Applications of Active Systems for Noise and Vibration Abatement in Automotive Environments

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CIRA, the Italian Aerospace Research Center
Applications of Active Systems for Noise and Vibration Abatement in Automotive Environments

Index

The Italian Aerospace Research Center, an Overview
Low Noise: Synthesis and Main Project Attainments
SARISTU – AS02; The Adaptive Trailing Edge Device – ATED
A Short Presentation of the Computational Acoustics Lab.
An Overview of CIRA, The Italian Aerospace Research Centre
Overview of CIRA
Centro Italiano Ricerche Aerospaziali
A non-profit public-private partnership among:
- ASI (Italian Space Agency) - 47%
- CNR (National Council for Research) - 5%
- Campania Region - 16%
- Italian Aerospace Industries - 32%

- 370 employees and approx. 50 university students and PhD candidates a year

- Partner of the main European research programs in the aerospace field (*JTI CLEAN SKY, SESAR, MIDCAS, etc.*)

In 1989, the Italian Government entrusted CIRA the management of the Italian Aerospace Research Program (PRORA) to support the competitiveness of the Italian aerospace community by the:
- development of strategic research programs,
- development and operation of strategic testing facilities,
- enhancement of scientific competences and expertise.

CIRA performs PRORA management under the control of Ministry of Research (MIUR).
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Main gate</td>
</tr>
<tr>
<td>2</td>
<td>Aeronautics and Space Division</td>
</tr>
<tr>
<td>3</td>
<td>Canteen</td>
</tr>
<tr>
<td>4</td>
<td>Headquarters, Supercomputing Centre</td>
</tr>
<tr>
<td>5</td>
<td>Modeling and Design Methods Laboratories</td>
</tr>
<tr>
<td>6</td>
<td>LISA – Crash Test Facility</td>
</tr>
<tr>
<td>7</td>
<td>Experimental Aerodynamics and Transonic Wind Tunnel</td>
</tr>
<tr>
<td>8</td>
<td>HVAC, cooling towers, main compressed air station</td>
</tr>
<tr>
<td>9</td>
<td>IWT – Icing Wind Tunnel</td>
</tr>
<tr>
<td>10</td>
<td>PWT – Plasma Wind Tunnel</td>
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<td>11</td>
<td>Airport (IT MoD property)</td>
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</table>
**IWT – Icing Wind Tunnel**
Operational since 2003, is world unique for size, test envelope. Capable to simulate clouds within current and foreseen certification envelopes to test safety critical thermal protection systems of space vehicles.

**PWT – Plasma Wind Tunnel**
Operational since 2002, is world unique for power and size. Capable to simulate high speed orbital and super-orbital re-entry to test safety critical thermal protection systems of space vehicles.

**LISA – Crash Test Facility**
Operational since 2003, is world unique for testing envelope. Capable to simulate landing scenario in case of accidental ground impact to improve passenger and payload protection.

**PT1 – Transonic Pilot Tunnel**
Operational since 1999, for transonic and supersonic aerodynamic simulation (M<0.4 cont. M<1.4 int.)
MAIN REFERENCES

• Full Title: NEW TECHNOLOGIES AND MATERIALS FOR NOISE ABATMENT IN CAR VEHICLES
• Acronym: LOW NOISE
• Call: MIUR 2010
• Type of Action: Research
• Topics: Advanced Transports and Logistics
• Duration: 3 Years

OBJECTIVES

• To reduce noise and vibration with sustainable solutions that minimize the impact on weight and other vehicle features that may have negative consequences on fuel consumption and emissions

GLOBAL VALUE AND EXTENSION

• Overall Budget: 10 Millions Euro
• Project Duration: 36 months

PARTNERSHIP

• Number of Partners: 9
• Industry: 2; Universities: 4; Research Centres: 3
► Digital Active Noise and Vibration Control applications
  • *Active Vibration Control by Piezoceramic actuators of a car rear under-seat floor panel*
  • *Active Vibration Control of a mounting bracket for automotive gearboxes*

► Design, Simulation, analysis and testing of Low Noise configurations and Active Control devices:
  • *Optimal Mass/Stiffness distribution during design*
  • *ANC to further enhance interior comfort*
## OR1 - SPECIFICATIONS

<table>
<thead>
<tr>
<th>OR3 - SEALING</th>
<th>OR2 - SOUNDPROOFING</th>
<th>OR2 - SOUNDPROOFING</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR4 - ACTIVE CONTROL</td>
<td>OR6 – ROLLING NOISE</td>
<td>OR6 – ROLLING NOISE</td>
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<td>OR5 - AEROACOUSTICS</td>
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**INTERIOR NOISE**

**INTERIOR NOISE**

**EXTERIOR NOISE**

## OR7 - METHODOLOGIES
1. SMA based adaptive seals for sound insulation
2. Semi-active tonal vibration reduction of internal automotive subsystems
3. Active tonal vibration reduction of internal components by piezoceramic stacks
4. Active tonal distributed vibration control by piezoceramic patches
5. Reduction of the rolling wheel noise through a distributed active vibration control of the backseat area by PZT
Title: SMA based adaptive seals for sound insulation

Objective: Increase of the sound insulation capability of automotive seals, to compensate the leakage effects due to the aerodynamic loads acting on the doors during the cruise phase

Reference persons: S. Ameduri, A. Brindisi, M. Ciminello, A. Concilio

Publications/IPR aspects: Patent pending
Concept/strategy adopted:
Expansion cells integrated within the seal cavities, actuated by SMA linear elements to press the seal foam against the door and the cabin frames, thus enhancing the adhesion.
FE cell modeling

Non linear FE analysis aimed at estimating:

- strain
- axial cell activation force
- radial displacement
- radial force transmitted to the sealing
ABS prototypes

Lab setup

Prototype for integration

Integration

Results & Benefits

SMA Seals – Experimental Results

Use or disclosure of the information contained herein is subject to specific written approval from CIRA.
Title: Tonal vibration reduction of internal automotive subsystems

Objective: Feasibility study of a «switched shunt resonator» for the vibration reduction of a wiper windshield at resonances in the frequency range of 600-850 Hz.

Reference persons: M. Ciminello, R. di Leo, M. Viscardi (UniNA)

Publications/IPR aspects:
Paper Submitted to JTAM 10-jun-2016 Paper ID: 23353276
Concept / strategy adopted 1/3: Preliminary vibro-acoustic characterization of the device under test and control system design.

Measured parameters:
- Acoustic level outside the vehicle
- Acoustic level inside the vehicle

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>2.2 mm</td>
</tr>
<tr>
<td>Area</td>
<td>9384.8 mm²</td>
</tr>
<tr>
<td>E</td>
<td>180 Gpa</td>
</tr>
<tr>
<td>ρ</td>
<td>7800 Kg/m³</td>
</tr>
</tbody>
</table>

The windshield wiper produces noise levels two magnitudes higher than the noise produced by the car engine.
Concept / strategy adopted 2/3: Experimental evaluation of the strain map of the bracket by using the vibro-meter laser.

The measured voltage amplitude is about 200mV
At lower frequency the shunt resonator produces some effects when a sine excitation is provided.

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Control</th>
<th>Velocity (mm/s)</th>
<th>Displacement (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>69</td>
<td>OFF</td>
<td>67.64</td>
<td>156.02</td>
</tr>
<tr>
<td>69</td>
<td>ON</td>
<td>33.67</td>
<td>77.17</td>
</tr>
<tr>
<td>69</td>
<td>% Difference</td>
<td>-50%</td>
<td>-50%</td>
</tr>
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</table>

The shunt resonator needs a supply of 0.5V.
Title: Active Tonal Vibration Reduction of Internal Components

Objective: Feasibility study of a feedforward control system for the vibration reduction of a gearbox bracket in the frequency range of 500-3000 Hz.

Reference persons: M. Ciminello, I. Dimino, D. Magliacano, M. Viscardi (UniNA), A. Concilio

Publications/IPR aspects:
Concept/strategy adopted 1/2: Preliminary characterization of the device under test and control system design.

FEM and Experimental validation of the bracket with
- Resonance search test
- Sweep excitation 500-2000Hz
- 6 triaxial accelerometers
Concept/strategy adopted 2/2: Piezo stack selection and layout design.

<table>
<thead>
<tr>
<th>Model</th>
<th>Displacement (µm)</th>
<th>Diameter (mm)</th>
<th>Length (mm)</th>
<th>Blocking force (N)</th>
<th>Capacitance (nF)</th>
<th>Max Voltage supply (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-010.20</td>
<td>30</td>
<td>10</td>
<td>30</td>
<td>2100</td>
<td>130</td>
<td>1000</td>
</tr>
<tr>
<td>P-016.20</td>
<td>30</td>
<td>16</td>
<td>29</td>
<td>5500</td>
<td>340</td>
<td>1000</td>
</tr>
<tr>
<td>P-885.55</td>
<td>17</td>
<td>11.2</td>
<td>22.5</td>
<td>850</td>
<td>1500</td>
<td>120</td>
</tr>
</tbody>
</table>
The blue curve is the baseline response. The red curve is the effect of the control system on the bracket vibration using a force of 1 N acting in phase opposition, while the yellow curve is the structural response by using a force of 1.3 N with an optimized phase of 169 deg.

The feedforward control system provide a vibration reduction of 75% (-12dB).
Title: Active Tonal Vibration Control by Piezoceramic Actuators of a Car Rear Under-Seat Floor Panel

Objective: Implementation of a FF ASAC control through a PZT network

Reference persons: I. Dimino, A. Concilio, D. Magliacano, M. Viscardi (UniNA)

Concept / strategy adopted:
• Problem identification through Transfer Path Analyses
• FE modeling and prediction of the PZT effectiveness in reducing noise
• Active Control System logic development and DSP implementation
• Setup preparation
• Test validation
Numerical optimization and performance estimate

Modal strain plots – experimental data

Sensors / actuators location
Under-seat Panel – Experimental Results

Noisy signals
Title: Reduction of the rolling wheel noise through the active control of the supporting structure of the backseat

Objective: Implementation of a collocated feedback control through a PZT network installed onto the back seat structural support

Reference persons: S. Ameduri, I. Dimino

Publications/IPR aspects: Journal papers preparing
Concept/strategy adopted:

- Topologic optimization driven by the energy transmission map of the back seat supporting panel
- FE modeling of the panel for predicting the effectiveness of the PZT network in reducing the noise levels
- Setup preparation and backseat panel integration with PZT patches
- Validation tests
Numerical optimization and performance estimate
Transmission energy maps computation and identification of the most effective location of the PZT patches
Setup design and preparation

Installation of the PZT network

Estimated power = 100 W

Achieved results

SPL significant abatement over 1000Hz (2 actuators):
- -7.3dB at 1600Hz
- -7.0dB at 3150Hz
- -6.6dB at 4000Hz
SARISTU – AS02
The Adaptive Trailing Edge Device – ATED
Leader: Airbus, 64 Partners from 16 EU Countries, 51M€ budget, duration 09.11-08.15. Addressing two full-scale integrated demonstrators: a Multi-functional Fuselage Structure and a **Morphing Wing** section. Referring to the latter, the project targeted to WTT advanced technologies to enhance A/C performance (fuel consumption, weight, operative costs, noise emissions, …).
Technology Overview

Goal
Civil AC flight profiles are quite standard but different missions may be flown (fast or slow, at low or high altitude). Lift coefficient can vary between tenth to unit while weight reduces by a quarter as the fuel burns. The best configuration then changes, having to match new conditions.

Objectives
The project addresses medium-range AC (around 3h cruise flight). Chord-wise camber variations are implemented through TE adaptations to get optimal geometry for different flight conditions.

Benefits
Upgrades are herein measured as reduction of fuel consumption or increase of range, estimated about 3% or more. L/D ratio is the parameter that may synthetically express these performance variations, kept to its optimal value while weight and angle of attack variate. Because span-wise adjustments may lead to RBM reduction and then to design weight decrease, this potentiality can be exploited.

Concept Illustration

Concept fundamentals
Morphing is enabled by a multi-finger architecture driven by load-bearing actuator systems (hidden in the figure). To provide camber variation, devices are designed to work synchronously but can be activated differentially. A control system drives the actuators action after info gained by a strain sensor network. Skin absorbs part of the external loads and insures a smooth profile. The system keeps its structural properties while actuated. Loaded static & dynamic responses are considered.
The Adaptive Trailing Edge Device (ATED) is one of the three adaptive wing components developed within SARISTU and integrated into the full-scale WT Demonstrator.

Polimi computations show a reduced CD respect to the Onera ones (probably due to viscous effect not properly taken into account in the Euler code)

Wing adaptation benefits are higher with a morphing flap respect to a plain flap (without gap) in the normal aircraft operating range.
ATED, the Adaptive Trailing Edge Device
ATED Team Leader: CIRA, 14 Partners, around 5 M€ budget, 09.11 – 08.15
The ATED Team (SARISTU AS02)

This presentation is aimed at providing the status of the AS02 developments at the date, attained by the joint effort of people from different partners. The following colleagues & friends provided their valuable support:

Saverio CORBO, Valerijan COKONAJI, Yasser ESSA, Federico MARTIN De La Escalera, Victor MUNOZ, Augusto OTERINO (AERNNOVA)
Steffen BAUSS (AIRBUS), Giovanni Marco CAROSSA (ALENIA)
Okan GULAÇ, Sermar GÜNTER, Hatice NAROĞLU, Enis OKAN, Cem SAPMAZ, Hakan TEKIN (ATARD)
Monica CIMINELLO, Ignazio DIMINO, Gianluca DIODATI (CIRA)
André GRATIAS, Mathias LIPOWSKI, Martin SCHUELLER (FhG-ENAS)
Andreas LUEHRING, Christof NAGEL, Bernd SCHNEIDER, Oliver SCHORSCH, Michael WOLF (FhG-IFAM)
Moshe STEINBUCK, Shlomo ROSENTAL, Avner VOLOVICK, Lior ZIVAN (IAI)
Christos KOIMTZOGLOU (INASCO)
Haim ABRAMOVICH, Eyal PRESENTE (INNOWATTECH)
Marco BELLUCCI, Alfonso CELANO (MARE)
Antoine DUMONT, Jean-Luc GODARD, Fabien HUVELIN, Cedric LIAUZUN (ONERA)
Francesco AMOROSO, Leonardo LECCE, Marco MAGNIFICO, Rosario PECORA (UNINA)

Other people supported in many ways our activity, involved in other parts of SARISTU:
Katrin GENZEL, Ben NEWMAN, Piet Christof WOELCKEN (AIRBUS), Alfonso APICELLA, Salvatore RUSSO, Giuliano CATTANEO, Domenico CAVEZZA, Carlo RICCIARDELLI, Lorenzo ROSSI (ALENIA), Kristina DITZEL, Andreas KOETTER, Rebecca WALDLEICH (ALTRAN), Salvatore AMEDURI (CIRA), Sergio RICCI, Alessandro DE GASPARI (POLIMI), Michelangelo GIULIANI (REDAM), Rolf EVENBLIJ, Merlijn KUIN, Iskander DEERENBERG (TECHNOBIS)

To all of them, I would express my sincere thanks…. To Ignazio & Rosario a special acknowledgement for their continuous assistance in carrying out the AS02 scenario ☺... Antonio CONCILIO
The ATED integrated to the Adaptive Wing Demonstrator with other morphing devices
Info Reserved. For public info please refer to:

http://tsagi.com/pressroom/news/2192/?sphrase_id=13887

Or

http://www.saristu.eu/2015/06/saristu-end-of-project-meeting-conference/
Division of Environmental Impact of Air Transport

Computational Acoustics Lab.

CI RA
Italian Aerospace Research Center

Points of Contact
Aeracoustics: Mattia Barbarino (m.barbarino@cira.it)
Vibroacoustics: Pasquale Vitiello (p.vitiello@cira.it)
Development of methodologies and numerical tools for Aeroacoustics and Vibroacoustics:

- Aerodynamic noise generation and radiation models
- Noise shielding and propagation models
- Fluid-structure interaction, transmission loss and radiation efficiency

Simulation, analysis and design of Low Noise configurations and devices:

- Tiltrotor, Rotorcraft, Aircraft, Engines and Automotive components
Fuselage Scattering on Noise Radiated by Aircraft, Rotorcraft and Tiltrotor

Broadband Noise Prediction by means RANS-based models

CAA approaches for low-noise technologies design

Low-Noise Rotor / Propeller Design

Noise Human Response

Interior noise prediction and control
Interior noise prediction and control.

Noise generated by TBL pressure field - Convected field effects on acoustic properties of metallic and composite panels.

Projects:

- ENABLE: Environmental Noise Associated with TBL Excitation - EU funded Program
- AMACA: TBL noise transmitted by composite panels – Alenia funded Program

References:


Launcher Aero-Vibro-Acoustic prediction during the lift-off.

- **Hybrid empirical-CAA approach for external noise generation and radiation.**
  An improvement of the Eldred standard model has been formulated in order to investigate the sources correlation effects and to propagate them through a wave equation. The noise prediction obtained with the revised Eldred-based model has then been used for formulating an empirical/BEM hybrid approach that allows to evaluate the scattering effects. In the framework of the European Space Agency funded program VECEP, these models have been applied for the prediction of the aeroacoustic loads of the VEGA launch vehicle at lift-off and the results have been compared with experimental data.

- **Hybrid FEM/SEA approach for vibration and internal noise prediction.**
  The external acoustic field has been used for the Inter-Stages structural and interior cavity response in the mid frequency range by employing an Hybrid FEM-SEA model. Acquisition of Equipment acceleration level to assess their qualification status required them to be modelled as concentrated mass rigidly connected to the Inter-Stage skin. Due to the large Inter-Stage dimensions and the extension of the frequency range to be investigate an appropriate balance between accurate dynamic response and computational cost containment was achieved by recurring to the Hybrid modelling approach. An acoustic diffuse excitation field was assumed for each Inter-Stage and the response of the FEM modelled Equipment acquired at their attachment points.

**Project:**
- VECEP Program, funded by AVIO SpA

**References:**
Real part of the acoustic pressure at $kR=5.5$. Launcher altitude 0m.

SPLs in third band octave at interstage level. Comparison between Eldred models and experimental data.

Hybrid FEM-SEA model of a VEGA Launcher Inter-Stage
BEM-DbbFMM

**Numerical solution of convected Helmholtz equation:**

- Pressure based (Lighthill) and potential based (Pierce) formulation;
- Boundary conditions (rigid, vibrating, impedance wall, ...);
- CHIEF regularization of the spurious frequencies handling complex geometries;
- Numerical scheme based on centered cells and isoparametric formulation;
- Interface with FW-H for scattering problems;
- Directional Black-Box Fast Multipole Method (DbbFMM).

**Writing/reading interface:**

- Compatible with several visualization packages and softwares (tecplot, fieldview, AVS ...)

**References:**

Barbarino, M., Bianco, D., *BEM-FMM Simulation of Uniform mean flows with a new internal-point Algorithm for the CHIEF Spurious Solutions Removal*, ICSV2016 Conference (Athens, 10-14 July 2016)

The work herein presented is the result of the efforts of many researchers and colleagues, working at CIRA, University of Napoli and other companies, who contributed in different ways and in several moments to the development of the «Adaptive (or Smart) Structures» technology…

Really, nothing (or very few) could have been done without the enthusiastic concurrency of so many expertises, engineering and not.
THANKS FOR YOUR ATTENTION!