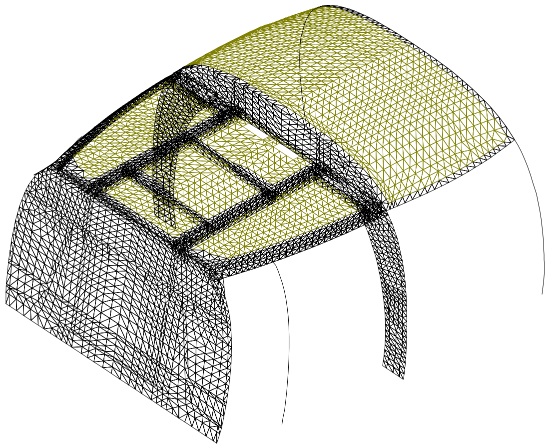

Figure 2: FE structural meshing of Dauphin fuselage used to calculate MF responses

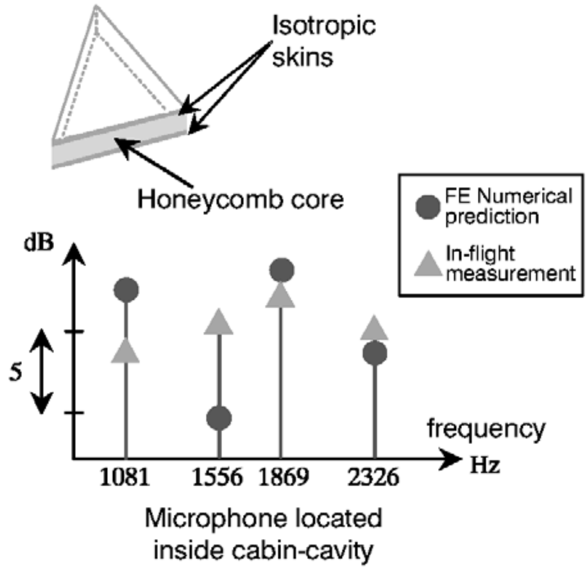

Figure 3: Comparison between numerical prediction and in-flight measurement of internal pressure levels for different MGB emergent frequencies

Application of SEA method has been performed on internal noise prediction within Ecureuil helicopter cabin [15] which is submitted in-flight to four main different sources of excitation (presented at **Fig. 4**).

Fig. 5 shows comparison between the envelope of SEA prediction and in-flight measurement within cabin for this helicopter.

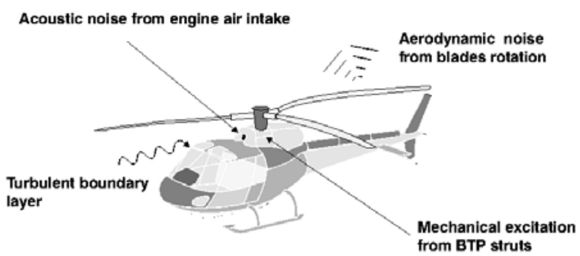

Figure 4: View of Ecureuil helicopter subjected to different sources of excitation

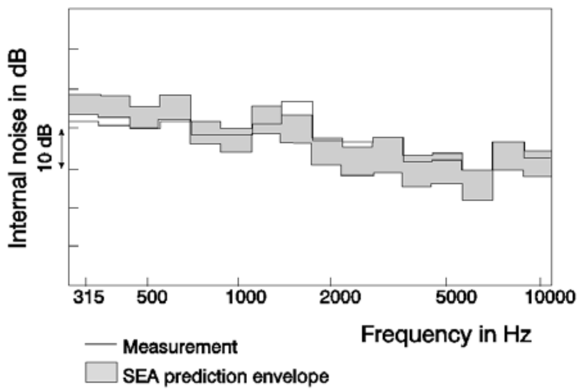

Figure 5: Comparison between SEA prediction and in-flight measurement of Ecureuil cabin-cavity induced noise

3.2 Applications for planes

Onera-MF method and SEA method have been both applied to the prediction of internal noise inside cabin-passengers of a Falcon (from Dassault) airframe [14, 17] when structure is excited by a set of four mechanical excitations applied at left engine anchorage points, as shown in **Fig. 8**. Structure of fuselage and cabin-passengers acoustic cavity have been discretized by FE method (see **Fig. 9**) for MF approach and all the structure was cut up in nine subsystems (see **Fig. 10**) for SEA analysis.

Figure 6: Falcon 2000 test airframe

Figure 7: Interior, looking to the back, with microphones in place

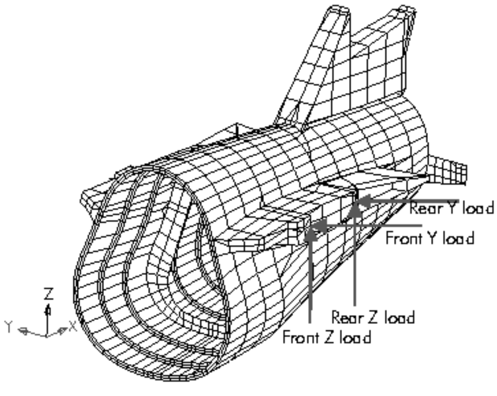

Figure 8: Applied mechanical excitations

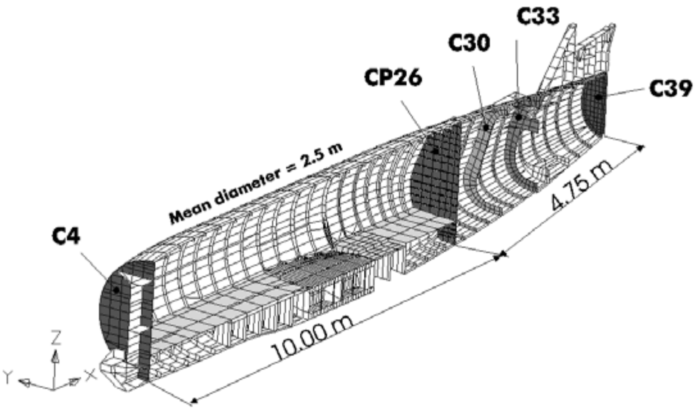

Figure 9: Semi-longitudinal section of Falcon fuselage FE meshing

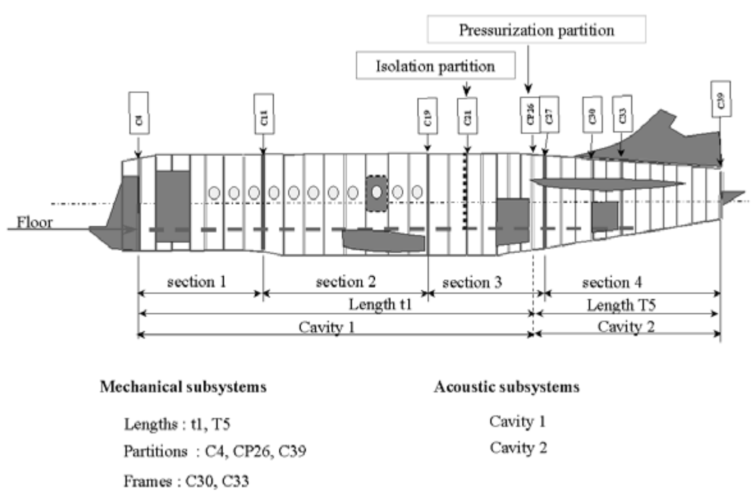

Figure 10: Breakdown of Falcon airframe into SEA subsystems

Fig. 11 and **Fig. 12** illustrate comparison between measurements and the two predictive methods on the mean quadratic pressure obtained inside cabin-passengers cavity, for LF and MF band [0, 400Hz] and for HF domain [125, 1250Hz].

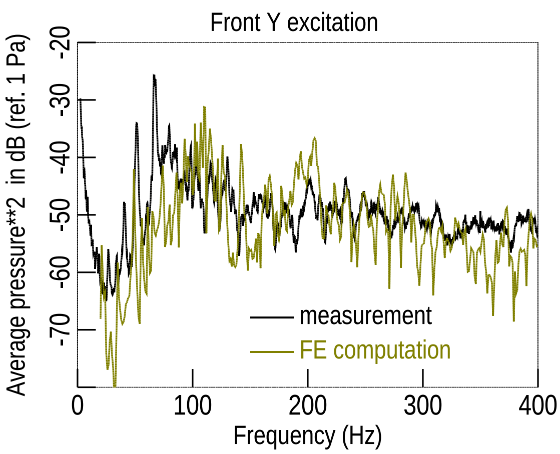

Figure 11: Average quadratic pressure for passengers-acoustic cavity

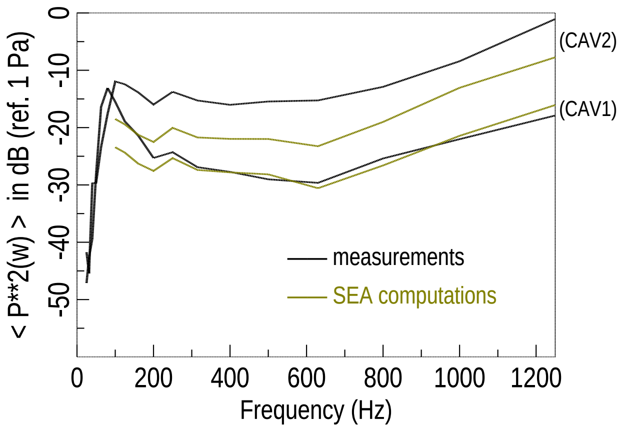

Figure 12: Mean quadratic pressure inside the two acoustic cavities

Another main application of SEA method concerns prediction of TBL excitation induced noise inside cockpit of an Airbus A340 in-flight (see **Fig. 13**). This application allowed to validate a SEA model developed at ONERA to quantify power input injected to structure by TBL external excitation for large structures.

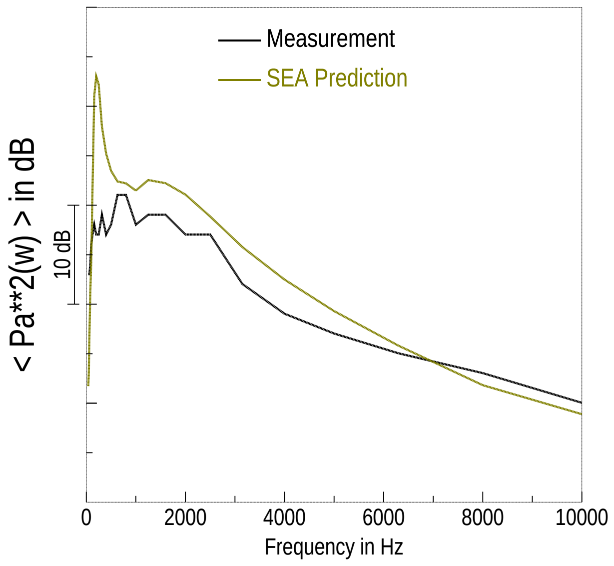

Figure 13: Comparison between SEA prediction and in-flight measurement of internal noise inside A340-cockpit cavity for external TBL excitation

4.0 CONCLUSIONS

Some efficient methods developed at ONERA allowing to deal with external and internal vibroacoustic problems of complex structures in LF, MF and HF domains and their applications to aeronautical structures have been presented in this paper. Other future applications of SEA method are planned in next few months for two large aircraft: helicopter Super-Puma of Eurocopter and Airbus A380.

5.0 ACKNOWLEDGMENTS

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6.0 REFERENCES

[1] H-J-P. Morand, R. Ohayon, *Fluide Structure Interaction* , RMA23, Wiley, New York, 1995.

[2] R. Ohayon, C. Soize, *Structural Acoustics and Vibration*, Academic Press, San-Diego, London, 1998.

[3] C. Soize, "Medium frequency linear vibrations of anisotropic elastic structures", La Recherche Aerospatiale, **5**, pp. 65-87, 1982.

[4] C. Soize, P-M. Hutin, A. Desanti, J-M. David, F. Chabas, "Linear dynamic analysis of mechanical systems in the medium frequency range", Computers and Structures, **23**(5), pp. 605-637, 1986.

[5] C. Soize, A. Desanti, J-M. David, "Numerical methods in elastoacousticity for Low and Medium frequency ranges", La Recherche Aerospatiale, **5**, pp. 25-44, 1992.

[6] R-H. Lyon, R-G. DeJong, *Theory and Application of Statistical Energy Analysis,* Second Edition, Butterworth-Heinemann, Boston, 1995.

[7] J-M. David, C. Soize, *Prediction of the high-frequency behavior of coupled fluid-structure systems by the SEA method and applications*, in J-M. Crolet and R. Ohayon (Eds.), Comput. methods for fluid-structure interaction, Longman Scientific and Technical, Harlow, pp. 55-77, 1994.

[8] J-M. David, C. Soize, "Statistical Energy Analysis: formulation and software developments at ONERA", EURO NOISE'95, Lyon (France), March 21-23, **2**, pp. 631-635, 1995.

[9] M. Dussac, P. Martin, H-J. Marze, F. Chabas, J-M. David, A. Desanti, N. Meidinger, C. Soize, "A Finite Element method to predict internal noise levels at discrete frequencies for a partially composite helicopter fuselage", AHS Annual Forum, Boston (Ma), May 22-24, 1989.

[10] C. Soize, J-M. David, A. Desanti, "Dynamic and acoustic response of coupled structure/dense fluid axisymmetric systems excited by a random wall pressure field", La Recherche Aerospatiale, **5**, pp. 1-14, 1989.

[11] O. Voisin-Grall, A. Desanti, J-M. David, "Numerical methods for LF and MF elastoacoustics", Colloque National en Calcul des Structures, Giens (France), May 11-14, 1993.

[12] C. Valor, "Benchmarks for vibroacoustic software", Commission de Validation des Progiciels de calcul vibroacoustique SFM-SFA, 1996.

[13] J-M. David, "Vibroacoustics of a cylinder in air and in water. Prediction by numerical methods and statistical energy analysis and experimental comparisons", GDR1138/Vibroacoustics Colloque, Le Mans (France), March 3-4, 1997.

[14] J-M. David, L. Guillaumie, "Vibration and internal noise prediction of an aircraft fuselage in the low- and medium-frequency ranges", ISMA 25 Conference, Leuven (Belgium), September 13-15, 2000.

[15] A. Morvan, J-M. David, "In-flight vibroacoustical measurements and internal noise prediction on an Ecureuil helicopter", AGARD FVP Symposium on Advances in Rotorcraft Technology, Ottawa-Ontario (Canada), May 27-30, 1996.

[16] T-J. Monger, K-H. Heron, A-P. Payne, J-M. David, A. Morvan, L. Guillaumie, C. Soize, "Statistical energy analysis predictions of the DOVAC box experimental results", EURO NOISE'98-Designing for Silence-Prediction, Measurement & Evaluation of Noise & Vibration, Munich (Germany), October 4-7, 1998.

[17] L. Guillaumie, J-M. David, O. Voisin-Grall, "Internal fuselage noise: comparison of computations and tests on a Falcon airframe", J. Aerospace Science and Technology, **4**(8), pp. 545-554, 2000.

[18] J-M. David, M. Menelle, "Validation of a medium-frequency computational method for the coupling between a plate and a water-filled cavity", J. Sound and Vibration, 265, pp. 841-861, 2003.

[19] J-M. David, "TBL excited plate in MF and HF ranges: comparison with experiments between Finite Element approach and SEA method", ICSV11 International Congress on Sound and Vibration, St. Petersburg (Russia), July 5-8, 2004.

Detailed Analysis or Short Description of the AVT-110 contributions and Question/Reply

The Questions/Answers listed in the next paragraphs (table) are limited to the written discussion forms received by the Technical Evaluator. The answers were normally given by the first mentioned author-speaker.

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A third contribution to this very important problem, taking into account with the habitability and the resulting safety problems: the author extensively described the LF, MF (uneasy to define) and HF (High Frequency) approaches: the classical MEF under 100 Hz, a specific ONERA-MF method (tested a.o. for a cavity filled with water) implemented in the Nastran Code , and a statistical energy analysis (SEA) over 300 Hz. Example are given (Dauphin helicopter (MF), Ecureuil helicopter, Falcon (SEA), …The author concluded on the future applications of SEA method planned in next few months for two large aircrafts: the helicopter Super-Puma of Eurocopter and the Airbus A380

Discussor's name: B. Masure
Q. For cavities filled with water, is the water considered as a compressible medium?
R. It doesn't matter in MF method that the water is considered as a compressible medium. In MF approach, the dynamics of both structures and internal fluids is included within the formulation and also within the model. Only, in modal approach, we need to consider the water as an incompressible fluid. In MF method, fluids can be compressible or uncompressible.
Q. This question deals with the excitation forces in your calculation methods. For instance, in your presentation, you spoke of the excitations of a structure associated with a turbulent boundary layer (TBL). Could you explain how exactly you do to define these excitations?
R. The taking into account of excitation by TBL depends on the approach used. In SEA method, a model of mean power input due to TBL excitation was developed and this model uses the mean wall pressure and the correlation lengths. In MF approach, the model is defined by the data of a cross-spectral density function. A finite element discretisation of this model is performed, giving us a spectral matrix of excitation.

Discussor's name: D. Chan
Q. How do you determine the boundary between the MF and HF frequency domains?
R. We don't have any criteria to determine this boundary. We are able to determine this boundary when we have measurements. In fact, this boundary doesn't exist really but that we are sure is the difference between LF modal domain and HF domain and this intermediate domain is the MF domain. Only experience can define the MF domain. We consider HF domain as the domain where modal densities are high and constant with frequency. If it is not the case for a complex structure, we can conclude that we still are in the MF domain and the boundary between MF and HF is not yet reached!