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# ACOUSTIC TESTING OF AN ADVANCED TECHNOLOGY FUSELAGE STRUCTURE

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## ABSTRACT

A simplified helicopter fuselage structure was built to investigate the many aspects of introducing new materials and technology in the design and manufacture of helicopters. The acoustic behaviour of this structure was examined using conventional parameters, i.e. transmission loss and radiation efficiency. In addition, Statistical Energy Analysis was applied to the structure and a theoretical model was formulated which described the reaction of the structure. Comparisons were made between the response of the complete fuselage and the response of a single panel made of the same materials used to skin the fuselage. Finally, as more and more emphasis is being placed on the use of composite materials in the real helicopter, the composite honeycomb panel used to skin the fuselage was acoustically compared with a conventional aluminium skin/stringer panel.

## 1. INTRODUCTION

Noise within the helicopter cabin is becoming increasingly important, particularly as the helicopter is finding greater application and usage in the civil role, where the operator is specifying and the paying passenger is expecting low cabin noise levels.

The problems of reducing noise levels in the cabin have been the subject of research and development at Westland Helicopters Limited, for a number of years. Early work concentrated on soundproofing treatments such as acoustic foam and vibration damping materials, because of their obvious benefits (Ref.1). These solutions do however have their limitations, namely that there are weight penalties and also the scope for improvement of the soundproofing materials, i.e. lighter materials with good noise attenuating properties, is limited. More recent studies have been directed towards panel structures which could be used to skin a cabin framework, in an attempt to introduce the attenuation at the design and manufacturing stages. This work consisted of theoretical and experimental analysis of simple skin/stringer panels and honeycomb panels tested in a laboratory situation (Ref.2). There have also been attempts to study and assess the cabin noise problem in a 'whole aircraft' situation (Ref.3), however the results of these exercises have often been clouded by experimental problems and also the magnitude and complexity of the task.

It became apparent that there was a need to bridge the gap between simple panel configurations and the complex total helicopter. A good deal was already known about the former but very little was known of the latter, for example how these various panels would react when constrained to frames etc. etc.

The opportunity recently arose to enable this gap to be bridged. A simplified fuselage structure, known as the Advanced Technology Fuselage (ATF) was made available for acoustic test work.

## 2. THE ADVANCED TECHNOLOGY FUSELAGE RESEARCH PROGRAMME

The ATF research programme had its beginnings in the late 1970's. A major objective of the programme was to evaluate the claims made for new materials and structural configurations, particularly in relation to reduced weight and cost. In addition though, the programme was to provide useful engineering information and experience in the design, manufacture and test of advanced structures. To this end the ATF programme had a large and wide ranging series of tests including static strength, crashworthiness, dynamic characteristics, electrical/EMC properties and acoustic performance.

Two fuselage structures representing the centre section of a helicopter were designed and manufactured for the overall programme. One was constructed using three titanium alloy frames pitched 1m apart, to which were bonded carbon skinned honeycomb sandwich panels. The second fuselage is identical, apart from the frames which are of carbon composite construction. Figure 1 shows the titanium framed fuselage.

As well as providing information for the ATF programme, the simple fuselage therefore presented the ideal opportunity to 'bridge the gap' referred to earlier, between acoustic measurements made in the laboratory on simple panels and the acoustic behaviour of a complete helicopter.

To date the titanium framed fuselage has been tested, and this paper now goes on to discuss the acoustic work carried out on that fuselage. The acoustic tests are split into three sections, namely

acoustic transmission loss
radiation efficiency
statistical energy analysis

and for the purpose of this paper they will be examined and discussed in the same order.

Reference 4 gives more information on the actual ATF programme and details of the other tests conducted on the fuselage.

## 3. ACOUSTIC TRANSMISSION LOSS

The Acoustic Transmission Loss is simply the amount (generally expressed in dB's) by which sound incident on a partition is reduced in transmission through it.

The standard expression for the experimental derivation of Transmission Loss (TL) is

$$\mathrm{TL\ (dB)} = \mathrm{NR} + 10\log_{10} S - 10\log_{10} A$$

where NR is the time-space average sound pressure level noise reduction of the partition, S is the surface area ($m^2$) of the partition and A is the absorption (metric Sabine) of the receiving enclosure. The transmission is considered to be purely airborne, there being no flanking paths or structure borne noise. Our past experience of the measurement of TL has been confined to laboratory tests in the Reverberant Rooms at WHL, where it has been possible to measure the TL of various panels, in a controlled environment.

Transferring the measurement technique to a fuselage structure was straightforward but does require some explanation. As the structure was too large to fit in a truly reverberant room, the actual test site had to be chosen with care to ensure that a uniform sound field was capable of being created. The fuselage was isolated from the floor to prevent any structure borne sound transmission paths. The ends of the fuselage and the window were acoustically sealed, making an enclosure within which a noise field was created. The ends were designed to provide 10dB additional attenuation over that given by the fuselage skin, so that the external noise field was the result of sound transmission through the skin. Figure 2 shows the ATF set up for measurements. By monitoring the internal and external sound pressure levels and correcting for absorption and surface area, the TL of the fuselage was calculated for each third octave frequency band between 250Hz and 8kHz. Theoretically the sound transmitted through a partition is independent of the direction of transmission. To verify this, as a check on our experimental technique, the situation explained earlier was reversed and now a noise field was set up in the space outside the sealed fuselage. As before the TL was calculated.

Figure 3 shows the results of these two tests, plotting TL as a function of frequency. It is interesting to note that apart from the region around 250-400Hz, there is an approximate constant 2dB difference between the two tests. The low frequency deviation can be explained as the difference in room volumes and characteristics, i.e. when the sound field was set up outside the fuselage, an array of loudspeakers created a uniform field but when the situation was reversed, the fuselage acted as a single noise source and was unable to set up a uniform sound field outside the fuselage. The most likely explanation for this 2dB difference is accounted for by considering the surfaces through which the sound is transmitted. When the sound is transmitted through into the fuselage interior, the under surface does not contribute significantly to the transmitted sound pressure level, principally as this area is shielded by the floor upon which the fuselage rests. When the transmission occurs in the reverse direction, the undersurface of the fuselage does transmit. When the difference in the effective surface areas is taken into account by the $10\log_{10}$. A term, a difference of 1.5dB results, which is independent of frequency. When this difference is applied to Figure 3 it can be seen that the two measurements are, within experimental error, the same.

A carbon/honeycomb nomex/carbon panel, of the same construction as the panels used to skin the fuselage, was made up and its TL measured in the laboratory. The result is shown in Figure 4 where it is compared with the TL of the whole fuselage structure. Again within experimental error these two measurements are identical.

The results given in Figure 4 are important as they imply that the TL of a typical fuselage structure is not affected by its frames and stringers, and that it is a characteristic simply of the skin panel. This was not fully appreciated previously and now means that the Airborne Transmission Loss of a fuselage structure can be predicted simply from a knowledge of the skin panel Transmission Loss.

## 4. RADIATION EFFICIENCY

The previous discussion was concerned only with airborne sound transmission, however, there are other paths by which noise can be introduced into the cabin, namely via the structure, i.e. where vibrational energy, from sources such as the gearbox, is transmitted through the fuselage frames and panels to be radiated finally as acoustic noise. It has been estimated elsewhere (Ref.3) that structure borne noise and airborne noise are of equal importance in the final analysis of cabin noise levels, and this chapter attempts to examine the structure borne problem.

A useful measure of the effectiveness with which a vibrating surface radiates energy into the air (or any other medium) is the radiation efficiency or radiation ratio, denoted $e_r$. It is essentially the ratio of the radiated sound power, of for example a panel surface, to the average velocity of the panel surface, and is generally defined as

$$e_r = \frac{P}{\rho c A \overline{v}^2}$$

where P is the power radiated, $\rho$ and c the density and speed of sound in air, A the area of the radiating surface and $\overline{v}$ the average velocity of the surface.

Similar to the measurement of TL described previously the measurement of radiation efficiency is a simple laboratory experiment, and the transfer of the technique to the fuselage situation was straightforward. Briefly the structure was excited by attaching an electromagnetic vibrator to one of the frames, and a total of 26 accelerometers were used to measure vibration levels on the panels and frames of the fuselage. For the purpose of these tests the structure was considered to be symmetrical about two of its axes, enabling the distribution of the accelerometers to be concentrated, so that more local variation of vibration could be monitored, without losing a global appreciation of how the structure was reacting. The general definition of $e_r$ also requires the sound power level generated or radiated by the excited structure to be measured, therefore, as before for the TL measurements, the fuselage was acoustically sealed. Finally, the fuselage was isolated from the floor to prevent it from radiating through the floor, or being vibrationally damped by it.

The definition of $e_r$ given earlier can be expressed in terms more easily arrived at by experiment. It can be shown that (Ref.5)

$$e_r = \frac{13.8\, V \omega^2 Sp}{TS\, \rho^2 c^3\, Sa}$$

where V = the volume of the reverberant space into which noise is radiated

$\omega$ = angular frequency
T = the reverberation time of the volume V
S = the surface area of the radiating panels of interest which enclose the volume V
$\rho c$ = the density of air and speed of sound in air
Sp,Sa = the sound pressure spectral density within the volume V and the radiating panel acceleration spectral density.

This expression can be simplified as $\frac{Sp}{Sa} = \frac{p^2 rms/\Delta f}{a^2 rms/\Delta f}$

where $p^2$rms = the root mean square sound pressure (Pa) within the volume V
$a^2$rms = the root mean square acceleration ($ms^{-2}$) of the radiating panel
$\Delta f$ = in this situation a bandwidth of $\frac{1}{3}$rd octave.

Using this expression, with values of p rms, a rms and T obtained by experiment, the radiation efficiency of the fuselage as a whole was calculated. It is customary at WHL to plot the radiation efficiency in the form $10\log_{10} e_r$ v. frequency, and Figure 5 shows these results. Similar to the TL measurements referred to earlier, the $e_r$ of a panel made the same as the panels used to skin the fuselage was measured in the laboratory, as a comparison to the $e_r$ measured for the fuselage; this is also shown in Figure 5.

It can be seen that up to the 2kHz $\frac{1}{3}$rd octave frequency band the panel and fuselage values of $e_r$ are the same. Above this frequency the two curves differ significantly, the reason for this is not yet known, except that the frames are influencing the response of the panels. The good agreement between the 250 and 2kHz $\frac{1}{3}$rd octave frequency bands is reassuring as it encompasses those frequencies most likely to excite the structure, e.g. meshing frequencies of the main gearbox, and means that simple panel measurements of $e_r$ can predict with reasonable accuracy the situation of a simple fuselage.

## 5. STATISTICAL ENERGY ANALYSIS

Statistical energy analysis (SEA) is in essence a method of analysing the vibrational energy flow around a structure or system. The method breaks down the system into various subsystems, each of which can store, dissipate or transfer to another subsystem, energy. The theory assumes high modal density and uses average modal density and loss factors etc. These properties of the subsystems can be calculated from simple formulae and if the vibrational input power to the whole system is known, then the theory estimates the energy in each subsystem. From a knowledge of the energy, it is possible to calculate other dynamic variables e.g. displacement, acceleration etc.

SEA is not a new analysis method, the earliest work identifiable with SEA was carried out in 1959 (Ref.6 and 7). Since then the theory has been applied in many engineering fields e.g. automotive, aerospace and shipbuilding industries but it had not (to the author's knowledge) been applied to helicopter structures. Therefore, as for two previously described acoustic tests, the ATF provided the ideal opportunity to develop our knowledge of SEA.

It is impossible within the confines of this paper to go into anything other than a rudimentary description of the theory and application of SEA. The purpose of this paragraph is simply to examine the correlation of the SEA theory applied to the ATF with experimental data. The data, in the form of acceleration levels, was acquired in a similar manner as described in the previous section on radiation efficiency. The only significant differences in experimentation being that the exciting force applied to the structure was measured (this enabled the power put into the system to be calculated) and the acoustic end plugs were removed, primarily because they were not required but also due to foreseen difficulties in modelling them for inclusion in the SEA theory.

The actual application of the SEA theory to the ATF is attributed to Dr. D. Hawkings, Head of Theoretical Studies at WHL and his work is the subject of an internal research paper (Ref.8) which examines the issues involved in greater detail.

Briefly though, for the purpose of the theoretical model, the ATF was broken up into 20 subsystems, 5 panels and 14 frame elements with an additional element to represent the acoustic cavity which would exist if the fuselage was enclosed. Figure 6 identifies these components. For the purpose of this work, only the out-of-plane flexural waves in the panels and beams were considered as the main energy bearing modes. Torsional and in-plane flexural waves do exist in the beams but are not considered to be significant and, therefore, are ignored. Standard theoretical expressions were used to calculate the modal densities and wave group velocities of the beams and panels for inclusion in the final energy flow equations. Similarly, formulae were used to calculated beam-to-beam and panel-to-panel coupling loss factors. Once having established all the flow equations, several different models based on various combinations of the subsystems of the ATF were evaluated and compared with the experimental data. It is unnecessary in this paper to look at all the models considered, as again these are fully discussed in Ref.8, however it is of interest to look at the model which most closely agrees with the test results. This model consisted of all the frame and panel elements and included the acoustic cavity element in the energy flow equations. The reason for the inclusion of an acoustic cavity in the model was to improve the agreement of the model with the test data and to relate the model to the acoustic reaction of the structure it was representing, as opposed to its structural reaction only. Figure 7 shows the theoretical cavity acoustic level obtained by SEA, for a range of internal panel damping ratios compared with the actual experimental level, and it can be seen that there is in general good agreement. A range of panel damping ratios is given as this quantity is an imprecisely defined parameter but the range 0.1% to 1.0% included here is consistent with accepted values for honeycomb sandwich panels.

This admittedly limited and unrefined SEA study has nevertheless demonstrated its usefulness and prediction potential in the helicopter cabin noise field. For a simple but representative fuselage structure, mechanically excited, the SEA theory has accurately predicted the nosie levels found within the fuselage.

## 6. CONCLUSIONS

Apart from providing data for the ATF programme, the intention of the acoustic test work on the ATF was to use this simple, but representative fuselage structure as a 'stepping stone' in the transfer of experimental techniques from simple measurements in a laboratory environment to measurements in the complete helicopter. Additionally the ATF gave the opportunity for direct comparisons to be made between the acoustic properties of single panels and these same panels attached to a framework i.e. the ATF.

It was found that the standard laboratory measurements of transmission loss and radiation efficiency could be easily transferred to the fuselage structure and ultimately, given the opportunity, the measurements could be applied with confidence to a complete helicopter cabin.

The Transmission Loss measurements of the ATF agrees closely with the simple panel TL measurements. The implication of this is that for the type of structure examined here, the TL is independent of the reaction of the frames and stringers. Similarly the Radiation Efficiency measurements of the single panel reflect, within an order of magnitude, the response of the ATF.

The ATF programme also presented the ideal opportunity for Statistical Energy Analysis theory to be applied to a simple structure for which experimental data for the purpose of correlation could be easily obtained. It was found that the acceleration levels predicted by the SEA model of the ATF agreed well with the measured data. More important, however, was the SEA's accurate prediction of the acoustic level generated within the ATF by mechanical excitation.

This paper began by saying that one of the major overall objectives of the ATF programme was to examine the potential of materials thought most likely to be used in the future for the manufacture of helicopters. It would be appropriate, therefore, to very briefly look at the acoustic properties of conventional materials in relation to the ATF results. Figure 8 compares the Transmission Loss of an Aluminium panel 0.7mm thick fitted to 2 frames and 2 stringers weighing 2.8 kg/m$^2$ (including the frames and stringers) with the ATF skin panel weighing approximately 3 kg/m$^2$, both panels being tested in the laboratory. The same figure also compares the radiation efficiency. It should be stressed, however, that the honeycomb panels on the ATF were not chosen for acoustic reasons. Previous studies (Ref.9) have shown how honeycomb panels can be optimised acoustically although this involves some compromise with structural requirements. With regard to airborne noise (TL) the Aluminium panel is seen to be up to 5-6dB better than the composite panel above 1kHz, and at 500Hz, a typical frequency associated with gearboxes, the composite panel is around 18dB more efficient at radiating noise via structural excitation than the Aluminium/Stringer panel. In terms of the effect on cabin noise in a real helicopter, it is difficult to predict the actual noise change one would expect by replacing the conventional panels with these non-acoustically optimised composite ones as it depends on how much of the noise generated is airborne and how much is structure borne. As a conservative estimate, an increase in noise of at least 6dB could be expected. In practical terms, this would mean doubling the weight of soundproofing in the cabin of such a composite fuselage to achieve the same noise levels as in the cabin of a conventional type fuselage.

Many issues are involved in the desire to use composite materials in the design and manufacture of helicopters, most of them advantageous compared with conventional materials. However, it is clear from the results reported in this paper that a great deal of thought is necessary in the initial design stage of an aircraft so that theoretical studies, such as SEA can be used to evaluate the acoustic properties of a structure.

## 7. ACKNOWLEDGEMENTS

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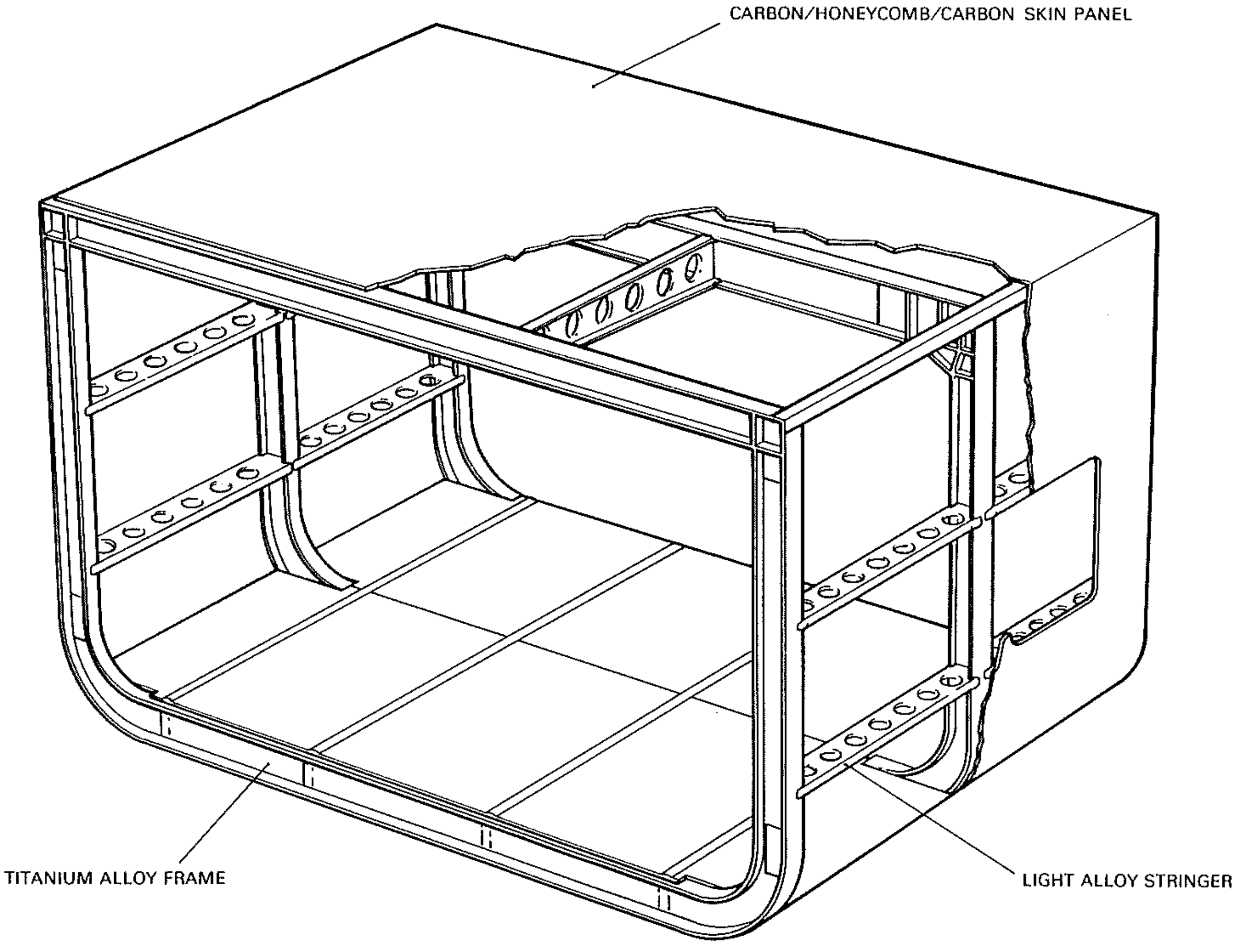

FIGURE 1
THE ADVANCED TECHNOLOGY FUSELAGE

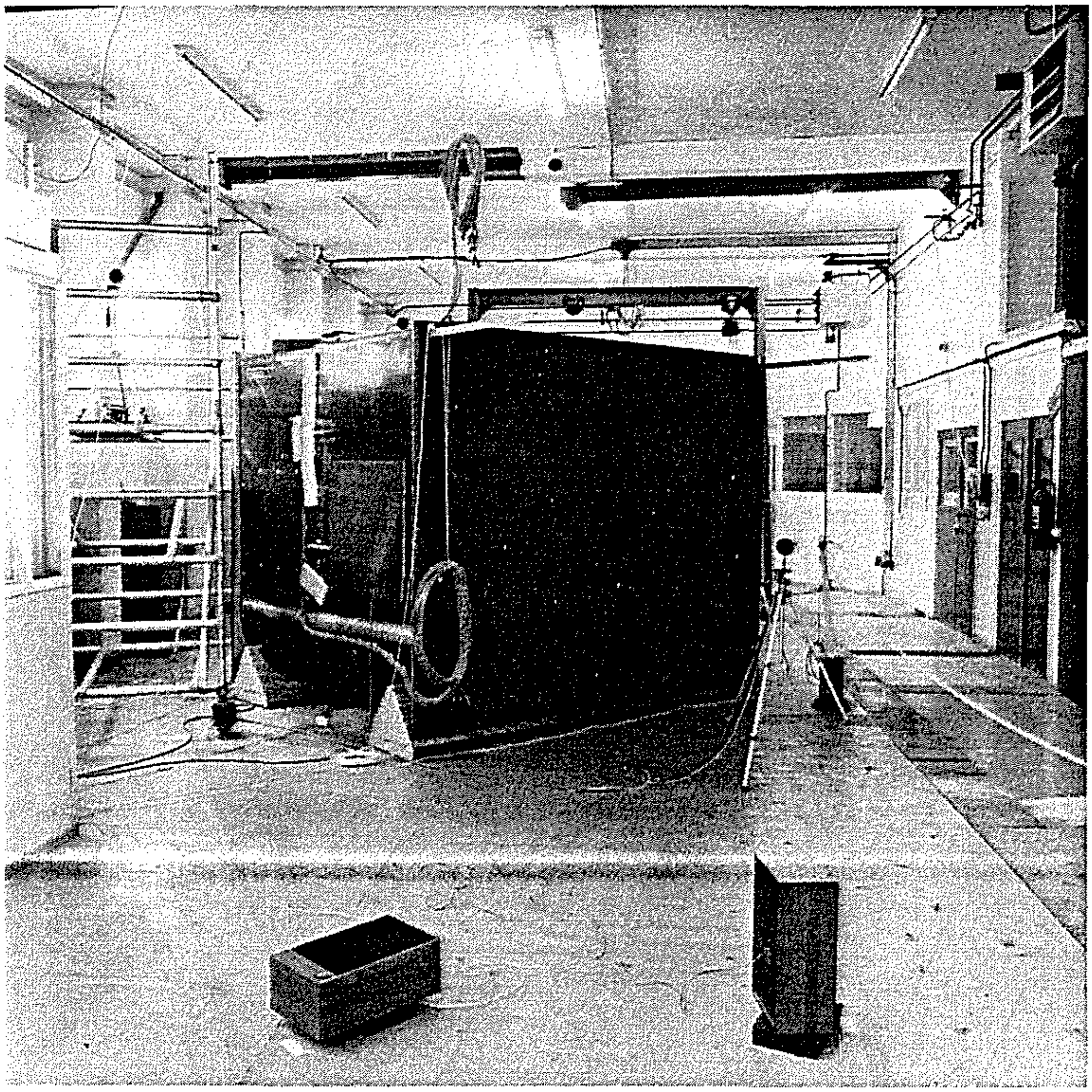

FIGURE 2
THE ATF IN THE TEST SITE

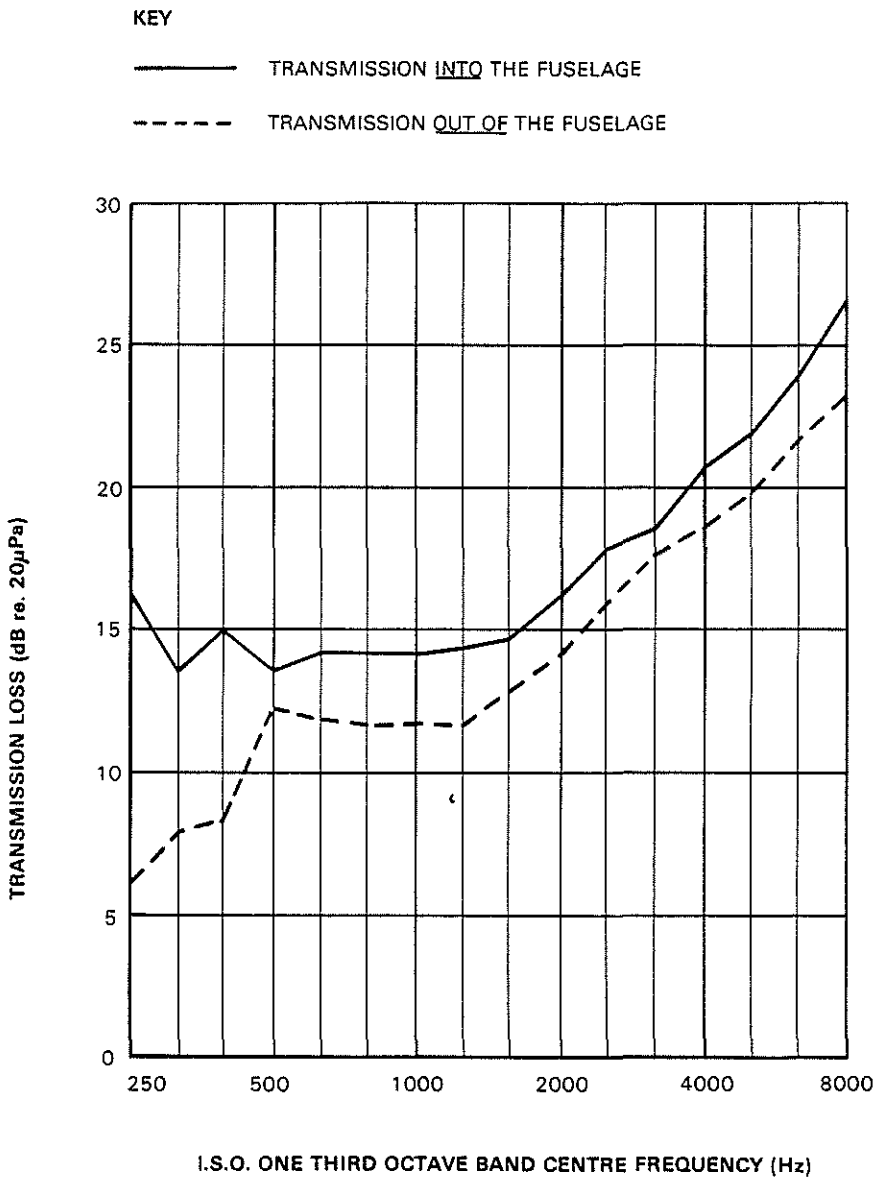

**FIGURE 3**

**TRANSMISSION LOSS
OF THE ADVANCED TECHNOLOGY
FUSELAGE STRUCTURE**

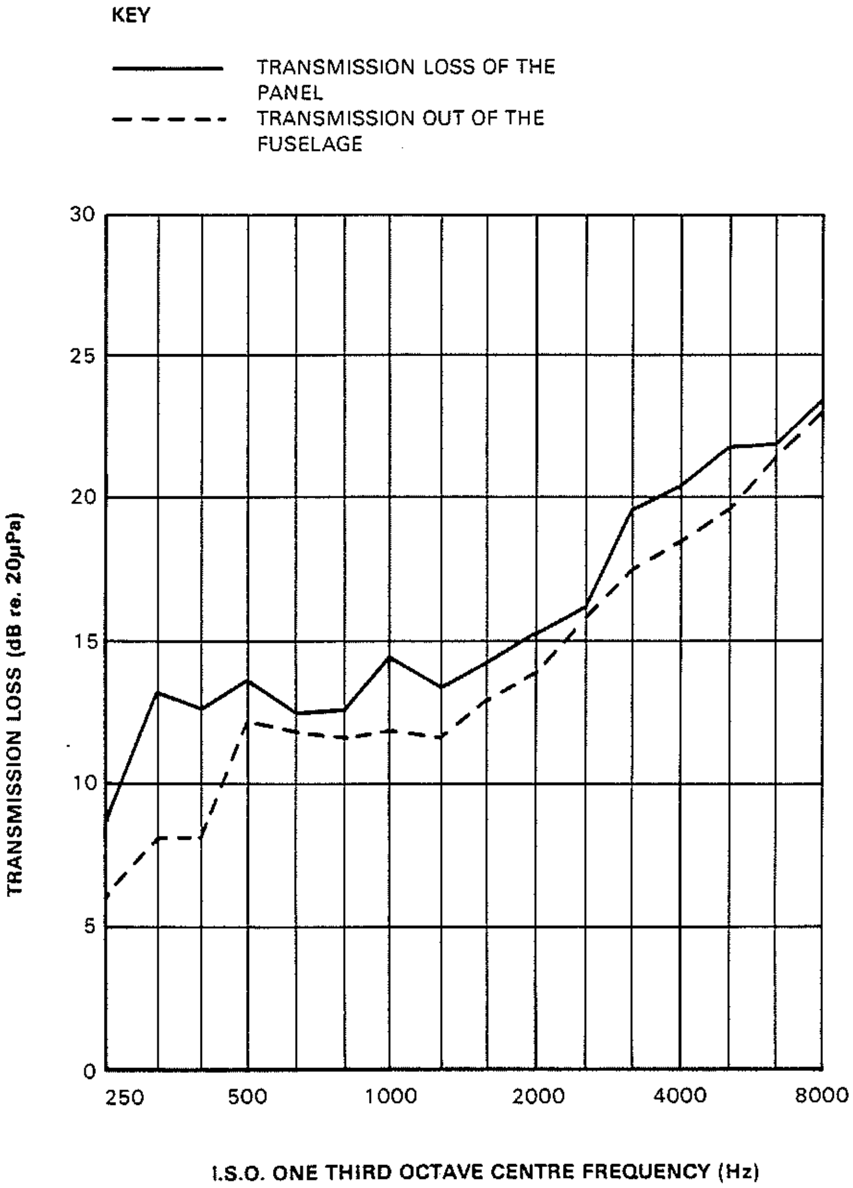

FIGURE 4

TRANSMISSION LOSS OF
THE PANEL COMPARED WITH THE
FUSELAGE

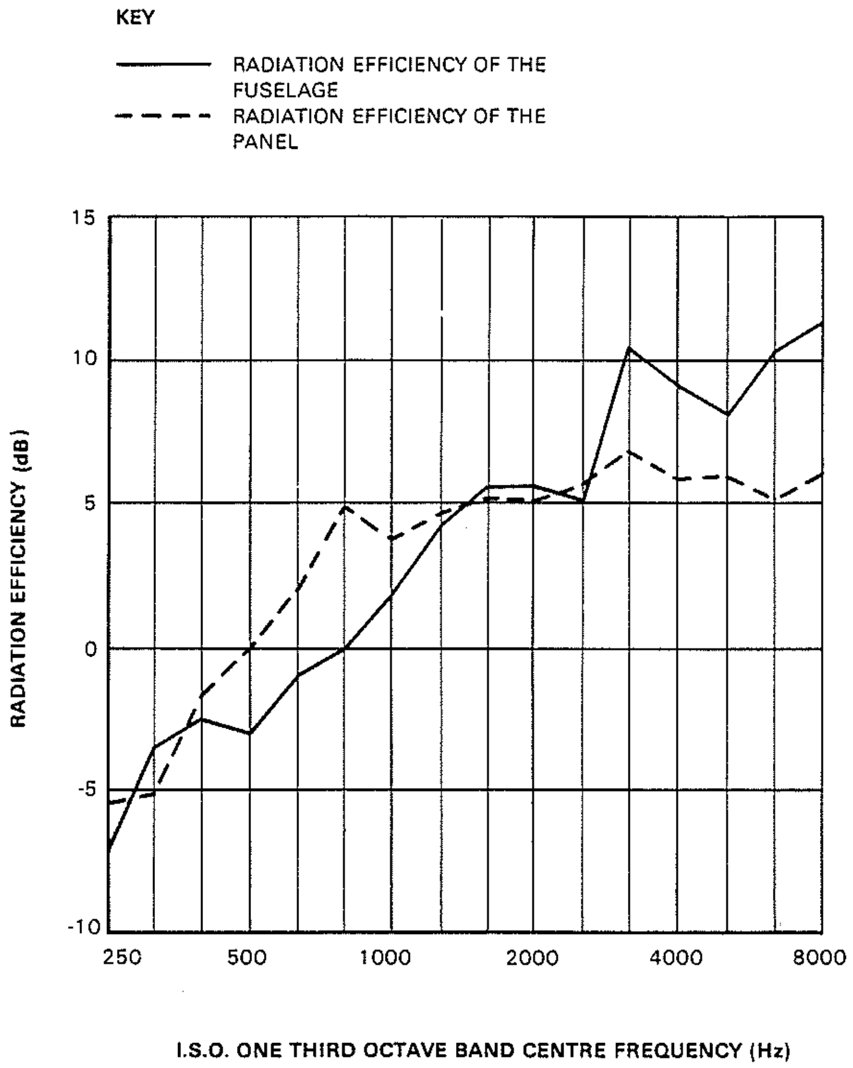

**FIGURE 5**

RADIATION EFFICIENCY OF
THE FUSELAGE COMPARED WITH THE PANEL

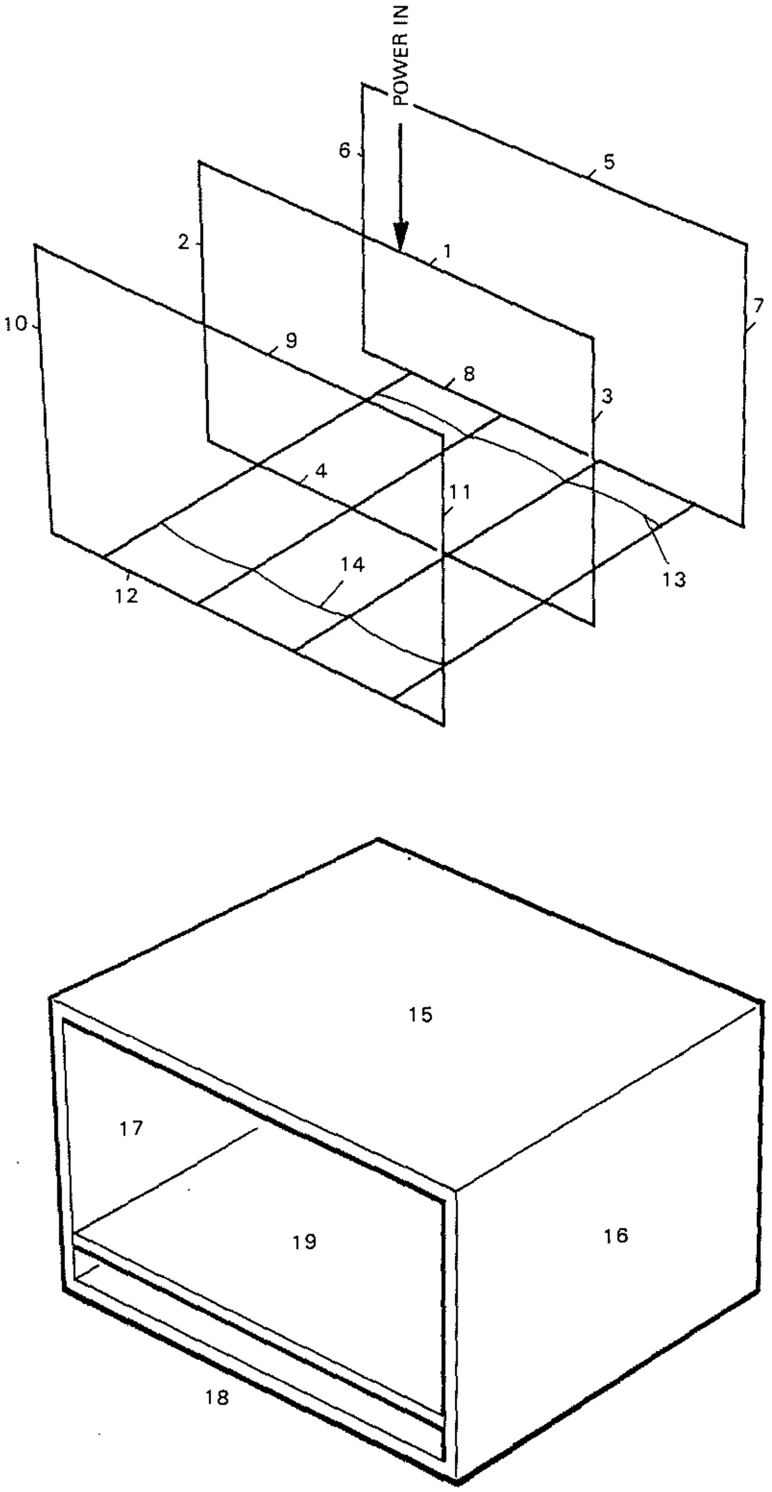

FIGURE 6

FRAME AND PANEL ELEMENTS USED IN THE SEA MODEL

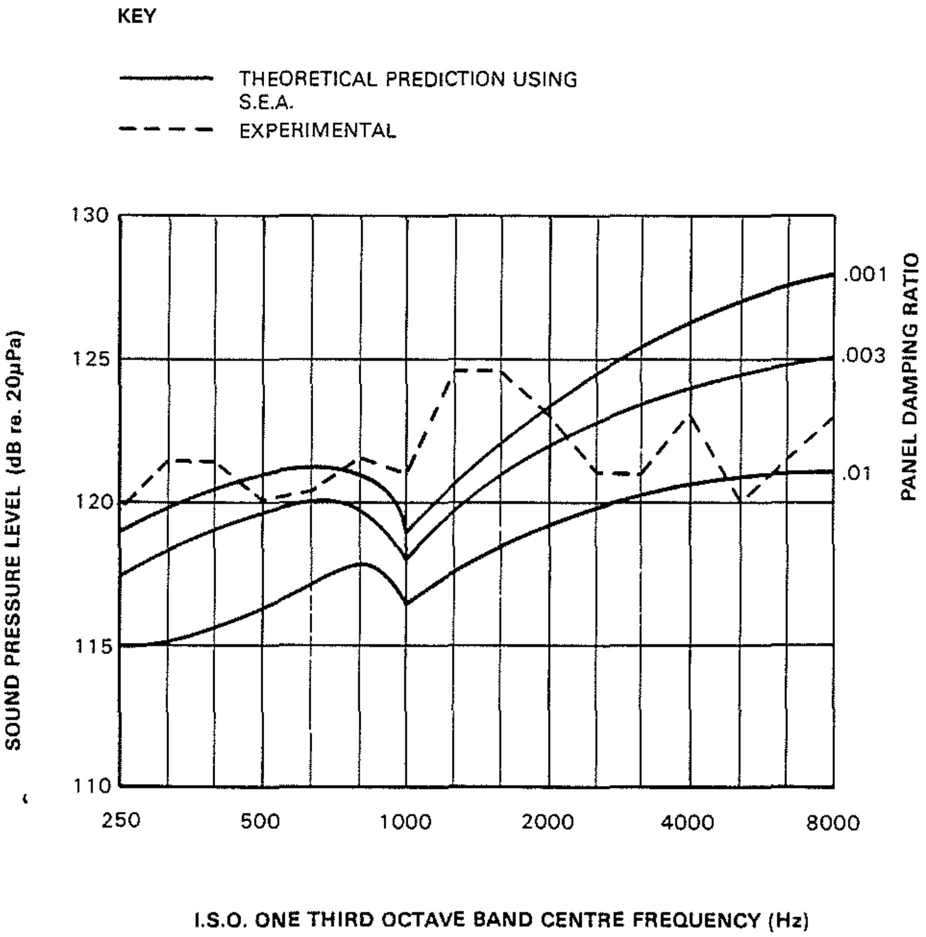

FIGURE 7

CAVITY ACOUSTIC LEVEL

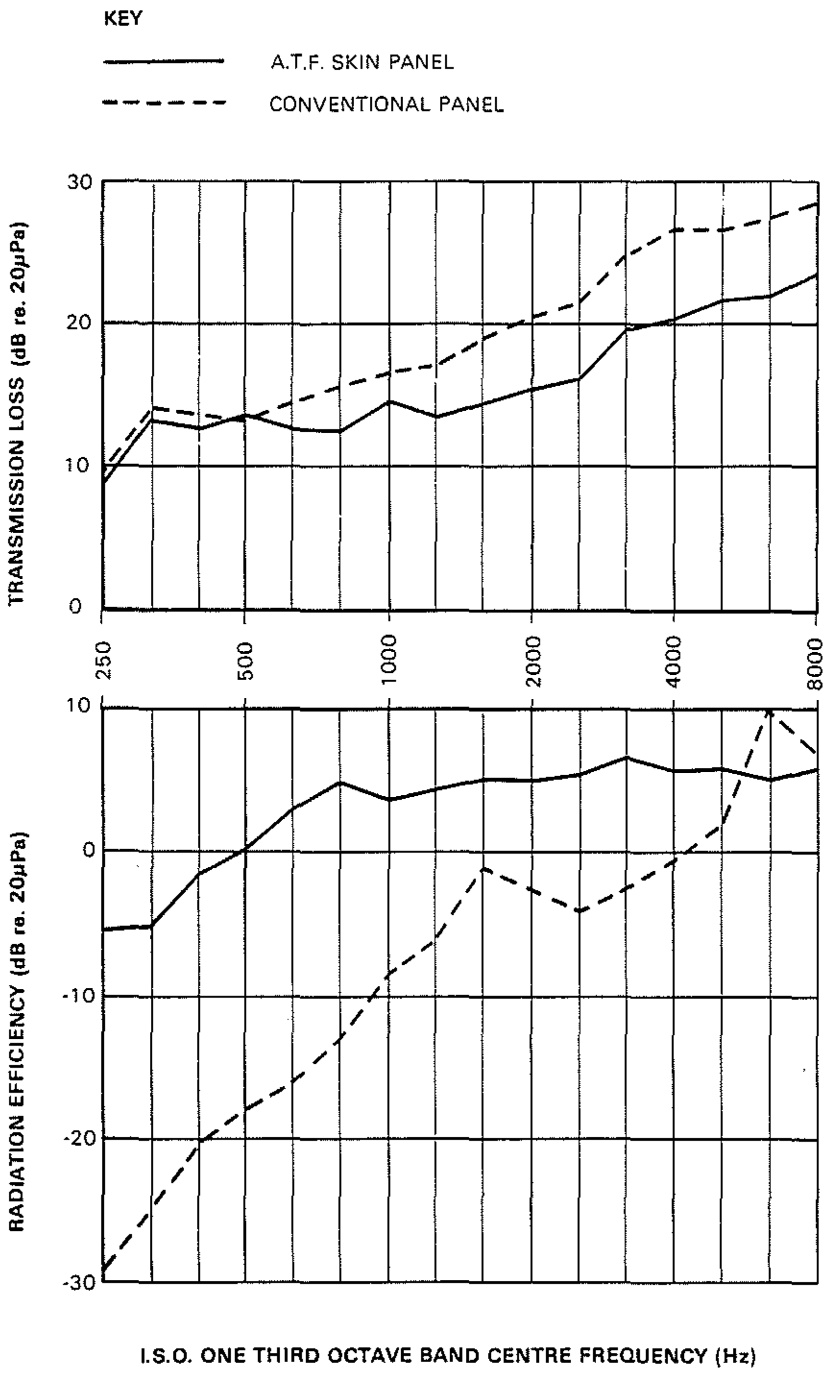

**FIGURE 8**

**COMPARISON OF THE A.T.F. SKIN PANEL WITH A CONVENTIONAL PANEL (i.e. AL + FRAMES + STRINGERS) FOR TRANSMISSION LOSS AND RADIATION EFFICIENCY MEASUREMENTS**