MOCK-UP OF A LOADMASTER AREA FOR ACOUSTIC GROUND TESTS

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OVERVIEW

An active noise reduction (ANR) system will be implemented in the loadmaster area (LMA) of a military transport aircraft. This system attenuates unwanted primary noise, produced by the turboprop engines, with generated secondary noise. The ANR – system shall be investigated with acoustic ground tests. Therefore, a mock-up of the load master area, which is located in the military transport aircraft, based on the latest construction design data was built. This test bed represents the acoustic behaviour of the semi closed volume coupled to a larger cavity like a cargo compartment. An adaptive algorithm was implemented in order to synthesize the primary noise distribution in a simplified mock up of the LMA. External loudspeakers were used as sources for the primary sound pressure at discrete locations in the load master area, which is known from vibro-acoustic Finite Element (FE) calculations and aeroacoustic measurements. The control algorithm reproduces the sound field with amplitude and phase at the chosen locations by calculating appropriate drive signals for the external primary sound sources. The design of the mock-up and the method for synthesizing the primary sound field will be presented in this paper.

1. INTRODUCTION

Propeller driven aircraft are widely used for military purpose due to the high payload and manoeuvring potential. A new military transport aircraft driven by advanced turboprop propulsion systems will be manufactured by Airbus [1]. The propeller blades produce disturbances when passing the fuselage in a certain blade pass frequency (BPF). This excitation induces high tonal noise levels in the low frequency range at the BPF and its higher harmonics in the aircraft interior, see FIG. 1. The sound pressure level in the cargo compartment may be above 100 dB(A) without special treatments. The payload inside the cargo compartment is monitored and controlled by the loadmaster.

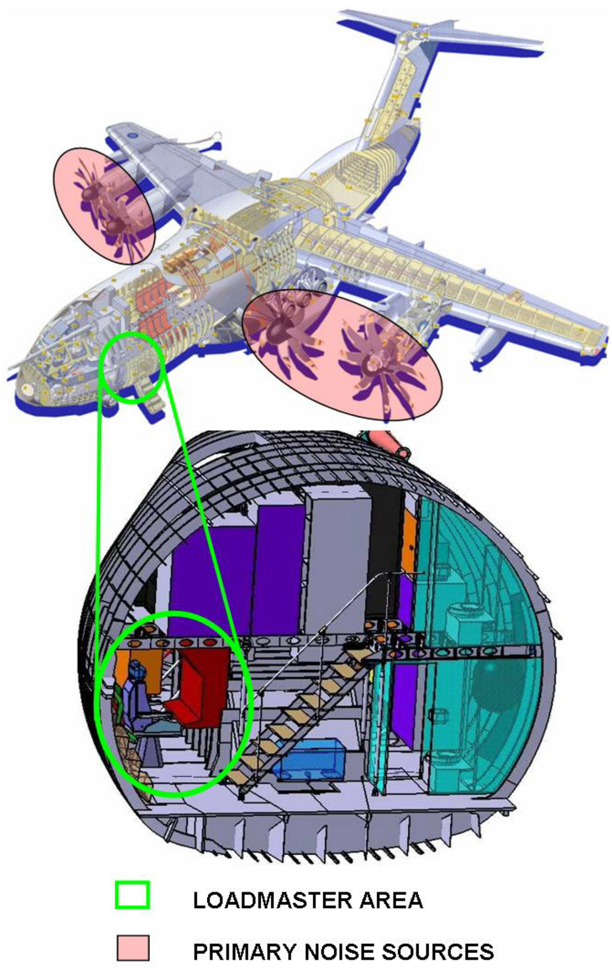

FIG 1. Military transport aircraft with location of LMA [1]

Noise reduction inside the semi closed loadmaster area is required because of given work safety regulations and comfort. In order to reduce the noise level inside the fuselage of aircraft different systems and strategies have been applied. In recent years research has been focused on active noise reduction for the use in the low frequency range (<500Hz) due to mass reduction as a major aspect in aircraft design [2]. An ANR – system consists of loudspeakers and microphones, connected to a controller which calculates loudspeaker drive signals for minimizing the disturbing sound pressure (primary noise) at the sensors using destructive interference [3], refer to FIG 2.

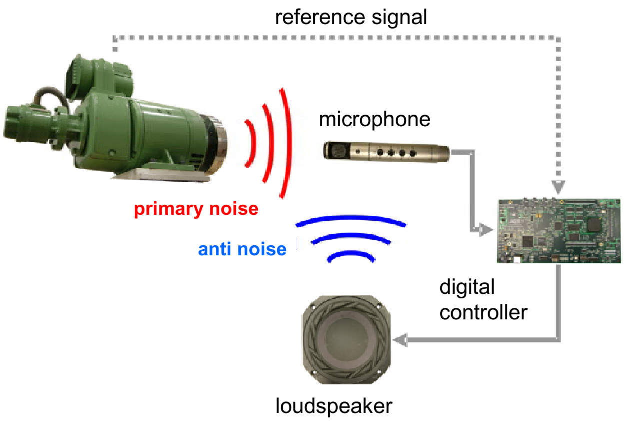

FIG 2. Outline of an ANR - system

The level of attenuation obtained by an ANR – system depends on several attributes of the system like hardware and software in use as well as loudspeaker and sensor locations [4]. In order to determine the performance capability of such a system a realistic test bed is required. Then ground tests can be conducted for optimizing the ANR – system before flying and money as well as time can be saved.

2. CONSTRUCTION AND DESIGN OF LMA MOCK-UP

To simulate the room acoustics of the loadmaster area, an accurate model of the semi closed cavity is required. Therefore, original construction data was extracted from a digital mock up. In the next phase, the necessary parts, which define the cavity of the LMA, were redesigned to eliminate negligible details of the original set of data, see FIG 3. In order to adapt the design to available material sizes for manufacturing further simplifications were required. FIG 4 shows the wooden mock-up.

2.1. Experimental environment

The cavity of the LMA is not the only point which has to be considered for acoustic ground tests. As stated before, the LMA is a semi closed volume which is coupled to a larger cavity. Therefore, the geometry of the surrounding laboratory plays an important role. In reality the LMA is connected to the cargo compartment. It has an overall length of approximately 32 m. A fraction of 18 m is designed like a cylindrical enclosure with floor. The aft portion of the cargo is cone-shaped. Another aspect is the integration of acoustical lining which has an effect on the room acoustics of the loadmaster area as well as an appropriate loadmaster dummy.

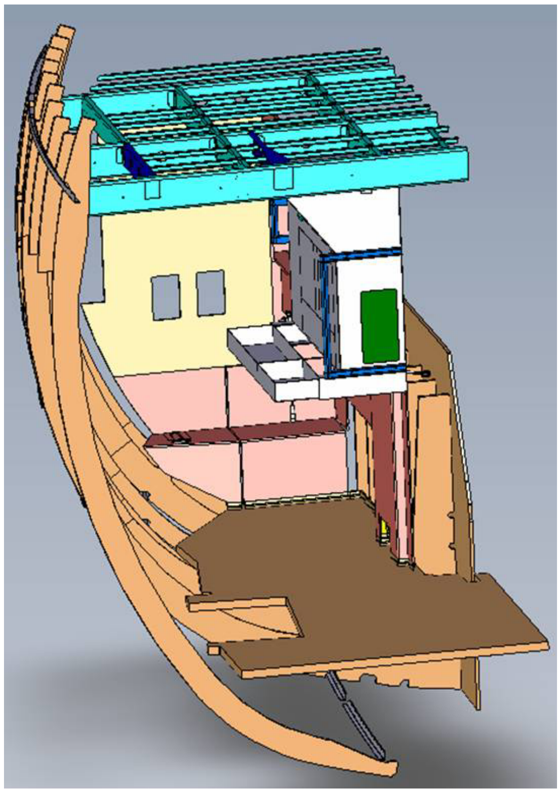

FIG 3. Drawing of partly redesigned original structure

FIG 4. Wooden LMA mock-up at HSU-HH

2.1.1. Laboratory at HSU-HH

A laboratory at the Helmut-Schmidt-University / University of the Federal Armed Forces Hamburg (HSU-HH) was chosen to simulate the cargo. This room has almost the same dimensions as the cylindrical portion of the cargo compartment of the military transport aircraft, refer to FIG 5. But it must be kept in mind that even with comparable volumes the eigenmodes and eigenfrequencies of these two cavities differ from each other due to different geometries.

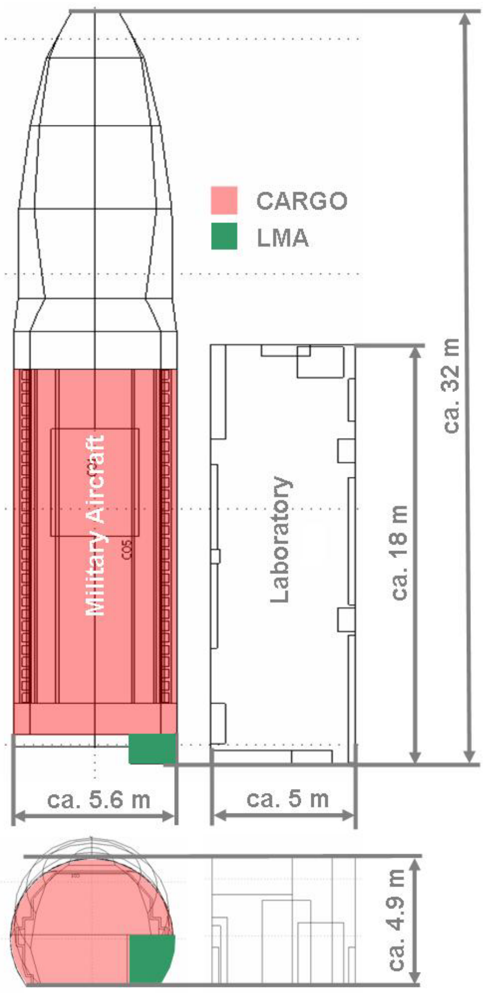

FIG 5. Comparison of dimensions of aircraft cavity and laboratory at HSU-HH

The side walls and floor of the laboratory can be assumed to be sound hard in contrast to the ceiling where sound absorbing material has been installed. The resulting reverberation time was measured with an average of around 0.5 s over the frequency range of interest (80-500 Hz).

2.1.2. Loadmaster Dummy

The reference of the system performance is the achieved sound pressure level attenuation at the loadmaster ears. The controller reduces the sound pressure at the distributed error microphones but it can not be ensured that the sound pressure level at the loadmasters head will be attenuated as well. For this reason, a dummy of the loadmaster was built. Therewith the performance of the ANR – system can be determined in presence of a head and a torso which will influence the acoustic field near the head. Furthermore, it can be measured if the ANR – system meets the require performance criteria in terms of sound level attenuation at the loadmasters head. An artificial head of HEAD Acoustics© was chosen as the upper part of the dummy. The sound pressure can be measured with integrated ear microphones. The wooden torso box was covered with felt in order to simulate the absorbing acoustic properties of a human body, refer to FIG 6.

FIG 6. Dummy of loadmaster torso and head

3. SYNTHESIS OF PRIMARY SOUND FIELD

One key point of setting up a test bed for acoustic ground tests is the environment which has already been described. Another important factor is the synthesis of the primary field. Several methods can be applied for this purpose. For example, the spectral colouring, in terms of sound pressure level, of the BPF and its higher harmonics, which are considered during control, can be adjusted at the ears of the loadmaster with external primary noise sources [5]. At least it can be ensured that a comparable sound pressure level exists at the loadmaster's head. Nevertheless, the phase and amplitude information of the spatial sound field which is generated in order to simulate a primary noise distribution can be totally different compared to the noise distribution in a flying airplane. Therefore, a new approach has been applied.

3.1. Methodology

The chosen method is based on the synthesis of sound pressure with amplitude and phase at discrete distributed points in a given volume [6], refer to FIG 7. The sound pressure at the chosen locations will be given, based on Finite Element (FE) simulations or in flight measurements [1]. Multiple microphones have to be placed at the discrete points, for example at loadmaster ears. Then an adaptive digital controller will drive external primary loudspeaker so that the sound pressure at the microphones will match the given pressure values derived from previous measurements or FE simulations. The controller is based on the multi channel filtered x least mean square algorithm (FxLMS) [7], refer to FIG 7. A reference signal x will be filtered with a model **S'** of the secondary paths **S** (DA – converter, filter, amplifier, loudspeaker, acoustic transfer to microphones, amplifier, filter, AD –converter) and then fed into a least mean square algorithm together with the error signals **e**, which are the differences between the measured sound pressure at the microphones $\mathbf{p_S}$ and the given pressure $\mathbf{p_P}$. The algorithm calculates the filter coefficients of a finite impulse response filter (FIR) so that the mean squared error is minimized. The drive signals **q** are calculated by filtering the reference signal x with the FIR filter.

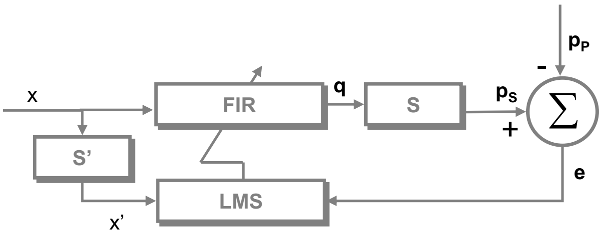

FIG 7. FxLMS algorithm for primary field synthesis

3.2. Experiment

In order to verify the performance of this method a simple test bed was implemented, which was oriented on the subsequent task of synthesizing a primary noise field inside the LMA.

3.2.1. Test Bed

A semi closed square form cavity with approximately the same volume as the LMA and sound hard side walls was placed into the laboratory [6], see FIG 8. Two loudspeakers were acting as primary sources. One was placed outside the volume and the other inside. Four microphones were located in a reference plane inside the cavity. All transducers were connected to a digital controller where the previous described FxLMS – algorithm was implemented. First, the primary sources were actuated with different drive signals and the resulting pressure and the microphones were measured. In the next step the pressure data at the four discrete positions were fed into the digital controller as $\mathbf{p}_P$. With optimal control the loudspeaker drive signals should be the same as applied during the first measurement. This experiment shall show the accuracy. This method was applied to tune a given pressure at multiple locations in terms of amplitude and phase with an optimal set up, where the position and kind of the assumed and real primary sources are exactly the same.

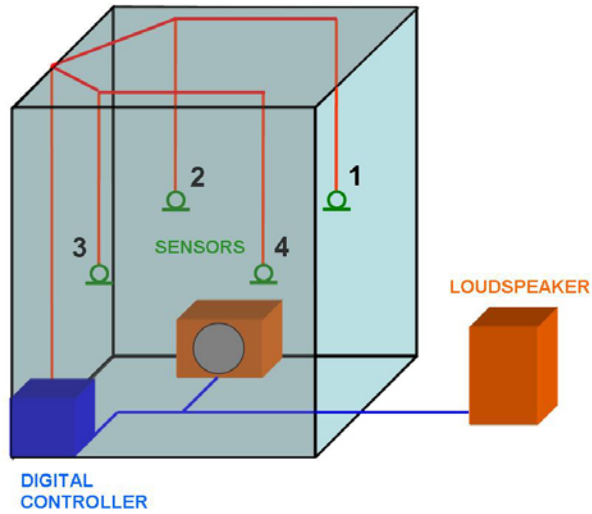

FIG 8. Outline of test bed for primary field synthesis

3.2.2. Results

The resulting sound pressure levels after applied control were compared with the given pressure values. The relative amplitude errors e_i at the i-th micorophone in percentage between the amplitudes of the pressures at the four microphones are shown in FIG 9 for five different frequencies (100 Hz, 200 Hz, 300 Hz, 400 Hz, 500 Hz).

$$(1) \quad e_i = \frac{|p_{Pi}| - |p_{Si}|}{p_{Pi}} 100\%, \quad i = 1..4.$$

The maximum error in terms of amplitude difference is less than 10 %. This means a difference below 1 dB in the logarithmic scale. It can be seen that the amplitude error is alternating with frequency and spatial position of the examined microphones.

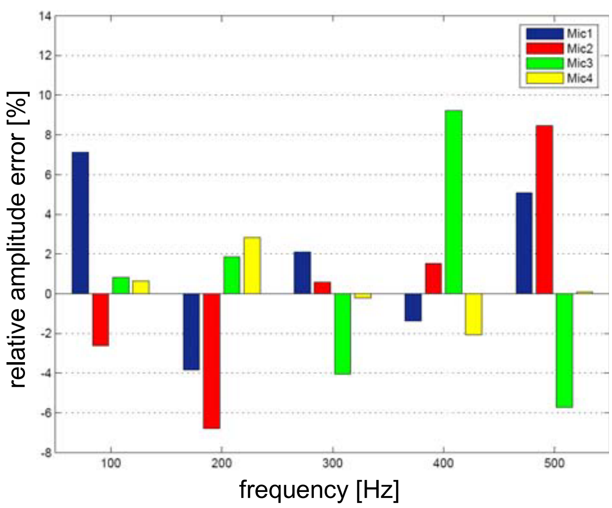

FIG 9. Relative amplitude error in percentage for different frequencies

The phase of the sound pressure was obtained in reference to microphone 1. The maximum phase error between the given pressure and the pressure after applied control is around 4°. The phase error is depending on frequency and position. The results show that the algorithm is able to adjust a given pressure at spatial distributed points. Nevertheless, the performance of the primary sound field synthesis strongly depends on the given pressure data, which is derived from measurements and calculations, as well as the physical ability of the used primary sources to generate such pressures in connection with the room acoustics of the surrounding test environment.

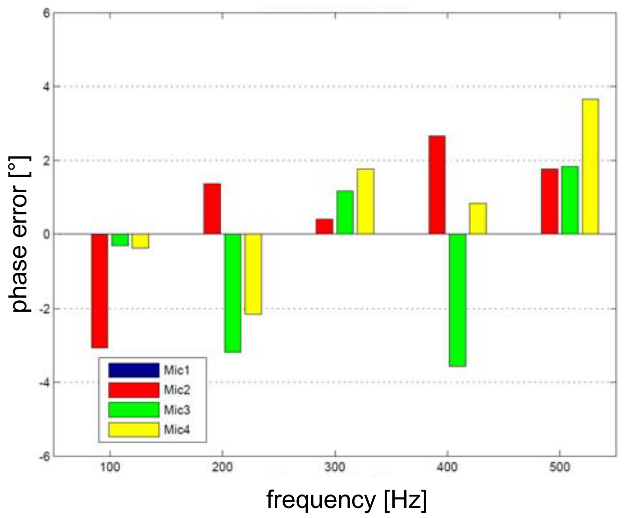

FIG 10. Phase error in degree for different frequencies

4. CONCLUSION

The test bed and primary noise generation of acoustic ground tests for an ANR – system in a loadmaster area of a military transport aircraft has been discussed. The mock-up was built according to newest design data. An experimental environment was chosen with almost the same volume and dimensions like the cargo compartment of the specified aircraft. A loadmaster dummy was designed in order to simulate a seating person and to measure the performance of the ANR – system. A method for the synthesis of a primary sound field was introduced. The algorithm is able to generate specified sound pressure at spatial distributed points. The given sound pressure was determined during previous measurements with the same test arrangement. Of course the use of this test bed can not replace in flight measurements, nevertheless the placement of the sensors and actuators and the function of the hardware can be checked as well as the physical behaviour of ANR applied to a semi closed volume, which is coupled to a larger one.

The prospective tasks are the implementation of the designed ANR – system, provided by an external supplier, into the mock-up and the realisation of the acoustic ground tests.

5. REFERENCES

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