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VIBRO-ACOUSTIC STUDY OF ARIANE V LAUNCHER DURING LIFT-OFF

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ABSTRACT
This paper gives an overview of numerical methods used to predict vibro-acoustics behaviour of ARIANE V launcher during lift-off and presents the following aspects: reciprocity method application on a BEM model and axisymmetric modelling of payloads.

1 - INTRODUCTION AND PROBLEM STATEMENT

The launcher's upper parts (ie the fairing, the SPELTRA or the VEB (electronic brain)) which enclose the payloads are exposed to very severe external noise during lift-off. The jet noise generated by solid rocket boosters is then reflected by launch pad or reinjected into environment after a trip inside the water ducts.

To avoid damages of sensitive parts of the payloads, high noise levels must be significantly attenuated by the payload compartment structure itself or an additional acoustic protection.

The prime contractor (CNES, French Space Agency) and the other contributors of the ARIANE V programme (AEROSPATIALE MATRA, DORNIER, CONTRAVES,...) need to understand deeply the vibro-acoustic behaviour of the launcher since design stage.

For this purpose tests are performed on earth on scaled models (Fauga or Martel bench) and on full scale substructures (Fairing in a reverberant chamber), together with numerical computations.

STRACO and CNES established in the early 1990's a step by step common project with the goal of obtaining at the end reliable and relevant numerical models of launch configurations. Analysis approach was, at each step, validated by accompanying test campaigns.

2 - MIXED BOUNDARY AND FINITE ELEMENTS METHOD (BEM/FEM)

STRACO develops a general code called RAYON® integrated into the environment of I-DEAS™ developed by SDRC company. This code is based on a mixed variational formulation [1] which couples Boundary and Finite Element Methods (BEM/FEM).

To model launcher upper parts and to take advantage of their geometry of revolution, the axisymmetrical version of RAYON® is used. RAYON-AXI ® uses a circumferential Fourier's serie decomposition of the acoustic pressure and of the structure displacement fields. Using RAYON-AXI ®, only the generating curve is meshed, this reduces a lot the size of the numerical models and allows to do computation in higher frequency ranges.

During pre-analysis of the vibro-acoustic problem of the upper part of the ARIANE V launcher. The fairing was found to be the structure the most critical concerning Noise Reduction (NR). Two independent concepts of an acoustic protection were investigated:

- Application of Helmholtz resonators inserted into patches of foam (Special Acoustic Absorbers) onto the outer wall of the payload compartment (see fig. 1).
- Air of the payload compartment purged by helium.

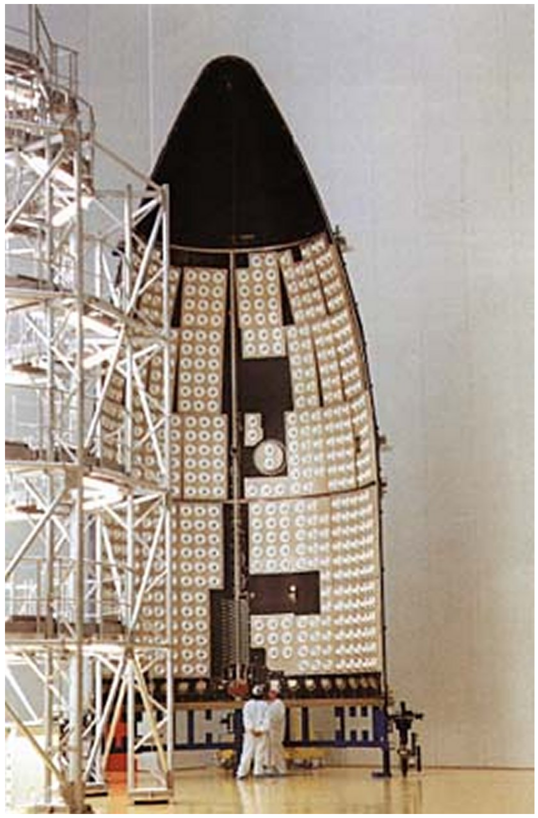

Figure 1: Acoustic protection.

The SAA increase the absorption capability on the inner payload compartment volume. This results, in an increased ratio of the internal acoustic energy absorbed by the structure. The SAA are tuned to the low frequency range, where NR requirements are most severe.

To test the ability of RAYON-AXI® to predict the vibro-acoustic behaviour of a space structure protected by SAA. DORNIER set a benchmark: it consists of a test cylinder defined by acoustically scaling the SPELTRA cylindrical part by a 1:4 factor (see fig. 2).

In the numerical model, the SAA are modelled by a surfacic complex impedance added to the prescribed Boundary Elements belonging to those of the surface coating of the fluid mesh of the cavity. The characteristic impedance of the absorbers is measured in a tube Kundt at DORNIER facility. The tube is made of concrete and has a diameter of 90 cm which allows to measure a patch made of 7 resonators. The good correlation of measurement and analysis results concerning NR is documented in figures 3, 4 and 5. Figure 3 shows 1/3 octave comparison for bare structure. The dark columns show the discrepancy. The 2 to 3 dB deviation is excellent in view of all the assumptions that were made for the test and the analysis. Figure 4 shows same comparison for air purging (90% helium), again we have to state a good correlation which gives us confidence for the full scale fairing analysis with helium treatment. Finally, the plot in figure 5 presents the comparison for SAA application, again the prediction is quite good.

This first test campaign which took place in 1991-1993 was fully confirming the accuracy of the numerical approach by RAYON-AXI®.

3 - INVERSE BOUNDARY ELEMENT METHOD (IBEM)

In 1993-1995, a test campaign was performed in a reverberation chamber to qualify ARIANE V fairing. The test object is large compared to the chamber dimensions and, at frequencies for which the acoustic wavelength is of the order of the free space between test object and chamber walls, the sound field generated by the horns is dominated by standing waves. The specification given for diffuse sound field is no more valid.

To overcome the problem, it was asked to STRACO to reproduce the test numerically, then to suppress the chamber influence and to compute the vibro-acoustic behaviour of the fairing in free field.

In the chamber, the incident acoustic field is created by blowing pressurized nitrogen through exponential horns opening on the reverberant chamber. The noise level in the chamber is controlled by a feed back

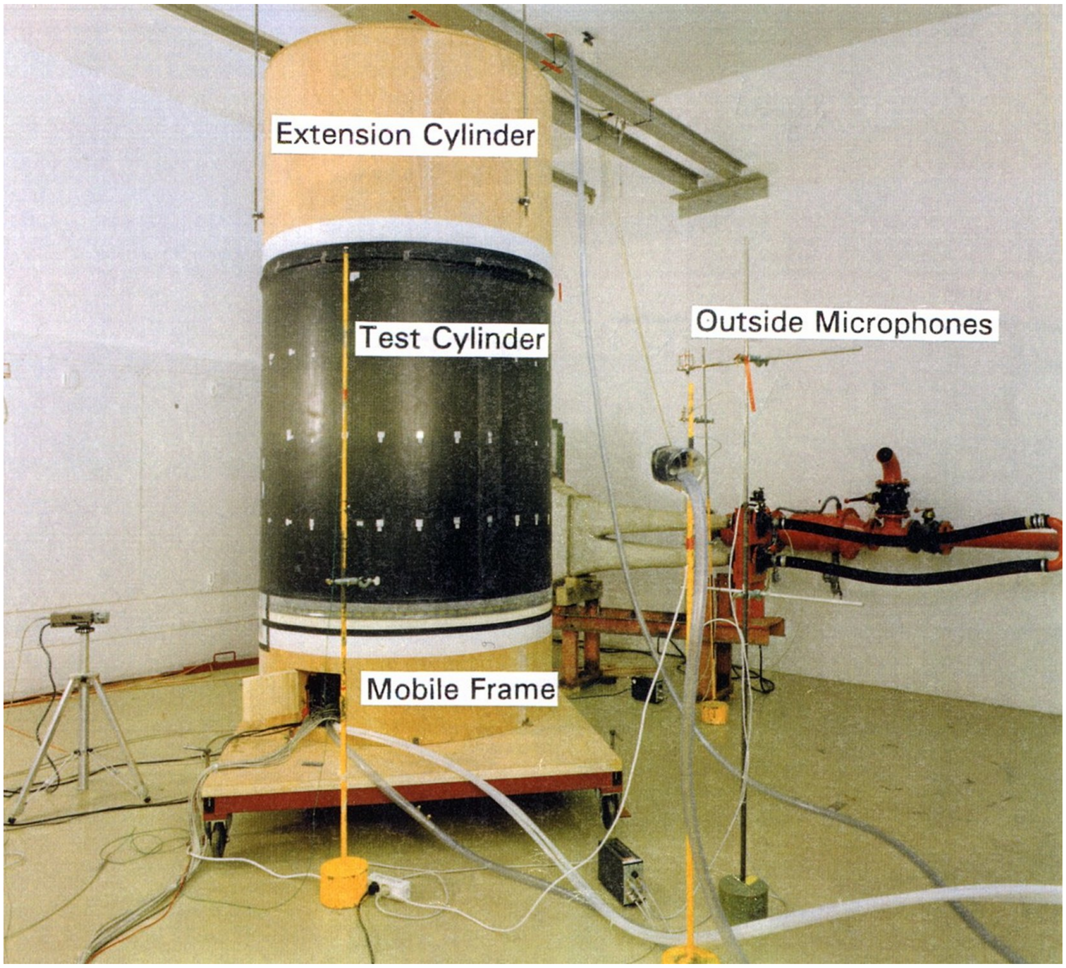

Figure 2: Test cylinder measures.

loop which measures Sound Pressure Levels (SPL) at microphones located in the chamber.

Such an excitation is difficult to model because the effects are known (control microphones) but the causes are unknown (no identification of horns). The problem is handled by using an inverse approach: The horn openings are modeled as vibrating rigid pistons of unknown acceleration. The control microphones become acoustic source monopoles of unit amplitude. With a coupled BEM/FEM approach, the transfer functions between piston accelerations and acoustic pressure at microphone positions in the chamber are calculated. Then, the reciprocity concept helps us to evaluate which complex acceleration spectra, to put on each of the three horns surface, to radiate the same noise as the real ones. This is done by minimizing with a Least Mean Square method (LMS) the deviation between computed and measured acoustic pressure at microphones locations.

This new numerical method developed inside RAYON-3D® is friendly and versatile. The user can choose freely among all the measured frequency signals, how much he wants to use into the optimization process as well as their nature: auto and/or cross PSD values. He can even ask for the selected measures to be referenced to a probe signal he specifies. He can keep the unused measured frequency signals to check if the synthesized numerical model of the sources is correct.

Fig. 7 shows the IBEM model of the reverberant chamber and of the Fairing. From the available 36 external microphones in the chamber, only 17 were selected in the formulation of the acoustic source characterization problem. Fig. 8 shows the computed power spectral density (PSD) of one of the unused microphones in the chamber that is compared to the measured PSD.

Such an inverse approach to model numerically complex acoustic sources may be also of great interest for other industrial domains: for example, STRACO used a similar approach to identify the radiation characteristics of car's engines [2]. The measurements were done in an anechoic room. Then the simplified equivalent BEM model of the engine was assembled into the vehicle and a frequency response run was performed to predict the interior and pass-by noise.

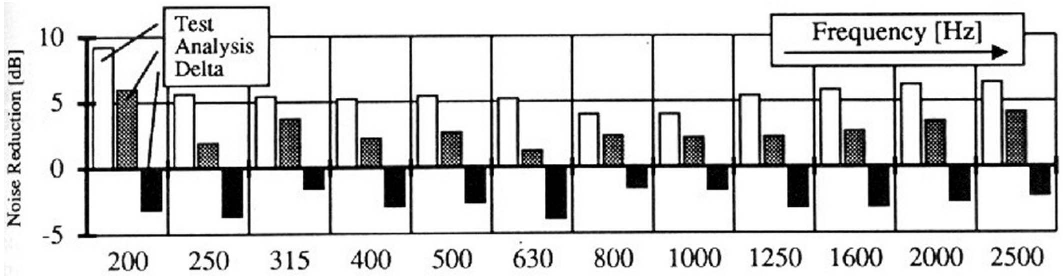

Figure 3: Test and analysis NR for 1:4 bare test cylinder.

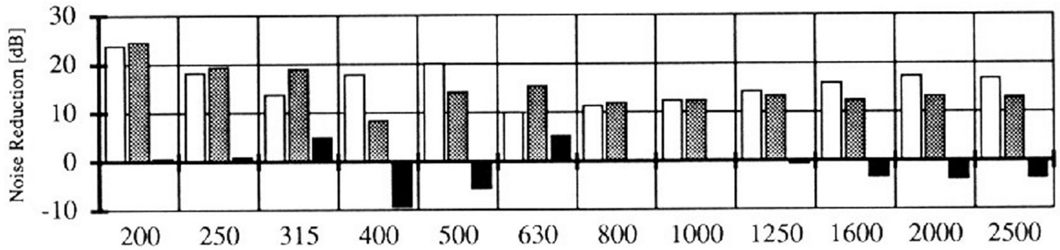

Figure 4: Test and analysis NR for 1:4 test cylinder purged by helium.

This inverse numerical technique has been implemented in RAYON-3D ® which is commercially available in the task "Vibro-Acoustics" of I-DEAS Master Series™ 8.

4 - LIFT-OFF CONFIGURATION NUMERICAL MODELLING WITH RAYON

The above described test campaigns proved that the noise attenuation capability of the ARIANE V payload compartment structures can be predicted with good confidence by numerical tools.
Here below is given the general procedure followed by STRACO to establish numerical models of flight configurations:

- **Vibro-Acoustics launcher's structures:**
  Use axisymmetrical models generated and updated with respect to ground tests in reverberation chambers: (Fairing at ESTEC LEAF, SPELTRA, EPS and VEB at INTESPACE).

- **External lift-off sound field:**
  An inverse method is applied to the measurement from a microphone array antenna, at a 1:15 scaled launch pad, test facility to determine a set of uncorrelated plane waves which reproduce the measured external noise.

- **Payloads:**
  The dynamical behaviour of the payload is predicted by applying on the external surface of the fairing, the 3D blocked pressure computed by RAYON-AXI ®.

5 - CONCLUSION

IBEM and BEM-AXI were applied and validated in the context of space structures. The modular implementation of the numerical methods in RAYON® package allows great flexibility and significant time and money savings: 2D modelling of 3D problems, or reuse of the same launcher model between each flight only the payload is remeshed (internal problem). Finally, the software reinforced by IBEM yields to analyse other industrial problems with complex sources of noise like aircraft and car engines.

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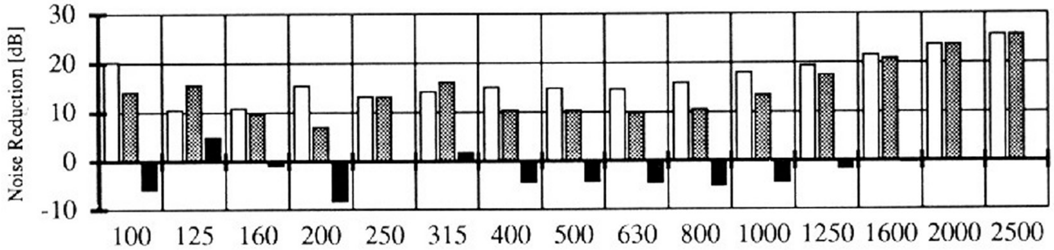

Figure 5: Test and analysis NR for 1:4 test cylinder with SAA.

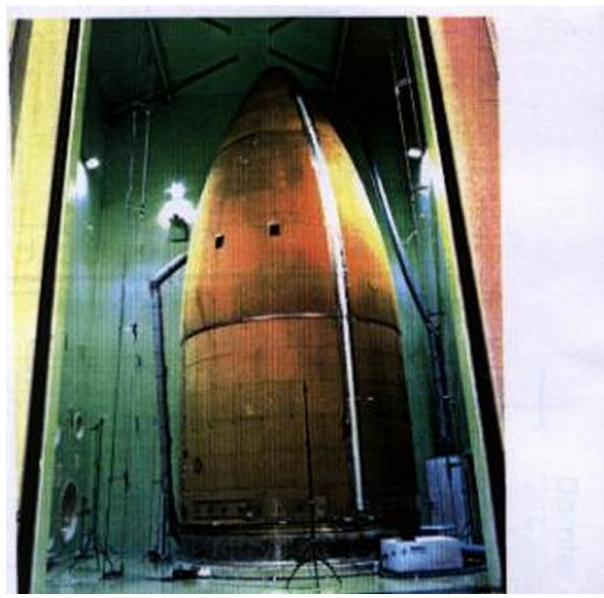

Figure 6: Fairing test.

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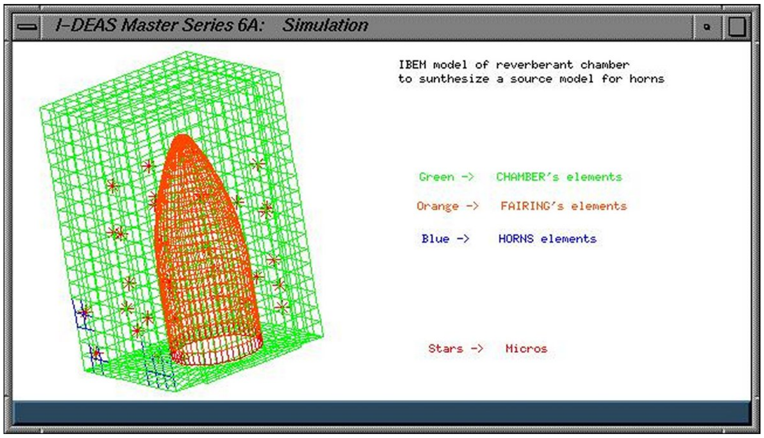

Figure 7: IBEM model of fairing in large european acoustic facility (LEAF).

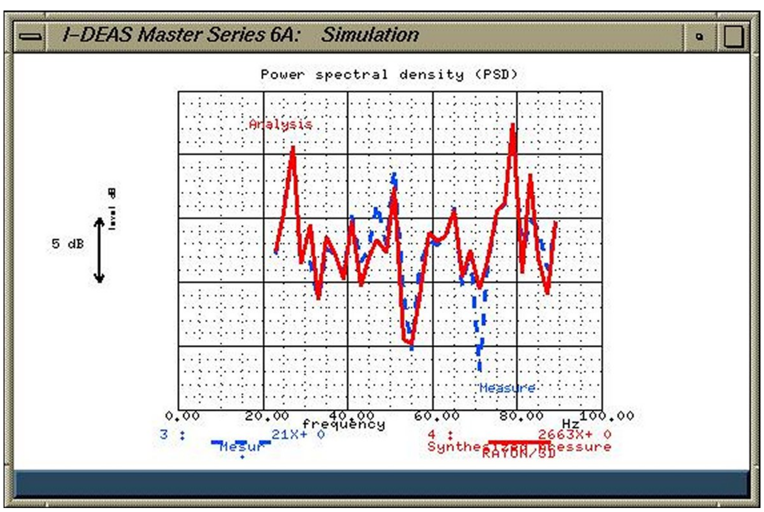

Figure 8: PSD of one microphone not used in the optimization.

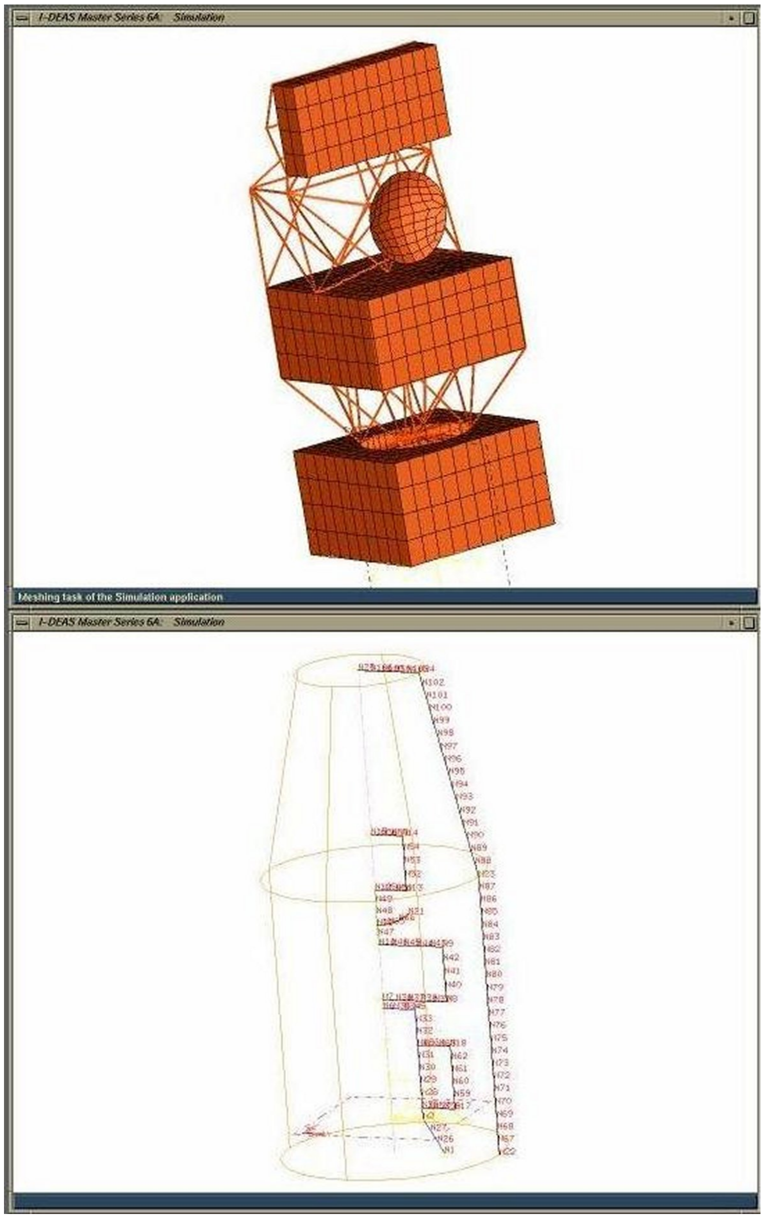

Figure 9: ERS-1 modeling by EAM.

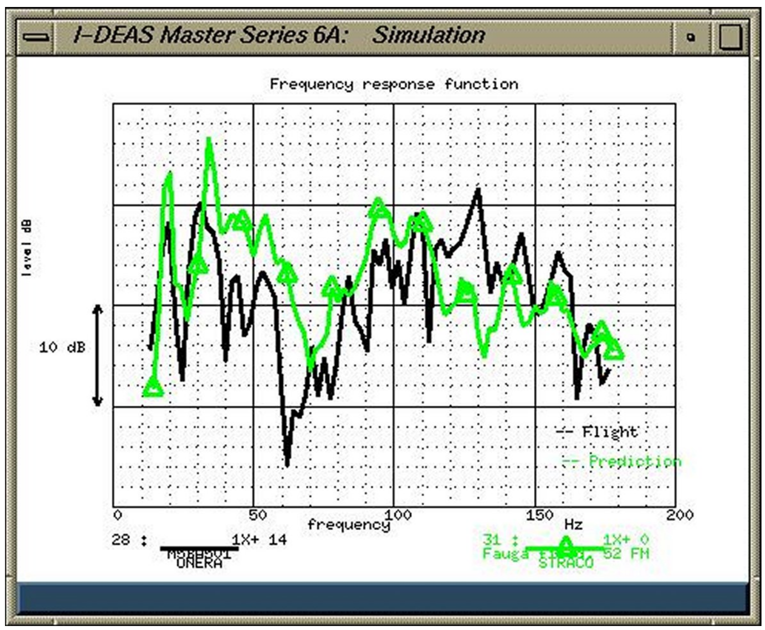

Figure 10: Flight/analysis comparison of V501.