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Vibration and noise reduction techniques used in aircraft

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ABSTRACT

This paper is all about the various techniques for controlling or reducing noise and vibrations produced in an aircraft. This basically uses the ANC (Active Noise Control) and AVC(Active Vibration Control) technologies. Objective, risks and Cost-benefits of the technology to noise & vibration control are discussed.

KEYWORDS

Active Noise Control(AVC), Active Vibration Control(AVC), Active Noise &Vibration Control(ANVC), Active Mass Dampers(AMD), Hybrid Mass Dampers(HMD), Tuned or Passive Mass Dampers(TMD).

1. INTRODUCTION

1.1 Noise Control

Noise control or **noise mitigation** is a set of strategies to reduce noise pollution or to reduce the impact of that noise, whether outdoors or indoors.

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As in the case of roadway noise, little progress has been made in quelling aircraft noise at the source, other than elimination of loud engine designs from the 1960s and earlier. Because of its velocity and volume, jet turbine engine exhaust noise defies reduction by any simple means.

The most promising forms of aircraft noise abatement are through land planning, flight operations restrictions and residential soundproofing. Flight restrictions can take the form of preferred runway use, departure flight path and slope, and time-of-day restrictions. These tactics are sometimes controversial since they can impact aircraft safety, flying convenience and airline economics.

In 1979, the US Congress authorized the FAA to devise technology and programs to attempt to insulate homes near airports. While this obviously does not aid the exterior environment, the program has been effective for residential and school interiors. Some of the first airports at which the technology was applied were San Francisco International Airport, Seattle-Tacoma International Airport, John Wayne International Airport and San Jose International Airport in California.

The underlying technology is a computer model which simulates the propagation of aircraft noise and its penetration into buildings. Variations in aircraft types, flight patterns and local meteorology can be analyzed along with benefits of alternative building retrofit strategies such as roof upgrading, window glazing improvement, fireplace baffling, caulking construction seams and other measures. The computer model allows cost effectiveness evaluations of a host of alternative strategies.

In Canada, Transport Canada prepares noise exposure forecasts (NEF) for each airport, using a computer model similar to that used in US residential land development is discouraged within high impact areas identified by the forecast.

In 1998, the flight paths in all of Scandinavia were changed as the new Oslo-Gardermoen Airport was opened. These new paths were straighter, reducing fuel use, and disturbing fewer people, however, vociferous protests came from people near the new paths who had not been disturbed before, and they took legal action (NIMBY effect).

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1.2 Vibration Control

In earthquake engineering, vibration control is a set of technical means aimed to mitigate seismic impacts in building and non-building structures.

All seismic vibration control devices may be classified as passive, active or hybrid where:

- passive control devices have no feedback capability between them, structural elements and the ground;
- active control devices incorporate real-time recording instrumentation on the ground integrated with earthquake input processing equipment and actuators within the structure;
- hybrid control devices have combined features of active and passive control systems.

When ground seismic waves reach up and start to penetrate a base of a building, their energy flow density, due to reflections, reduces dramatically: usually, up to 90%. However, the remaining portions of the incident waves during a major earthquake still bear a huge devastating potential.

After the seismic waves enter a superstructure, there is a number of ways to control them in order to soothe their damaging effect and improve the building's seismic performance, for instance:

- to dissipate the wave energy inside a superstructure with properly engineered dampers;
- to disperse the wave energy between a wider range of frequencies;
- to absorb the resonant portions of the whole wave frequencies band with the help of so-called mass dampers.

Devices of the last kind, abbreviated correspondingly as **TMD** for the tuned (passive), as **AMD** for the active, and as **HMD** for the hybrid mass dampers, have been studied and installed in high-rise buildings, predominantly in Japan, for a quarter of a century.

However, there is quite another approach: partial suppression of the seismic energy flow into the superstructure known as seismic or base isolation which has been implemented in a number of historical buildings all over the world and remains in the focus of earthquake engineering research for years.

For this, some pads are inserted into all major load-carrying elements in the base of the building which should substantially decouple a superstructure from its substructure resting on a shaking ground. It also requires creating a rigidity diaphragm and a moat around the building, as well as making provisions against overturning and P-delta effect.

In refineries or plants snubbers are often used for vibration control. Snubbers come in two different variations: hydraulic snubber and a mechanical snubber.

- Hydraulic snubbers are used on piping systems when restrained thermal movement is allowed.
- Mechanical snubbers operate on the standards of restricting acceleration of any pipe movements to a threshold of 0.2 g's, which is the maximum acceleration that the snubber will permit the piping to see.

1.3 Objectives:

• To improve passenger comfort and crew effectiveness by reducing cabin and cockpit noise and vibration levels.
Currently, pilot flying times are limited by exposure to noise and vibrations in turboprop and helicopter aircraft.
Future workplace health and safety regulations will establish more rigid standards for exposure to cabin noise.
• To increase the performance characteristics of commercial and military aircraft by reducing vibration levels.
Operational performance, manoeuvrability and fuel efficiencies are expected to increase with active vibration control of aircraft structures which are exposed to high levels of turbulence and buffet loads creating wing flutter, acoustic resonance in open bomb bays,

rotor resonances and fuselage vibrations.

• To increase the lifetime of aircraft and improve component life cycle costs by decreasing fatigue loading which is produced by noise and vibration.

2. Background

2.1. Active Noise Control (ANC)

Sound is a pressure wave, which consists of alternating periods of compression and rarefaction. A noise-cancellation speaker emits a sound wave with the same amplitude but with inverted phase (also known as anti-phase) to the original sound. The waves combine to form a new wave, in a process called interference, and effectively cancel each other out – an effect which is called destructive interference.

Modern active noise control is generally achieved through the use of analog circuits or digital signal processing. Adaptive algorithms are designed to analyze the waveform of the background aural or nonaural noise, then based on the specific algorithm generate a signal that will either phase shift or invert the polarity of the original signal. This inverted signal (in antiphase) is then amplified and a transducer creates a sound wave directly proportional to the amplitude of the original waveform, creating destructive interference. This effectively reduces the volume of the perceivable noise.

A noise-cancellation speaker may be co-located with the sound source to be attenuated. In this case it must have the same audio power level as the source of the unwanted sound. Alternatively, the transducer emitting the cancellation signal may be located at the location where sound attenuation is wanted (e.g. the user's ear). This requires a much lower power level for cancellation but is effective only for a single user. Noise cancellation at other locations is more difficult as the three-dimensional wave fronts of the unwanted sound and the cancellation signal could match and create alternating zones of constructive and destructive interference, reducing noise in some spots while doubling noise in others. In small enclosed spaces (e.g. the passenger compartment of a car) global noise reduction can be achieved via multiple speakers and feedback microphones, and measurement of the modal responses of the enclosure.

2.1.1 Applications

Applications can be "1-dimensional" or 3-dimensional, depending on the type of zone to protect. Periodic sounds, even complex ones, are easier to cancel than random sounds due to the repetition in the wave form.

Protection of a "1-dimension zone" is easier and requires only one or two microphones and speakers to be effective. Several commercial applications have been successful: noise-cancelling headphones, active mufflers, and the control of noise in air conditioning ducts. The term "1-dimension" refers to a simple pistonic relationship between the noise and the active speaker (mechanical noise reduction) or between the active speaker and the listener (headphones).

Protection of a 3-dimension zone requires many microphones and speakers, making it more expensive. Noise reduction is more easily achieved with a single listener remaining stationary but if there are multiple listeners or if the single listener turns his head or moves throughout the space then the noise reduction challenge is made much more difficult. High frequency waves are difficult to reduce in three dimensions due to their relatively short audio wavelength in air. The wavelength in air of sinusoidal noise at approximately 800 Hz is double the distance of the average person's left ear to the right ear; such a noise coming directly from the front will be easily reduced by an active system but coming from the side will tend to cancel at one ear while being reinforced at the other, making the noise louder, not softer. High frequency sounds above 1000 Hz tend to cancel and reinforce unpredictably from many directions. In sum, the most effective noise reduction in three-dimensional space involves low frequency sounds. Commercial applications of 3-D noise reduction include the protection of aircraft cabins and car interiors, but in these situations, protection is mainly limited to the cancellation of repetitive (or periodic) noise such as engine-, propeller- or rotor-induced noise. This is because an engine's cyclic nature makes fast Fourier transform analysis and the noise cancellation easier to apply.

2.2. Active Vibration Control (AVC)

Active vibration control is the active application of force in an equal and opposite fashion to the forces imposed by external vibration. With this application, a precision industrial process can be maintained on a platform essentially vibration-free.

Many precision industrial processes cannot take place if the machinery is being affected by vibration. For example, the production of semiconductor wafers requires that the machines used for the photolithography steps be used in an essentially vibration-free environment or the sub-micrometer features will be blurred. Active vibration control is now also commercially available for reducing vibration in helicopters, offering better comfort with less weight than traditional passive technologies.

In the past, passive techniques were used. These include traditional vibration dampers, shock absorbers, and base isolation.

3. Importance

The development of **Active Noise and Vibration Control (ANVC)** technologies is driven by the regulatory bodies and competitive nature of commercial aerospace companies which require higher performance aircraft in order to maintain their market share. The importance of these systems are discussed in the following:

• Currently, the world research and development efforts focus on the reduction of cabin noise and vibration levels in regional aircraft. This is expected to increase passenger acceptance, leading to a larger market share while meeting the European workplace health and safety regulations.

• Active noise and vibration techniques are expected to reduce the noise and vibration levels while meeting the competitive need to produce light weight structures. Meeting this need will require innovative well engineered systems.

• The commercial airlines exert strong pressure to reduce life-cycle cost, including purchase cost and cost of maintenance. Aircraft which do not have a competitive balance of price, performance, durability and efficiency will rapidly lose market share.

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• Military driven requirements for ANVC technology in helicopters, in fixed wing aircraft and high performance aircraft. In these applications control of vibrations in both primary and secondary structures can greatly increase the performance of these aircraft and lead to innovative new designs which were not implemented in the past due to problems associated with vibration.

4. Maturity and Risk

4.1. Maturity of Technology

Recently, active noise and vibration technologies have been applied to a number of prototype systems and are commercially available in certain niche markets. Active noise control systems which are commercially available or under development, include transformer quieting, cabin and cockpit quieting systems, fall and blower ducts, active headsets and active mufflers. Active vibration control systems are also being developed for active engine mounts, active suspensions and flutter control.

5. Technological Risks

Effectiveness of ANVC is dependent on accurate modeling of the system which is being controlled. Errors in the initial modeling could lead to inefficiencies in the performance of the ANVC system. In addition, a number of reliability issues associated with ANVC still need to be addressed, such as fatigue lifetime and structural integrity. As a result, each potential aerospace application will have to be designed individually and the reliability issues associated with each design must also be treated independently. These noise and vibration reduction goals must be achieved at minimal cost and weight penalty in the face of fierce international competition. In addition, the new A *VCI* ANC systems must not impose an undue maintenance burden on the operator.

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6. Availability

Currently, all of the required component technologies necessary for successful implementation of ANVC are available: sensors, actuators and digital signal processing control systems. A variety of suitable sensors are utilized in ANVC applications, including microphones, strain sensors, fiber optic sensors, velocity sensors, accelerometers and strain gauges. The design criteria for choosing point or distributed sensors for ANVC applications, include accuracy, bandwidth, reliable in the aerospace environment, weight and cost.
A number of actuators are utilized in ANVC applications, including: piezoelectric, magnetostrictive, shape memory alloy, electromagnetic and hydraulic actuators. The design criteria for choosing actuators for ANVC applications, include accuracy, bandwidth, displacement, load carrying capabilities, reliable, weight and cost.
Powerful DSP chips and general purpose CPUs are available for incorporation into ANVC systems. These components can incorporate complex algorithms for the fast data manipulation required in ANVC applications.

7. Breadth of Application

These technologies are of interest to fixed and rotary wing airframe manufacturers and to sensor/actuator and avionics suppliers. As discussed earlier, potential applications exist in the automotive, industrial and consumer sectors.

8. Cost-Benefit Analysis

The cost of the initial systems will include research and development of ANVC systems for specific applications. These costs will include modeling, design, performance and reliability testing and prototyping. The majority of the work will be to implement existing technologies into the an ANVC smart system which can easily and reliably interface with the existing aerospace control systems, including power, software and hardware specifications.
The benefits of this technology include:

• Longer flying times

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• Better fuel efficiencies
• Large payload capabilities
• Longer distance travel (larger aircraft range)
• Increased passenger comfort

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