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CONTROL OF INTERIOR NOISE IN ADVANCED TURBOPROPELLER AIRCRAFT

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ABSTRACT

The importance of limiting interior noise of a new generation turboprop commuter aircraft, the AERITALIA/AEROSPATIALE ATR-42, has rerequired a continuing effort, started during the preliminary design phase and presently under way with the aircraft in its initial production. The analytical and experimental tools developed during the program execution are described. The related results, with some comparison between theoretical and experimental findings, obtained before flight testing, are brifly discussed. Some comparison of preliminary data from acoustical flight tests, with finding from experimental results obtained in the full-scale fuselage section model, are also presented. Studies presently under way to define means for further reduction of noise in the fuselage of the new ATR -72 program, are described and current developments of theoretical models capable to predict the acoustical performance of a fuselage are discussed.

1. INTRODUCTION

Several studies are presently under way on the interior noise control of propeller aircraft. The vast majority of published works was originated by the recognized need for research in this field, to develop technology required to make feasible the advent of propfan. Some work has been performed to quiet existing aircraft, civil and military.

The research aimed to control of propfan noise has provided several results concerning the noise source (1), the mechanism of noise generation (2) and transmission (3) to the fuselage, the means for reducing internal noise acting on the source (4), (5). These results have been partly used in new commuter aircraft. In addition, a large effort is under way to fully model the relationship between internal and external noise and to validate the theoretical results. No studies are available in the technical literature, to the knowledge of these authors, concerning correlation of theory with full scale results. Little is published on means being studied to achieve noise reductions larger than those given by conventional primary fuselage structures and add-on systems, without increasing the sidewall mass to unrealistic values.

Some reports exist on noise reduction program performed on existing aircraft (6), (7) whose main indication is the need for working at the same time on the several factors affecting internal noise, because of the relatively small effect of each. The propfan research follows the goal of achieving a full understanding of all the mechanisms involved, given the time frame considered for this propulsion technology. The work on existing aircraft is more concerned with achieving some practical results, soon.

This paper presents the acoustic design approach and some of the results obtained in the ATR-42 program that has been started with the purpose of developing the acoustic configuration of this new design turboprop commuter, well in advance of its introduction in service.

The results of the first preliminary flight tests on the said aircraft show a good correlation with those calculated in the design phase, evidencing in this way the validity of the followed design approach.

Improvements of the theoretical and experimental models used during this program, together with a more deep and generalized use of the cabin noise reduction techniques, are scheduled, and herein shown, for the starting program of the stretched version: the ATR-72.

2. CABIN NOISE DESIGN APPROACH FOR THE ATR-42 AIRCRAFT

Interior noise control of ATR-42 has been considered from the first phases of aircraft configuration definition. Achievement of a maximum level of 78 dBA-aisle seat, passenger head position, typical cruise condition -, the aim set for this airplane in a fully developed acoustic configuration, was soon understood to be possible only giving due consideration to the following items:

A - The general configuration of aircraft
B - The external noise sources
C - The structural configuration of the

fuselage

D - The cabin interior
E - The internal noise sources

AIRCRAFT GENERAL CONFIGURATION

Propeller distance from fuselage is an obvious factor in determining the noise level set on cabin exterior. However, the strong influence that it exerts on the vertical stabilizer size requires a convinced commitment toward the acoustical quality of the aircraft to let it to be influenced by noise considerations. The selected distance of propeller tip from fuselage skin is 0.82 m, corresponding to a distance to propeller diameter ratio of 0.207, one of the largest values for this class of aircraft.

Structural vibration excitation of noise is a well known effect to turboprop aircraft manufacturers. The G222, a medium sized military transport powered by two General Electric T64 engines with Hamilton Standard three bladed propellers and, alternatively, by two Rolls-Royce Tyne's with BADG four blade propellers, presents an increasing internal noise from the wing section to the rear that has been explained with the excitation of its low tail by propeller wakes.
This led to the recommendation for a high tail configuration, that is the solution selected for the aircraft.

PROPELLER SELECTION

Tip speed, diameter, blade number, blade load distribution and planform shape are the main factors that influence both noise generation and propulsive efficiency and, some of them, weight. These factors were evaluated with the manufacturers resulting in the selection of Hamilton Standard 14SF, 3.96m diameter, four blade propeller.

FUSELAGE STRUCTURE

Fuselage sidewall construction has a strong effect on low frequency propeller tone transmission to cabin interior as demonstrated by analysis of stiffened panel dynamic response. Consideration of interior noise in fuselage sidewall design led to theoretical and experimental developments treated in some detail in following sections.

CABIN INTERIOR

Differences found in flight tests performed on G222 in one configuration having thermal insulation blankets on fuselage structure and in a so-called VIP version featuring an elastically suspended sidewall trim and a commercial transport type interior, with seats, carpets and overhead bins, provided a first insight in the acoustic performance of interior treatment. Since the intended sidewall construction of ATR-42 was so much different from G222, it was decided that a theoretical and experimental development of cabin interior, based on the close modelling of configuration being considered, was needed.

INTERNAL SOURCES

This item has also received attention from the beginning of program. It will not be discussed in this work.

3. DESIGN MODEL ANALYSIS

The ATR-42 acoustic design has been performed using the model approach. Theoretical models of fuselage dynamic response and sidewall trasmission loss has been prepared as following reported, and theoretical results by these procedure have been compared with those obtained by experimental tests on model.
The experimental program has been established with the main purpose of developing the acoustic configuration of fuselage sidewall structure and add-on systems, namely the thermoacoustical insulation, the interior trim panels with their mounting. Most of the studies are performed on a full scale fuselage section, 6 bay long (3.25m). Part of the sidewall structure and add-on system work has been done on flat panels.

3.1 THEORETICAL MODELS

Priority has been given to the development of analytical tools, capable of a detailed representation of fuselage structure dynamic behaviour. Sidewall treatment insertion loss and cavity acoustical modes have also been modelled.
These models can become parts of a more general procedure for the analysis of sound transmission inside the fuselage. Such a development will be attempted once experience gained in this production program will have shown the limits of validity of each tool and indicated more appropriate analysis techniques, as reported afterward. In the following, models of the dynamic behaviour of the structure and of sidewall treatment transmission loss are discussed.

3.1.1 Fuselage Structural Dynamics

In recent years some analytical methods to predict aircraft interior noise have been developed, among which (8),(9), (10). A very useful analysis of limitations and capabilities of these methodologies is reported in (11) and (12), that with their 171 and 135 references give a wide overview of contemporary research status. Here it is of interest to point out that to allow a numerical evaluation of interior noise these procedures have to make some simplifying assumptions of the configuration of the structure under analysis. If this can be acceptable for prelimonary evaluations of noise transmission inside fuselage, when attempting a detailed analysis of structure dynamics for design purpose it is of importance to have the capability to model the contribution of all structural components, consistently with limitations posed by computation power availability.

After a critical evaluation of methods being developed (16), it was decided to implement the structural dynamic analysis methodologies proposed by Sen Gupta (13), (14), (15).

These techniques combine transfer matrix and wave approach (TMWA) to derive closed form solutions of the displacement of a periodic structure under acoustic pressure excitation.

Two computerized procedures have been realized, based on these methods: PESAL (16) and NAT-DASC (17), (18).

Subsequent developments have been carried out for the implementation of more realistic numerical Finite Element Models of the typical fuselage structures, i.e. stiffened panels and frames (22), (23).

For a detailed discussion of the methods used and results obtained reference should be made to papers previously mentioned.

Program PESAL allows studies of the modal dynamic response of the fuselage interframe periodic structure, assuming it to be flat, infinite and simply supported by two rigid elements simulating fuselage frames (figure 1), taking into account the structural details of panel and stringer, under pressurization loads. Curvature effects are simulated by a ficticious plane stress increase. The acoustic field excitation used in ATR-42 studies has a white noise spectrum and infinite trace velocities along the circumferential and longitudinal directions.

Program PESAL has been used to perform a parametric study of the ATR-42 fuselage structure configuration, on which selection of some structural parameters was based. This followed experimental corroboration obtained by flat panel model tests. Some of these results are presented in a following section.

Program NAT-DASC calculates the modal dynamic response of the "Cylindrical Shell-Frame" periodic structure, taking into account, among the various parameters pressurization effects and warping, non-simmetry and excentricity of frame section (figure 2).

A white noise spectrum, infinite trace velocity along both directions, acoustic excitation is usually considered.

This program has not been used in fuselage configuration definition, lacking an experimental confirmation of its results. A later comparison of NAT-DASC outputs with data obtained in the fuselage section test has shown strong differences, leading to the conclusion that the present status of the procedure cannot be used in fuselage design studies.

With reference to the Finite Element Models used in the design process, at first a frame model near the propeller plane has been selected and analyzed with the well-known MSC/NASTRAN FEM computer program. This model has 80 nodes and 81 beam elements (Fig. 3) in order to obtain a very careful structural detail of the geometric characteristics of the frame and the floor supporting structure. The inertial properties include the lumped masses of the beam and those of the panels, stringers, crease-beams, floor and windows belonging to the two half-bays,, that can be considered as attacched mass in the motion of the frame.

Successively such model has been modified in order to model a complete bay, i.e. to the two frame models, as previously described, have been added the panel, the stringers and the crease beam structure, with the possibility to include all the real elements in calculating the dynamic response of the fuselage.

To reduce the costs associated to such detailed model, it uses the simmetry property of the aircraft fuselage, for which only one half part of the structure is modeled. However this half model is realized with 360 (136 CROD, 140 CQUAD4 and 84 CBAR) elements connecting 188 nodes.

Both these models have been used to perform as modal analysis as dynamic response studies in order to be able to gather a better understanding of the fuselage structural elements dynamic behaviour under simulated aeroacoustical loads in airborne path due to propeller excitation.

3.1.2 Sidewall Treatment Trasmission Loss

The sidewall treatment (fiberglass batting, blanket cover, trim panel, air gap, septa) effect has been described with reference to Beranek and Work model (19). The fuselage, the trim panel and the septa (including blanket covers) are assumed in the calculations as limp masses. Transmission in the sidewall treatment is considered normal to the wall. The resulting computer program, NAT-TPL, after being found in agreement with experimental results on flat panel treatments, has been used to perform trades on different configurations and materials of the sidewall for selection of the aircraft solution. Some results are discussed in a following section.

3.2 EXPERIMENTAL MODELS

3.2.1 Dynamic Response Flat Panels Test Set-Up

Two test articles are available, resembling structural solutions being traded.

Each article is made up of a panel, hav-

ing the width of a fuselage bay, and of seven, eleven stringers spaced as on the aircraft respectively. Damping is applied at the two shortest edges to reduce wave reflections at these discontinuities.The sample is attached to very rigid frames on the two long edges, and is free at the two short. This installation simulates the infinitely long, rigid frame, stringer/panel model described in the analytical model section.
A modal analysis has been performed on the centre bay, using the Single Input Transfer Function technique.

3.2.2 Sidewall Treatment Flat Panel T.L. Set-Up

The same test articles and a similar fixture as in previous test are used, ABS trims, of different surface densities,are bolted to the rigid fixture. Fiberglass blankets with covers typical of aircraft applications can be installed in the trim/ panel gap. Fixture is connected to the edges of a window opened on one wall of a semi-anechoic chamber, 1.5 x 1.5 x 1.5 m. Acoustic excitation is obtained through a loudspeaker system driving an acoustic horn resting on the sample fixture. One external microphone at the tip of a probe mounted at center of the horn reads sound pressure on sample surface.
Several microphones are mounted inside the chamber. Chamber walls are lined with constant thickness fiberglass providing absorption characteristics as in a typical furnished aircraft.
This set-up is used to acoustically test sidewall treatments coupled to the fuselage panel.

3.2.3 Full Scale Fuselage Section Test Set-Up

The test article (Fig. 5) duplicates the fuselage structure construction, including windows, floor structure and antiicing protection.

The interior of the test article (fig.6) can resemble the various solutions taken under consideration for the aircraft. The baseline configuration consists of three longitudinal beams for each side, elastically suspended on the frames, to which ceiling panels, baggage bins, and the lateral trim panels are attached. Acoustical effects of seats and carpeting are simulated by some foam material distributed in the test article (fig. 7).
The test section is terminated at each end by a reinforcing flange riveted to the skin, through which the article is suspended to the holding structure.
The test rig is designed to allow section pressurization. The cylinder is closed at the two ends (fig. 8) by heavy caps - about 350 Kg. each - bolted to flanges, 9 PSI being max allowed pressure differential. The caps are connected by means of a pring system to the fixture, with a resulting isolation above 20 Hz. The suspension system is designed so to allow longitudinal motion of one section end to avoid loads not present on aircraft. The interior of the end caps is covered with 0.1 m deep fiberglass.
Two types of tests are performed on the fuselage section, modal analysis and noise reduction.
Figures 9,10 are schematics of the instrumentation used. Figure 11 shows the test article assembled on the fixture, with the point force and the acoustical excitation in place.
The single point force excitation is provided by an electrodynamic shaker having a force output of about 40 N. The acoustic excitation is given by two pairs of high and low frequency electrodynamic drivers installed on the rear wall of a box having the opposite side open. The box is placed with its open side close, but not in touch, to the fuselage skin.
In the modal test, acceleration at about 200 points has been measured, using 2 gr accelerometers for panel and 11 gr accelerometers for frame vibration tests.
In the acoustic test 9 1/2 inch pressure type microphone (fig. 7) are used inside and 7, 1/4 inch pressure type microphones outside the fuselage, reading skin pressure. One external microphone is flush mounted at the center of a window with its membrane tangent to window skin, its body being inside the fuselage at the interior pressure. Rear side of membrane is vented outside.
The other external microphones are installed with membrane perpendicular to fuselage skin. One of them is mounted near the flush microphone to provide an indication of the installation effect, that is applied to the readings of remaining external microphones.
All tests are performed using a semi-automated procedure started by the test operator during the data acquisition phase. Data are stored on the magnetic mass memory of the test dedicated computer, a GOULD 32/27, for the following analysis and presentation.

4. DISCUSSION ON MODEL RESULTS

Theoretical and experimental studies have been conducted, having the main purpose of providing information for selection of fuselage structural and interior elements having an impact on the interior noise of the aircraft.
Contribution to the definition of fuselage structure configuration has been given on the basis of results obtained by the panel/stringer theoretical model, confirmed by flat panel tests available at the time configuration was frozen. Later, data collected during modal testing of fuselage section brought to the decision to add shear ties between frames and panels where they lacked in the baseline configu

ration. Development of sidewall treatment has been based on theoretical analysis and on the output of tests performed on flat panels and on the fuselage section.

This test article, still undergoing experimentation for the ATR-72 noise treatment program, has been the heart of the development program under discussion.
It is felt that, if used for the purpose of deriving comparisons among different acoustical solutions, the results of this experimentation are reliable. Although the program being discussed has not as its main purpose the development and the validation of theoretical procedures, results obtained can be used to infer limits and merits of the analytical approach used.

Lack of previous experience in the use of such experimental methodology does not allow yet to take the output of this test as an absolute estimate of aircraft behaviour. In particular, model scale effects are not clear at design time. Flight test results compared with model results are presented in the following where some of these effect are discussed.

4.1 FLAT PANEL DYNAMIC BEHAVIOUR MODELS

Extensive utilization, during the structural definition of the ATR-42 aircraft fuselage, has been made of the PESAL program.

Many and different effects on dynamic response of the panels have been evaluated with this code, particularly those related to:

a) tuning of the frequencies of the panel and the stringer through the selection of the stringer-pitch, its stiffness and inertial characteristics, and panel thickness;

b) damping;

c) differential pressure, and so on.

The validity of such metodology has been confirmed by the experimental results obtained on flat panels test set-up.
Two configurations of fuselage interframe structure have been realized with test articles consisting of flat panels with stringers mounted at a constant pitch, 0.12 m and 0.24 m respectively.
The panel resonant frequency, as found in the test and from program PESAL analysis, in the no pressurization case, is as follows:

PANEL	STRINGER PITCH(m)	FRAME PITCH(m)	RESONANT FREQUENCY (Hz) THEOR.	EXPER.
1	0.12	0.53	124	122
2	0.24	0.53	78	77.7

From this comparison it results evident that the periodicity hypothesis which is the basis of the PESAL program is reliable and useful for the evaluation of the dynamic response of the fuselage, at least in a limited frequency range (15).

4.2 FLAT PANEL ACOUSTIC PERFORMANCE MODELS

The sidewall treatment acoustic performance has been studied theoretically using the procedure NAT-TPL described in a preceding sections, and experimentally with results from the semi-anechoic chamber facility; it is to be noted that the experimental set-up is finalized to read a "Noise Reduction" parameter, obtained as the difference between external sound pressure level and the average of the levels at some microphones in the chamber. Semi-anechoic chamber room constant is similar to that of typical commercial aircraft interior, at the middle-high frequencies. This set-up is meant to furnish the relative effects of different sidewall treatments at the speech interference frequencies. At lower frequencies, dimensions of chamber and possible effects of curvature on sidewall treatment performance advise to use a different approach for this particular evaluation. Test on the fuselage section has provided this information.
To the purpose of comparing experimental results with those from the theory, a "Transmission Loss" parameter was derived from test data using sound pressure readings close to double wall structure.
Some comparisons are shown in figures 12, 13. It is clear that agreement greatly improves for configurations including fiberglass blankets in the gap between trim and stringer-skin structure. This may be caused by the fuselage panel and the trim panel being simulated in the analytical procedure as limp masses.
Agreement in the configurations that include fiberglass is consistently good at the frequencies of interest. Instrumentation dynamic range limitations and some possible leakage effects can explain the large differences at high frequencies.
The analytical procedure and the experiments have been used to accomplish a trade on effects like distribution of the mass between trim and blankets, air-gap/fiberglass sequence, fiberglass density, thickness and flow resistance.
Results have confirmed solutions presently used on commercial aircraft. Specifically, low density, high flow resistance materials are found to provide best compromise between weight and attenuation, wherever space available for treatment allows to obtain requested isolation effectiveness with blanket thicknesses smaller or equal to trim/structure gap.

4.3 FUSELAGE STRUCTURAL DYNAMICS BEHAVIOUR

Several studies, (9),(12), (20), concerning aircraft interior noise have evidenced the need for performing modal analysis of the fuselage structure as a means for a better understanding of acoustic transmission inside the fuselage. Examples of this approach are reported in (21),(22).
An experimental modal analysis can provide the following results:

1 - Definition of structure natural fre-

quencies
2 - Mode shape analysis and contribution of various structural elements
3 - Loss factors associated to modes
4 - Definition of factors having an effect on the use of noise attenuation devices like vibration absorbers, damping materials, anti-vibration mounts for the interior furnishing.

An experimental modal analysis using the Single Input Transfer Function technique of fuselage structure has been performed (19) on the fuselage section test article. The experimental analysis has first evaluated some effects concerning the test set-up. The six rigid body frequencies of test article have been determined, all being below 15 Hz. Two excitation types, one vertical on the fuselage bottom and a second horizontal at window height, both at panel/frame interfaces, have been tried. The horizontal excitation has been selected, more modes and with higher amplitudes being generated. Three different pick-up arrangements have been used to the purpose of defining contributions of various structural elements. Test has covered frequency ranges from 50 to 500 Hz. Pressurized and unpressurized conditions have been tested.
A comparison has been made of resonant frequencies and loss factors of the first modes, for the bare fuselage structure, with and without pressurization, as well as for the furnished fuselage. It confirms the expected effect of pressurization on resonant frequencies, shown for one mode in Figure 14. A large impact on T.F. is found by adding the sidewall treatment, overhead bins and ceiling, and masses simulating items attached to interior holding secondary structure and hand carried baggage.

The mode shapes analysis in this case has given some difficulties principally due to the non-proportional nature of the damping that gives as results, complex mode shapes.

A comparison of experimental modal analysis data with theoretical predictions has been performed; mode shapes and frequencies have been calculated using the theoretical FE frame and bay models.

Figure 15 compares mode shapes of first modes found theoretically with FE models and experimentally, for the non pressurized, unfurnished fuselage test article. Table 1 provides the list of natural frequencies found with the two FE theoretical models (frame and bay) and experimentally.

Some agreement and general resemblance of FE models and experimental output is visible in these comparison, if it is taken in the account the differences in lenght between these models.

4.4 FUSELAGE BEHAVIOUR WITH ACOUSTIC EXCITATION

Acoustic tests are being performed on the fuselage section, with various interior configurations, to the purpose of developing understanding of optimum solutions for items of furnishing having an effect on interior noise.
Other model tests of a similar nature have been conducted (9),(20). The intent in these cases has been to validate theoretical prediction methods and to obtain experience on heavy double wall systems.
Results of experiments on the fuselage section cannot be simply extrapolated to full scale aircraft, reason being the scale effects inherent to this test. At this time, scale effects can be identified as follows:

A - Geometry. Cross section of test article is full scale, length is 3.256m, versus 10.2 m of aircraft fuselage, from forward baggage compartment partition with passenger cabin to aft cabin-galley partition.
Low frequency structural modes, below propeller noise fundamental frequency, and acoustics of the cabin are influenced.

B - Source. Level distribution and phase relationship of sound on fuselage surface are different from aircraft.
Noise is generated on one side only of test article. Effect of asymmetry of real acoustic field (1) on the two sides of fuselage is not taken into consideration.
Absolute level of excitation has been determined to be uninfluential up to 130 dB, limit of the source system used, other than for usual noise floor problems at the low amplitudes.
Effect of pressurization on noise transmission inside the fuselage is taken into consideration in this test, differently from the other mentioned above (9), (20).
This effect is mainly determined by fuselage structure response and by the larger characteristic resistance of the receiving space.
Figure 16 reports the Noise Reduction functions for a furnished configuration of test article, with and without pressurization. Acoustic excitation used to derive these data is white noise. The reduction of attenuation in the pressurized condition varies with frequency, being larger at higher frequencies.
This result, and other similar obtained during the program, demonstrate the need for including pressurization among parameters to be taken into account in model tests.
Figures 17 presents accelerations measured on the elastically suspended secondary structure holding the interior and on the lateral trim panel, both ratioed to acceleration measured on a frame, at the point of attachment of anti-vibration mount. Below 250Hz trim panel vibration is much larger than motion transmitted through the elastic suspension. Acoustic excitation from fuselage panels and trim panel resonan

ces cause these differences.
At higher frequencies, attenuation provided by acoustic insulation blankets in configurations typical for this class of aircraft makes the lateral panel motion similar to vibration input, in the average.

Noise reduction comparison between furnished and bare fuselage is presented in fig. 18 and 19. Fig. 18 shows the 1/3 octave band Noise Reduction measured on fuselage test section; it is clear that fiberglass and double wall treatment have no influence up to 250 Hz as usual for this type of treatment; at higher frequencies the noise abatment is in according with flat panel results. The lower values at frequencies higher than 5 kHz are not real but due to the dynamics recorder limitation of acoustic analysis system.

Fig. 19 shows the narrow band analysis between 0-500 Hz and confirm the no influence of add-on treatment up to 250 Hz; instead the big difference at 360-400 Hz are connected with the different acoustic mode inside the test set-up due to the interior furnishing.
Table 2 presents an analysis on the Noise Reduction spectrum of furnished and bare fuselage section configurations, where frequencies at which attenuation is in a dip are cômpared to main structure and interior resonances. Analysis is based on 1.25 Hz bandwidth spectra. Both configurations where pressurized. The correspondance between attenuation minima and some of acoustical and structural resonances is good.

5. ATR - 42 FLIGHT TEST - MODELS COMPARISON

Flight tests performed on the ATR-42 aircraft have confirmed the very confortable acoustic environment predicted for this aircraft on the basis of models data evaluation. Although the flight test program performed on the aircraft has not as its main purpose the development of the validation of models used in the design phase; results obtained can be used to infer limits and merits of the theoretical and experimental models used.

A comparison between Noise Reduction measured in the fuselage section test set-up and propeller tone Noise Reduction measured in flight on the aircraft in the propeller cabin area at different engine RPM and power setting and altitude,in cruise condition, has been made. Fig. 20 shows one of these comparison: good agreement was found, confirming the high confident level on the full scale fuselage section test article results, in developping the aircraft noise treatment configurations. So this model will be used to define the ATR-72 acoustic interior configuration and any others ATR-72/42 particular noise improvement.

6. ATR-72 ACOUSTIC IMPROVEMENT ACTIVITIES

The ATR-72 is the streached version of the ATR-42 having 30 more passenger.It has about 4.5 m longer fuselage, with higer power engines (+33%) and hinger cruise speed (+40 Knots); hinger noise level is therefore expected in the fuselage cabin.

Interior noise levels qual to the ATR-42 levels is the design objective, therefore the new fuselage noise treatments,im impruving the Noise Reduction of the fuselage, are actually under development.

6.1 NOISE REDUCTION ACTIVITIES

The programmed acoustic improvement activities are presented in the following paragraphs; the theoretical and experimental models, before discussed and the flight test measurements on ATR-42 are being used to their development.

6.1.1 RPM reduction

Engine RPM reduction at cruise conditions has been tested in flight Noise Reduction and the others aircraft performances have been evaluated, it has been found that on ATR-42 a 9% RPM reduction can be performed with no significant aircraft performance penalities, producing 4-5 dB(A) in the noise level reduction in a large area around propeller plane in the passenger cabin. Same effect is predicted on ATR-72.

6.1.2 Cabin Wall Improvements

Some cabin wall treatments have been defined. Theoretical and experimental studies on vibration and sound wall insulation are developing. In particular the ATR-42 vibration isolation system of interior wall is improving to performe an higher vibration decoupling from primary structure and the fiberglass treatment configuration is now redifining to allow the higher aerodynamic noise due to the increased speed of the aircraft.

6.1.3 Dynamic Vibration Absorbers

It is well noted that the dynamic vibration absorbers, both on jet as turbopropeller aircraft, has been used with effectiveness as device for reducing the noise and/or vibration level inside the fuselage.

In these application the design guidelines have been deduced essentially from long and expensive laboratory or flight tests (6), (24), even if, in Ref. (24), a Finite Element Model was used for preliminary studies and for comparison of different devices for the reduction of cabin noise level.

Following this last approach and identifying in the Finite Element frame model, already showed, the most suitable for a theoretical evaluation of the effects of the dynamic vibration absorbers application, a parametric study for a preliminary selection and optimization of such devices has been performed (25), (26).

The frame dynamic response, with and without dynamic absorbers, to an acoustic type excitation has been analyzed using the modal approach available in the MSC/NASTRAN program. In these investigations, the bare structure of the fuselage has been considered, i.e. without interiors and payload.

The acoustic loading with spectral content very similar to real propeller excitation has been applied radially and with uniform amplitude along the frame, neglecting every phase and amplitude variation effects.

In fig. 21 (A) the bare frame undamped dynamic response to the acoustic excitation for the first three blade passage frequencies (70, 140 and 210 Hz) is shown. An example of the frequency response on the top ceiling point of the bare frame is shown in fig. 22.

Both the peaks due to the structure resonances and those due to the excitation are evidenced. In the same plot, the dynamic response determined with structural damping equal to 0.01 is reported.

Based on this investigation, the analysis of the application of dynamic vibration absorbers has been performed. The dynamic absorbers have been modeled as single d.o.f. spring-mass system with, whenever considered for the structure, one per cent structural damping.

Following an approach similar to that of Ref. (24), a parameter related to the square root of the sum of the squared velocities of the points around the frame, has been used as index (IFv) for the evaluation of the effectiveness of the dynamic absorbers installation for a specific excitation frequency.

A more global index (IFp), taking into account the weighted frame response at various tonal excitation of the propeller, has also been evaluated and used.

Based on the previous considerations, several dynamic vibration absorber configurations, Fig. 23, have been numerically tested.

The main aim of this preliminary analysis has been to evaluate the effectiveness of the dynamic absorbers in terms of: added mass, tuning frequency, selection of the number and location of the application points, effect of the excitation frequency variation (RPM variation).

Some examples of the results obtained from this parametric analysis are shown in Fig. 21,24 and in Tab. 3.

In Fig. 24 is shown the effect of the variation of the mass ratio between dynamic absorber and bare frame, on damped frequency response at same point of Fig. 22 with dynamic absorbers tuned at 140 Hz.

In Tab. 3 is further reported the result of a parametric study among different configurations of application points on the frame of the dynamic absorbers, Fig. 23.

In this table, for the tested configurations, the following items are successively indicated: the mass ratio, the number of absorbers applicated, the tuning frequency and the first three indexes of total efficiency (respectively for the first three BPP of the propeller) and finally the weighted index on such excitation frequency.

Such indexes are reported in terms of dB variation of their value with the application of the dynamic absorbers, respect to that obtained for the frame without them.

Such results have been used for the selection of two or three configurations which will be experimentally tested on the full scale fuselage test article, before their definitive application and flight validation for the related aircraft.

6.1.4 Damping Treatment

No damping treatment is used on the ATR-42. To reach ATR-72 higher fuselage noise trasmission loss at low - middle frequencies, this type of treatment is under evaluation. Panel tests to select appropriate material and correlate theoretical and experimental models is actually under development. Tests on full-scale fuselage section set-up and flight tests on ATR-42 are programmed to develop a minimum weight treatment configuration versus optimum noise abatment.

6.2 MODELS IMPROVEMENTS AND UTILIZATION

The results and the theoretical and experimental comparisons presented and discussed previously have clearly shown the reliability and the rightness of the followed approach in using different structural models until the first design phases of the aircraft, and increasing their intrinsic complexity with the aircraft definition going on.

During the use of such models it has been possible to verify their application limits and consequently to define what and how limits remove addressing the theoretical and the experimental study for the improvements or definition of new models.

Surely, when the structural definition is close to its final configuration, the use of a Finite Element Modelization is important and almost mandatory.

This consideration has been the reason for the development of the Finite Element Model of the bare frame and successively of a complete bay between two frames. In addition to this, now under progress, is the Finite Element Modelization of the cavity using the structural-acoustic analogy.

In order to obtain the most possible precise information from the Finite Element models, it is probably necessary to model also the air volume enclosed by the structure and then realize the structural-acoustic coupling which is the real physical phenomenon.

These studies are now developing and together with those already obtained will constitute the model and the methods for the acoustic improvements necessary for the developing stretched version: the ATR-72.

Finally from the flight tests and results now in progress for the developed aircraft, the ATR-42, we will be able to define the scale effects between the laboratory tests on the full scale model and the aircraft, in order to obtain for the future the necessary feeling to understand from the lab tests the expectable final result so to define almost definitively the best configuration, or what may be the necessary modifications to achieve a required cabin noise level.

7. CONCLUSIONS

The design approach using theoretical detailed structural models (FEM) and full-scale fuselage section test article, appare is the more reliable tool to define the interior acoustic configuration of a new turboprop commuter aircraft. ATR-42 flight tests have been confirmed the validity of this approach.

To improve this design capability, a more complete acoustic-elastodynamic models, considering coupling of structural dynamics and interior acoustics behaviour, are under development.

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	NUMERICAL MODELS		EXPERIMENTAL
	FRAME	BAY	TESTS
MODE SHAPE	FREQUENCY [Hz]	FREQUENCY [Hz]	FREQUENCY [Hz]
2 A	17.30	17.70	60.60
2 S	20.98	29.52	71.40
3 A	49.58	53.52	81.00
3 S	79.15	78.87	75.10
4 A	92.94	93.06	87.70
4 S	131.71	128.25	101.16
5 A	141.15	139.02	110.84
5 S	154.40	133.57	128.28
6 A	205.59	177.92	142.04

TABLE N. 1 - Experimental-Numerical Modal Analysis Correlation

n A : n Circumferential Waves , Antisymmetrical Mode Shape
n S : n Circumferential Waves , Symmetrical Mode Shape

BARE FUSELAGE			FURNISHED FUSELAGE		
STRUCTURE MODE (Hz)	ACOUSTIC MODE (Hz)	NOISE REDUCTION DIP (Hz)	STRUCTURE MODE (Hz)	ACOUSTIC MODE (Hz)	NOISE REDUCTION DIP (Hz)
61.4				60	63
74.4				70	69
79.2				72	
87.2	84	84	80.9	78	78
95	97		91.5	90	87
115.8	115	114	94.5	105	
129	126	126	115.5	117	117
131.8			126	129	129
144.1	145	144	135.4		
148.5			137.3	137	
154.5			142.1	141	141
158.8	159	156	143.5		
162			150.2	155	156
169.6	168	168		163	
174				165	
178.3	180		173	174	
182				180	
188.7		186	193	198	195
194.3	192		206.5	207	
198	198		224.5	225	
206.9	204	210		240	240
235.6	235	240	255.8		
248.1			261.9	258	
249.4	250			276	276
259.4	264	258			
271.9					
273.1	276				

TABLE 2 - Fuselage section Noise Reduction Analysis -

CONFIG. IDENTIF.	MASS RATIO	ABSOR. NUMBER	TUNING FREQU. [Hz]	TONE N. R. INDEX [dB]			AVERAGED N.R.INDEX [dB(A)]
				1°	2°	3°	
A . 1	.1	4	140	+5.6	−8.5	−3.1	−3.2
A . 2	.1	6	140	+2.9	−8.2	−2.6	−4.0
A . 3	.1	8	140	+5.4	−1.4	−5.5	−1.2
A . 4	.05	6	140	+1.2	−8.9	−1.7	−4.2
A . 5	.2	6	140	+11.3	−7.7	−4.1	+0.4
B . 1	.1	6	210	+3.9	−1.0	0.0	−0.1
B . 2	.1	6	210	+1.7	+0.7	+5.8	+3.1
B . 3	.1	12	210	+3.0	+1.1	−11.0	−0.2

TABLE N. 3 − Dynamic Vibration Absorbers Performance Evaluation
Relative to Configuration WHITOUT Absorbers
(−) Noise Decrease (+) Noise Increase

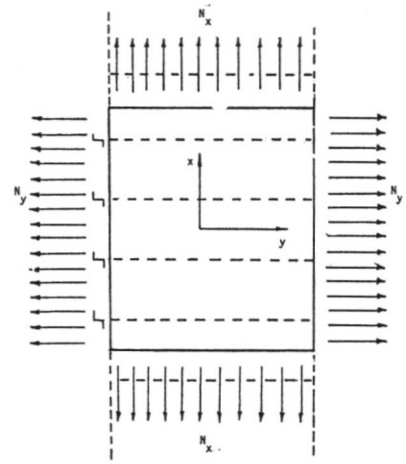


Fig.1- Periodic "Stringer-Panel" Model

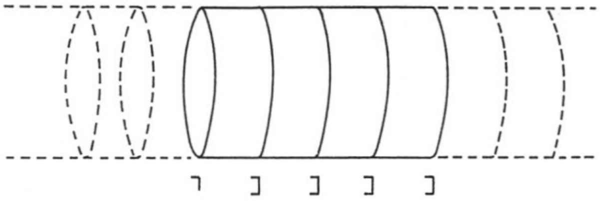


Fig.2- Periodic "Cylindrical Shell-Frame" Model

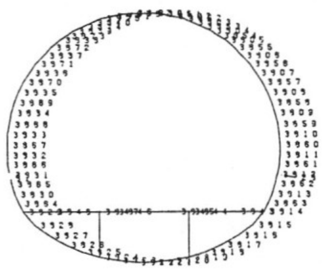


Fig.3- FE Frame Model

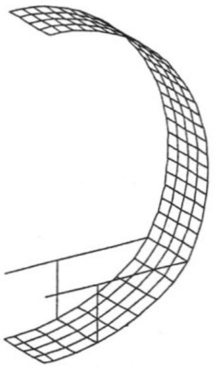


Fig.4- FE Complete Bay Model

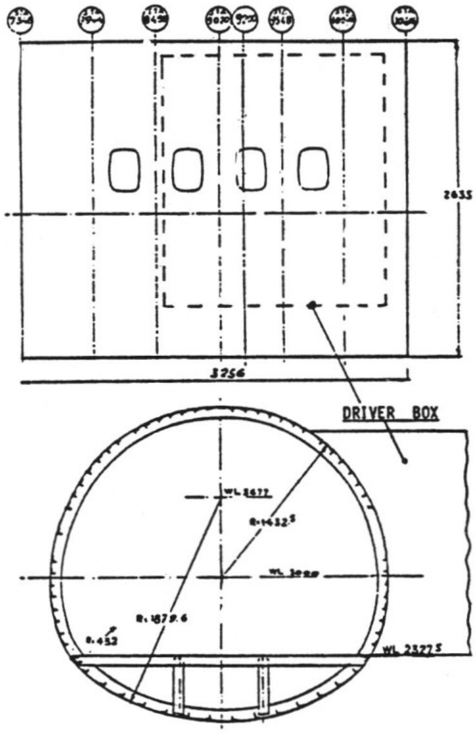


Fig.5- Full-Scale Fuselage Section Test Article

Fig.6- Fuselage Test Article Interior

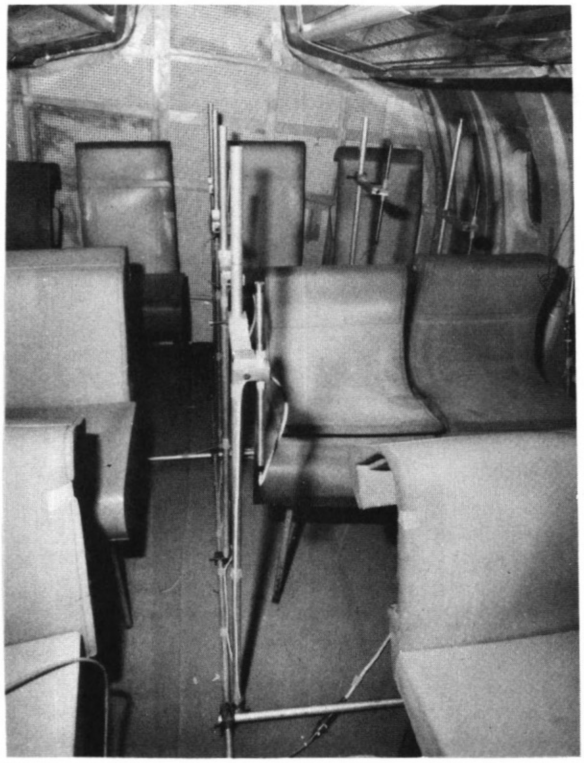


Fig.7- Fuselage Test Article Furnishing Configuration and Microphone Arrangement

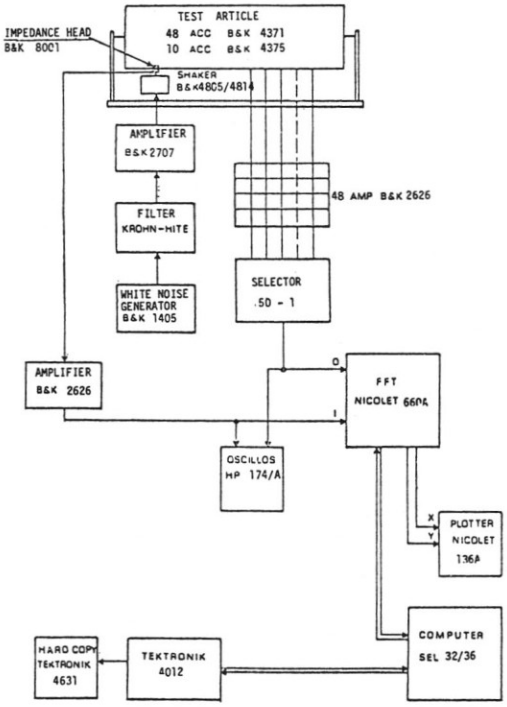


Fig.10- Instrumentation Scheme for the Mechanical Excitation Tests

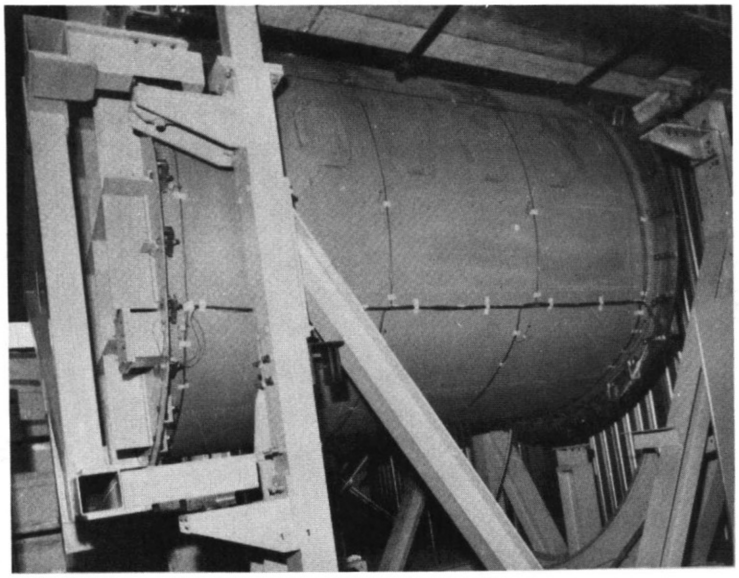


Fig 8- General View of the Complete Installation of the Fuselage Test Article.

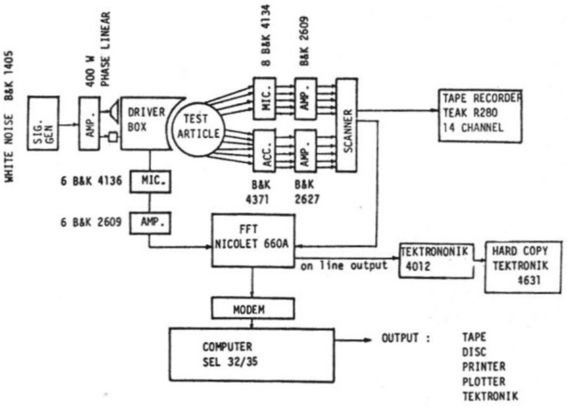


Fig.9- Instrumentation Scheme for the Acoustic Excitation Tests

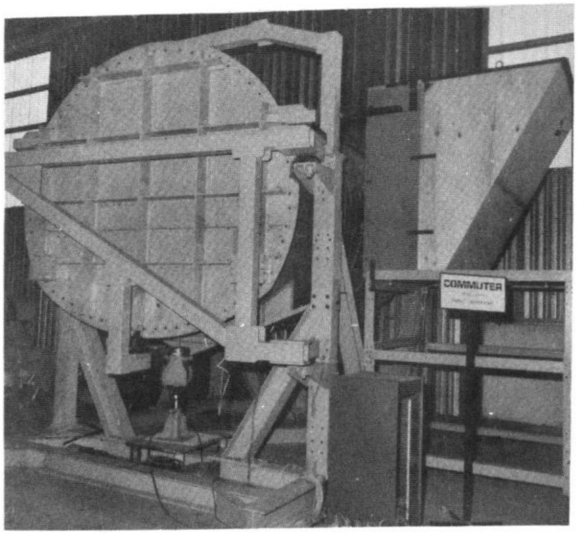


Fig.11- Acoustic Excitation Test Set-Up

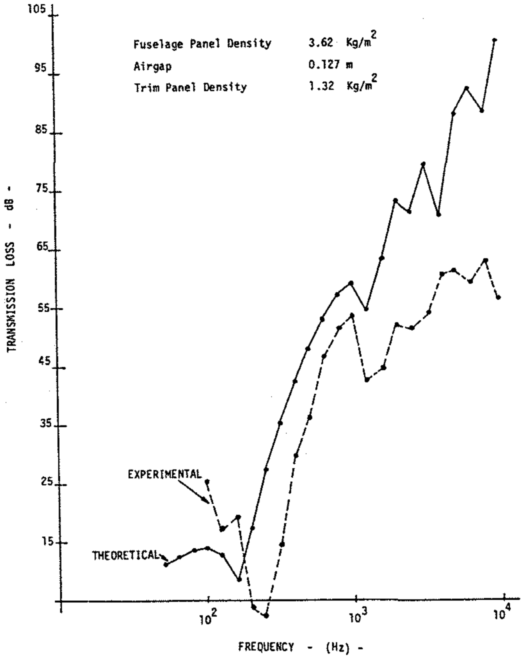


Fig.12- Theoretical and Experimental Transmission Loss Comparison for Sidewall Treatment without Fiberglass

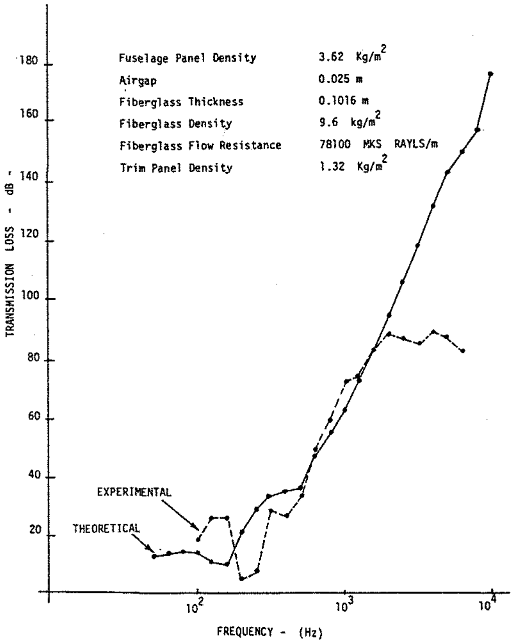


Fig.13- As Fig.12 with Fiberglass Treatment

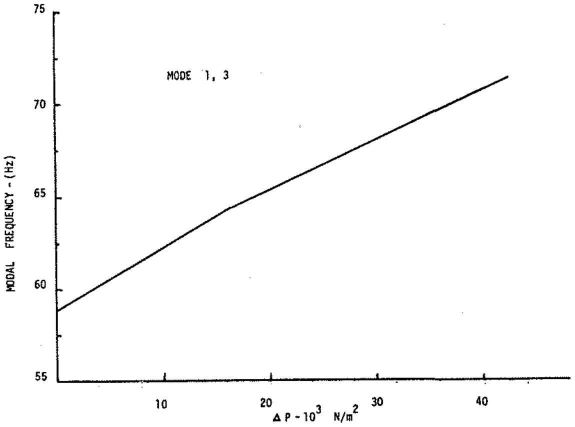
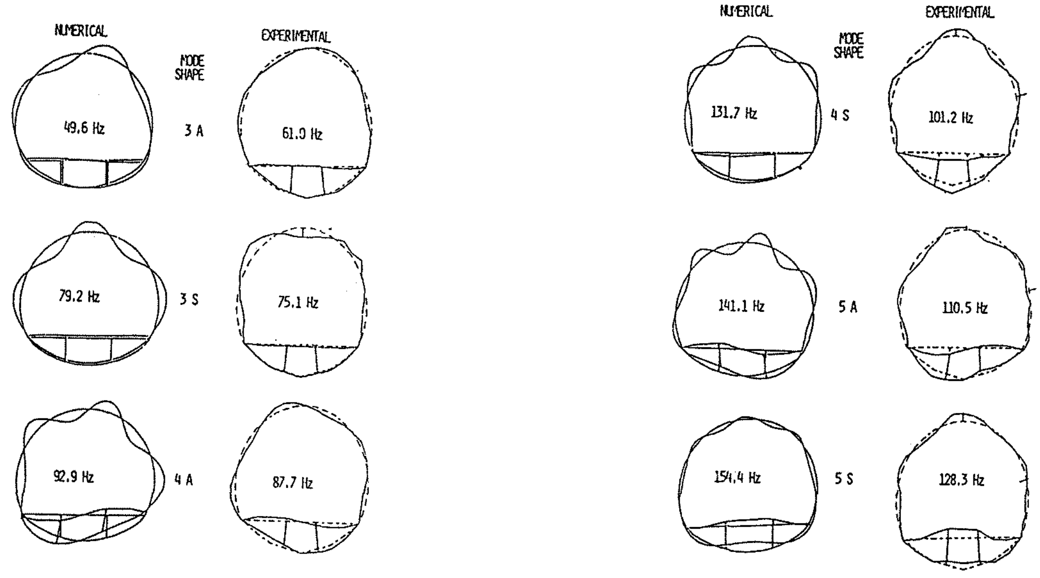


Fig.14- Example of Experimental Pressurization Effect on Fuselage Natural Frequencies

Fig.15- Numerical-Experimental Mode Shape Correlation



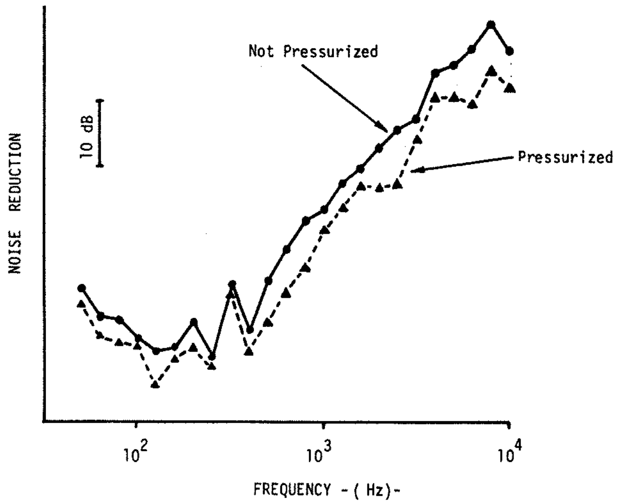


Fig.16- Pressurization Effect on Fuselage N.R. in Furnished Condition

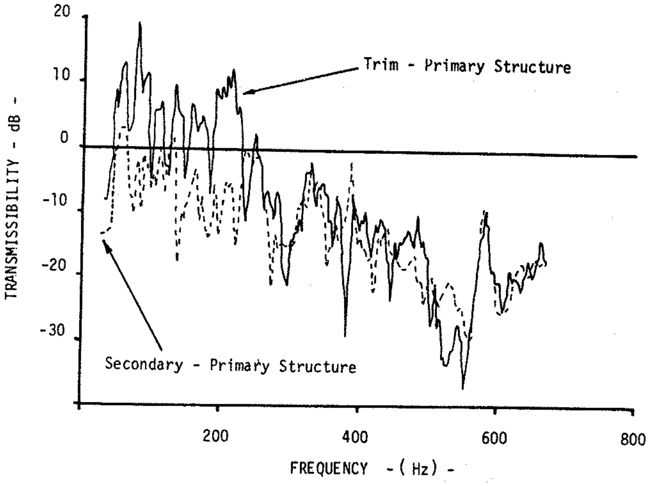


Fig.17- Trim Panel and AVM Acceleration Trasmissibility

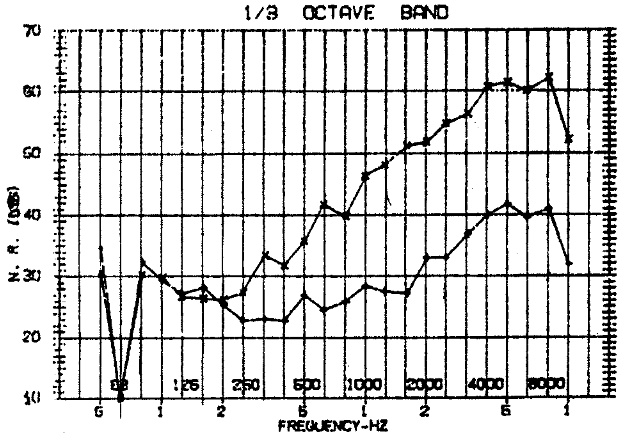


Fig.18- Furnishing Effect on Fuselage N.R.(1/3 O.B.)

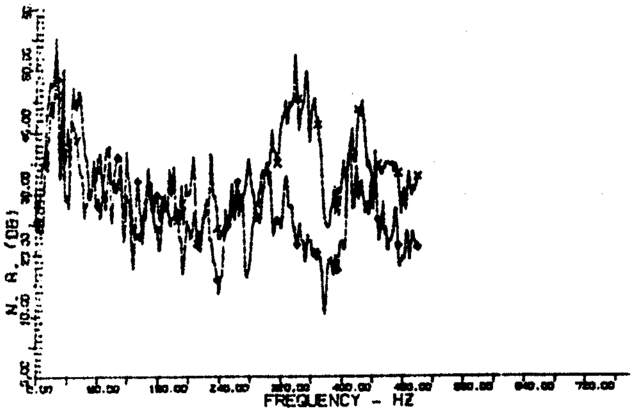


Fig.19- Furnishing Effect on Fuselage low Frequency N.R. (Narrow Band)

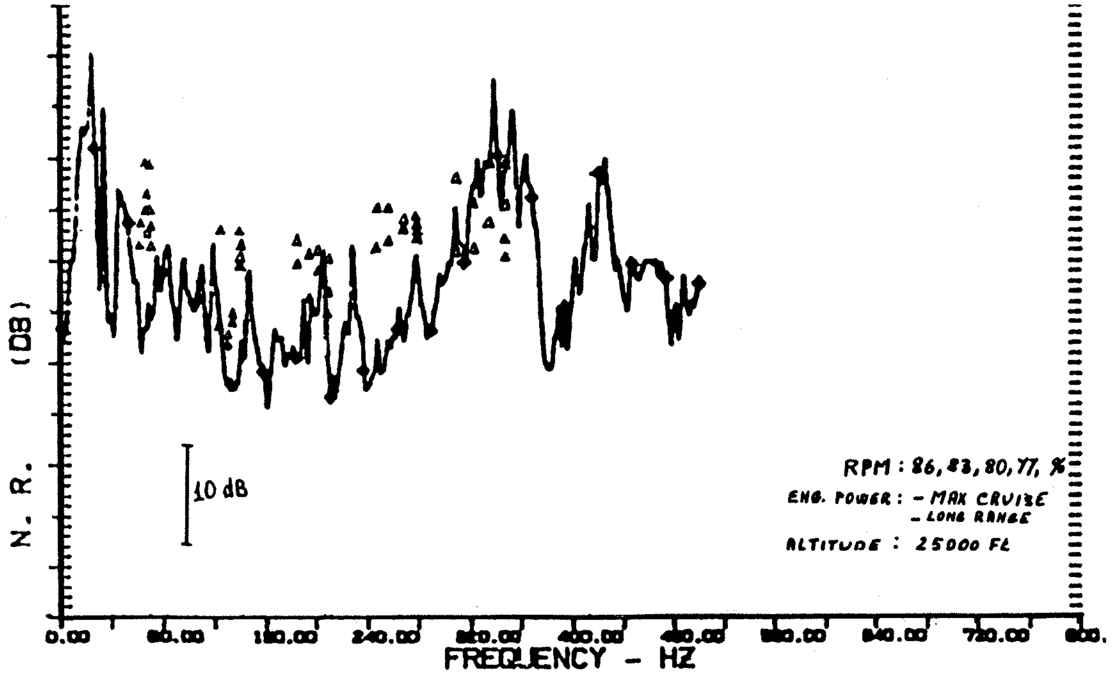


Fig.20- Full-Scale Fuselage Section Test Article and ATR-42 Flight Tests N.R. Comparison

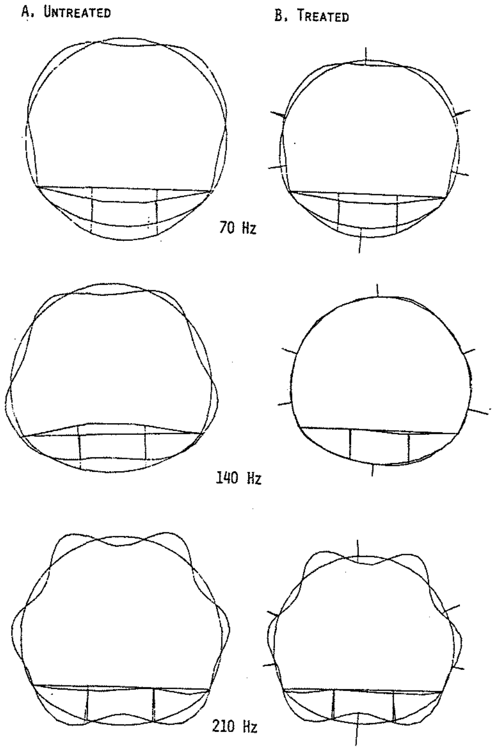


Fig.21- Frame Dynamic Response Effect at 1st, 2nd, 3rd Propeller Harmonic Excitation. Absorber Tuning Frequency = 140 Hz; Mass Ratio = 0.05

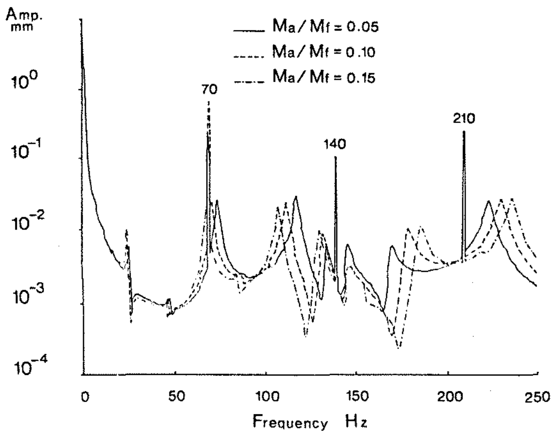


Fig.24- Frequency Responses at Sqme Point of Fig.22 with Dynamic absorber as in Configuration A3, Tuned at 140 Hz, for Different Mass Ratios and .01 Structural Damping

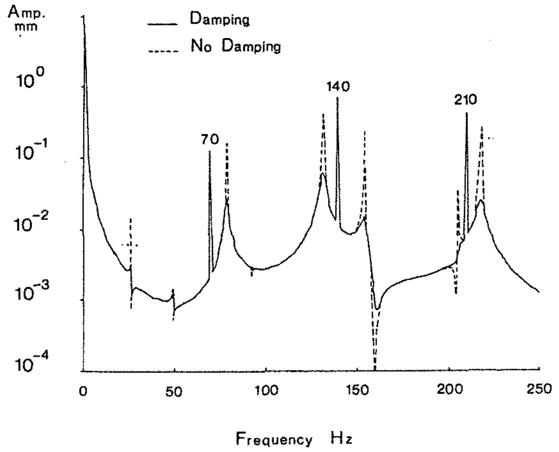


Fig.22- Frequency Response at Top Ceiling Point of the Frame without Dynamic Absorbers

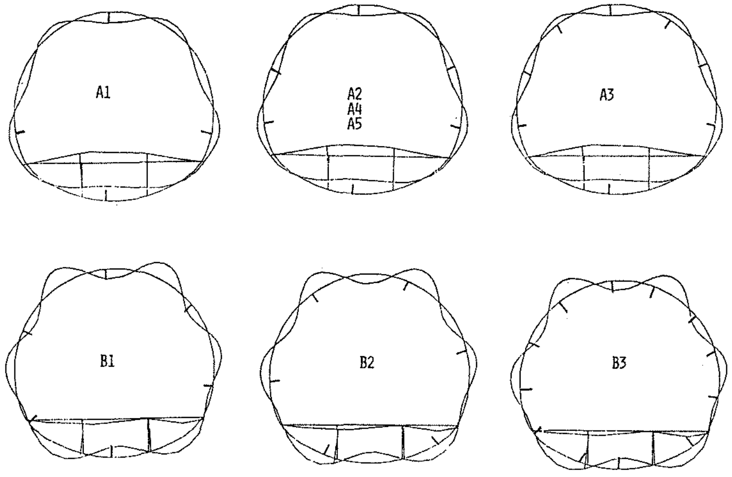


Fig.23- ATR-72 Dynamic Vibration Absorbers Configurations. A: Tuning Frequency= 140 Hz; B: Tuning Frequency= 210 Hz