Influence of Seals in Sound Insulation Prediction of Steel Double Panel Doors

HERRERA, J.M.[1], **RECUERO, M.**[2]

[1] *Acoustic Engineer. Soluciones Acústicas C.A, Caracas, Venezuela.+58(212)514.75.41.info@solacus.com*

[2] *I2A2. Campus Sur. UPM. Carretera de Valencia Km. 7, Madrid 28031. Spain. +34(91)336.53.10.*

manuel.recuero@upm.es

0. ABSTRACT

The study of sound insulation door is divided in two paths: structural transmission through the door leaf and leak transmission through the slits.

Sharp's model was used to predict structural sound insulation in double panel steel doors. Factors such as cavity sound absorption, interpanel connections in the door edges and sound barrier in cavity are included in this model. The influence of sound barrier and sound absorption on resonance and critical frequency is also studied.

Jones' theory was used to predict leak transmission which assumes perfect transmission through slits.

Hongisto's model was used to calculate total sound insulation using Sharp's and Jones' models.

The main goal of this paper is to show accurate prediction models for high sound insulation door design under laboratory conditions using a larger quantity of seal models compared to Hongisto's research. By using these models, designers can reduce costs in mass increase or seal selection.

In order to compare laboratory results with Hongisto's model, a high structural transmission loss door was used to study the influence of sealing in high insulation doors (level effect).

Several seal models were used to compare laboratory results with Hongisto's model; these included a different combination of adjustable side and top double neoprene, single and double floor neoprene and cushion bronze seals. These seals used different installation and sealing principles. Hongisto's model proved to be a good prediction model because it offers ± 5 dB error in a wide frequency range (160 Hz – 2000 Hz) for most seal combinations. When cushion bronze seals are only used in the door perimeter and double floor neoprene, Hongisto's model is not accurate.

Finally, it was found that adjustment, material, and seal combinations as well as sealing principles are very important factors to be considered when Hongisto's prediction model is used.

1. INTRODUCTION

Door sound insulation is an exceptional topic in the field of noise control due to the number of variables to consider and the scant bibliography. It seems contradictory that so little door sound insulation literature exists for such a common partition which is used in recording studios, conference halls, theatres, etc. Despite its wide use in the field of acoustics, it is typically one of the weakest partition from the point of view of sound insulation [Hongisto 2000].

The scarce bibliography on the subject leads consultants to use solutions such as mass increase of the door leaf instead of using other types of structural improvements or leak sealing, and thus saving costs. It can be said that the structural improvements are as important as leak sealing, which is even more important inhigh sound insulation doors (STC 50 or superior)

In this research, a combination of models proposed by Sharp [Sharp 1973] [Sharp 1978], Jones [Jones 1976] and Hongisto [Hongisto et al 2000], were used to predict insulation in doors.

Sharp's model [Sharp 1973] [Sharp 1978] has proved to be reliable for predicting insulation in partitions without leaks. Its margin of error is ± 1.5 dB up to the middle of the critical frequency.

On the other hand, Jones [Jones 1976] studies sound transmission through slits and assumes that transmission in this case is perfect; in other words, TL equals zero throughout the frequency range.

Hongisto [Hongisto 2000] used Sharp's Model to predict transmission through the leaf, and Jones' Model for transmission through slits because better results were obtained when these were sealed with gaskets. In addition, Hongisto adds factors as the space that remains between the seal and the leaf.

This research used a greater variety of seal models than Hongisto's research [Hongisto et al 2000]. The selection of the seals was based on the material and installation method.

It was demonstrated that Hongisto's Model [Hongisto 2000] is a reliable model in a wide range of frequencies and that variables such as the material, installation and combination of seals are very important factors to consider.

2. BIBLIOGRAPHY REVIEW

Few studies exist regarding STC or STC "in-situ" (FSTC) insulation that take into account the influence of leaks.

Gompers used simple mathematical models for circular and rectangular slits [Gompers 1972]. For a circular slit with a finite depth, Wilson and Soroka also suggested solutions in terms of radiation impedance [Wilson 1965].

[Higginson 1971] researched the effect of the incidence of sound to determine the origin of the dispersion in the measured data. Similarly, he suggested several principles to unify the FSTC in buildings.

Jones [Jones 1976] compared the FSTC [ASTM 1970] with his model in gypsum panels. His model included the insulation parameter by means of the slits.

More specifically on the topic of sound insulation in doors, a study sponsored by the BBC [Pluma et al 1994] concluded that magnetic seals along the perimeter and automatic door bottom seal for the floor provided the best sound insulation option for existing doors in the BBC studios. The work consisted of measuring door insulation with different types of seals and from different manufacturers (Zero International, Raven and Sealmaster).

Up to August 2000, one of the latest recorded works which study the influence of leaks insulation in situ was prepared by Kang, Kim, Kim and Kim (Kang et al 2001].

The study consisted of analyzing the influence of leaks when the laboratory insulation were compared to the "in-situ" predicted insulation in partitions on ships. The leaks studied were those that appeared during the installation process for the panels.

3. THEORY

The transmission of sound through doors involves two factors: structural transmission (τ_{struct}) and transmission through slits, or leaks (τ_{leak}), as shown in Figure 1 [Hongisto 2000].

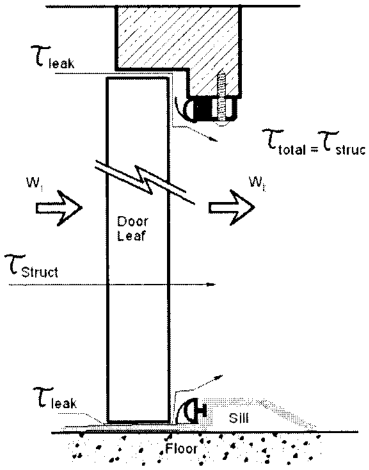

Figure 1: **The principle of sound transmission through doors (cross section). Transmission through leaks and leaf are separate [Hongisto 2000]**

A total of four parameters for sound insulation in doors can be defined based on the factors described in Figure 1: $R_{w\ struct}$ (transmission solely through the leaf), $R_{w\ total}$ (transmission through the leaf and leaks), $R_{w'\ struct}$ ($R_{w\ struct}$ "in situ") and $R_{w'\ total}$ ($R_{w\ total}$ "in situ"). $R_{w\ struct}$ and $R_{w\ total}$ can be measured in the laboratory using ISO 717-1 standard (in the U.S.,ASTM E 90-04 standard is used and STC is substituted for the R_w nomenclature).

R_w (STC in the U.S.) is the official insulation parameter for doors, however this is different "in situ" because the installation, absorption and geometry of the room are variables that must be considered. The sound reduction index, SRI (R_{struct}) is determined by sealing with duct tape or mastic in the slits and the lock.

Sometimes the same sound insulation can be obtained "in situ" as in the laboratory by improving leak sealing and making structural changes as compared to more expensive doors because the cost increase is typically due to the increase in mass [Hongisto 2000].

In order to simplify the study of sound transmission, the influence of the frame will not be taken into account due to its minimal surface area in relation to the total surface area of the door (10% of the area), its weight and rigidity in comparison to the leaf. Moreover, to calculate the frame transmission loss is extremely complex [Hongisto 2000].

Based on described above, Hongisto presents his model, called the sound reduction index as R_{total} [Hongisto 2000]:

$$R_{total} = 10\log\left(\frac{R_{struct} + R_{slit}}{S_{struct}\,10^{-R_{struct}/10} + S_{slit}\,10^{-R_{slit}/10}}\right)\ [dB] \qquad [1]$$

Where S_{struct} is the surface area of the door, S_{slit} is the total area of the slits, R_{struct} is the SRI calculated for the door leaf, R_{slit} is the SRI of the slits.

Sharp's Model [Sharp 1973] [Sharp 1978] was used for calculating the structural sound reduction index (R_{struct}), which establishes four parameters: resonance frequency (f_o), acoustic bridge frequency (f_B), critical frequency (f_C), limiting frequency (f_l) and the TL increase due to the presence of acoustic bridges ($\Delta TL_{WL,}$ in the case of a door without internal reinforcements, only the bridges along the perimeter, which behave like linear bridges, ΔTL_{WL}, should be considered).

The resonance frequency (f_o) is provided by [Sharp 1973]:

$$f_o = \left[\frac{113}{\sqrt{m_e . d}} \right] \qquad m_e = \frac{2 m_1 . m_2}{m_1 + m_2} \, [Hz] \qquad [2]$$

Where m_1 is the mass of panel 1 in kg/m^2, m_2 is the mass of panel 2 in kg/m^2 and d is the depth of the cavity in meters.

The sound contribution through acoustic bridges is significant above f_B, which is provided by [Sharp 1973]:

$$f_B = f_0 \left(\frac{\pi b f_C}{2c} \left(\frac{m_1}{m_1 + m_2} \right)^2 \right)^{1/4} \qquad [3]$$

Where b is the distance of the linearly connected bridges in meters, C is the speed of airborne sound in meters / second.

The limiting frequency, f_l, is provided by [2]:

$$f_l = \frac{55}{d} \quad [Hz] \qquad [4]$$

Under the hypotheses described above, we can predict TL as:

$$TL = 20 \log (W.f) - 48 \quad [dB] \quad f < f_o \qquad [5]$$

$$TL = TL_1 + Tl_2 + 20 \log (f.d) - 29 \, [dB] \; f_o < f < f_l \quad [6]$$

$$TL = TL_1 + Tl_2 + 6 \quad [dB] \quad f > f_l \qquad [7]$$

Where W is equal to the sum of the mass of both panels plus reinforcements, glue, soundproofing, etc. in kg/m^2 and,

TL_1 = transmission losses of panel 1, 20 log (W_1.f) – 48 (Mass Law)
TL_2 = transmission losses of panel 2, 20 log (W_2.f) – 48 (Mass Law)

In the three previous intervals, $\Delta TL_{WL,}$ could be placed in front, which will take effect after f_B and will be parallel to the Mass Law [Sharp 1978]:

$$\Delta TL_{WL} = 20 \log (b.f_c) + 20 \log \left[m_1 / (m_1 + m_2) \right] - 18, [dB] \quad [8]$$

Where: b is the separation between the reinforcements (meters), f_C is the highest critical frequency of the two panels. According to Beranek, Cremer and Heckl [Cremer et al. 1957], F_c is equal to:

$$h.f_c = 12.4 \qquad [9]$$

Where h is the Plateau height of the panel material

It should be pointed out that Sharp's equations, [Sharp 1973] [Sharp 1978], do not take into account the coincidence phenomenon and, therefore, this theory is only valid up to ½ f_c.

In Hongisto's model [Hongisto 2000], zero transmission through slits is assumed as proposed by Jones and, therefore, R_{slit} equals zero.

4. EXPERIMENTAL DATA

The measurements were taken in Architectural Testing Inc Laboratory. located in York, PA, USA. All of the equipment used complies with ANSI standards established in ASTM E90-04 Standard. The laboratory is accredited by the National Institute of Standards and Technology (NIST) [NIST 2006] under the National Voluntary Laboratory Accreditation Program [NVLAP 2006].

4.1 CALCULATION METHODS

Microsoft Excel was used to model the Sharp and Hongisto models. The equations used were [1] through [8].

A tool known as the "Feeler Gauge" [Eastern Industries 2004], which consists of a set of steel blades with different thicknesses, with its respective margin of error, was used for calculating the slit area (S_{slit}).

4.2 DOOR CONSTRUCTION

A high insulation door (STC 55) was selected to best study the influence of sealing. The door dimensions were 2.13 x 0.91 x 0.04 m. The distance between frame and leaf was 3 mm. The door was made of steel. The first panel thickness was 1.90 mm (14 gauge) and the second was 3.42 mm (10 gauge). Two vinyl barriers were attached to the interior of the first panel. The first had a thickness of 3.20 mm and the second of 9.53 mm. The density of both barriers was 3.29 kg/m^2. The rest of the internal cavity (25 mm) was filled with fibreglass with a density of 18 kg/m^3. (Figure 2). Total weight of the door leaf was 114 kg.

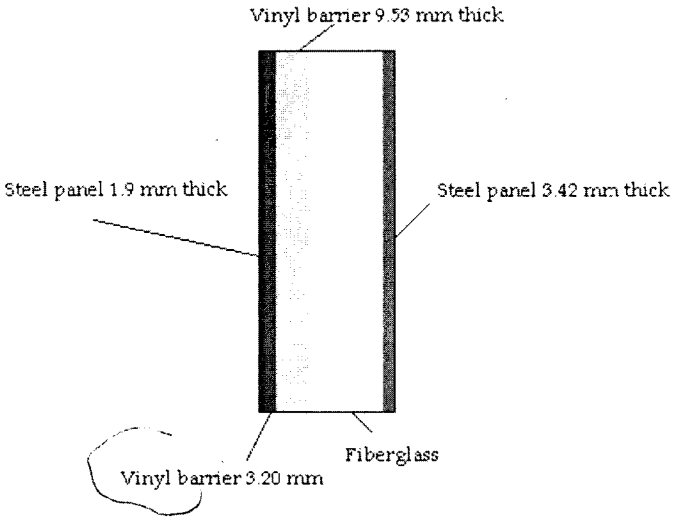

Figure 2: Detail of test door construction

5 LABORATORY MEASUREMENTS OF DIFFERENT SEAL COMBINATIONS

5.1 SEAL COMBINATIONS.

The sound insulation of five seal configurations was measured using the door described above. All of the seals used are shown in Figure 3 and their bulbs are made of an alloy of ethylene and propylene commercially known as neoprene ~~EPDM~~.

Below we will describe each configuration:

- *Configuration A*: all possible leaks were sealed with mastic or duct tape. These materials were applied along the entire perimeter of the leaf, the perimeter of the frame, lock and knob for the purpose of achieving the STC or $R_{w\ struct}$

- *Configuration B*: The Zero International model # 7770A sealing system [ZERO INTERNATIONAL 2007] was installed in the perimeter, and model # 564A [ZERO INTERNATIONAL 2007] was used to seal the space between leaf and floor. The 7770A seal consists of an aluminium casing that contains a mechanism that permits varying the pressure of a double neoprene bulb against the leaf. The casing is screwed to the doorframe (See Figure 3). The pressure of the neoprene bulbs is regulated by screws along the length of the casing on the side opposite the bulbs. On the other hand, the 564A seal is an aluminium frame in the form of a step, with a simple neoprene bulb at one of its ends, designed to be anchored to the floor using screws.

  The leaks between the frame and 7770A seal and between frame and was sealed with mastic. Similarly, the slit between the 564A seal and the floor was sealed with the same product. Before proceeding to determine the insulation, the sources in the source room were turned on in order to identify leaks that were poorly sealed by the gaskets using a stethoscope. Leaks were, in fact, detected in the corners and the 7770A seal was adjusted accordingly.

- *Configuration C:* Configuration B with the addition of the 367A seal (See Figure 3). The 367A is known as a "scissors" type seal because it has a lever-type mechanism which causes the double neoprene bulb to exert pressure on the floor when the door closes and lift when the door opens, reducing the wear on the rubber as it does not drag when the leaf moves. The installation of the 367A seal [ZERO INTERNATIONAL 2007] is such that its rubber bulb rests on the flat surface of the 564A to achieve a double seal.

- *Configuration D:* Configuration C with the addition of the 119WB seal [ZERO INTERNATIONAL 2007] along the entire perimeter (See Figure 3), including the bottom of the door to achieve a triple seal in this zone. The 119WB seal is a bronze cushion seal with a thickness of 0.325 mm which moves when pressure is applied and returns to its initial position when the pressure stops. Its shape permits sealing between the leaf and the frame. The seal is attached to the frame by means of a self-adhesive material.

- *Configuration E*: Configuration C without the 7770A perimeter seals, such that only the 119WB seal remained along the entire perimeter, with the exception of the floor, given that the triple seal made up of 119WB, 367A and 564A remained there.

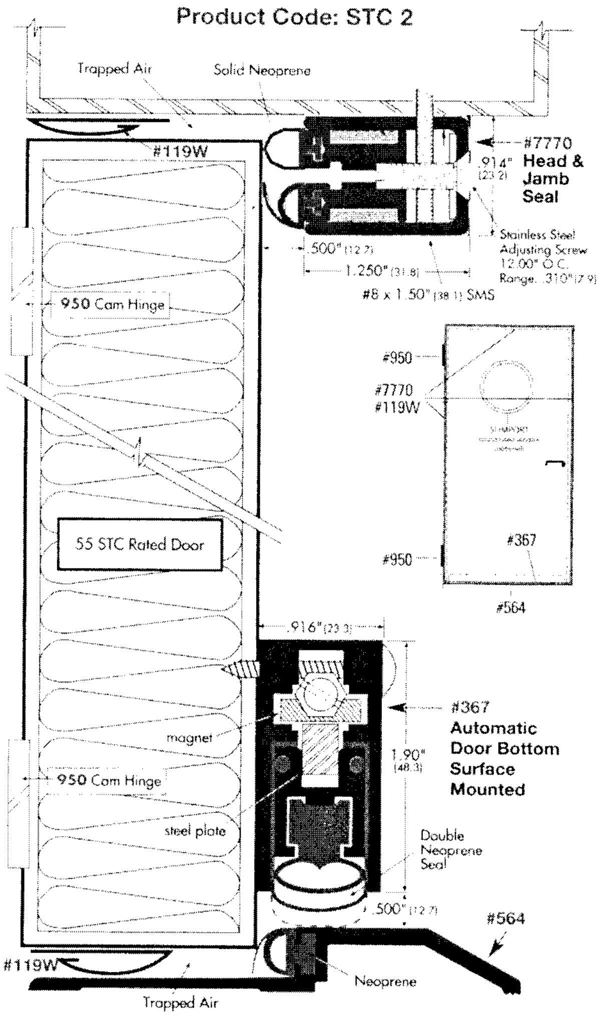

Figure 3: Seals used in the laboratory measurements

5.3 MEASUREMENTS

The results obtained with the different seal configurations are shown below:

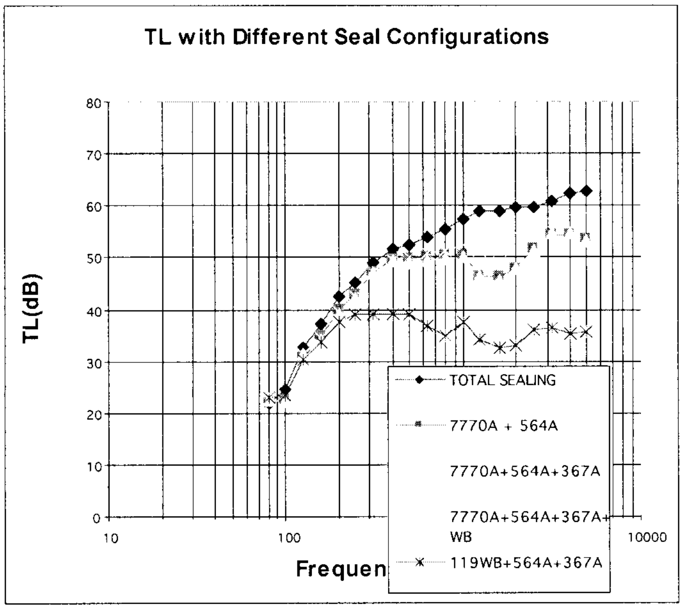

Figure 4: Graph showing sound insulation for all seal configurations

6 THE EFFECT OF THE DIFFERENT COMBINATIONS OF SEALS IN THE PREDICTION OF SOUND INSULATION

Different graphs appear below showing the laboratory measurements compared to the Sharp and Hongisto Models. Table 1 lists parameters for the calculation of these graphs, such as: Fo, Fl, F_B, F_C, and ΔTL_m. It is assumed that the transmission through slits is perfect, in other words, that TL equals zero as suggested by Jones [Jones 1976].

fo (Hz)	fl (Hz)	f_B (Hz)	f_C Steel Panel # 1 (Thickness 1.9 mm) (Hz)	f_C Steel Panel # 2 (Thickness 3.2 mm) (Hz)	ΔTLm (dB)
136	1823	190	3543	6526	14

Table 1: Parameters that define the sound insulation of the test door according to Sharp

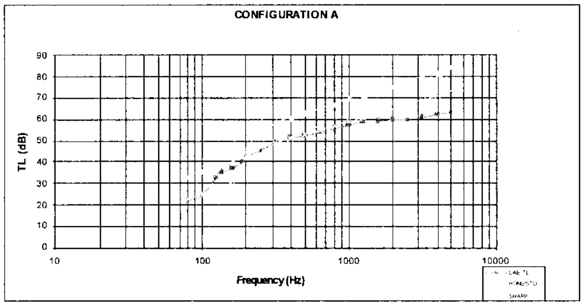

Figure 5: Comparison of the Sharp and Hongisto Models with laboratory measurements. Total area of slits used: 0 m^2

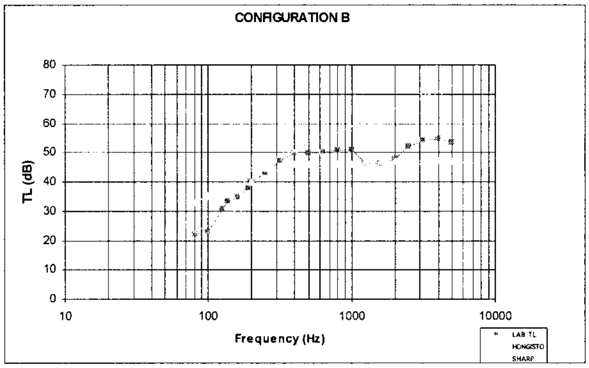

Figure 6: Comparison of the Sharp and Hongisto Models with laboratory measurements. Total area of slits used: 0.00123 m^2

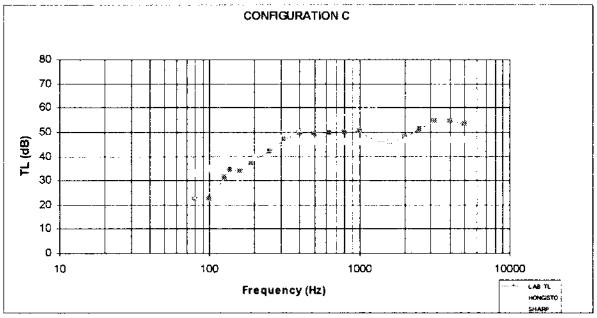

Figure 7: Comparison of the Sharp and Hongisto Models with laboratory measurements. Total area of slits used: 0.00123 m^2

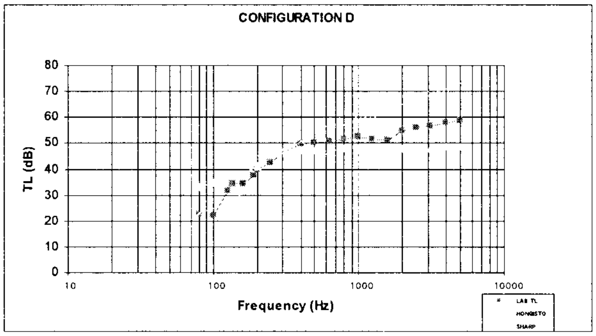

Figure 8: Comparison of the Sharp and Hongisto Models with laboratory measurements. Total area of slits used: 0.00092 m^2

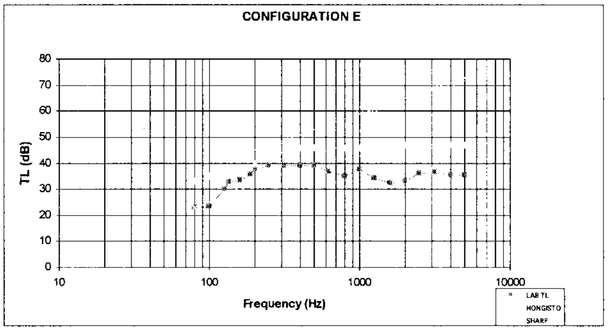

Figure 9: Comparison of the Sharp and Hongisto Models with laboratory measurements. Total area of slits used: 0.00123 m^2

7 CONCLUSIONS.

- The "level effect" is apparent when comparing the TL achieved with the triple seal (Configuration D) to the TL achieved by Hongisto when using double neoprene seals with a bar [Hongisto et al 2000]. A triple seal was used in both cases. In the first case, STC = 51 ($R_{struct} = 55$) was achieved and in the second, $R_w = 45$ ($R_{struct} = 48$). The difference between the door that was totally sealed with mastic or dust tape (this seal was applied to the possible leaks found in the lock, door handle and between the leaf and the frame) for the first case was 4 and for the second was 3. The abovementioned differences demonstrate that a better seal was achieved in the first case (the improvement of the sealing was basically achieved by the adjustment option), because of the influence of the leaks is more critical for achieving STC = 51 than $R_w = 45$ (Level Effect). This demonstrates the importance of the "in-situ" adjustment of the seals for achieving a continuous seal, as is the case with the 7770A model seals. However, it should not be forgotten that, apart from the adjustment of the seals, the construction of the frame of the door are also very important parameters to consider.

- The seal is more effective at the middle and high frequencies. This conclusion can be reached by comparing the curves in Figure 4. With an intermediate seal (Configuration B), a greater than 6 dB valley in TL can be seen at 1,000 Hz when compared with optimum sealing (Configuration D). When the sealing conditions improve, the TL increases at the middle and high frequencies. This conclusion contrasts with that of Hongisto [Hongisto et al 2000], as he concluded that the seal was more important at the high frequencies (from 2,000 Hz) in his multiple measurements.
With intermediate sealing conditions, Hongisto [Hongisto et al 2000] perceives a valley between 2,000 Hz and 2,500 Hz, while it appears between 1,000 Hz and 2,000 Hz (Configuration B) in this study.
What is interesting is that in the Hongisto study [Hongisto et al 2000], the valleys recorded with intermediate sealing conditions are only found in this study in Configuration E. The reason for this behaviour is not clear, although factors such as the installation, modes in the edges of the corners influence the results.
- The sealing principle and the material used are very important factors in the final TL. This can be noted in Configuration E. The sealing principle of model 119WB is friction, not pressure as in the case of the 7770A, 564A and 367A. Pressure gaskets seal slits better than friction ones. On the other hand, model 119WB consists of a very thin (thickness of less than 1.5 mm) bronze strip. In effect, upon using a 119WB seal with a length of over 90 cm, this sags due to gravity, causing very high sound transmission through it. Therefore, we can conclude that friction seals should only be used to complement pressure seals.
- The best insulation was obtained using a triple seal, through the combination of pressure and friction seals (Configuration D).

- Additional insulation is not always obtained by adding a seal. This is apparent in the differences in the TL between Configurations B and C. In addition, it is clear that the TL is higher in the first case (although only by 1 dB) at a larger number of frequencies in comparison to the second case.

The reason for these differences could have been that when installing the 367A, the pressure of the 564A moved slightly. Another reason for these slight differences is that the 564A seal was so good that the addition of a second seal did not provide significant results. Although in laboratory situations the use of the 364A is not justified, field conditions may require it because irregularities in the floor sometimes make it difficult to obtain a continuous seal using only the 564A. On other occasions, the 564A cannot be installed because it obstructs the movement of the equipment carts used in TV studios.

- The model proposed by Hongisto [Hongisto 2000] and Jones [4] overestimates the TL in the absence of leaks, while Sharp's Model provides the best estimation up to $f_C/2$. (Figure 5).
- The model proposed by Hongisto [Hongisto 2000] and Jones [Jones 1976] predicts very well the TL measured in the presence of several seal combinations, with the exception of the case in Figure 9. The deviations from 160 Hz to 2,000 Hz do not exceed 5 dB and therefore these models provide good estimations for the applications for which the STC was considered (speech, radio, TV, etc.). In contrast, at frequencies higher and lower than the range between 160 Hz and 2,000 Hz, the deviations exceeded 5 dB, making the models unreliable. Factors such as the error associated with the measurement of the slits with the "Feeler Gauge" and the models themselves could be the cause of the differences between the predicted and measured results.
- When the seals permit sound transmission through them, and their sealing principle is friction, the Sharp [Sharp 1973] [Sharp 1978], Hongisto [Hongisto 2000] and Jones [Jones 1976] models are not good (Figure 9), making it necessary to use gaskets with pressure elements which have sufficient mass and pressure (also flexibility for comfortable door closure) so that the models can predict the results more exactly.

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9. BIBLIOGRAPHY

[Hongisto 2000]. "Sound insulation of doors- Part 1: Prediction models for structural and leak transmission." *Journal of Sound and Vibration* 230, 133-148 (2000)

[Sharp 1973] "A Study of Techniques to Increase the Sound Insulation of Building Elements," HUD Contract H-1095, *Clearinghouse for Federal Scientific and Technical Information*, Springfield, Virginia (1973).

[Sharp 1978] "Prediction Methods for the Sound Transmission of Building Elements," *Noise Control Engineering* 11, 53-63(1978).

[Jones 1976] "How to Accurately Predict the Sound Insulation of Partitions." *Sound and Vibration Magazine* 10, 14-25 (1976)

[Hongisto et al. 2000] "Sound insulation of doors- Part 2: Comparison between Measurement Results and Predictions," *Journal of Sound and Vibration* 230, 149-170(2000).

[Gompers 1972] "The Sound Insulation of Circular and Slit Shaped Apertures," *Acustica 14*, 1-16(1972).

[Wilson 1965] "Approximation to diffraction of Sound by a circular aperture in a rigid wall of finite thickness." *J. Acoustics Society of America*. 37(2), 286-297(1965).

[Higginson 1971] "A Study of Measuring Techniques for Airborne Sound Insulation in Building." J. Sound and Vibration, 5 (10): 12-16 (1971).
[Pluma et al. 1994] "The Sound Insulations of Studio Doors: Part 2: Door Seals," *Research and Development Report*, BBC (1994).
[Kang et al. 2001] "Influence of Sound leaks on in situ sound insulation performance." *Institute of Noise Control Journal* 49, 113-119 (2001).
[Cremer et.al 1957]: translated and revised by E.E. Ungar (1973)
[NIST 2006]. Available at http://www.nist.gov/ (2006).
[NVLAP 2006] (Online). Available at http://ts.nist.gov/ts/htdocs/210/214/214.htm. (2006)
[Eastern Industries 2004] Eastern Industries Inc. *(Online).* Available at www.easterngage.com/standard-feeler-gage-sets.asp (2004)
[ZERO INTERNATIONAL 2007] (Online). Available at http://www.zerointernational.com (2007)