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INSULATION OF ALUMINUM FRAME-DOUBLE GLAZING WINDOWS BY MEAN OF BEA/FEA MODELING

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ABSTRACT
This paper presents significant results of the research program on the insulation of aluminum framed windows glazed with sealed double glazings conducted by a consortium of partners. This consortium involves industrial partners which develop window components i.e.: SAINT GOBAIN for double glazings, HUTCHINSON for seals, TECHNAL and A.S. for aluminum window frames. The vibro-acoustic simulation of the window is conducted by STRACO by using I-DEAS Vibro-Acoustics and RAYON solver. The window insulation analysis is conducted both numerically and experimentally: i) Experiments are performed by partners with their transmission facilities in order to compare results and validate models. ii) Simulation are conducted by using an original FEA/BEA modeling approach capable to represent the transmission problem by taking into account structural details related to seals, frame and glass as well as internal acoustic cavities and external radiation. Comparisons between experimental an numerical insulation results show a good agreement and a parametric analysis provides indications on the influence of parameters which characterize seals, frame and the double glazings.

1 - INTRODUCTION
The development of high acoustic performance window is nowadays an important issue for window manufacturer particularly regarding improvements needed to follow community regulations and also final customer requests for isolation comfort. In the mean time, new product should be developed in a shorter delay which necessitates to reduce the number of prototype and to increase the use of the simulation approach earlier in the design process.
In such way, lot efforts have been done to develop simple and more refined numerical models which have been mostly applied to analyze and to improve glazings and double glazings Transmission Loss (TL) [1,2] but a complete window was out of the scope of such analysis.
As a complete window is in fact the assembly of interacting components (ie: glazings, frame and seals) and taking advantage of recent advance on modeling capabilities, a dedicated R&D program have been conducted both experimentally and numerically by a consortium of 4 partners (Saint Gobain vitrage for glazings, Hutchinson for seals, A.S. and Technal for aluminum frame, and Straco for numerical modeling) in order firstly to evaluate the modeling approach developed by Straco which is based on an original

FE/BEA general formulation [3,4] and secondly to analyze the influence of each components on the acoustic performance of the window.
All Window configurations tested in this project are based on high acoustic performance double glazings in order to better evaluate component influences. Some of them have been prototyped and tested experimentally by partners with their own facilities (Hutchinson and Saint Gobain).
This paper briefly describes the window configuration tested, the numerical and experimental procedures used and some of the most significant results showing the relative contribution of each window component: double glazings, aluminum frame and seals.

2 - WINDOW DESCRIPTION

As shown in figure 1, configurations tested are based on a 1370 $\times$1000 mm^{2}framed window for which component parameters are summarized on the Table 1. The complete window is made of a double glazing in which glazings are separated by a spacer and an internal cavity. The double glazings is connected to the opening frame by 2 seals (Joe, Jop). The opening frame itself is sealed to the fixed frame with two seals (Joi and Jd). Structural connections corresponding to hinge-pins and the locking mechanism are also taken into account.
Window configurations are chosen in order to evaluate influences of double glazings / frame area ratio, interlayer stiffness and seals stiffness.

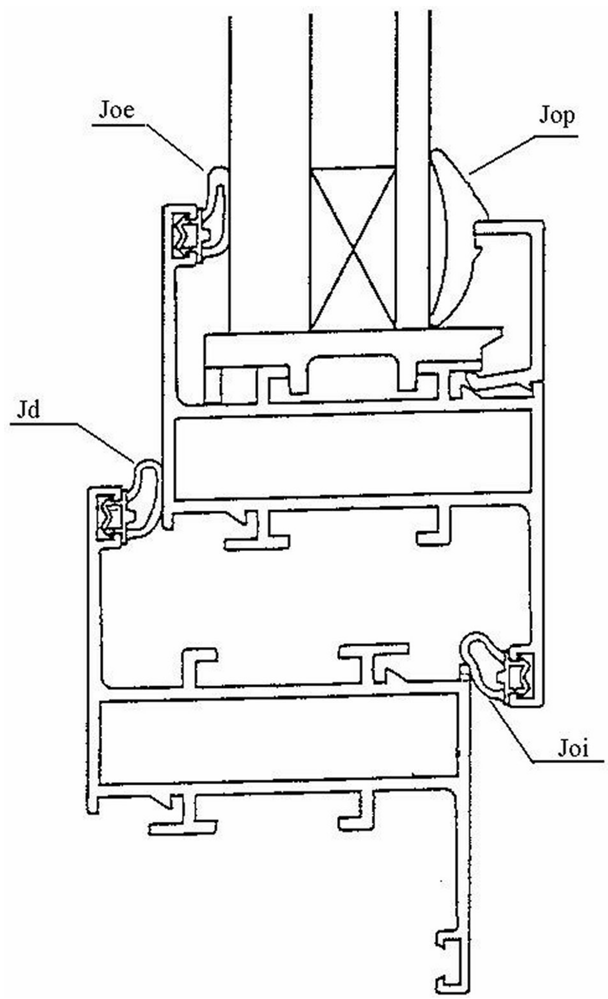

Figure 1: Window description.

	Dimensions	Glazings	Spacer	Seal type
Double glazings	Dim1: 1117 ×747 (61%) Dim2: 1245 ×875 (79%)	DV1: mono—10—10—4— DV2: lamin—4-1-4—6—8—	SP1 (stiffer) SP2 (less stiff)	
Seals (Joe,Joi,Jd)				Cellular Compact
Aluminum frame	Dim1: ”large frame” Dim2: ”small frame”			

Table 1: Window parameters.

3 - MEASUREMENT AND CALCULATION PROCEDURES

3.1 - Measurement procedures

The Transmission Loss Measurements have been conducted by two partners with their own facilities following the regular ISO 140 procedure for ST GOBAIN and a dedicated procedure developed by HUTCHINSON which is based on S31-100 (project) using the intensity method and capable to provides narrow band and 1/3 octave band Transmission Loss factor. A part of prototypes have been tested and compared in both laboratories.
Some complementary measurements have been carried out by HUTCHINSON to characterized seal equivalent complex stiffness which is needed for the seal structural model.

3.2 - Calculation procedure

The window Transmission Loss is modeled by using an original FE/BEA multi-domain formulation implemented by STRACO in IDEAS Vibro-Acoustics and the RAYON solver [3,4]. The vibro-acoustic model, shown in figure 2, is characterized by the coupling between a refined FEA structural model describing the dynamic behavior of the complete window, a FEA acoustic model describing the internal double glazings air cavity and two external BEA models which represent two semi infinite domains separated by infinite baffle at the window location: in one side, the source domain which contains a diffuse sound field modeled by a set of uncorrelated plane waves and, in the other side, the semi infinite receiver domain where the acoustic energy radiated by the window is evaluated.
Experiments and computations analysis are focused on the low and medium frequency range from 50 Hz to 1000 Hz where the TL is mainly driven around the resonance frequency band by loss of insulation due to high elasto-acoustic resonant effects.

4 - RESULTS

4.1 - Comparison experiments/model

As illustrated in figures 3a and 3b, numerical TL in 1/3 octave band as well as narrow band agree pretty well the experimental results. Discrepancies remain within a range of $2 - 3$ dB which are in the same range or less than those find by comparing the two laboratories results. Below 250 Hz, in the resonance frequency region, the numerical model underestimates the insulation at mode resonant frequencies because of an underestimated damping. For laminated glazing cases, results show that the equivalent isotropic structural model which has been used in this study to represent laminate glazing, is not quite satisfactory and a more refined multilayered model for that part should be used.

4.2 - Double glazings spacer influence

Both numerical and experimental results show that the spacer influence is clearly sensitive above 400 Hz. The softer the spacer is, the better the insulation is. The effect remains in the range of 2 to 3 dB by comparing spacer 2 (less stiff) and spacer 1 (stiffer).

4.3 - Seals influence

Many configurations combining the 3 seals (Joe, Joi, Jd) made of compact (stiffer) or cellular material have been tested. Results show a poor influence (less than 1dB) except for the Jd seal for which the cellular material (less stiff) improve the insulation up to 3dB above 400Hz. A parametric analysis conducted by playing with very low to very high stiffness shows that seal configurations studied are in fact very close to the low stiffness asymptotic branch. In the opposite case, increasing the seal stiffness will decrease the TL up to 4dB over all 1/3 Octave bands.

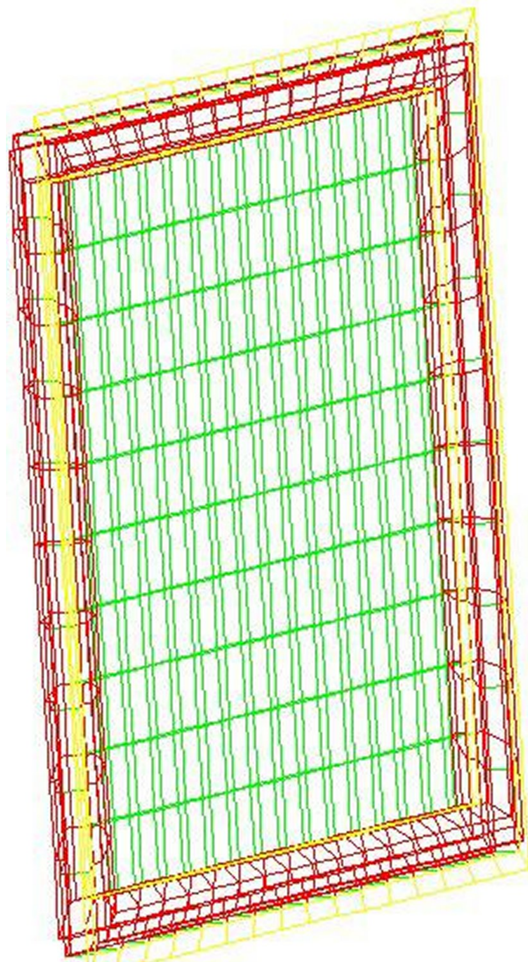

Figure 2: Vibro-acoustic model.

4.4 - Glazings/Frame area ratio influence

Analysis performed on several configurations of Frame/glazing ratio dimensions show that for high performance double glazings, the window frame is a sensitive parameter which influences the complete window performance. Tendency conclusions deduced from the modeling analysis have been confirmed by the experiments.

5 - CONCLUSION

One of the most significant result obtained during this project concerns the numerical approach based on the FEA/BEA method which provides a reliable and efficient tool to analyze and to improve the acoustic performance of complete windows in the low and medium frequencies. As it is shown, results derived from the modeling analysis remain, in a most of the case, within the range of inter-laboratory comparison. Model precision is mostly driven by the complete window structural model accuracy which could necessitate refined model description as for instance for the laminate glazing.

Furthermore, even if the double glazings remains one of the most important component which control window acoustic performance and which is highly influenced by parameters as glazings and air cavity thickness, monolithic and/or laminate glazings and interlayer stiffness [1,2], results obtained in this project show that high acoustic performance windows necessitate to take into account seals and frame interaction effects. As it is shown, window insulation could be influenced by the frame design and dimension. Seals should be soft enough otherwise window insulation could decrease up to 4 dB.

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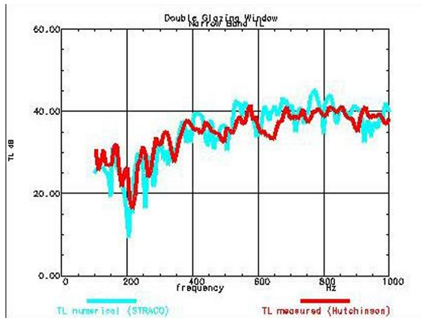

Figure 3(a): Exp. / Num. Narrow Band TL.

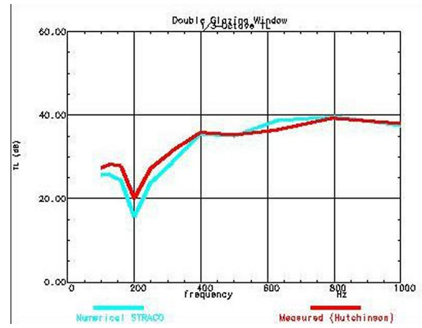

Figure 3(b): Exp. / Num. 1/3 Oct TL.

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