Analysis phase: Requirement matrix and support documentation

Concerto Project

Cabin nOise reductioN ground Checked by nEw loudspeakeR exciTatiOn

GA # 886836

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Project Abstract

The current race for green mobility is changing the design philosophy in all engineering disciplines; this is tangible especially in aeronautical segment, where optimization and innovation are the key for a sustainable future mobility. In addition, the comfort of passengers is a critical issue for both, manufacturer and airlines, and the noise levels in the passenger cabin of turbopropeller-driven aircraft are typically higher than the levels in comparable turbofan-powered aircraft [1]-[2].

The noise generated during cruise phase is dominated by frequencies originated from boundary layer flow, whereas during the others flight phases noise is dominated by the propellers and engine rate; currently noise reduction development is based on experimental tests that, in the most cases, are very time consuming.

The **CONCERTO** project aims to develop an innovative cabin/fuselage noise testing equipment for regional aircraft platforms that will be user-friendly and fully configurable in all its parts to speed-up test procedures in several configurations and improve results accuracy. Scope of this research project will be the design, development, manufacturing and integration of an innovative Noise Generation System (iNGS) to test and validate new technologies for Regional Cabin Interior Noise evaluation. The innovative system, implementing advanced algorithms able to generate and control the real noise spectrum distributions and levels for all the flight conditions, will pave the way to a new scenario for cabin noise testing.

Main expected project outcome is to deliver a ready to use smart testing system that would be:

- Innovative: it will be adopted a closed control loop to obtain high speed performance with a control strategy and a pre-test analysis to reduce the number of control microphones, time and costs in the test set-up.
- Modular: its mechanical structure and software will be designed to accept fuselage of different diameters (from 2.5 m to 4 m) and customizable speakers/microphones configurations.
- Advanced: a dedicated software implementation will be developed in order to allow an easy and user-friendly interface.

Executive Summary

This document analyses, in a first part, the state of the art of Noise Generation System (NGS), the characteristics, strengths and limitations of existing systems as the actual system available at Leonardo premises in Pomigliano d'Arco and the Airbus NGS located in the Centre for Applied Aviation Research (ZAL). Then, the second part defines the hardware and software necessary to realize the noise generation system, defining which and how many components to use.

Applicable Documents

[AD1] H2020-CS2-CFP10-2019-01

[AD2] Proposal number: 886836

[AD3] Concerto proposal granted part B

References

[1] J. S. Mixson and C. A. Powell, " Review of Recent Research on Interior Noise of Propeller Aircraft," AIAA/NASA 9th Aeroacoustics Conference, AIAA Paper 84-2349, Williamsburg, VA., October 1984

[2] J. F. Wilby, "Aircraft Interior Noise", Journal of Sound and Vibration, 1996

[3] A. von Flotow, M. Mercadal, `"The Measurement of Noise and Vibration Transmitted into Aircraft Cabins," Sound and Vibration, pp. 16-19, October 1995

[4] S. J. Elliott, P. A. Nelson, I. M. Stothers, C. C. Boucher, ``In-flight experiments on the active control of propeller-induced cabin noise,'' Journal of Sound and Vibration, vol. 140, no. 2, pp. 21-238, 1990

[5] S. Fidell, K. Pearsons, L. Silvati, and M. Sneddon, "Relationship between low-frequency aircraft noise and annoyance due to rattle and vibration", The Journal of the Acoustical Society of America 111, 1743 (2002)

[6] S. R. More, "Aircraft Noise Characteristics and Metrics," Purdue University PhD Thesis, Cambridge, 2011.

[7] S. Johansson, "Active Control of Propeller-Induced Noise in Aircraft," Blekinge Institute of Technology PhD Thesis, Ronneby, 2000.

[8] W. S. a. G. Kni, "Technology and Benefits of Aircraft Counter Rotation Propellers," Anaheim, 1982.

[9] D. Zimcik, "Active Control of Aircraft Cabin Noise," Prague, 2004.

[10] "Eurekamagazine," 23 September 2016. [Online]. Available: https://www.eurekamagazine.co.uk/design-engineering-news/airbus-opens-acoustic-lab-to-study-noise-reduction/146058/.

[11] M. A. Simpson, M. R. Cannon, P. L. Burge and R. P. Boyd, "Interior Noise Control Ground Test Studies for Advanced Turboprop Aircraft Applications," Hampton, Virginia, 1989.

[12] "Technical manual and specifications 2225H/J".

[13] G. G. Fleming, "Aircraft Noise Measurement Instrumentation & Techniques," Cambridge, 1996.

[14] M. Misol, "Experiments On Noise Reduction In Aircraft With Active Sidewall Panels," Braunschweig, Germany, 2018.

[15] S. Khardi "An experimental analysis of frequency emission and noise diagnosis of commercial aircraft on approach", JAE paper 26-290.

Table of Contents

List of figures

List of tables

List of abbreviations

ACRONYM / SHORT NAME	MEANING
ADC	Analog-to-Digital Converter
ANSI	American National Standards Institute
ASAC	Active Structural Acoustic Control
BPF	Blade Passage Frequency
CAN-bus	Controller Area Network bus
CONCERTO	Cabin nOise reductioN ground Checked by nEw loudspeakeR exciTatiOn
CROR	Counter-Rotating Open Rotor
CSD	Cross Spectral Density
DAC	Digital (to) Analog Converter
GLR	Graphic Level Recorder
IEC	International Electrotechnical Commission
iNGS	innovative Noise Generation System
LT	Lead Tech
MIMO	Multi-Input Multi-Output
NGS	Noise Generation System
PSD	Power Spectral Density
SDM	Spectral Density Matrix
SIL	Speech Interference Level
SPL	Sound Pressure Level
ZAL	Centre for Applied Aviation Research

Introduction

This deliverable aims to present the state of the art of Noise Generation System (NGS), analyzing the characteristics, strengths and limitations of existing systems and to define the hardware and software necessary for the development of an innovative Noise Generation System (iNGS).

1. State of the Art of Noise Generation System

The Cabin noise in turbo-propeller driven aircraft can cause crew and passenger discomfort.

One major source for aircraft interior noise is the propulsion system [3]. In particular, for propeller aircraft the cabin noise is dominated by harmonic low frequency noise produced by the propellers. The most disturbing noise is typically the first three or four harmonics of the Blade Passage Frequency (BPF). The noise is transmitted through several paths into the cabin, see Figure 1. Vibrations from the engines are transmitted through the engine mounts into the wing structure, which in turn excites the whole aircraft body; turbulence from the propellers excites the rear wing which in turn causes vibrations in the rear part of the aircraft. Another important path is through the fuselage in the plane of the propellers; the propeller blades cause very high-pressure fluctuations at the outside of the fuselage which are transmitted into the passenger cabin. The importance of the different transmission paths varies with frequency. At the BPF, the sound field is usually excited throughout the whole cabin, while the harmonics tend to be excited primarily in the plane of the propellers [4]. In multi engined airplanes, pressure cancellation and augmentation due to phase effects can result in quite rapid spatial variations in interior sound pressure level, even at low frequencies where the wavelengths are long.

Fidell, Silvati, Pearsons, Lind, and Howe [5] claim that the low-frequency (10 - 250 Hz) energy in aircraft noise is the primary cause of annoyance due to aircraft noise and dominates any effects caused by energy in higher frequency bands. [6].

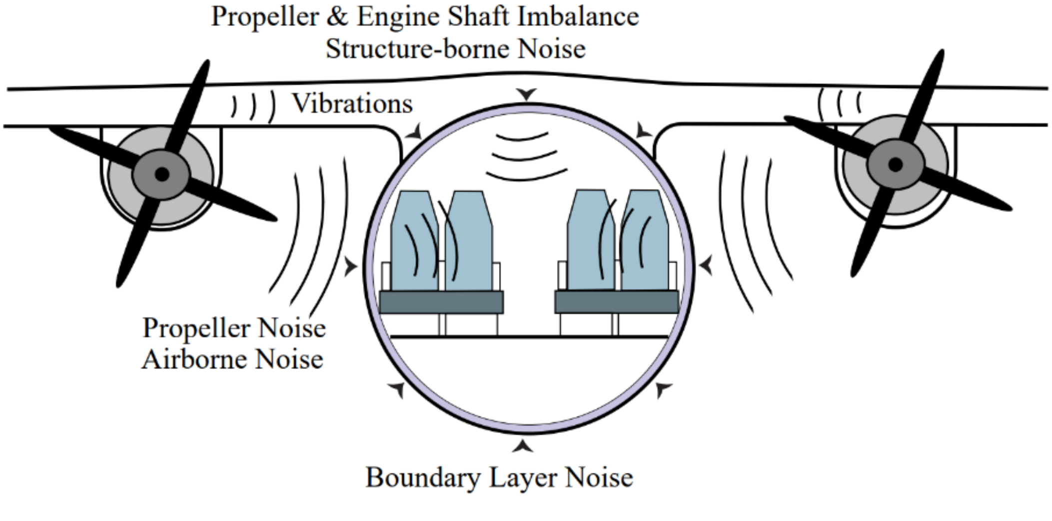

Figure 1 The dominant cabin noise is of two different types: boundary layer noise

In the specific case of a turboprop regional aircraft, propeller-induced noise and vibrations consist of several low-frequency tonal components related to the propeller Blade Passage Frequency (BPF) and some of its harmonics. A typical cabin noise spectrum is shown in Figure 2. These noise/vibrations are caused by the periodic pressure fluctuations acting on the fuselage [7].

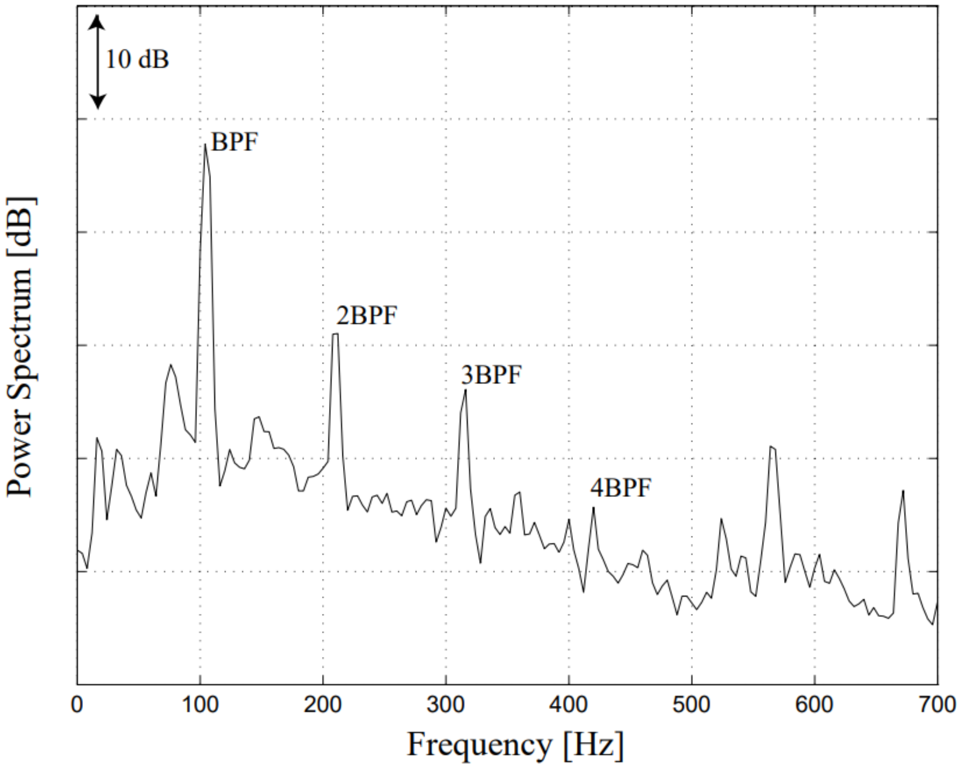

Figure 2 A typical cabin noise spectrum from a propeller aircraft *(Johansson, 2000)*

The fundamental BPFs, depending on the rotational speed and the number of propeller blades, typically occur at frequencies around 100 Hz with peak sound pressure levels at the fuselage surface of up to 140dB (Figure 3). At such low frequencies, the noise reduction along the fuselage side wall – without any specific low frequency noise treatment – is low and therefore the passengers and crew inside the aircraft cabin are exposed to unacceptably high cabin sound pressure levels. For example, the cabin sound pressure levels within the Tupolev Tu-114 – one of the first commercial airliner powered by CROR engines and still the fastest propeller-driven aircraft in the world – could reach values up to 112 dB, which is much larger than today's health and cabin comfort requirements would allow [8].

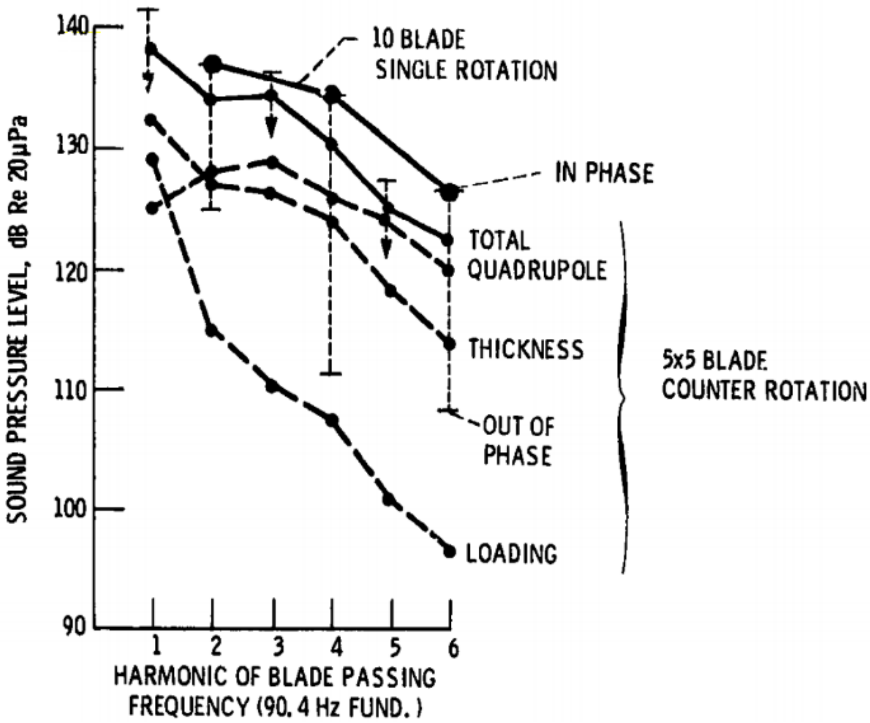

Figure 3 Near-field noise components *(Kni, 1982)*
(tip speed- 700ft sec; power loading =32 SHP/D^2; M 0.8 cruise at 35000ft)

The techniques used for the ground assessment of cabin noise are presented below. Currently the effectiveness of the noise test systems, is limited by the following aspects:

1) fixed fuselage diameter and fixed position;
2) fixed loudspeakers position;
3) fixed loudspeakers number for testing;
4) non-Feedback input control.

1.1. Bombardier de Havilland Solution

The NGS developed at Canada's National Research Council (NRC) by the D.G. Zimcik 's group to test Bombardier de Havilland Dash 8, in Figure 4, shows a fixed structure and a speaker setting which does not wrap around the entire fuselage diameter, so it can be used for panel absorbing characteristics analysis (Transmission Loss, Damping), but it does not offer a precise acoustic excitement for a pseudo-acoustic test setting [9].

Figure 4 NGS installed on de Havilland Dash-8 S-100/200 aircraft

The objective of the present project was not to recreate the entire propeller field, but rather to represent the phase and magnitude characteristics (using accelerometers) over the key region close to the propeller plane and control cabin noise.

The approach used to noise control is designed to weaken the coupling between the exterior and interior acoustics of turboprop aircraft. This approach of Active Structural Acoustic Control (ASAC) involves the use of structural actuators, such as piezoelectric devices (to generate a secondary control sources), and acoustic or structural sensors to accomplish noise attenuation.

In this case, the fuselage rested on a cradle fitted trailer except during testing when an overhead crane raised the fuselage using steel cables which were attached to the fuselage at the wing-fuselage interface. This arrangement was deemed to subject the fuselage to support conditions that resemble steady level flight.

The port side exterior propeller pressure field was simulated using the sound field generated by a bank of four loudspeaker units. Each unit had two sections, a sealed plywood enclosure which formed the speaker box and a horn section which positioned the speakers at a distance of 60 cm from the mouth of the unit. The four speaker units were connected together to form a circumferential speaker-ring which covered an arc of approximately 100° on the fuselage.

The speaker-ring was maintained at distance of approximately 25 mm from the fuselage surface to allow for the blending of the sound from the individual speaker elements to provide a uniform sound field across the mouths of the wave-guides.

Because of the blending of sound fields from each speaker, it was not possible to directly use the desired magnitude and phase at the regions of the fuselage located adjacent to the four speakers as the magnitudes and phases of the waveforms supplied to each speaker. The approach employed here was to determine the transfer function matrix between the relative magnitudes and phases of the four speaker inputs, and the resulting magnitudes and phases of the sound field at a number of distinct locations. Using this approach, the desired and achieved relative magnitude and phase of the propeller field at fuselage exterior were found to be in good agreement. Only the port side exterior sound pressure field was simulated using the speaker-ring unit. However, the present speaker-ring can be extended to provide a more complete simulation of the propeller field if required for further investigations.

In order to monitor the noise reduction performance, microphones were positioned at the seated head height for the two port side seats and at standing height for the aisle center for seat rows 1, 2 and 3.

Characteristic:

- non-Feedback input control,
- quick and easy setting,
- structure designed to operate at low frequencies (propeller noise is significant approximately 50 to 300 Hz),
- coverage of an arc of approximately 100° on the fuselage,
- non-feedback input system,
- fixed speaker number for testing,
- sliding along the fuselage.

1.2. Leonardo actual solution

NGS actually available at Leonardo premises in Pomigliano d'Arco solution, Figure 5, shows a fixed structure and the speaker are settled around the entire fuselage diameter, so it can be used for panel absorbing characteristics analysis (Transmission Loss, Damping) and also offers a precise acoustic excitement for a psychoacoustic test setting.

Figure 5 NGS installed in Pomigliano d'Arco

Characteristics:

- non-Feedback input control
- slow setting,
- total coverage of the fuselage,
- non-feedback input system,
- fixed speaker number for testing,
- fixed fuselage diameter and fixed position;
- fixed loudspeakers position,
- restricted sliding along the fuselage.

1.3. ZAL solution

Centre for Applied Aviation Research (ZAL) solution, in Figure 6, employed by Airbus, shows a fixed structure and an adjustable speaker setting. The sliding speaker array can move along the fixed supporting structure. This setting can be used for panel absorbing characteristics analysis (Transmission Loss, Damping), but it can't offer a precise acoustic excitement for a pseudo-acoustic test setting [10].

Figure 6 ZAL Acoustics Lab

This system is located in a large semi-anechoic chamber (d x w x h: 22.72 m x 11.92 m x 8.71 m) for determination of sound power and levels according to ISO 3745 (accuracy class1) for Aircraft fuselages of every size up to the A350.

Characteristic:

- 128 individually controllable speakers,
- sliding speaker array around the fuselage,
- coverage of an arc on the fuselage,
- Meets acoustic requirements according to ISO 26101 up to a track length of 6.90 m above 80 Hz

1.4. The new iNGS

This solution proposes an array of modules for loudspeakers (Figure 8) that is created to be placed around fuselages with a variable diameter of 2,5 to 4 meters. To adapt this structure to a given fuselage is enough to remove or add modules (Figure 7).

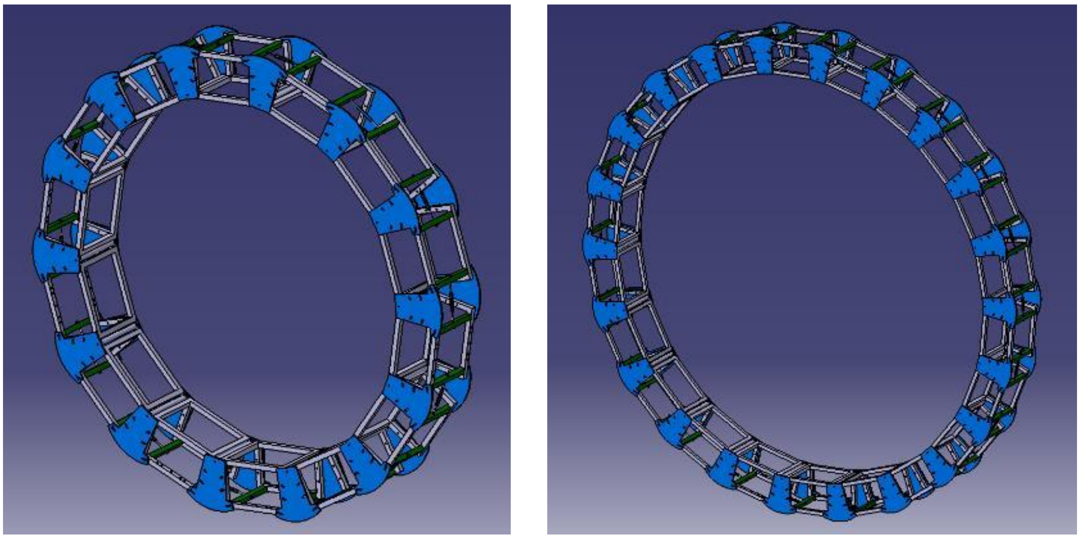

Figure 7 Loudspeaker arrays solutions for two different diameters

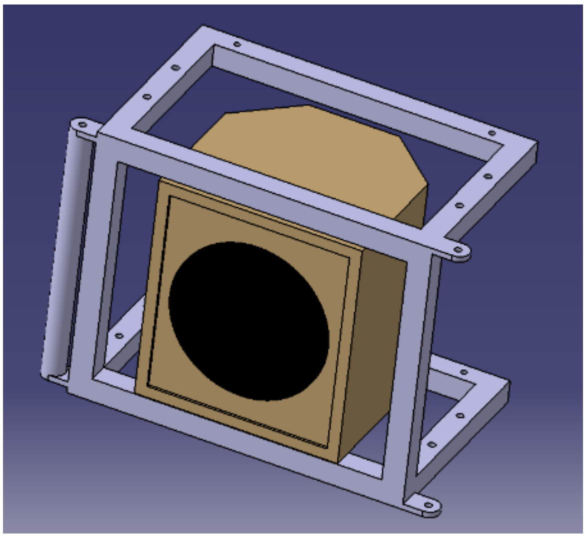

Figure 8 Loudspeaker module

Reinforcement plates, Figure *9*, and adjustment bars, Figure *10*, located between each module, are able to avoid any kind of vibration of the structure and modify the curvature.

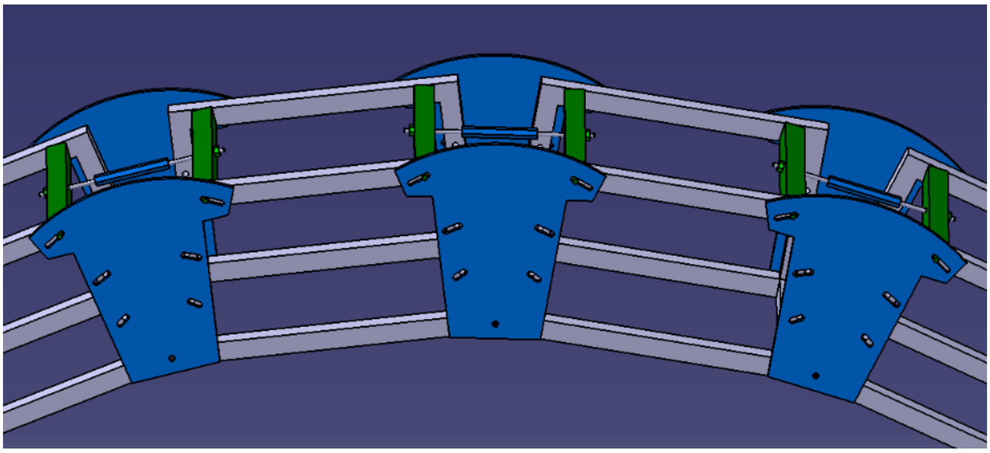

Figure 9 Reinforcement plates

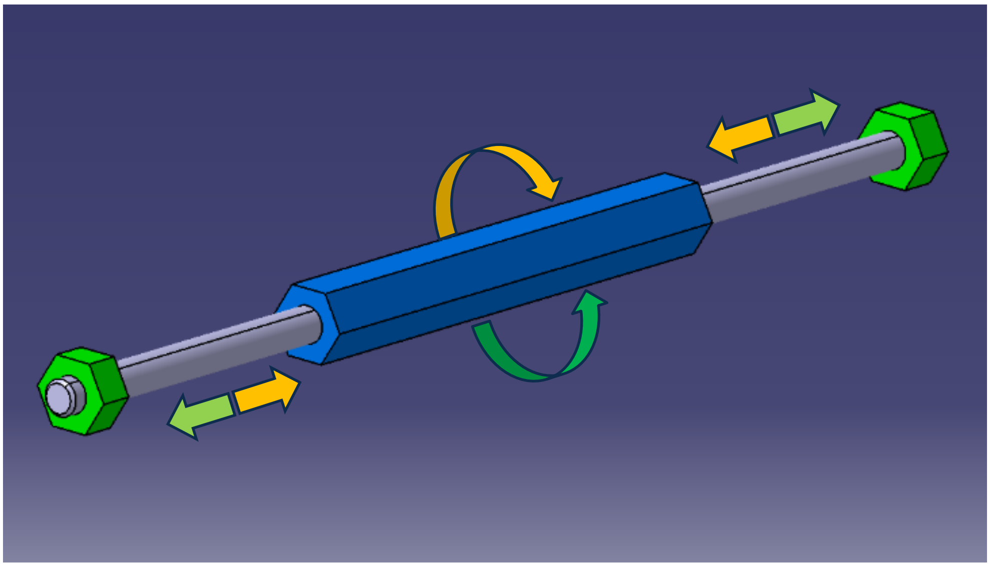

Figure 10 Adjustment bars

The solution involves three loudspeakers arrays to reproduce a realistic acoustic condition around the fuselage (Figure 11) and it is movable in all directions. Each trolley has lateral swivel supports so that two or more arrays can be placed side by side (Figure 12).

Characteristic:

- Modular system in which every module is made in small carpentry, even if the final structure can reach several meters of diameter
- The structure is self-supporting (no need of support bridges)
- Equal density of loudspeaker per unit of length for all diameters
- No parts need to be produced specifically for a particular geometry (just increase or decrease the number of modules)
- Adjustments are possible without disassembling anything (just loosen, adjust and then re-tighten the involved joints)
- The number of different components per every module is minimized
- Other shapes are possible in addition to simple circumferences (ovals, ellipses, etc.) by acting on the only internal adjustments
- The structure is light but at the same time stiff thanks to reinforcement plates
- Fine adjustments are possible even by one person, thanks to a simple clockwise/anticlockwise screw system capable of maintaining the assembled structure even during adjustment
- Several arrays of loudspeakers can be placed next to each other thanks to trolleys with swivel supports
- In principle, it is possible move radially each loudspeaker in its speaker frame in order to adjust the distance from the fuselage even without changing the number of modules

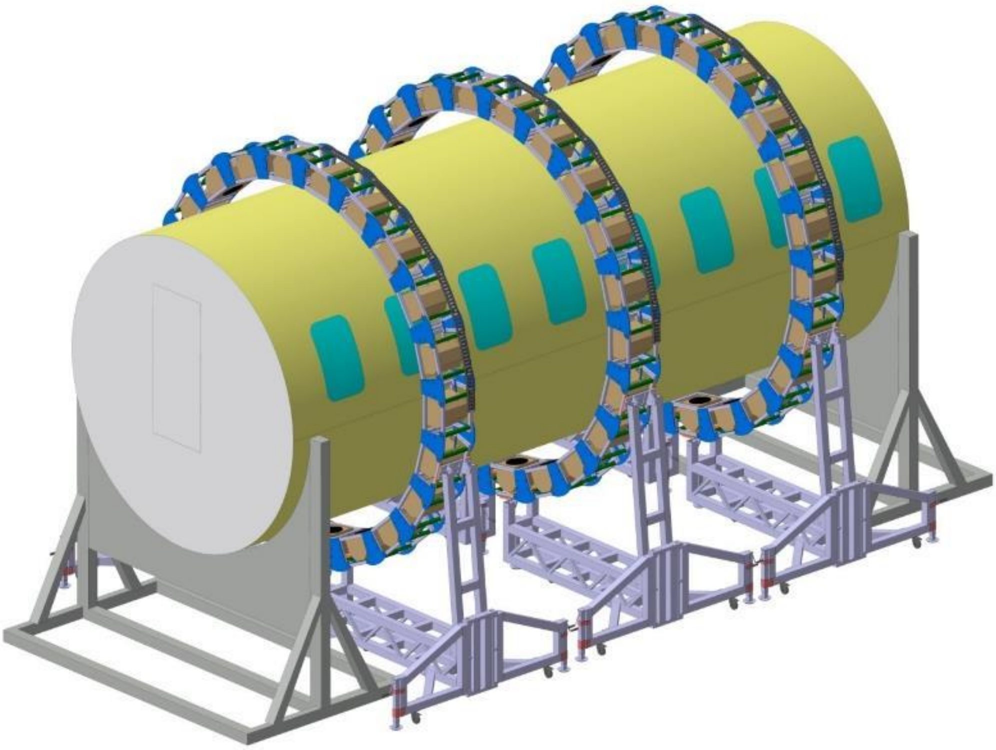

Figure 11 Example of configuration

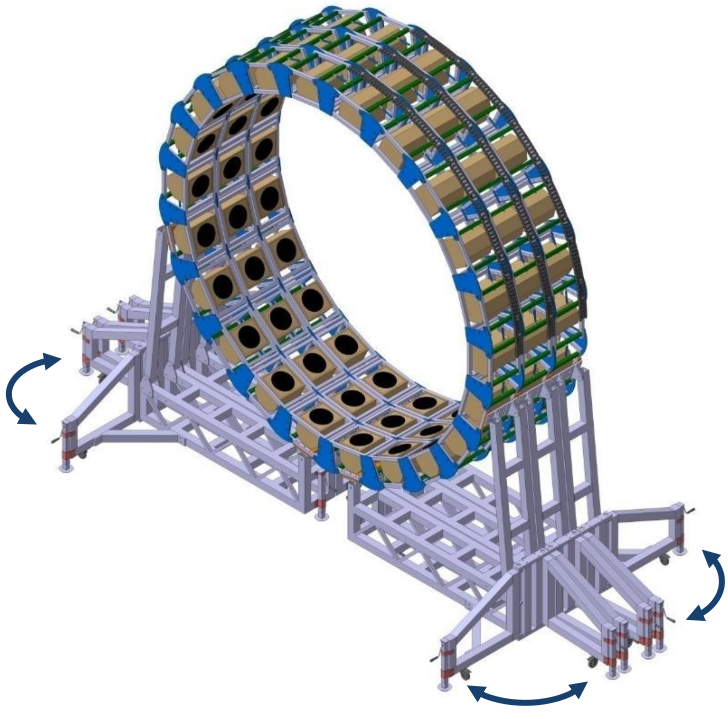

Figure 12 Three arrays placed side by side

1.5. Systems Comparison

	Bombardier Solution	Leonardo solution	ZAL solution	CONCERTO solution
Quick to set up	YES	NO	N/A	YES (few hours)
Modular structure	NO	NO	NO	YES
Scalable structure	NO	NO	NO	YES
Movable supporting structure	YES	YES	YES	YES
Simplified connectivity	N/A	N/A	N/A	YES
Size flexibility	YES	NO	YES	YES
Number of structures around the fuselage	1	1	1	3
System coverage	100°	360°	N/A (small angle)	3x 360°
Number of speakers	4	22	128	22 per ring @4m diameter
Fixed speakers number	N/A	YES	N/A	NO
Fixed speakers position	YES	YES	NO	NO
Distance between the speakers and the surface	25 mm	NO	NO	NO
Adjustable speakers	NO	NO	θ direction	NO
Bandwidth of the speakers	N/A	N/A	N/A	44-11.200Hz
N. of microphones between the loudspeakers and the fuselage	0	0	0	6 per ring

Table 1 Hardware characteristics of the previous systems and target point

2. NGS requirements

As stated in the Concerto Proposal, the high-level objective of the Project is to have an iNGS able to reproduce acoustic loads with high accuracy, from levels, time-frequency structure and phase spatial distribution point of view, in order to:

- reproduce to the cabin demonstrator occupants the acoustic perception and feeling of a real flight;
- allow to assess effectiveness of innovative solutions identified for improving the cabin vibroacoustic comfort;
- contribute to enable a more accurate validation of vibroacoustic numerical models of the fuselage-cabin demonstrator, needed for the assessment of "virtual passenger models" developed in other CS2 project

The iNGS will be able to reproduce the external sound field around a fuselage section of regional aircraft, with a bandwidth of the loudspeakers between 44 and 11.200 Hz and a max amplitude of 130 dB, in order to measure the cabin interior noise distribution map.

More specifically, the system will be able to generate on the fuselage barrel noise levels similar to a typical spectrum as follows.

Frequency band, Hz	SPL, dB
50	107
60	105
80	115
100	125
150	110
200	115
300	112
500	111
1000	110
1500	110
2000	110
3000	108
4000	107
5000	105
10000	102

Table 2 Example of noise levels to be generated

3. Acoustic test system definition

It is necessary to use a dedicated hardware and software system to realize an iNGS fast to set up and easy to use.

A user interface has been designed to manage:

- number of speakers, microphones and rings;
- signal spectrum;

- decibel of the acoustic signal;
- distance between the loudspeakers and the fuselage.

A Multiple-Input Multiple-Output (MIMO) acoustic control technique are proposed to allow to ensure specific spatial correlation properties of the acoustic field, driving the loudspeakers by multiple independent electrical signals, in order to produce the “real” acoustical excitation on the fuselage structure.

3.1. Software

	Bombardier Solution	**Leonardo solution**	**ZAL solution**	**CONCERTO solution**
Quick to set up	N/A	NO	N/A	YES (few hours)
Feedback input control for reverberance and distortion delete	NO	NO	NO	YES
Flexible speakers number	YES	YES	YES	YES
Flexible microphones number between the loudspeakers and the fuselage	N/A	N/A	N/A	YES

Table 3 Software characteristics of the previous systems and target point

In order to realize an innovative Noise Generation System including a real time feedback control for reverberance and distortion delete it is necessary to use a control system. Moreover, the selected system will be fully compatible with Leonardo’s SCADAS and test equipment, and it will be based on the latest computing strategy (deep learning).

3.2. Simcenter SCADAS

Simcenter™ SCADAS™ hardware can be adapted to all testing requirements. Simcenter SCADAS systems offer test engineers versatile and scalable high-precision measurement tools that can be used to conduct productive measurements during all development stages. The solution allows to quickly gain insight into the root cause of problems. Simcenter SCADAS systems help to increase productivity by delivering the data quality and format required to get the job done right the first time for a wide range of analog and digital sensors.

Characteristic:

- Measure and synchronize a large variety of analog and digital sensor data for processing and analysis in a single file
- Obtain high data throughput for both low- and high-sample rates
- Use a single system for multi-physics applications
- Streamline data acquisition, processing, analysis, reporting and sharing in a single integrated software application
- Facilitate plug-and-play deployment
- Combine various systems in a distributed setup
- Limited harmonic distortion
- Highly precise phase matching
- State-of-the-art signal-to-noise ratio and dynamic range
- Accurately synchronized time data for both low- and high-varying signals, even over long distances or in a distributed test setup

The configuration for iNGS includes:

- 1 Simcenter SCADAS Lab
- Simcenter Testlab (dedicated data analysis software)
- 17 DAC4 Modules
- 3 VM8 Modules
- 66 loudspeakers
- 18 microphones
- Cables

3.2.1. Simcenter SCADAS Lab

Simcenter SCADAS Lab,

Figure 13, hardware a rack-based, high-performance laboratory solution that offers Scalability from eight eight to more than 1,000 channels and highly reliable, high-speed throughput performance. Simcenter SCADAS Lab is well-suited for high-channel-count modal, aircraft ground vibration, acoustic, high-speed throughput or turbine testing applications.

Figure 13 Simcenter SCADAS Lab

Specifications:

- Up to 204.8 kilohertz (kHz) sampling rate per channel and throughput up to 19 mega samples per second (MSamples/s)
- 24-bit delta-sigma analog-to-digital (ADC) technology
- 150-decibel (dB) dynamic range
- Various signal-conditioning modules and a choice of commercially-available connectors, such as Bayonet Neill–Concelman (BNC), CAMAC LEMO® and Sub-D for patch panel configuration
- Can include onboard CAN-bus, dual tachometer and signal generator support
- 1.25-gigabit (Gbit) hotlink fiberoptic, master-slave connection with long optical cables for distributed system configurations
- Quality components with extended temperature range for optimized reliability

3.2.2. Simcenter Testlab

Simcenter Testlab is a complete, integrated solution for test-based engineering, combining high-speed multi-physics data acquisition with a full suite of integrated testing, analytics, and modeling tools for a wide range of test needs.

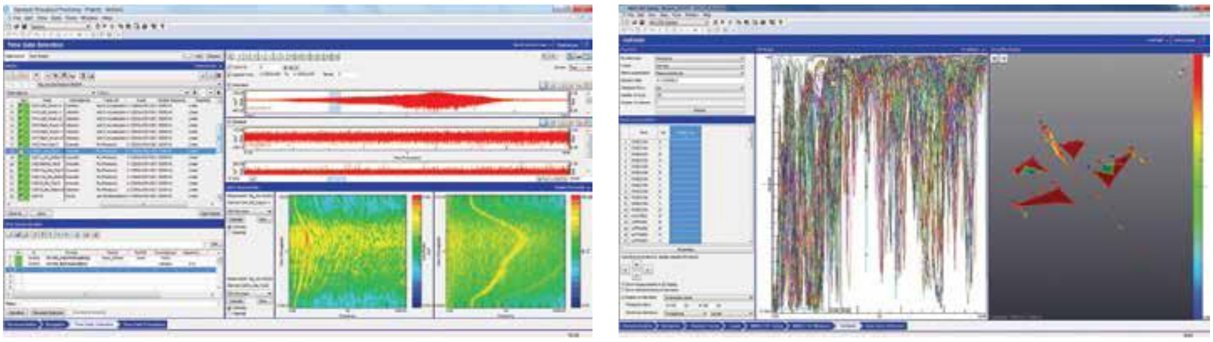

Figure 14 Screenshots of Simcenter Testlab

3.2.3. Four-channel general purpose signal output module (DAC4)

DAC4, in Figure 15, runs at a maximum sample rate of 204.8 kHz with useful bandwidth of up to 40 kHz for the generation of sine, sweep, random or user-defined signals

Figure 15 DAC4 Module

3.2.4. Eight-channel microphone input module (VM8)

VM8, in Figure 16, supports voltage input, piezoelectric ICP sensors and polarized or prepolarized microphones.

Figure 16 VM8 Module

3.2.5. Loudspeakers

In [11] two banks of 380mm diameter loudspeakers JBL model 2225H [12] are used for the simulation of advanced turboprop acoustic excitation. In Table 4 the architectural specifications are presented.

Nominal Diameter	380mm
Rated Impedance	8 ohms
Power Capacity	400W continuous program
Sensitivity	97db SPL. 1 W, 1 m
Frequency Range	30 Hz-2 kHz
Highest Recommended Crossover Frequency	1200 Hz
Minimum Impedance	7.3 ohms ± 10% @25°C

Table 4 Architectural specifications of JBL model 2225H. *(Technical manual and specifications 2225H/J)*

For CONCERTO purposes, it will be considered loudspeakers with a wider frequency range to match the reference as *Table 2* with a safety margin (range of interest 44Hz-11.2kHz)

3.2.6. Microphones System

A microphone transforms sound-pressure variation into electrical signals, which are in turn measured by instrumentation such as a graphic level recorder (GLR), a sound level meter or a one-third octave-band spectrum analyzer. These electrical signals are also often recorded on tape for later off-line analysis. Microphone characteristics are further addressed in IEC 1265, IEC 1094-1, IEC 1094-4, and ANSI S1.4-1983 (R 1990).

A compatible preamplifier, if not engineered as part of the microphone system, should also always be used. A preamplifier provides high-input impedance and constant, low-noise amplification over a wide frequency range. Also, depending upon the type of microphone being used, the preamplifier may provide a polarization voltage to the microphone.

Condenser (i.e., electrostatic or capacitor) microphones are recommended for a wide range of measurement purposes because of their high stability, reasonably high sensitivity, excellent response at high frequencies, and very low electrical noise characteristics.

The diameter of a microphone diaphragm directly affects its useable frequency range, dynamic range (or level sensitivity), and directivity. For example, as the microphone diameter becomes smaller, the useable frequency range increases; however, sensitivity decreases [13], so the considered microphones will be a technical compromise between the frequency range and suitable sensitivity.

3.3. Interior Noise Control Test

3.3.1. Test Article

To prepare the aircraft for experimentation, the forward portion of the vehicle was cut off, the wings were cut off, and the engines and vertical stabilizer were removed. A special flat bulkhead was installed at the forward end of the test section as a plug, in order to form a completely enclosed interior space. Use of this plug eliminated acoustic flanking paths, and also permitted pressurization of the cabin. Two-foot-deep fiberglass wedges were attached to the interior side of the bulkhead, to limit reflections from the bulkhead Wall. A special flat bulkhead was installed at the forward end of the test section as a plug, in order to form a completely enclosed interior space.

3.3.2. Noise Sources

The acoustic signal is created by one or more signal generators which feed either random, broadband noise or sine tones of selected frequencies through a series of amplifiers to any combination of speakers.

By using different speaker combinations for different frequencies, the noise level distribution on the exterior surface of the fuselage could be adjusted to simulate the distribution expected for a real condition.

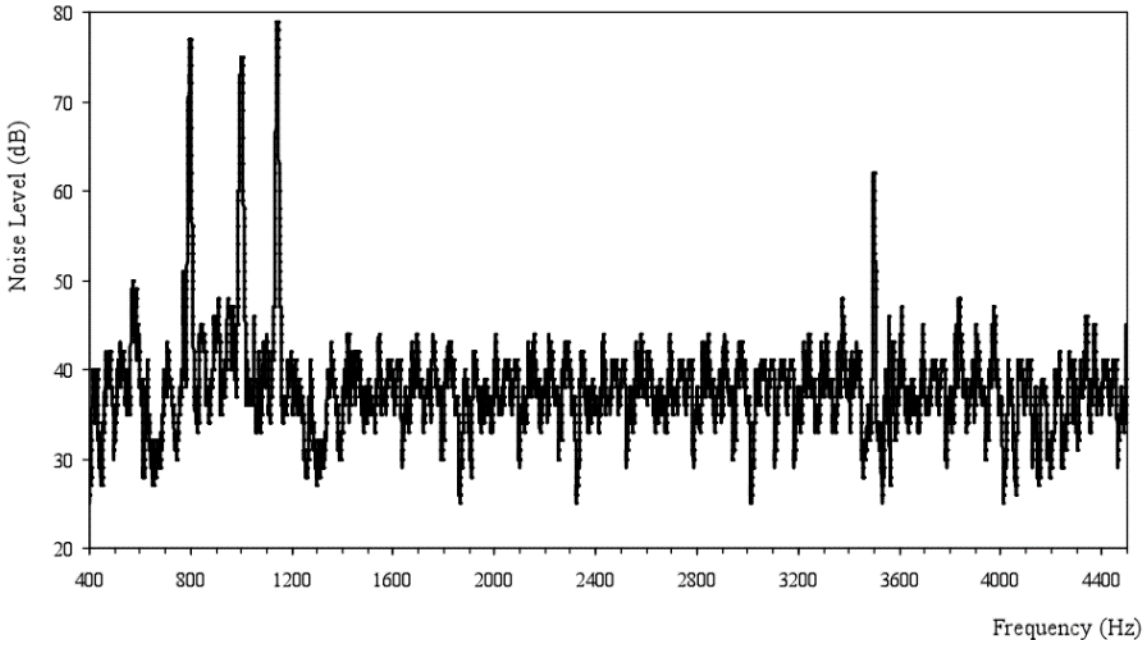

Figure 17 Example of Noise Level Spectrum

The excitation frequencies depend on the rotational speed and the rotor geometry. Simulation results for a generic counter-rotating open rotor (CROR) engine suggest that the strongest excitation occurs in the frequency range of 100–500 Hz. Therefore, the investigated active noise reduction system is designed for this frequency range, which contains the first five CROR frequencies (see first row of Table 5). Table 5 lists typical values of the SPL measured outside and inside the aircraft at the CROR frequencies. The values are intended to give a rough impression of the external and internal noise levels [14].

Frequency [Hz]	119.4	149.2	268.6	388.0	417.9
SPL fuselage [dB]	109	110	108	93	106
SPL cabin [dB]	69	72	62	48	62

Table 5 Typical SPL outside and inside of the aircraft

3.3.3. Measurement and Processing Instrumentation

During the various tests, external and internal microphones are used to monitor noise levels outside and inside the fuselage. Interior microphones are located at typical passenger positions. Data are recorded with the pre-existent platforms used in Leonardo for signal acquisition (24bit ADC, 92kHz bandwidth, 150dB dynamic range) and is processed to convert the digitized time series data into the frequency domain.

3.4. MIMO Control

CONCERTO addresses the problem of reproducing the external acoustic loads on the fuselage and passenger cabin of regional aircrafts.

The MIMO feed-back control concepts can be applied to develop innovative solutions that ensure the simulation of flight conditions during on-ground testing. In principle, MIMO acoustic control enables to drive a set of loudspeakers by multiple independent electrical signals to produce a user-defined acoustical excitation on a structure. While the temporal properties (randomness, stationarity, ergodicity, etc.) characterizing such excitation are, to some extent, given by the statistical features of the electrical signals driving the loudspeakers, MIMO control techniques also allow to target specific spatial correlation properties of the acoustic field. The latter is a key capability of MIMO control, and translates into spatially correlated loads that cause specific structural responses on the fuselage demonstrator.

The MIMO control techniques proposed, enable to tailor both, temporal and spatial, properties of random acoustic loads to accomplish user-defined test specifications. This is possible through two approaches: MIMO Random Control and Time Waveform Replication.

In the first approach, the Noise Generation System Enables to set test specifications in the form of a Spectral Density Matrix (SDM). Where such matrix is comprised by Power Spectral Density (PSD) and Cross Spectral Density (CSD) profiles targeting user-defined phases and coherences.

In the second approach, the frequency domain test specification is transformed into multiple time histories to proceed with a deterministic replication of the acoustic load characterizing the flight condition.

Conclusions

At the end of this analysis it is possible to conclude that there is no system capable of reproducing a realistic acoustic noise condition around the fuselage easy and quick to set up. In fact, Zal and Bombardier solutions reproduce the noise condition in a limited area, while Leonardo solution present a system with a slow setting and a fixed diameter.

To create an innovative Noise Generation System (iNGS) quick to set up and adaptable to different fuselage diameters it will have to use a feedback system and a modular structure.