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MEASUREMENT OF THE HUMAN PERCEPTION OF NOISE AND VIBRATION AIMED TO DEFINE A GENERAL COMFORT INDEX

A. CONCILIO, A. SORRENTINO

CIRA SCPA - CENTRO ITALIANO RICERCHE AEROSPAZIALI

F. CENEDESE

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ABSTRACT

This paper deals with the activities carried out during the 1st year of the Brite-EuRam funded, IDEA PACI project.

In terms of general performance, air transport technology is very advanced. Due to the increased use within the typical distances and area of the European Community, not only environmental impact, but also the internal, particularly vibro-acoustic, comfort has to be considered in the design process.

The link between noise and vibration levels appeared to be ruled by complex relationships, and the results, following the application of pure noise abatement systems, were surprising: people audited, stated a preference for high instead of low noise but high vibration levels. In that occasions then, by lowering interior noise levels, comfort was decreased.

Assuming that passenger welfare inside the aircraft is a complex function of both noise and vibrations (and other surrounding characteristics), to imagine that the design objective is to improve the comfort and not to suppress the noise, seems obvious.

The target of this basic research project is to define a general Subjective Comfort Index for commercial aircraft. This objective will be reached by means of the set-up of a "Virtual Passenger", defined on the basis of an Artificial Neural Network (ANN), aimed at simulating the transfer function between the external stimuli (physical variables) and the generic passenger response (subjective impression). Both acoustic and vibration data are planned to be taken into account.

Keywords : artificial neural network, ANN, cabin, comfort, noise, psycho-acoustics, vibration, virtual passenger.

1 INTRODUCTION

Air transport technology is very advanced in terms of performance, fuel consumption, velocity, noise emission etc.. Due to the increased use in highly industrialised areas within distances that are typical to the European Community, not only environmental impact has to be taken into account (as stated in the EC Green Paper "Future Noise Policy", [1]), but also Internal Comfort in general, and Vibration-Acoustic in particular, become important design parameters. Being already a standard approach in cars, the sound design for passenger aircraft is still lacking as regards general noise level reduction. On the other hand, it is increasingly reported that, apart of the desirable noise reduction from which noise emission as well as interior cabin noise benefits, subjective annoyance, disturbance and general comfort are important criteria for passengers, thus having a direct impact on acceptance and the market position of the European aircraft industry.

To assume that the passenger welfare inside the aircraft is a complex function of both noise and vibrations, separate from other surrounding characteristics, is almost trivial. Also, to imagine that the design objective is to improve the comfort and not to suppress the noise, seems obvious. Because comfort is a subjective matter, psychological studies play a fundamental role, [2]. The objective of IDEA PACI is to establish an aircraft passenger noise and vibration comfort index to relate subjective perception to mechanical and physical design properties. This will be accomplished by means of an Artificial Neural Network (ANN) meant to simulate a Virtual Passenger, i.e. the generic transfer function between external stimuli and human impressions. Though aimed at interior aircraft noise, the results will enable other transportation means to improve general features of comparable construction and developing processes, avoiding or substituting expensive experimental tests by the use of ANN.

The main steps of the research may be summarised as follows: before of all, a psycho-acoustic study is being carried out to identify suitable descriptors and to develop a tool that allows to translate the environmental solicitation in subjective impressions; then, experimental investigations both at ground and in flight, are being performed to produce a wide data-base for statistical investigations; on the bases of the first acquired results, the architecture of the ANN is being defined: it will be successively trained and assessed on the experimental data coming from the main test campaign, so defining the aforementioned "Virtual Passenger"; as the last step, ANN will finally predict comfort levels on both experimental and numerical (FEM) data: the physical parameters that mainly affect the passengers' welfare during the flight will be identified through proper simulations.

Being the project target, the identification of the relationship among the physical and the modelled environment and the human response, psycho-acoustic studies, numerical applications, experimental results and ANN definition are strictly interdependent. In the first year of the research, the attention was focused on psychological aspects and on technical definition of test arrangement and in particular: psycho-acoustic descriptors for interior noise were recognised; proper multidimensional input for the ANN were extracted from the preliminary experimental tests, up to now carried out, and the relative procedures were identified; a questionnaire oriented at defining comfort in aircraft cabins was preliminarily assessed; the test programs were defined. Some activities have also been spent in the approach to the problem of the index conversion by Artificial Neural Networks, principally targeted to define the most suitable architecture of the net.

These different arguments will be referred about in the body of the paper. The bases for the prosecution of the project in the next years were then established; the immediately next planned steps regards the performance of the main test campaign at the different industry plants, involved in the program (Agusta, Alenia and Dornier). The general output and the experience gained by these further activities will be also briefly reported, completing the first part of the research.

2 PSYCHO-ACOUSTIC PARAMETERS DEFINITION

In-flight passengers' subjective comfort is determined by a large variety of parameters. Since interior noise and vibrations are among the known main components, the investigation was concentrated on these peculiar aspects of well-being, namely the sound pressure levels and the accelerations, respectively. In particular, the most suitable psycho-acoustic descriptors, used in the subjective evaluations, were identified. Such a study will give the researchers a filtered background to focalise the attention on the "status of the art" on the matter, so defining a proper starting point.

After, a comprehensive questionnaire, precisely oriented to the passenger comfort inside aircraft cabins, was designed by the University of Oldenburg. Jet, propeller or helicopter aircraft were targeted; both vibration and noise disturbance are taken into account. Standard methods of evaluating test-subjects answers (factor analysis, paired comparison analysis, etc.) yield a set of psycho-acoustic parameters being identified as the most important descriptors contributing to a comfort index.

In order to have a sensibility about the test environments, the psycho-acoustic team (University of Oldenburg, ITAP and NLR) performed the so-called pre-tests, from which a guideline was defined for the identification of a proper questionnaire, starting from classical formulations. The differences among the used mock-up's, as well as the difference between the available test articles and the real aircraft could in fact affect the subjective impression, in a manner or another.

Moreover, in this first part of the project a qualitative analysis was performed to relate the psycho-acoustic descriptors to noise and vibration fields; in fact, psycho-acoustic parameters are easily correlated with acoustical and signal-related quantities like spectral parameters, signal envelope and other time-dependent features.

The characteristics of the exterior disturbance signals will be then related to the subjective impression, directly, in a qualitative way. The problem will be solved in two steps. Structural acoustics is concerned with the relationship between the exterior noise source and the produced interior noise field; in detail, its objective deals with the reduction of the sound (and vibration) field in enclosures. Psychological acoustics is instead concerned with the effects of the interior sound field on the human comfort feeling; its objective deals with the minimisation of the noise annoyance. Both the experiences will be combined, in order to better address the aircraft design "to noise".

3 EXPERIMENTAL TESTS

The ride quality refers to the interior environment of a transportation system like an aircraft in terms of the passenger response to the environment. The acoustic and vibration levels measured with conventional techniques may be considered as the main physical parameters; often, however, they are poorly correlated to the subjective perception of the passenger, that is in fact also related to other characteristics, like the distribution of amplitudes, the spectral composition and the temporal structure of the signal.

Acoustic and vibration measurements and the passengers response evaluation to the correspondent environment are being carried out, both in-flight, on a helicopter and at ground, on a helicopter cabin and two fixed-wing mock-up's. The results of this experimental campaign are expected to support the definition of a scalar comfort index as a function of aircraft vibration and interior noise fields.
During the first twelve months, the activities in this task have been focused to the organisation and preparation of both flight and mock-up tests. Pre-tests were performed in order to take confidence with the test facilities planned to be used in the main test campaign, in view of preparing the questionnaire to be used during the psycho-acoustic tests to report the passenger comfort perception. The test facilities were provided by Alenia, Agusta and Dornier, complete with interior furnishings and all the other necessary arrangements, including the noise and vibration excitation sources; flight tests data, recorded in previous campaign, have been collected, stored and selected for the experiments.

The pre-tests made possible to test "on the field" the proposed methodologies, in order to guarantee that the main experimental activity is very effective and productive. The performance of the pre- and the main tests are essentially devoted at determining the related physical and psycho-acoustical data. Here, for experimental psycho-acoustic data, the one are intended, coming from the evaluation of the questionnaire as submitted to the group of people under the defined excitation, in-flight or in the mock-up. In this way, two sets of records will result: a first, describing the physical environment, and a second, defining the related human response. The aim of the ANN to be developed, the "virtual passenger", is to find the relationship (or transfer function) between these two general parameters (scalar or vector). A data-base will be then built, on the basis of which the ANN will be trained and validated.

From a preliminary evaluation of the data, available at the end of the pre-test campaign, it came out that would have been difficult to have a sufficiently large experimental basis, so that all the possible configurations are covered and just an ANN is defined, for all the types of aircraft. In other words, the produced dataset is expected to contain a limited amount of physical psycho-acoustical correlated quantities, furthermore dealing with restricted variations of cabin environments (apart the noise-vibration signals, in fact, an essential remark stands on the fact that the mock-up's number is fixed to three).

According on these considerations, three different ANN's will be developed, dealing respectively with jet, propeller and helicopter aircraft. A unique ANN is still planned, trying to consider all the different kind of structures under investigations, also if limited to a performance verification, as a further approach.

4 EXPERIMENTAL ACTIVITIES

The experimental activities play a fundamental role in the project, being the starting point on which to develop and validate the related numerical models. A task of IDEA PACI is completely devoted to this objective; inside this package the mock-up's at Agusta (A109), Alenia (ATR42), Dornier (Do328 ATC) and ITAP (SVRS) are used, together with a real A109 vehicle, for a limited set of in-flight recordings. Due to the unavoidable constraints, the researchers' attention has been focused towards the major types of excitations, as cruise.

For the data being coherent, it is necessary that different individuals are subjected to the same noise and vibration field, with respect to fixed tolerance levels. This means that only few seats among the available in the test article could be referred to in a same excitation process, as belonging to a unique set of "homogeneous" places. Nevertheless, different sets may be found, so that one experiment produces the maximum amount of results. The paragraph is divided into two main parts, concerning the description of some test articles (the ones were the authors have been personally involved in the execution of the tests) and the definition of the related test procedure.

PRE-TESTS REQUIREMENTS

Pre-tests by a mobile expert group have been conducted for the exploration of the facilities for measurement. The main objective concerning this phase, was to get first impressions about noise and vibration and their synergism during realistic flights, in the available mock-up's and real aircraft, and in laboratory. University of Oldenburg developed a preliminary questionnaire, or pre-test guide. The data output by these procedures were the base for the development of research methods (especially the questionnaire) then applied for the assessment of subjective comfort data in the main test phase. Pre-test results have in fact to be used for all decisions on main test requirements and conditions, as well as the choice of the opportune psychological methods. The pre-tests considered an expert (fixed) group consisting of five to six people, involved in the project.

Due to the statistical basis of the subjective data analysis to be performed, a minimum number of 20 people is requested for each test condition. A better number of subjects for the main tests at the mock-ups of Agusta, Alenia and Dornier, was selected to be 30. In the same way, for the real helicopter flight situation 30 passengers should be involved in the experiments. As a consequence of the preliminary test campaign, the definition of the proper procedures at the different mock-up's and real aircraft, were issued. Following, the ones are reported, relative to the articles where the authors of the present paper have been personally involved.

TEST REQUIREMENTS AT ATR42 MOCK-UP

The main tests campaign on the ATR42 mock-up is planned to be held for a period of approximately ten days. Six tests should have performed in a day, for a total amount of sixty tests. About a month before that the tests campaign starts, some further pre-tests will be performed to assess the questionnaire for the evaluation of the comfort index as issued by the psycho-acoustic team: in fact, they may be affected by the environmental conditions.

The ATR42 fuselage section N.13 will be used as test article during the experimental campaign, following illustrated. It is made of 6 bays and is 3.5 metres long. It is elastically suspended at its extremities, by means of steel springs. Two caps close the cylinder. The fore one is movable, and through that side the internal access is permitted, through a small staircase. The fuselage section is completely furnished, in the same way as the corresponding flying aircraft.

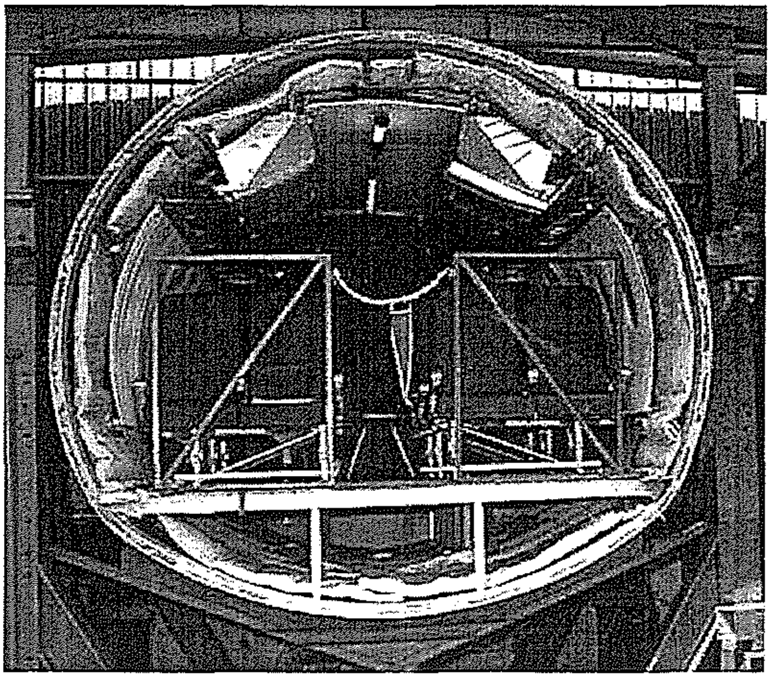

Figure 1, Inside view of the furnished ATR42 mock-up

The ATR42 mock-up is prepared with both external and internal instrumentation, in order to get the data concerning the outside and inside excitation, and the interior vibration-acoustic field. The tests will be performed at the plants of Alenia in Pomigliano D'Arco, where the mock-up is placed. Fig.1 shows an outside view of the cabin section. In Fig.2 a complete external and internal view of the mock-up is shown, together with all the used instrumentation.

Noise and vibration field will be acquired in correspondence of the 12 seats, installed inside the mock-up; in particular for each place, a microphone is placed at the passenger head height and a three-axial accelerometer is positioned at his feet. Globally, 48 acquisition channels should be available, apart of those aimed at monitoring the excitation signals to be transmitted to the shakers and the loudspeakers.

The psycho-acoustic tests are imagined to be carried out by simulating, for the different aircraft types (propeller, jet), real conditions of flight. The number of these simulations depends on the minimum number of seats that are exposed to a similar vibration-acoustic field. In this test campaign, sixty flight conditions are expected to be considered, this number corresponding to an optimistic forecast of the internal annoyance fields, based on pre-existing acquisitions.

The internal vibration-acoustic field is not homogeneous at each seat as it was evidenced during a great amount of experimental experiences, [3]; furthermore, the subjective impressions of at least 30 people exposed to the "same" internal field are necessary to extract a statistically relevant comfort index. These constraints make indispensable to have a map of the internal field (for each flight condition) on the basis of which homogeneous seats should be specified. A series of experiments was consequently planned to define these "families", according to a well-established tolerance criterion. The exact definition of the "families" allowed to determine:

- the minimum tests number, necessary to extract a properly evaluated comfort index;
- the global number of comfort indexes, expected from the whole test campaign.

Specific tests were then arranged, in order to get this information, in the completely occupied configuration (in this case, the involved people had the function of "sound field disturbers"). The same instrumentation was used, as in the main campaign.

Coming to the main tests performance, each was scheduled in 5 main parts:

1. A boarding phase, during which the involved people would have been boarded in the mock-up and each passenger would have been provided with a copy of the questionnaire and the related explanations and recommendations;
2. An excitation phase, when the mock-up would have been acoustically and vibrationally excited, through the selected actuators (loudspeakers and shakers).
3. An acquisition phase, dealing with the recording of the structural-acoustic responses (pressure and acceleration), at each seat.
4. The questionnaire is drawing up, once the excitation is stopped
5. The landing, when the passengers leave the mock-up.

In each test different excitation types were planned, so that the points 2-3-4 will be repeated. The global time was forecast about 60 minutes long.

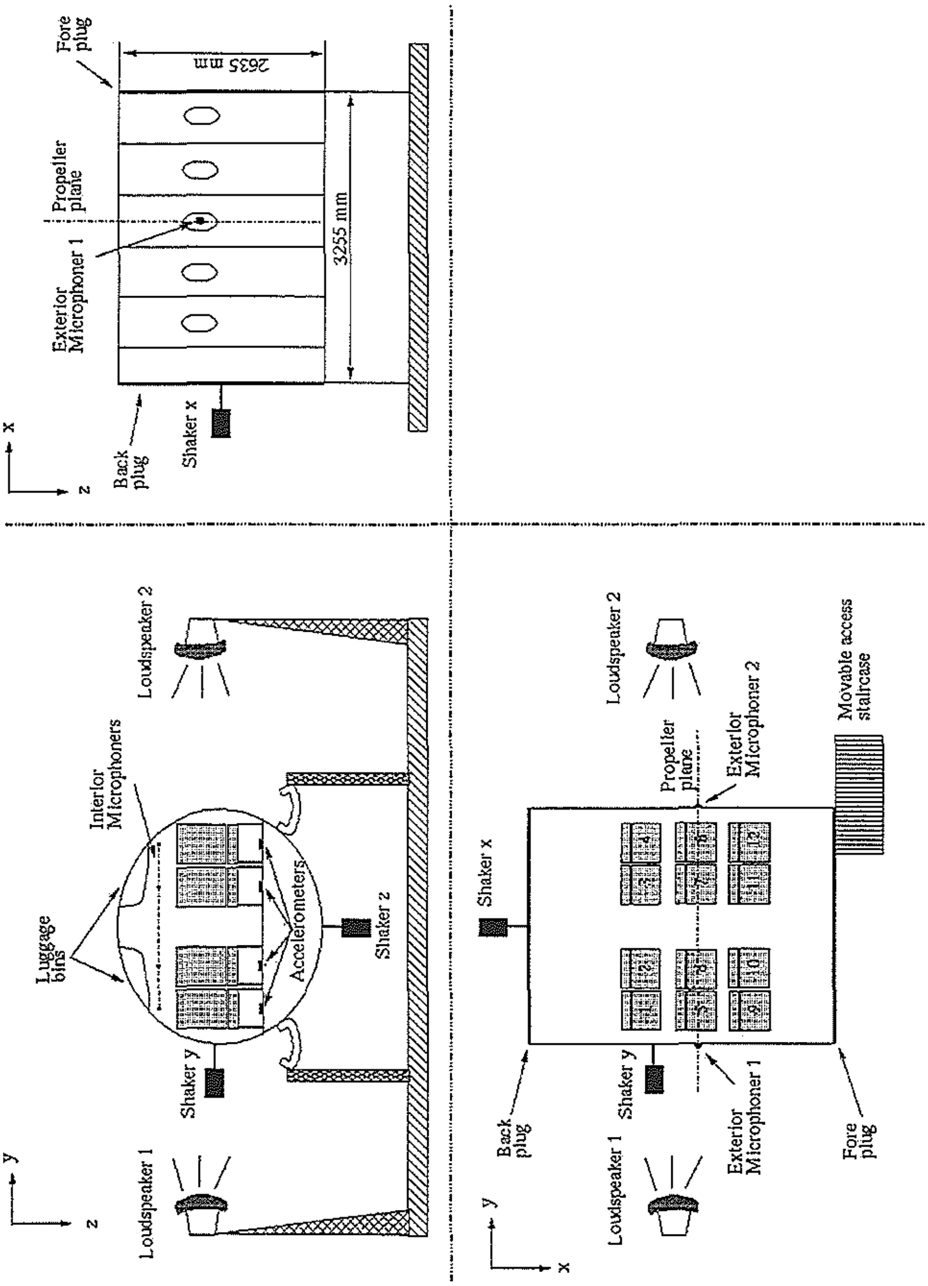

Figure 2 - Scheme of ATR42 mock-up with relative instrumentation.

The acquisitions will be done in time and changed in frequency domain in a linear band. The considered frequency ranges are: 10Hz - 15KHz for pressure; 2Hz - 200Hz for acceleration.

FLIGHT TEST REQUIREMENTS FOR AGUSTA A109

The A109 flight test campaign foresees about 4÷5 flight hours. Considering half an hour the time for each test, the total number of tests will be 8÷10. For each test 5 passengers will be boarded so as to obtain a final data base of 40÷50 persons. The figure could be extended to 60÷75 if the flight time is reduced to 20 minutes.

The A109 (Fig. 3) is a twin engine aircraft able to accommodate, in addition to the pilot and co-pilot, 5÷ 6 passengers depending on the interior kit (VIP or Executive respectively), for a maximum take-off weight of 2720 kg. The cabin dimensions are those of a small size helicopter about 1.44 m width. The maximum cruise speed is about 150 knots and with a long range cruise speed it achieves a maximum range of 778 km.

Figure 3 - Agusta 109

During the flight tests the instrumentation of the Acoustics and Vibration Laboratory consisting of accelerometers, microphones and tape recorder will be used. The accelerations in the 3 axis together with the noise level inside the cabin will be measured during the tests; for practical reasons the microphones will be fixed. During the flight tests, if required, the University of Oldemburg (ITAP) will use proper instrumentation for binaural measurement evaluation.

TEST REQUIREMENT ON A109 MOCK-UP

The measurement test campaign on the A109 mock-up is foreseen to last about one week. Considering an average of 1 hour per test, it is expected to perform about 4 tests per day for a total number of 20 tests. The mock-up used for the tests is a real helicopter cabin of the Agusta 109 model adapted with a standard interior kit. The mock-up is limited to the part shown in Fig.6, which do not include the tail boom, the rotors, the engines and the gearbox fairing. A dummy gearbox will be installed to obtain a better simulation.

The typical interior of the mock-up cabin is shown in Fig. 4, too. The tests will be performed using the Acoustics and Vibration Laboratory instrumentation described in the following. Oleo-dynamic shakers are used as vibration exciters, because at very low frequencies and high forces, they yield lower noise than the electro-dynamic ones. For the acoustic excitation of the mock-up, 3 couples of loudspeakers will be used. In order to verify if the acoustic and vibration environment inside the mock-up cabin is representative of the real flight, some accelerometers in the cabin floor and microphones at the seat will be installed. Before the beginning of each test, the sound and vibration field will be verified in order to expose the passengers to the same conditions. The CIRA mobile laboratory will support this activity during the entire test period.

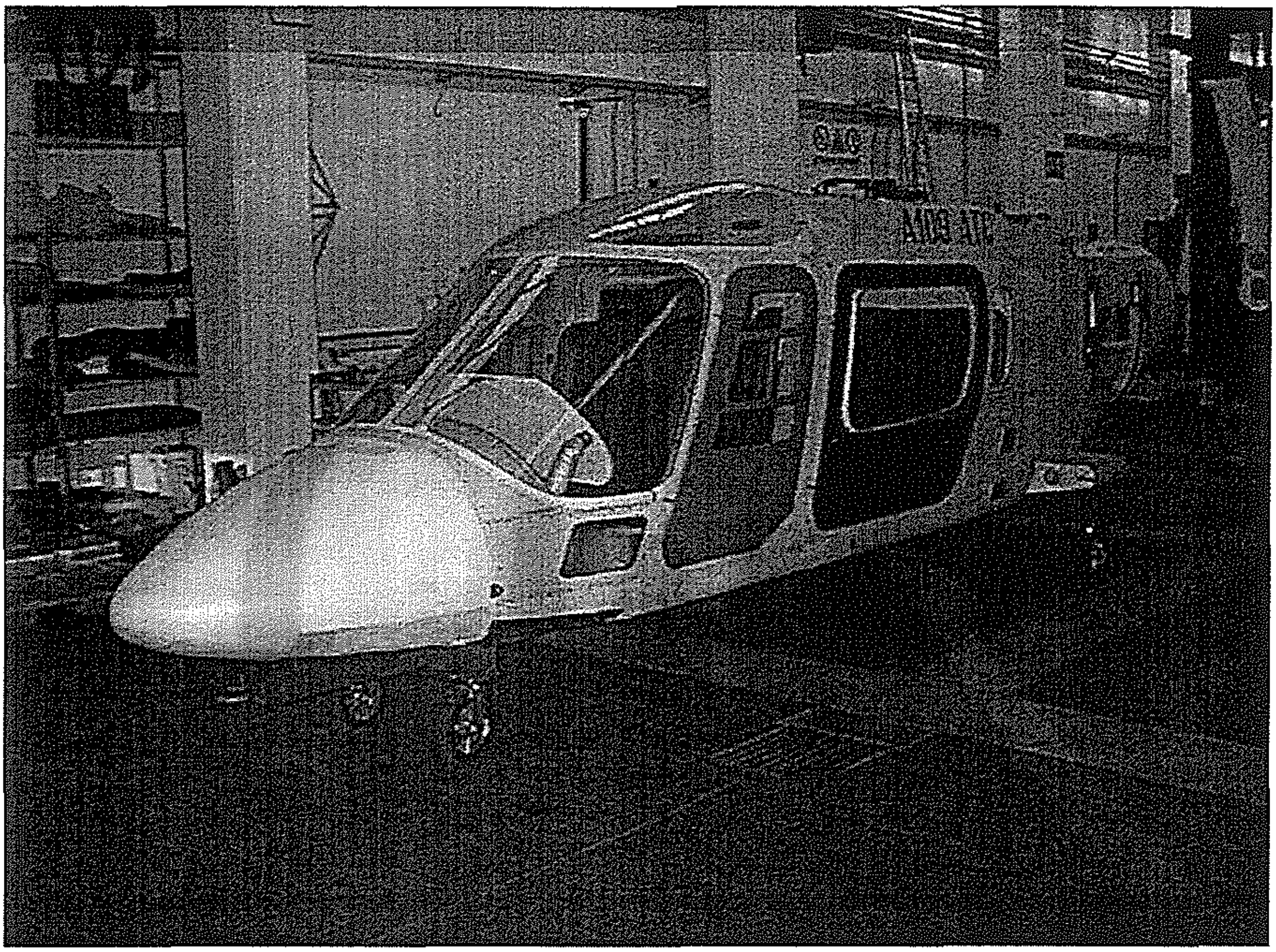

Figure 4 - A109 Airframe Reference Lines

For the psycho-acoustic tests, to simulate a certain number of real flight conditions, is required. The vibro-acoustic field inside the mock-up will be obtained using the available signals recorded in flight. The loudspeakers will simulate the acoustic field while the shakers the vibration environment. The signals used to simulate the noise and vibration environment in flight condition will be recorded during the real flight tests and will be then reproduced using tape recorders, amplifiers, loudspeakers for the acoustic excitation and shakers for the vibration excitation.

Each seat position in an aircraft cabin has a different acoustic and vibration field, depending on the aircraft type and cabin dimensions. In the A109 cabin, the variation of noise level inside the passenger cabin is about 2 dB A, mainly due to the higher tip speed on the advancing side and lower tip speed in the retreating side. The variation of the vibration environment inside the cabin is about 1.2 m/s^2 along the vertical axis, the most critical for the human body. These considerations lead to assume that all the seats are under the same internal field within the prescribed tolerances.

All the noise and vibration sources in a helicopter are located overhead the cabin. Therefore the shakers and loudspeakers will be installed overhead, where the main gearbox and rotor are located. The number of the excitation direction will depend on the results of the pre-tests. The test procedure is the same described in the previous paragraph.

5 VIRTUAL PASSENGER

For the completeness of the survey, the main points are illustrated, concerning the expected development of the ANN-based "Virtual Passenger". The main objective of this activity is to develop an Artificial Neural Network (ANN), [5], for the prediction of an internal aircraft comfort index. The development of the ANN will be articulated according to the following steps:

- assembly of the available experimental data-base's, taking advantage of the main tests results;
- definition of the ANN Architecture, where its structural parameters (number of layers, number of neurones per layer, activation function, etc.) as well as its training algorithm, will be selected;
- training of the ANN, by using the experimental data-base, assembled at the previous step
- assessment of the trained ANN (Virtual Passenger), through a validation set extracted by the assembled data-base.

In order to identify which parameters mostly affect the passenger comfort, an optimisation approach based on Genetic Algorithms, is planned to be applied. The experience of different partners in the development and the implementation of Artificial Neural Networks, as well as Genetic Algorithms, will provide the partnership a solid starting point.

- The working group came to the decision of elaborating three different net architectures, each dealing with different sets of input-output parameters:
- a first, made of two components: one, trying to relate the physical variables, referring to acoustics only, with the psycho-acoustical parameters; in a sense, this kind of net tries to reproduce what is just available on the market in terms of numerical codes, able to identify selected psycho-acoustic parameters from information on the noise spectrum; the reason to deal with this particular net lies on the consideration that through this approach, the ANN developers will have a possibility to associate a standard sound description with something similar to what is expected to be a comfort index, so acquiring some practical confidence with the problem under investigation; once the problem is satisfactorily approached, another net will be developed, according to scheme elaborated by the University of Patras, trying to relate the psycho-acoustical parameters defined in task 1, with the comfort index found from the experimental activity. In this case, the vibration field is not taken into account.
- a second architecture has been then selected, considering both physical sound and vibration information as input data (standard description, i.e. acoustic pressure and acceleration), together with the related psycho-acoustic parameters, calculated off-line by independent software. The output consists once more of the comfort index, identified by the experimental campaign, previously carried out. The overall aims of this activity is to realise a base on which trying to evaluate the real importance of each "classic" psycho-acoustic parameter with respect to the synthetic people comfort feeling, as characterised by the scalar comfort index.
- a third architecture will conclude the investigation and will try to relate directly the physical variables, characterising the cabin environment, in terms of vibration and acoustic field, under a determined excitation, with the human response.

It should be remarked that, by a proper comparison of the two last nets, general information about the capabilities of the different standard psycho-acoustic parameters, identified in task 1 in translating human perception, is expected.

6 ACKNOWLEDGEMENTS

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7 CONCLUSIONS

The objective of the project IDEA PACI is to define a general comfort index for aircraft, starting from the external environmental characteristics. In this paper, a survey on the main activities, carried out during the first year of the project, are recalled.

First of all, psycho-acoustic parameters that better can define the subjective human response are selected and defined.

After, a general description of the meaning and the aims of the planned experimental campaign, addressed at the identification of a suitable basis of comfort indexes, is given.

The consortium decided to perform a pre-test activity on the selected mock-up's, in order to get confidence with the test article and identifying proper investigation procedures.

Following, the final arrangement for the main tests have been drawn; in particular, in this paper the configuration of Alenia and Agusta facilities.

In the end, the main ideas about the development of the Virtual Passenger, an ANN-based numerical code, are summarised.

This numerical investigation will be the core of the third year of the project, taking advantage of the results that will be extracted by the experimental activities aforementioned and planned in the second year.

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