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ERRATUM

PAGE 10 - 6 Fig. 8

FREQUENCY REGION	RADIATION RATION
(1) $f < f_c$ P = PERIMETER S = SURFACE $\alpha = \left(\frac{f}{f_c}\right)^{1/2}$ f FREQUENCY f_c CRITICAL FREQUENCY	$\sigma_{rad} = \frac{\lambda_c^2}{S} \cdot g_1(\alpha) + \frac{P \cdot \lambda_c}{S} g_2(\alpha)$ $g_1(\alpha) = \begin{cases} \frac{8}{\Pi^4 \alpha} \left[\frac{1-2\alpha^2}{\left(1-\alpha^2\right)^{1/2}}\right] & \boxed{f < \frac{f_c}{2}} \\ 0 & \boxed{f > \frac{f_c}{2}} \end{cases}$ $g_2(\alpha) = \frac{1}{4\Pi^2}\left[\frac{\left(1-\alpha^2\right) \cdot l_n \left(\frac{1+\alpha}{1-\alpha}\right) + 2\alpha}{\left(1-\alpha^2\right)^{3/2}}\right]$
(2) $f = f_c$	$\sigma_{rad} = \text{maximum} \begin{cases} \frac{P}{\lambda_c} \\ \sqrt{10} \end{cases}$
(3) $f > f_c$	$\sigma_{rad} = \left(\frac{\alpha^2}{\alpha^2 - 1}\right)^{1/2}$

PANEL RADIATION RATIO σ_{rad}

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HELICOPTER INTERNAL NOISE TREATMENT
RECENT METHODOLOGIES AND PRACTICAL APPLICATIONS

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AEROSPATIALE - HELICOPTER DIVISION

MARIGNANE - FRANCE

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SUMMARY

Two types of actions have been studied by AEROSPATIALE in order to meet the requirements for improved auditory comfort in helicopter cabin :

a) Noise reduction at source by proper design of new engines, rotors and transmission assemblies for new models ;

b) Design of soundproofing solutions minimizing the added weight for given targets of internal noise levels.

The present paper addresses mainly the second topic. In close cooperation with CAMBRIDGE COLLABORATIVE, CAMBRIDGE N.J. and more recently METRAVIB, ECULLY, France, a general methodology has been set up, which is carried out in three stages :

a) Noise diagnosis of the internal noise problem to understand the contribution of every noise source to the cabin internal noise level and to acquire the cabin noise and vibration patterns for the helicopter to be treated ;

b) Definition of the acoustic treatments adapted at best on each panel structure for a given noise level reduction ;

c) Development, tests and improvements of internal noise treatments.

This paper mainly deals with the diagnosis phase (a) of this methodology. It is felt indeed that a good knowledge of the internal noise pattern in the untreated helicopter cabin together with the understanding of the transmission paths is of the utmost importance for designing a good soundproofing solution.

Applications of the above methodology is illustrated on the example of the SA 365 N DAUPHIN for which three mean noise level objectives have been set up and internal noise treatments successfully developed and tested.

1 – INTRODUCTION

Together with the increased development of helicopter civil applications, problems associated with auditory discomfort inside the cabin have become unceasingly more important during the last years.

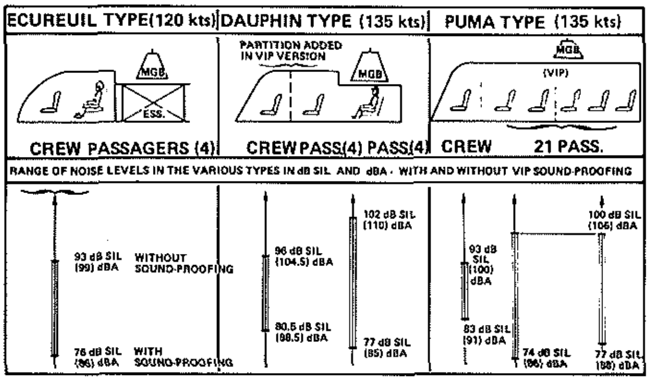


Fig. 1 COMPARING THE VARIOUS TYPES OF HELICOPTERS

Needless to say, as shown on Figure 1, the internal noise levels of helicopters, whatever the size or architecture of the latter, are intrinsically too high to allow for comfortable passenger transport if soundproofing treatments are not provided. In the worst case, where the main gearbox is located on top and very close to the passenger ears (case of the DAUPHIN) levels of 96 to 102 dB SIL are measured in the untreated helicopter cabin. This would obviously oblige the passengers to communicate, even at very short distance, only by shouts (see Figure 2) and it would be at the same time very tiring for the passengers even if they do not want to communicate.

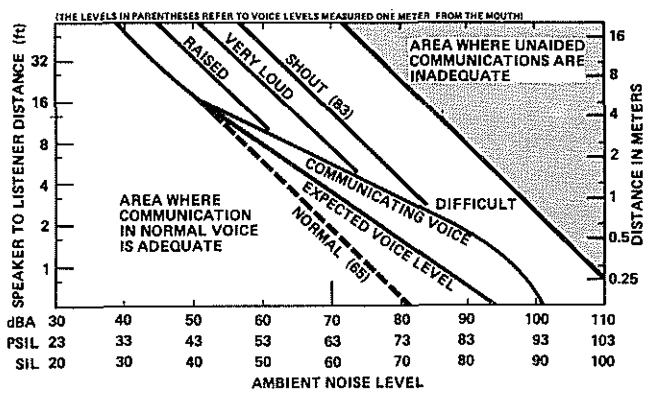


Fig. 2 PERMISSIBLE DISTANCE BETWEEN A SPEAKER AND LISTENERS FOR SPECIFIED VOICE LEVELS AND AMBIENT NOISE LEVELS

The AEROSPATIALE objectives regarding noise levels in helicopter cabins depends on the helicopter utilization since noise treatment generally means an increase in weight, i.e. loss of «construction efficiency». For VIP versions 72 to 78 dB SIL are generally set as objectives and they are reached - with a weight increase which can vary from 2 to 3 % of grossweight all interior trimmings included depending on the helicopter architecture. In other applications, where passenger auditory comfort is not a dominant request, levels up to 86 dB SIL are set as objectives, with correlatively a much lower loss in «construction efficiency».

Figure 3 provides some general comparisons between airplanes and helicopters as regards internal noise levels. Let us say briefly that a VIP soundproofed helicopter (DAUPHIN) lies between general aviation and large transport aircraft indices of comfort in the full range of audiofrequency while being under 500 Hz closer to the large transport aircraft category - and, above 500 Hz much closer to general aviation index of comfort.

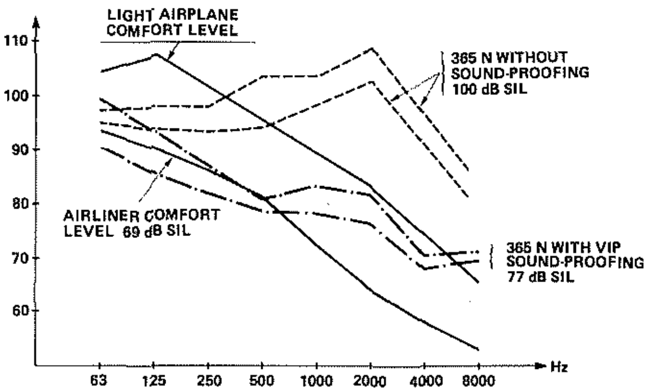


Fig. 3 NOISE SPECTRA AND LEVELS AS MEASURED ON BOARD AN SA 365 N WITHOUT AND WITH VIP SOUND-PROOFING CRUISE FLIGHT: 135 kt

This general trend, - i.e. the difficulty to reduce noise levels for frequencies above 500 Hz - originates from the high noise levels generated by the main gearbox (as shown in Figure 4) where meshing mechanisms give rise to high level «tones» in the noise spectrum, at frequencies equal to the number of gear teeth times gear rotational speed and their harmonics.

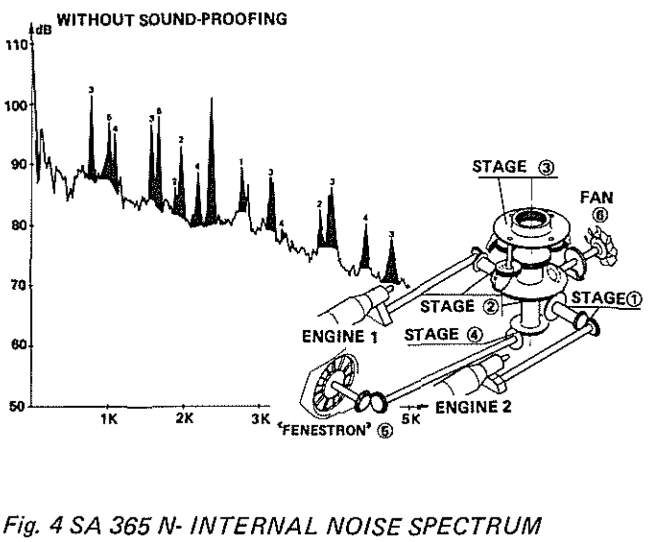


Fig. 4 SA 365 N- INTERNAL NOISE SPECTRUM (PASSENGER SEAT UNDER MGB)

This paper does not deal with gearbox noise reduction (or reduction of noise at source), since this topic can form the subject of a full conference. AEROSPATIALE have undertaken a research program, which has already given some good results : tone reduction of 10 to 15 dB has been obtained by proper design of spiral bevel and cylindrical gears and further work is conducted in this field.

The main topics discussed hereunder, address the methodology followed to get an insight into the internal noise problem to be dealt with, to design suitable soundproofing treatments and finally to test and refine the original definition in order to obtain given cabin noise level objectives. Practical applications of this methodology is illustrated on a SA 365 N DAUPHIN helicopter. Figures 5 and 6 present the main structural elements of this type of Helicopter.

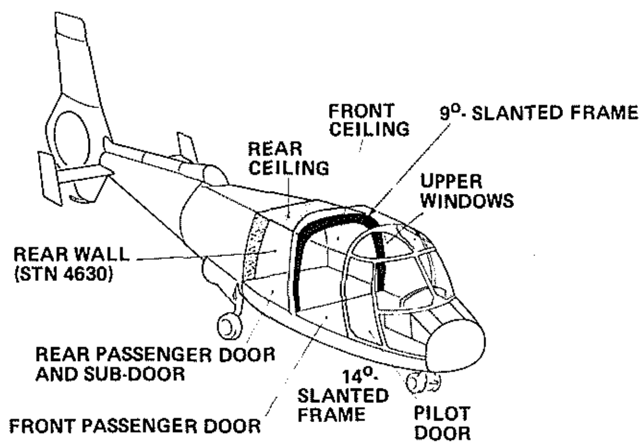
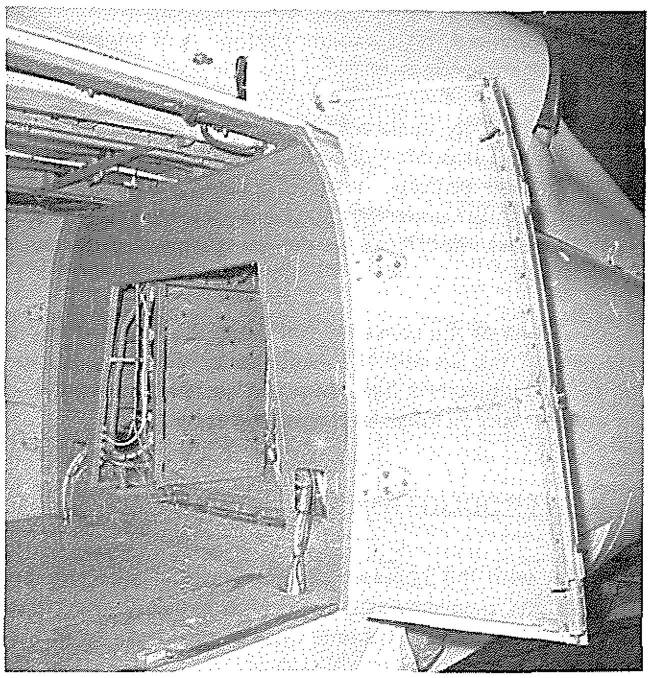


Fig. 5 SA 365 N STRUCTURE COMPONENTS



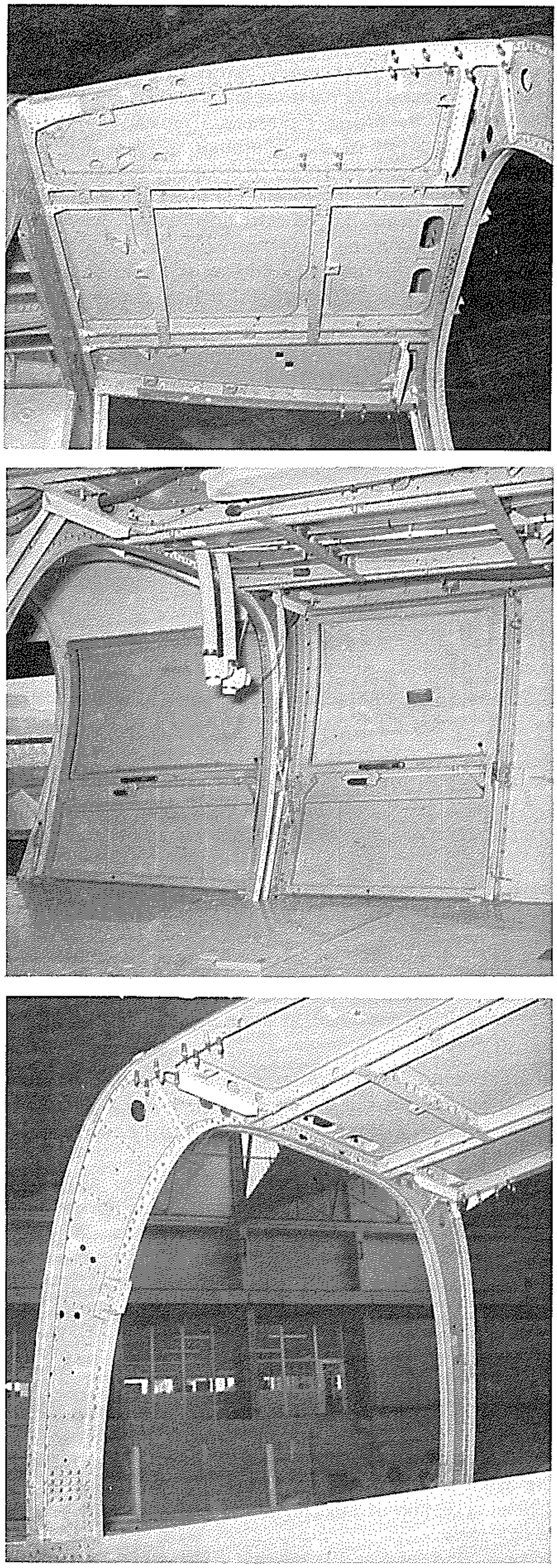


Fig. 6

2 — A METHODOLOGY FOR HELICOPTER SOUNDPROOFING

For correct helicopter cabin soundproofing - i.e. with relatively low weight penalty involved - the following obvious questions have to be answered :

a) Which are the major noise sources contributing to the internal noise disturbance ?

b) How much do they contribute to the measured noise level for passengers and crew ?

c) What type of soundproofing treatments are to be used to reduce noise levels and where do they have to be applied ?

d) After the helicopter is soundproofed, are our objectives reached ?

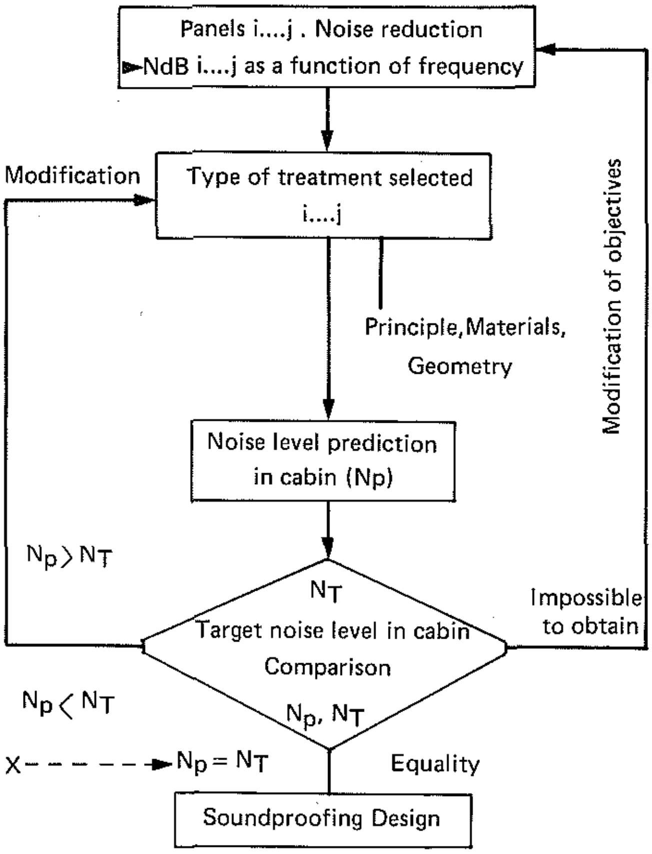
e) Does the designed soundproofing treatment fulfill all the other constraints ?

The methodology used by AEROSPATIALE to answer these various questions, for a given helicopter (available for testing) is divided into three phases :

1) Diagnosis
2) Design to provide the soundproofing definition
3) Validation and optimization.

The first phase, of utmost importance, is intended to identify the noise sources, to acquire knowledge on the structural and serial transmission paths from the sources to the cabin, to determine the main characteristics of noise radiation from all the cabin elements (frames, panels, doors, floor ...). It rests upon flight tests (measurements of noise levels inside the cabin and vibratory levels on the structure), on ground tests (structural and serial transfer dunctions from sources to cabin) and specific tests conducted in flight and based on acoustic intensimetry to get a better insight into the cabin acoustic field. This phase normally allows for a direct computation of noise levels in the cabin from the panel radiation characteristics - which can be compared to the direct acoustic measurement - and set the contribution of the different noise sources to the acoustic level in the cabin. Targets of noise reduction as a function of frequency for every individual structure element (Transmission floor, panels, doors, frames ...) can then be selected to reach the noise levels objective inside the cabin.

The second (design) phase consists in the detailed choice of types of soundproofing treatment to obtain the targets of noise reduction from the different structural elements. It is essentially a computation and design phase based on iterative procedures as represented in the following logistic diagram.



The last phase consists in manufacturing the prototype versions of the soundproofing treatments to be flight tested and compared to the original objectives. Some refinements to the prototype versions have normally to be made before starting the production line versions.

3 – APPLICATION OF THE GENERAL METHODOLOGY TO SA 365 N INTERNAL SOUNDPROOFING

The general methodology briefly explained hereabove will be illustrated on applications to the SA 365 N DAUPHIN internal noise treatments.

3.1 – GENERAL CONSIDERATION

For the given helicopter - available for testing, with no internal noise treatment - three research phases have to be conducted : diagnosis, concept design for soundproofing treatments, flight evaluation and refinements of the designs.

During the diagnosis phase - which leads to ground and flight testing of the helicopter - complementary experiments are conducted in order to set the proper objectives for the internal noise treatments and to acquire better knowledge on noise transfer from sources to the cabin. One has to realize, furthermore, that these experiments being conducted on a helicopter - normally under development - are expensive and time consuming. The new techniques - presently under development - as designated here under «acoustic intensimetry» - may allow for substantial expenses and time reductions, a feature which will be highly appreciated by Program Management.

3.2 – DIAGNOSIS

Flight experiments are conducted at different helicopter speeds to measure internal noise levels at different locations inside the cabin. Figure 7 presents a typical 1/3rd octave band data analysis of the recordings for four helicopter speeds, for a front passenger microphone location. Large noise variations are experienced with speed variations under 1000 Hertz mainly due to aerodynamic and rotor noise. Above 1000 Hertz (main gearbox noise), noise level variations are less important. Considering the normal usage of this type of helicopter, targets for noise reductions are set for a speed of 135 kts which is the normal cruise (economy) speed for this helicopter.

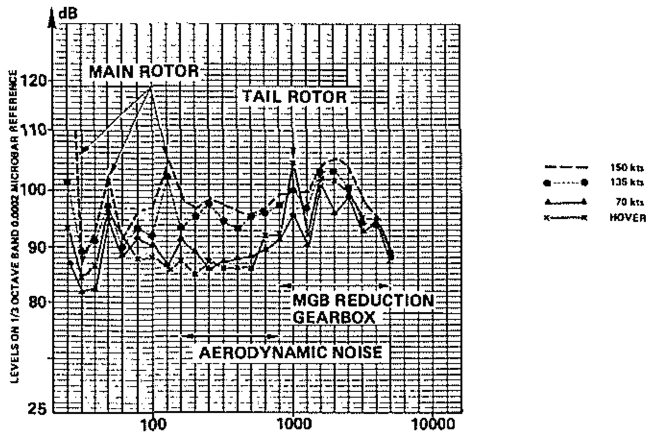


Fig. 7 VARIATIONS OF NOISE SPECTRA IN SA 365 N CABIN VERSUS FLIGHT SPEED AIRCRAFT WITHOUT SOUND-PROOFING - FRONT - PASSENGER

At this selected speed (135 kts), further experiments and computations have to be conducted in order to assess :

a) The contribution of the different elements of the cabin (Roof, frames, panel doors, glass pane ...) to the noise levels recorded at different passenger locations in the cabin.

b) The contribution of different noise sources to the noise levels measured in the cabin and if feasible -, the ways in which this transfer occurs (structural or aerial transfer).

Strictly speaking, the latter knowledge (b) is not required for the development of an adequate soundproofing treatment. In fact, it is known that whatever the transfer is from the helicopter noise sources to the cabin structure, it is this cabin sutrcture - that is to say the cabin physical envelope - which will be responsible for the noise radiation inside the cabin.

Nevertheless, as shown hereunder on a few examples, the knowledge of structural and aerial paths from source to cabin, may allow for noise / vribration transfer reduction to the cabin envelope at a lower cost / weight penalty. The following section of this chapter on DIAGNOSIS is divided in two parts

a) CONVENTIONAL APPROACH TO HELICOPTER NOISE DIAGNOSIS

b) POSSIBLE CONTRIBUTION OF «ACOUSTIC INTENSIMETRY».

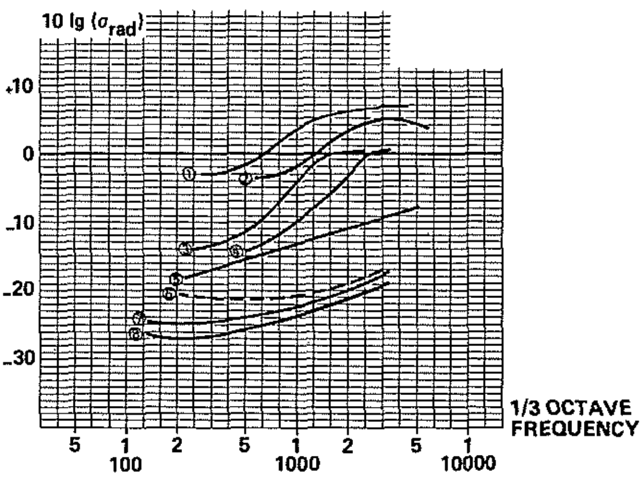
3.2.1 — Conventional Approach

Knowledge of the contribution of the different cabin elements to the noise measured in the cabin is obtained by use of the acoustic power radiated by each structural or panel elements.

The classical formula ($\Pi = \rho$ c As σrad $< Vs^2 >$) is used where the radiation efficiency σ rad is computed as a function of frequency using the formulae of Figure 8. Results of these computations for our given structure (SA 365 N) are presented on Figure 9 which shows the dominant radiation efficiency of the mechanical floor (Honeycomb sandwich for the front part - designated n° 1 - and Honeycomb sandwich — lateral reinforcements - designated n° 2 - for the rear part).

FREQUENCY REGION	RADIATION RATION
① $f < f_c$ P PERIMETER S SURFACE $\frac{f}{f_c}^{1/2}$	$\sigma_{rad} = \frac{\lambda_c^2}{S} \cdot g_1(\alpha) + \frac{P \cdot \lambda_c}{S} g_2(\alpha)$ $g_1(\alpha) \begin{cases} \frac{8}{\Pi^4} \left[\frac{1 - 2\alpha^2}{(1-\alpha^2)^{1/2}}\right] & f < \frac{f_c}{2} \\ 0 & f > \frac{f_c}{2} \end{cases}$ $g_2(\alpha) = \frac{1}{4\Pi^2} \left[\frac{(1-\alpha^2) \cdot l_n \left(\frac{1+\alpha}{1+\alpha}\right) + 2\alpha}{(1-\alpha^2)^{3/2}}\right]$
② $f = f_c$	$\sigma_{rad} = \text{maximum} \begin{cases} \frac{P}{\lambda_c} \\ \sqrt{10} \end{cases}$
③ $f > f_c$	$\sigma_{rad} = \frac{\alpha^2}{\alpha^2 - 1}^{1/2}$

Fig. 8 PANEL RADIATION RATIO σ_{rad}



1) FRONT-CEILING : HONEYCOMB SANDWICH STRUCTURE
2) REAR CEILING : HONEYCOMB STRUCTURE + LATERAL REINFORCEMENTS COMBINED STRUCTURE
3) 9°- SLANTED FRAME
4) 14°- SLANTED FRAME
5) REAR STIFFENED-SHEET METAL WALL AT 4530
6) PILOT DOOR WINDOWS (REDUCED AREA AND LOW BENDING RADIUS)
7) ALUMINIUM DOOR BOTTOM PANELS
8) PASSENGERS' DOORS PERSPEX WINDOWS (LARGE AREA AND BENDING RADIUS)

Fig. 9 MEASUREMENTS TAKEN ON PANELS

The quadratic mean vibratory speed $< Vs^2 >$ for each structural element of the cabin is obtained by flight measurements using piezo electric contact accelerometers scanning each element. Figures 10 and 11 present vibratory levels (accelerations in g's) as measured on structural panels (Figure 10 for front and rear mechanical honeycomb floor, rear partition and door structure) and on some fuselage elements (front passenger door, Figure 11). One can notice that structural panels (Figure 10) have similar acceleration spectra, peaking at rather high frequencies (f ≥ 2 KHz) while fuselage elements (door glass pane and door panel, C and B) have acceleration spectra with high energy content at much lower frequencies i.e. 100 to 2000 Hz.

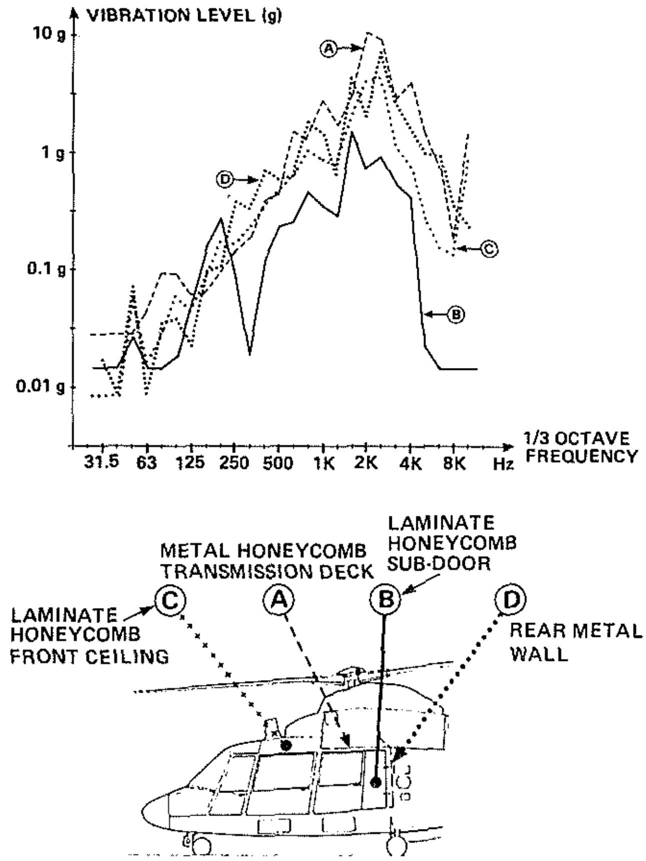


Fig. 10 VIBRATION SPECTRUM FLYING AT 135 kt

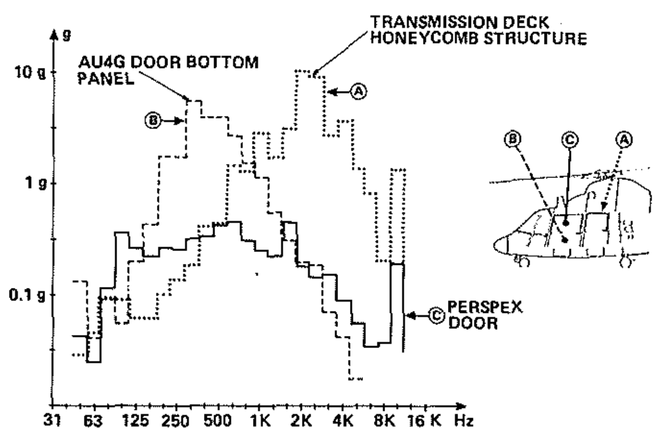


Fig. 11 VIBRATION SPECTRA ON VARIOUS PANELS FORMING THE SA 365 N, AIRFRAME CRUISE FLIGHT : 135 kt

Structural transfer functions from the vibratory source to the cabin structure are measured during a ground test on the helicopter, with engines and rotors non operative.

Figure 12, for example, represents in (1) the acceleration transfer function between a fuselage structural panel and an attachment of an MGB strut on the helicopter mechanical floor. In flight, the vibration level of this strut attachment is measured (see Figure 12.2). It is then possible (Figure 12.3) to set the contribution of the MGB strut excitation, to the fuselage panel acceleration. This general procedure is followed for each MGB strut attachment and each structural element of the fuselage.

Fig. 12 - 1

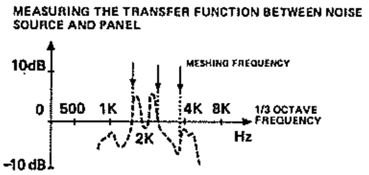
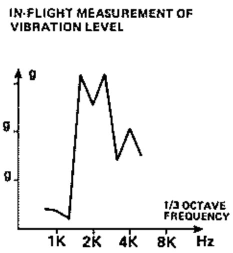


Fig. 12 - 2



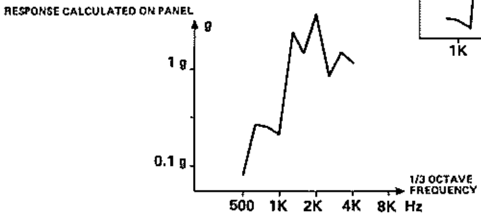


Fig. 12 - 3

An equivalent procedure is applied to define the contribution of helicopter noise sources to the cabin noise by aerial transfer. An example is shown on Figure 13 where contribution of the engines air intake noise to the cabin noise is set up.

Attenuation 1/3rd octave spectra are measured for the front roof and superior glass panel with source emitter located at engine air intakes (see Figure 13.1). Noise level spectra are measured in flight at the engine air intakes (see Figure 13.2). The noise level contribution of the engine air intakes can, then, be set as presented on Figure 13.3.

Fig. 13 - 1

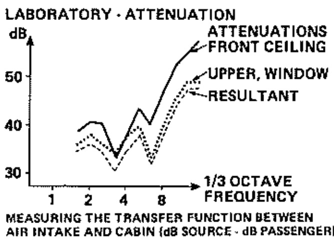
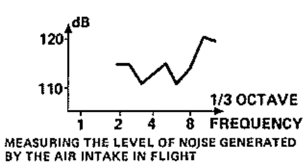


Fig. 13 - 2



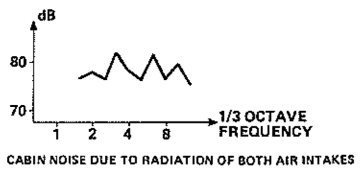


Fig. 13 - 3

From the previous experiments and data processing, two types of information can be obtained :

a) Contribution of the different noise sources to the cabin noise level at a given microphone station, with identification of the way in which this transfer has occured (structural or aerial paths).

b) Contribution of the different structural elements of the cabin to the noise level measured in this cabin, at a given passenger station.

Illustrations of these results are given in Figures 14, 15 and 16. Figure 14 shows that the main contribution to cabin noise above 500 Hz originates from structural transfer of the main gearbox vibrations and to a lesser extent from aerial transfer of the main gearbox noise.

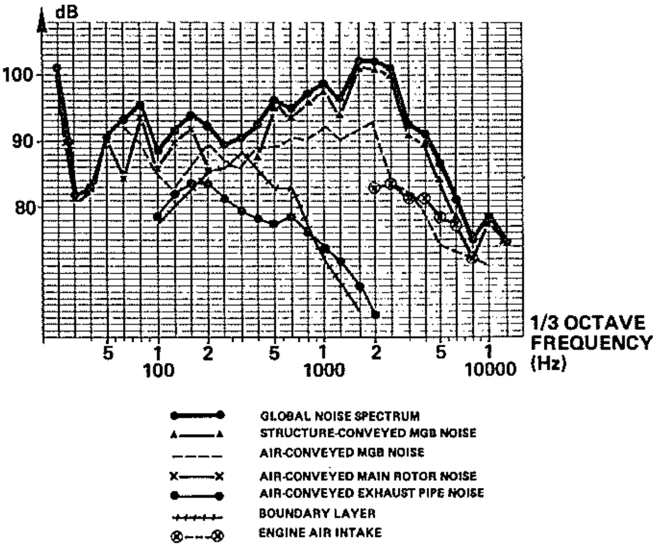


Fig. 14 NOISE SPECTRUM AT REAR OF CABIN SA 365 N 135 kt CRUISE FLIGHT

Figure 15 shows that for rear passengers, the rear part of the roof is the main contributor to internal noise above 500 Hz, while the rear cabin partition and the rear door glass pane are good contributors to the cabin noise at low frequencies. The «9 degree» structural frame is also a good contributor to the cabin noise between 200 Hz and 2000 z.

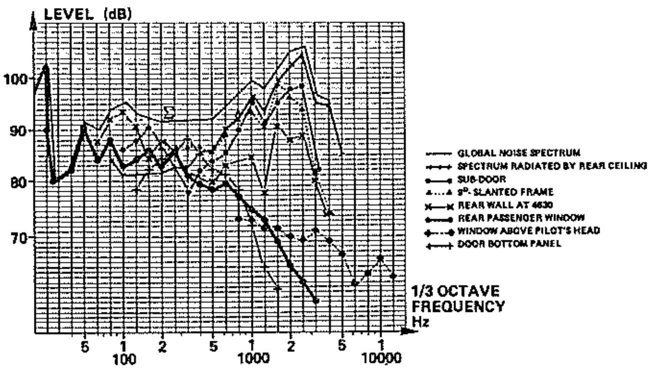


Fig. 15 GLOBAL NOISE SPECTRUM BREAKDOWNFOR REAR PASSENGERS ON BOARD AN SA 365 N FLYING AT 135 kt

Figure 16 presents, for front passenger locations, a similar contribution of the fuselage elements, to the cabin noise levels. It shows - in particular - the large contribution of the front and rear parts of the transmission floor to the cabin noise level.

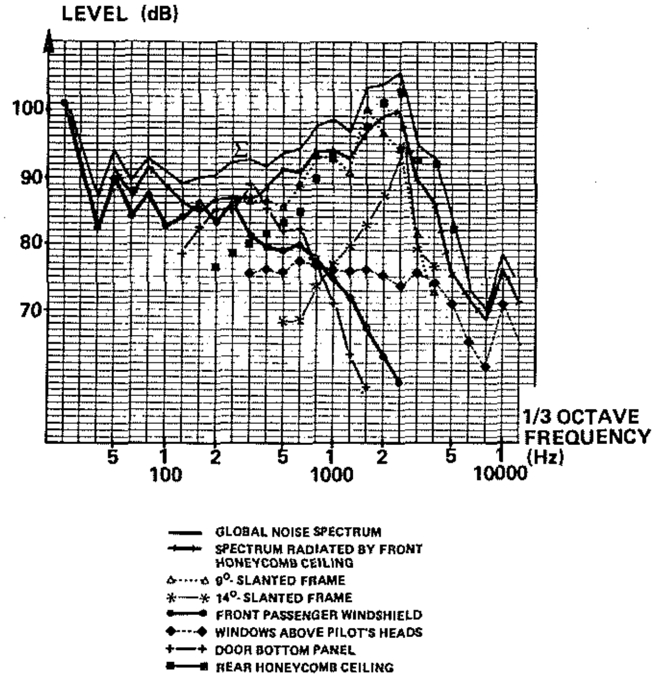


Fig. 16 GLOBAL NOISE SPECTRUM BREAKDOWN FOR FRONT PASSENGERS ON BOARD AN SA 365 N FLYING AT 135 kt

3.2.2 – Contribution of Acoustic Intensimetry to Helicopter Noise Diagnosis

In the previous, classical approach, to helicopter cabin noise and vibration diagnosis, one has to realize that a lack of knowledge remains on the acoustic wave patterns inside the cabin. It is indeed blindly assumed that the vibration levels of the cabin structural elements and ancillaries (access doors, door pane ...) contribute directly to the noise level measured at a given microphone station. On a given structural element, and for a given frequency it is not known, in particular, whether the acoustic waves propagate toward the helicopter cabin or away from this cabin.

In order to better understand the wave patterns inside the cabin, and more specifically in the vicinity of structural elements and ancillaries, further research has been engaged in cooperation between AEROSPATIALE HELICOPTER DIVISION and METRAVIB (ECULLY, FRANCE). Acoustic Intensimetry has been chosen as a means of further diagnosis for the following reasons :

a) A large background has been acquired by the latter company in the use of this technique for acoustic diagnosis.
b) Date processing codes were already available to easily obtain :
   - acoustic intensity vectors from dual microphone measurements
   - separation of the as measured acoustic field, from an array of dual microphones, into evanescent plane waves and farfield propagating plane waves
   - separation of the acoustic propagating field into direct and reflected acoustic fields.
c) Data acquisition in flight can be more rapid than conventional vibration measurements for all structural panels and ancillaries forming the helicopter cabin.

It is well known that measurements of two acoustic pressures P1(t), P2(t) on two microphones located at a well defined fixed distance one to the other, allow for determination of the acoustic intensity of the waves in the direction M1 M2.

Furthermore (see appendix 1), when a spatial array of intensimetric gauges (2 microphones per gauge) is used to scan the acoustic field with simultaneous measurements of all the microphone signals, it is possible to provide the following information on the acoustic field :

a) The local acoustic spatial intensity (amplitude and phase)
b) A spatial wave vectors representation of the acoustic field on the two planes of measurement
c) Identification, in this spatial wave vectors representation of the acoustic field, of the farfield propagating components and their associated acoustic plane power
d) Separation, in this propagating acoustic field, between incident waves (i.e. waves originating from the panel inspected) and plane reflected waves (i.e. waves coming from all other panels of the cabin envelope).

Some board results of an application of acoustic intensimetry to the SA 365 N acoustic diagnosis are illustrated hereunder. All the needed data has been acquired during three flights of one hour each: This is to be compared with about two weeks of ground and flight testing of the SA 365 N which were needed to acquire the more conventional data of paragraph 3.2.1.

Two types of experiment have been conducted on the SA 365 N using this acoustic intensimetry approach.

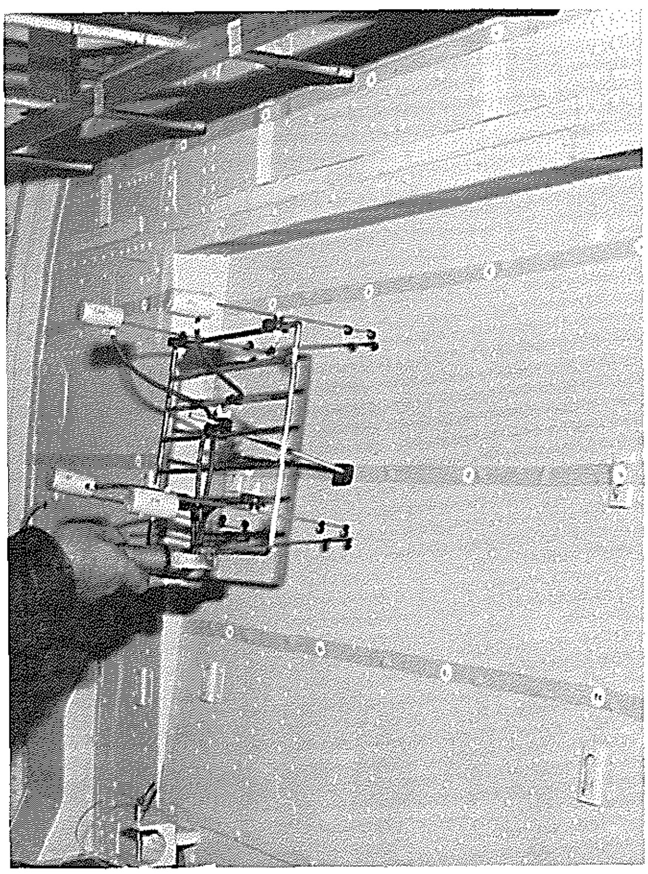


Fig. 17

(1) Figure 17 shows the array of four intensimetric gauges fixed on a light portable frame which can be set manually on predesignated measurement points on the cabin structure. One hundred and twenty locations of this array, at 20 cm spacing - allowed most of covering the internal structure of the cabin and to obtain acoustic intensity vectors normal to cabin panels. This experiment allows to set the acoustic power radiated by each structure sub assembly (rear bulkhead, doors, rear and front transmission floor ...).

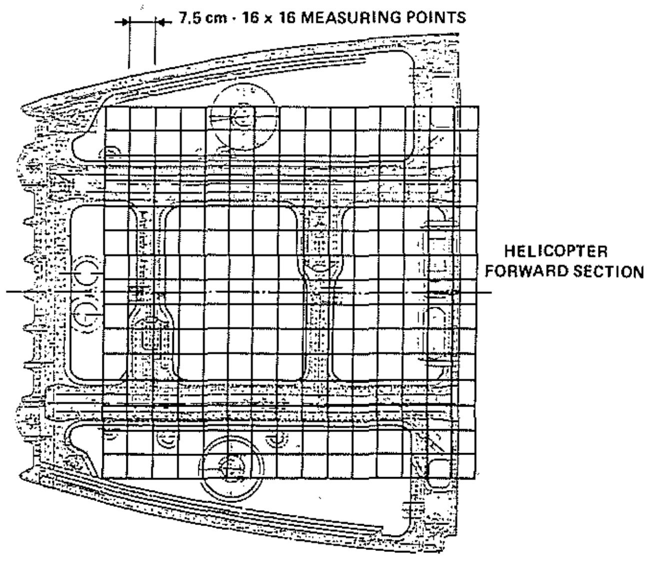


Fig. 18

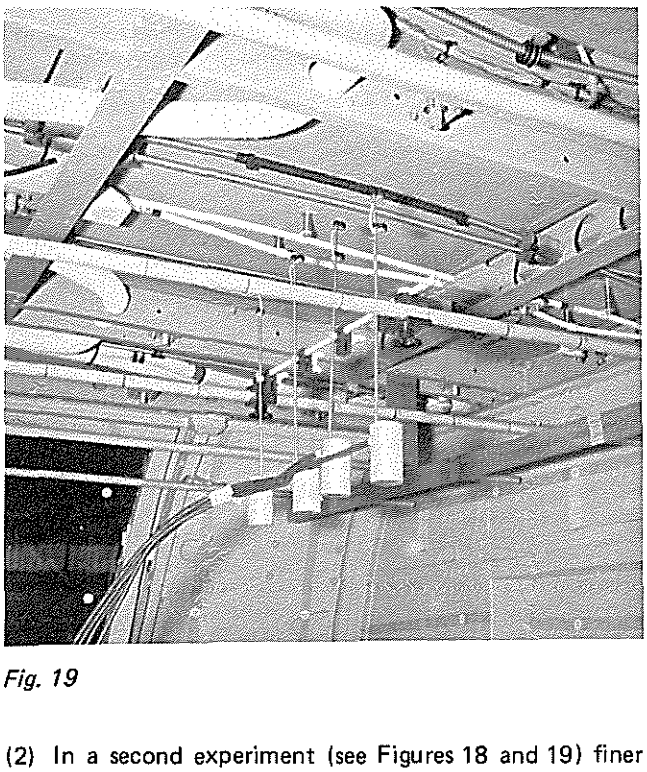


Fig. 19

(2) In a second experiment (see Figures 18 and 19) finer meshing (.075 m spacing) has been used to scan the transmission floor of the cabin, as it was shown in the first experiment - that roof structure was the main acoustic driving source for the helicopter cabin. Furthermore, a special array of five intensimetric gauges was also used to scan the «9 degrees» main frame (1/4 circle arrangement ...).

Signal conditioning is directly provided for the intensimetric gauges, through an on board «electronic box» and data recording is taken on a fourteen channels recorder. All recordings were synchronized with a microphone reference signal Pr.(t) permanently set in the center of the transmission floor. The spacing chosen, allows for a finer numerical treatment of the recorded data, to set acoustic fields up to 2200 Hz.

Data processing for acoustic intensity can be performed at octave - third octave - and/or any given narrow band SA 365 N centered frequency in the full audio spectrum. In this particular case narrow band analysis was limited to our main internal noise frequency sources : 9 natural frequencies from 787 Hz to 2370 Hz.

A few results are illustrated hereunder :

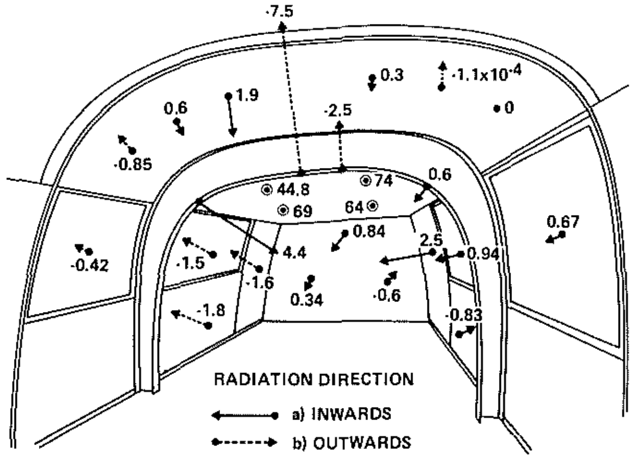


Fig. 20

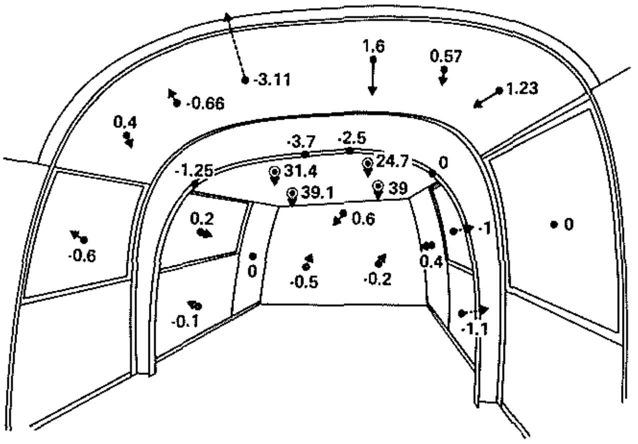


Fig. 21

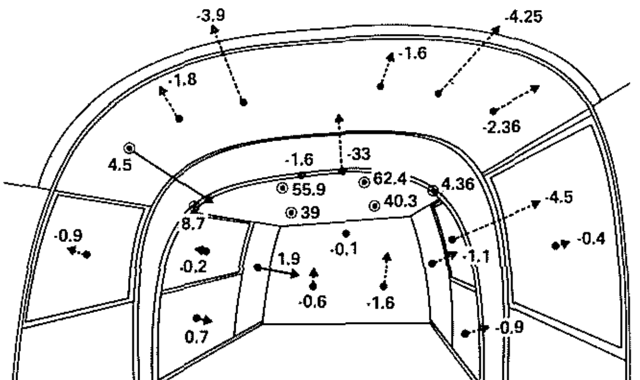


Fig. 22

a) Figures 20, 21 and 22 present narrow band, perpendicular to he wall, intensity fluxes for center frequencies of 1090 Hz, 1590 Hz and 2300 Hz respectively. Note that some of the fluxes are oriented toward the cabin while others are oriented away from the cabin wall (i.e. cabin waves leave the cabin volume for these panels). The wave patterns at cabin boundary is asymmetrical. The main acoustic energy into the cabin is coming from the rear part (after the 9 degrees structural frame) of the roof structure.

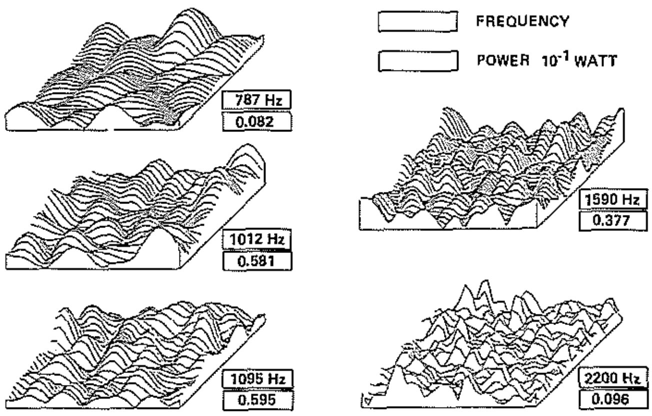


Fig. 23

b) Figures 18, 19 and 23 show respectively : the mesh patterns adopted for scanning the rear part of the transmission floor (cabin roof after the 9° structural frame) ; the rack used to scan this pattern with 4 intensimetric gauges (2 «ELECTRET» microphones for each gauge) ; the wave patterns and acoustic intensities for five narrow band natural frequencies ; as it can be noted the wave patterns are more complicated (number of vales and hills at higher frequencies and large amplitude differences are noticeable from one point to another for a given frequency. The highest total energy measured is in the 1000 Hz range of frequency.

c) Figures 24, 25 and 26 show some further data processing results for the transmission floor at one of these high energy frequencies (1095 Hz). The - as measured - total energy of the waves is 0.06 watts (Figure 24) ; when evanescent component of the wave energy is eliminated (Figure 25), incident and reflected waves can be separated. The standing wave «rate» (reflected power / incident power) can be computed and proves high (42.5 %). The data processing technique allows drawing amplitude and phase variation of the wave along any line of the scanned field.

Figure 26 shows wave amplitude and phase along an X line and this gives 1095 Hz wave shapes. Notice the high energy output around A and B (axis X, Figure 26). At points A and B hydraulic fluid tanks are set directly supported by the transmission floor (concentrated masses).

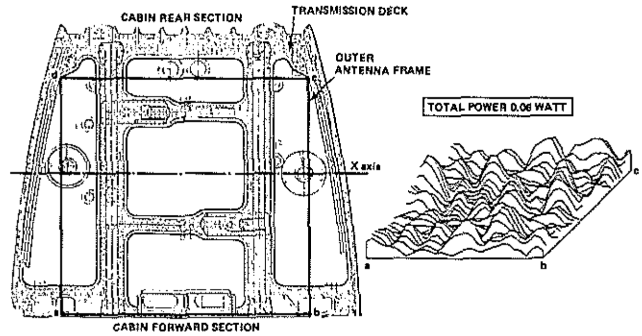


Fig. 24

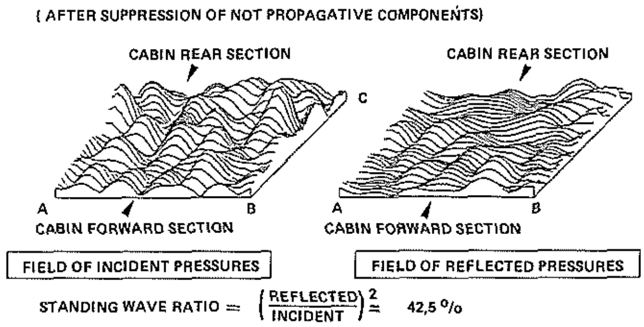


Fig. 25

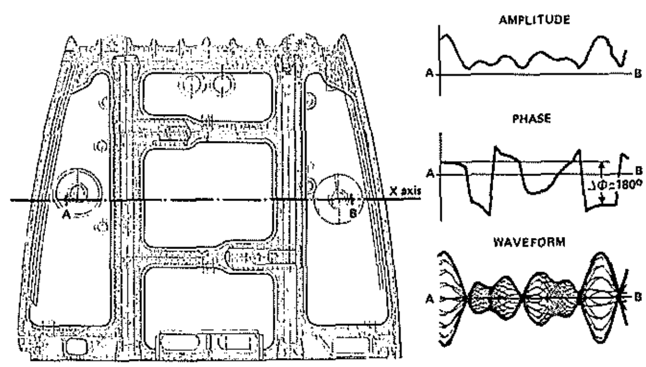


Fig. 26

c) Wave pattern analysis (amplitude, phase, shape), along a axis an AB line is also presented (Figure 27) for narrow band analysis at 787 Hz. A large radiation (A) is taking place on a frame support of the «Barbecue» filtering device installed on the SA 365 N for the 4 per revolution vibration attenuation.

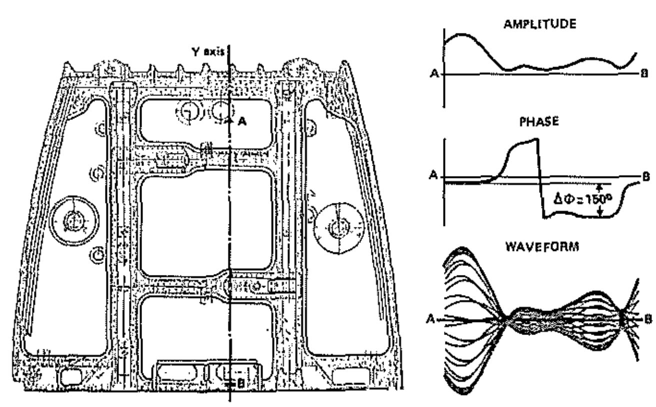


Fig. 27

e) Figures 28 and 29 show for all frequencies of interest : the rate of standing waves under the transmission floor (around 37 % except for one frequency, 1900 Hz, to which other panel make large contribution) ; the per- of evanescent waves next to the structure, which explains why passengers can be further annoyed if their ears are too close to a structure panel.

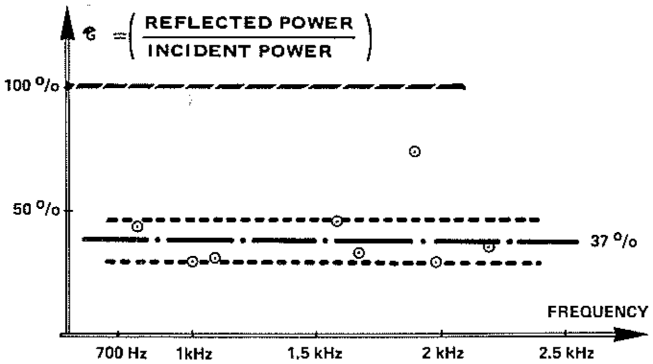


Fig. 28

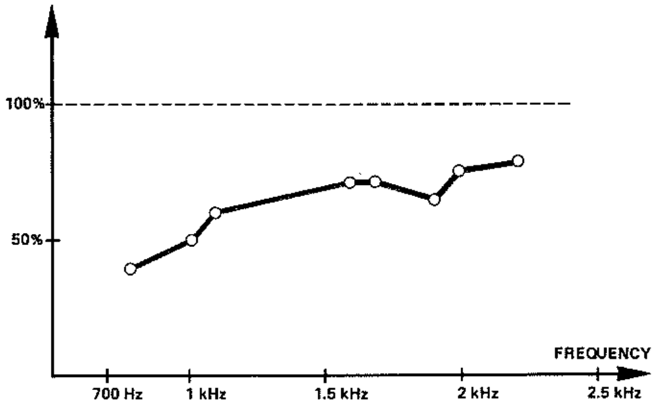


Fig. 29

From these two sets of experiments on the use of Acoustic Intensimetry as a tool for helicopter cabin noise diagnosis, several conclusions can be drawn :

((1) This tool provides a better insight in the acoustic wave pattern at close distances from the radiating cell.

(2) It is able to separate in-coming noise waves - which contribute to the helicopter noise - from out-going waves which leave the cabin, and can, by a proper numerical data processing method, select the part of the waves, which do propagate at large distances inside the cabin, from evanescent waves which will fade away after a few wavelengthes of travel.

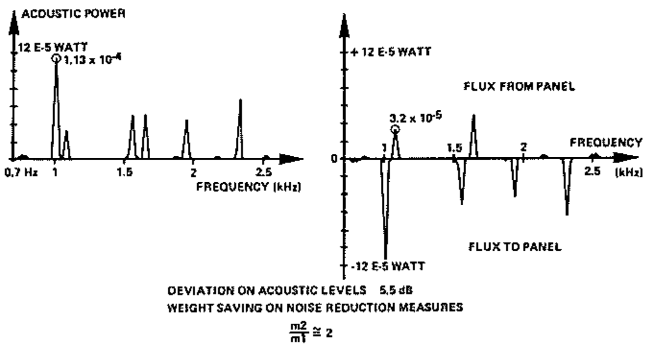


Fig. 30

To illustrate this potential benefit, Figure 30 presents the weight saved on one panel where the acoustic flux direction has been taken into account. For the same acoustic level in the cabin, 1/2 the weight of the soundproofing panel can be saved in this particular examples when true contributions of the in-coming waves instead of the full acoustic power are taken into account (noise difference between the two : 5.5 dB).

(3) It also provides better insight in local problems - For example, large radiation from transmission floor supported hydraulic fluid tanks, or other structural elements which may require a special acoustic or other localized treatment to save weight.

(4) Acoustic Intensimetry can be conducted in a rather short period in the helicopter cabin to quantify noise. When the experiment is properly prepared, it can be conducted in about two days, quite a short time when compared to the conventional approach.

(5) Full comparison between classical methods (vibration survey of all cabin elements and noise measurements in the cabin) and acoustic intensimetry has not yet completely been made. For this reason, acoustic intensimetry is not to be seen, as yet, as a full replacement of the previous method but it at least provides complementary information of great interest.

3.3 -- SOUNDPROOFING OBJECTIVES AND DESIGN CONCEPT

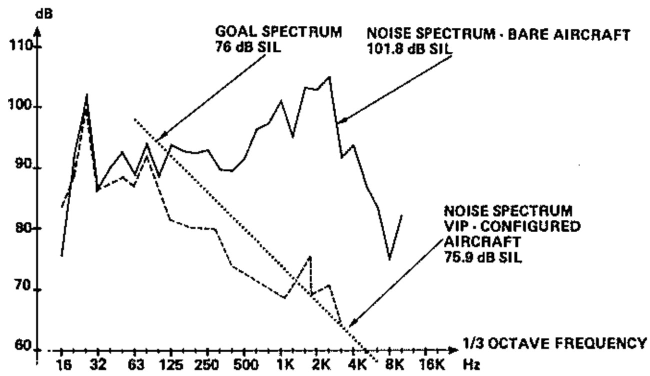


Fig. 31 SA 365 N PASSENGER SEATING IN THE MIDDLE OF REAR CABIN (FLYING AT 135 kt)

Figure 31 shows three noise level spectra (1/3rd octave band analysis)a rear cabin passenger position at the 135 kts economy speed : in.

a) Without soundproofing, the noise level is 101.8 dB SIL

b) An objective spectrum is defined to lead to a 76 dB SIL target for a VIP version as seen on Figure 31. Note that the soundproofing treatment has to be very effective between 500 Hz and 4000 Hz (up to 35 dB reduction needed around 2000 Hz).

c) After soundproofing : A 1/3rd octave spectrum, as defined on Figure 31, is obtained, leading to a 75.9 dB SIL internal noise level at this passenger location.

The design concept of the soundproofing treatment is based upon rather conventional materials and absorption characteristics :

– Trimming panels softly coupled to the structure panels with fiberglass filling between the two (structure / trimming).

– Damping materials bonded to the structure.

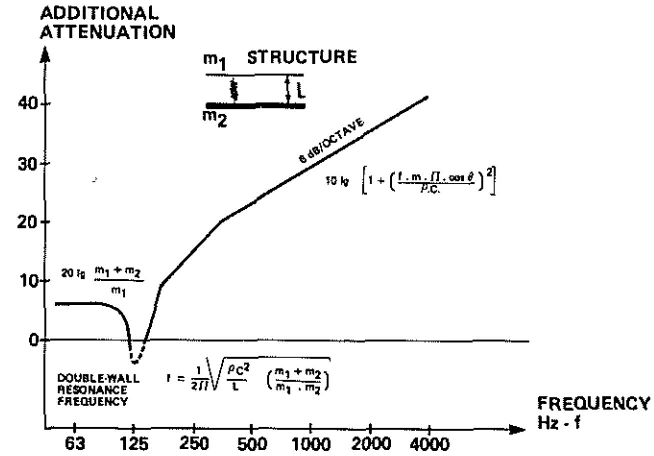


Fig. 32 ATTENUATION FOR AN ADDITIONAL SEPARATE WALL

Figure 32 presents the classical curve of supplementary attenuation (after weight effect) provided by soft mounted trimming panels, which are used in the design concept phase mentioned in chapter 2.

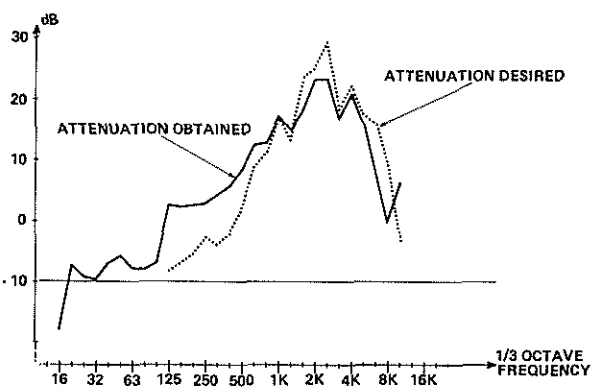


Fig. 33 SA 365 N- PASSENGER SEATING IN THE MIDDLE OF REAR CABIN FLYING AT 135 kt

Figure 33 directly presents the comparison between objective attenuation and obtained attenuation and shows a rather fair correlation.

For the acoustic treatment VIP version, a partition had to be added between pilots and VIP compartments and double glass panels had to be used on transparent upper doors.

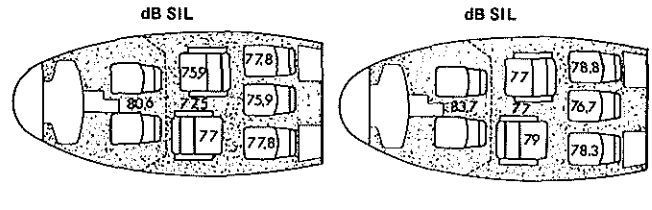
This partition the and doubled glass panels were not needed for less sophisticated soundproofed versions which were aiming at 82 dB and 86 dB SIL.

3.4 – FLIGHT TEST EVALUATIONS OF SOUNDPROOFING TREATMENTS

The three soundproofing treatment versions have been manufactured and test flown in the second half of 1984.

Flight test results are shown on Figure 34 for the VIP version at two speeds, 135 kts economy cruise speed (for which a level of 76 dB SIL was the test objective) and 145 kts. The increase in noise level at speed (1.7 dBA) is mainly due to aerodynamic noise. Figure 35 shows, for comparison purposes the same noise levels at each passenger position without the double partition and double glass panels, the remainder of the soundproofing treatments being the same. The increase in noise level with speed is here much greater, as can be expected.

Figures 36 and 37 presents internal noise levels for the other two soundproofed versions. The objectives set are fairly well met.

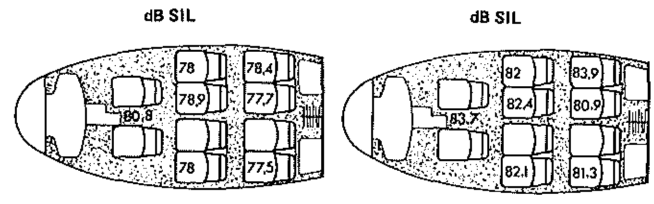


FLIGHT SPEED 135 kts
MEAN LEVELS 77 dB SIL (85 dBA)

FLIGHT SPEED 145 kts
MEAN LEVELS 77.8 dB SIL (86.7 dBA)

NOISE LEVELS ABOARD 365 N

Fig. 34 VIP SOUND-PROOFING WITH DOUBLE-GLAZING AND DOUBLE-PARTITION

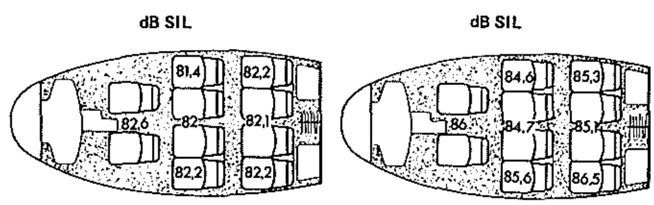


FLIGHT SPEED 135 kts
MEAN LEVELS 78.5 dB SIL (86.6 dBA)

FLIGHT SPEED 145 kts
MEAN LEVELS 82.3 dB SIL (90.1 dBA)

NOISE LEVELS IN dB SIL ABOARD 365 N

Fig. 35 VIP SOUND-PROOFING WITHOUT DOUBLE-GLAZING AND WITHOUT PARTITION

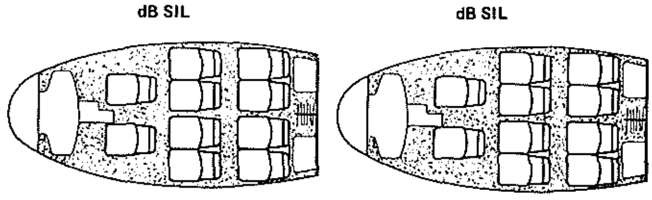


FLIGHT SPEED 135 kts
MEAN LEVELS 82.1 dB SIL (89.5 dBA)

FLIGHT SPEED 155 kts
MEAN LEVELS 85.4 dB SIL (92.9 dBA)

NOISE LEVELS ABOARD 365 N

Fig. 36 82 dB SIL SOUND - PROOFING



FLIGHT SPEED 135 kts
MEAN LEVELS 85.3 dB SIL (92.8 dBA)

FLIGHT SPEED 155 kts
MEAN LEVELS 88 dB SIL (95.2 dBA)

NOISE LEVELS ABOARD 365 N

Fig. 37 86 dB SIL SOUND - PROOFING

3.5 — GENERAL CONCLUSIONS

This paper has covered the broad field of helicopter cabin soundproofing technology, for which a general methodology has been defined and applied to an SA 365 N DAUPHIN helicopter. The methodology is conducted in three rational steps :

a) A diagnosis phase of the vibrations / acoustic problems to be solved on a non-treated helicopter

b) A design concept study phase of soundproofing treatments specifically conducted for given noise level objectives

c) A test evaluation and validation of the soundproofing treatments designed.

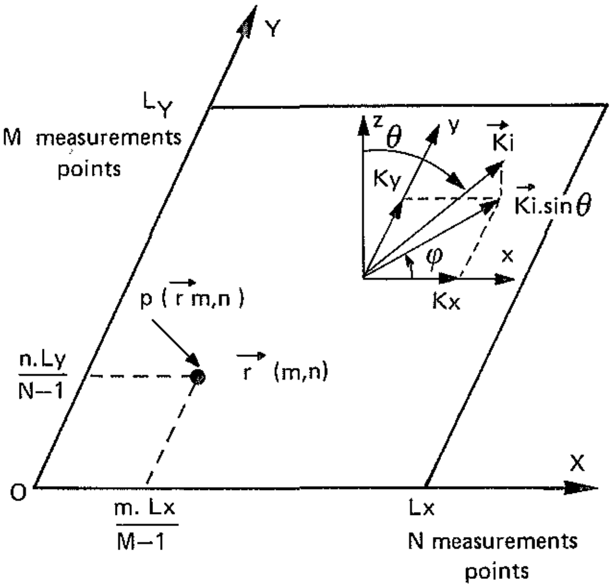
The method developed is apparently well suited to logical design approaches for given objectives. Test results have shown that for the three objectives set, the soundproofing concept developed ful-filled the targets initially set with satisfactory results.

The main part of this paper has been devoted to the diagnosis phase of this research, a phase of utmost importance to design for small added weight.

It has been shown that in this diagnosis phase, a new investigation tool - Acoustic intensimetry - presents a high interest for better knowledge of the wave patterns inside an helicopter and may provide sufficient details to efficiently reduce the added weight of the soundproofing treatments. Further studies seems necessary to completely validate the new approach to helicopter internal noise diagnosis, before we could envisage acoustic intensimetry as the only necessary tool for helicopter noise diagnosis. Taking into account the potential for reduction in costs and time, of this new diagnosis method, it is recommended that further studies be conducted in this field to ascertain its possible limitations.

Annex 1

Separation of the as measured acoustic field into evanescent plane waves and far field propagating plane waves



* Acoustic pressure $p\ (\vec{r})$

* Plane wave :

wave number K, amplitude P, angular frequency ϖ_o, phase ψ

$$p(\vec{r}) = P \,.\, e^{j(\varpi t + \psi)}\; e^{-j\vec{K}.\vec{r}}$$

With an array of microphones, m xn points

$$p(\vec{r}_{m.n}) = \sum_{i=1}^{(m\times n)/2} p_i\, e^{j(\varpi_o t+\psi_i)}\; e^{-j\vec{K}_i.\vec{r}_{m.n}}$$

$$p\left(\frac{m\,Lx}{M-1}, \frac{n\,Ly}{N-1}\right) = \sum_{\theta,\varphi} P_{\theta,\varphi} \,.\, e^{+j(\varpi_o t+\psi(\theta,\varphi))}$$

$$.\, e^{-jK_o \sin\theta\cos\varphi \frac{m\,Lx}{M-1}} \;.\, e^{-jK_o\sin\theta\sin\varphi\frac{n\,Ly}{N-1}}$$

This expression is equivalent to a two dimensional Fourier transform.

$$p(m, n) = \sum_{K=0}^{M-1} \sum_{l=0}^{N-1} \tilde{p}(k, l)\,.\,e^{-2j\pi\frac{mk}{M-1}} \,.\, e^{-2j\pi\frac{nl}{N-1}}$$

$$k = K_o \sin\theta\cos\varphi\ \frac{Lx}{2\pi} \qquad K_o = \frac{2\pi.f}{C_{air}}$$

$$l = K_o\sin\theta\sin\varphi\ \frac{Ly}{2\pi}$$

a) Acoustic pressure field $p\,(m, n)$ — M xN points on the area Lx xLy is given by $\tilde{p}\,(k, l)$

b) $\tilde{p}\,(k, l)$ consist of M xN plane waves. Directions of the plane waves θ,φ are characterized by k and l.

$$0 \leqslant k < M \qquad 0 \leqslant l < N$$

Propagating plane waves are defined

$$tg\,\varphi = \frac{Lx}{Ly}\cdot\frac{l}{k}$$

$$\sin\theta = \sqrt{\frac{k^2\lambda o^2}{Lx^2} + \frac{l^2\lambda o^2}{Ly^2}}$$

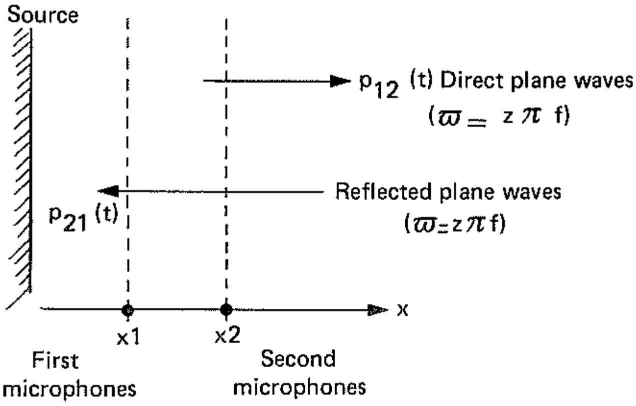
$$\lambda o = \frac{C_{air}}{f_o} \qquad \begin{cases} k\max \leqslant \dfrac{K_o\,Lx}{2\pi} \\ l\max \leqslant \dfrac{k_o\,Ly}{2\pi}\end{cases}$$

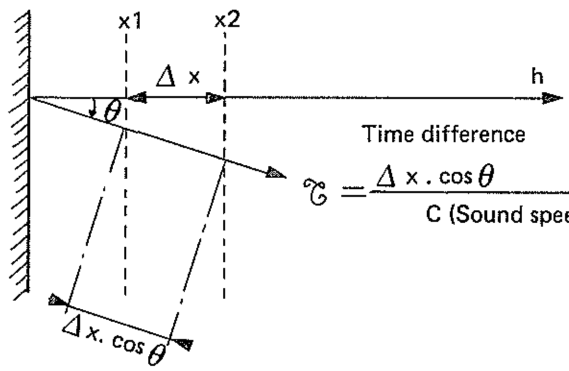
Evanescent waves are defined :

$$0\leqslant k< M \qquad \text{and} \qquad k\max > \frac{K_o\,Lx}{2\pi}$$

$$0\leqslant l < N \qquad\qquad l\max > \frac{K_o\,Ly}{2\pi}$$

Separation of the acoustic propagating field into direct and reflected acoustic fields





Time difference

$$\tau = \frac{\Delta x\,.\cos\theta}{C\ \text{(Sound speed)}}$$

1) Measures :

x_1 : p_1 (t)

x_2 : p_2 (t)

$$p_1(t) = p_{21}(x_1, t) + p_{12}(x_1, t)$$

$$p_2(t) = p_{21}(x_2, t) + p_{12}(x_2, t)$$

2) Calculations :

$$p_{12}(x_1, t) = \frac{p_1(t) - p_2(t)\;.\;e^{-j\varpi\tau}}{1 - e^{-2j\varpi\tau}}$$

direct plane waves

$$p_{21}(x_1, t) = p_1(t) - p_{12}(x_1, t)$$

reflected plane waves