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Overview of Active and Passive Systems for the Turboprop Modern Generation

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ABSTRACT

Nowadays, one of the main marketing objectives of the new generation of turboprop aircrafts is the noise control to enhance the internal comfort. The propellers represent in fact the main noise source whose amplitude and frequencies depend on some design parameters such as its rotational angular speed, number of blades, power at shaft generating aircraft thrust and blades geometry. The higher energy levels are within the low-frequency region, corresponding in particular to the first blade passing frequency and its harmonics. The design goal is therefore to increase the passenger comfort level by controlling the propeller tonal noise and related vibrations. The present paper is aimed at discuss some relevant technological solutions to minimize the fuselage internal noise field at the passengers positions at each of the first three tones of the propeller load as well as due to other external aero-acoustic sources.

***Keywords*:** Active Control; Noise and Vibration; Turboprop

1. Introduction

The current significant advancement process within the short haul aviation field is introducing more and more requests concerning the internal noise and vibration reduction. The main source of these disturbances of a typical turboprop is the propeller functioning whose level and frequency depend on its rotational angular velocity, number of blades, power at shaft generating aircraft thrust and blades geometry. The higher noise levels generated are concentrated at 1st Blade Passing Frequency and its harmonics; while a broadband components, mainly linked with the blade shape, the developed engine power and the Turbulent Boundary Layer (TBL), also contribute to the interior noise levels. This Broadband components have, generally, lower single frequency amplitude but are distribute over a wide frequency range covering all audible range, being more important at frequencies lower than 1000 Hz. The needs to increase the engine power as well as the aerodynamic performance, in order to improve the aircraft performances, are such to increase the broadband noise level whole contribution up to the tonal ones thwarting the improvements reached on the design and development of tuned vibration absorber (TVA), Figure 1. Hence, the need to improve the design and manufacturing of the current tuned vibration absorber devices and also study an innovative active/semi-active device able to act not only on the 1st Blade Passing Frequency. As background of the whole activity, it is provided the following fundamental consideration which motivate the entire study: one of the main comfort issue affecting the passenger comfort, into a regional aircraft cabin, is the propeller tonal noise with related vibrations. These design aspects have been addressed by the authors affiliation being involved by more than 30 years on propeller aircraft comfort issues, experience also gained having contributed to many research activities on the turboprop family development; also well-known are the main commercial impacts on selling a propeller regional aircraft due to its specific noise and vibrations comfort performance capable to compete on the worldwide market. The present paper deals with a general overview of the technological solutions within the modern research framework: both passive and active ways for the noise control are outlined.

2. Introduction to Active Noise Control System

Active Noise Control (ANC) systems are addressed to reduce any type of undesirable disturbance or noise signal provided by a noise source transmitted through an environment, whether it is borne by airborne, electrical, acoustic,vibration, or any other kind of noise generation media. Since the noise source and relevant transmitting

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environment are often time-varying, the noise signal will often be not-stationary with respect to frequency content, amplitude, and velocity. Typically ANC systems control noise by introducing a cancelling signal "anti-noise" into the controlled environment or media generated by an appropriate secondary source system, **Figure 2**.

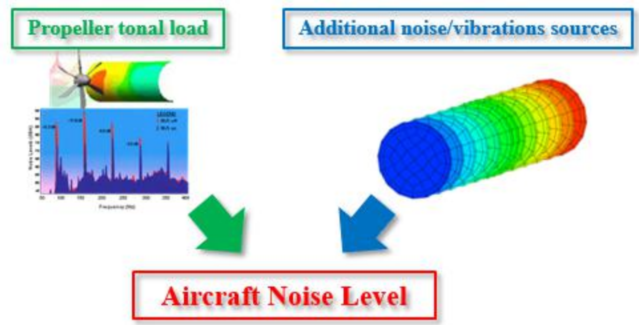

Figure 1; Turboprop Internal Comfort Evaluation Flow.

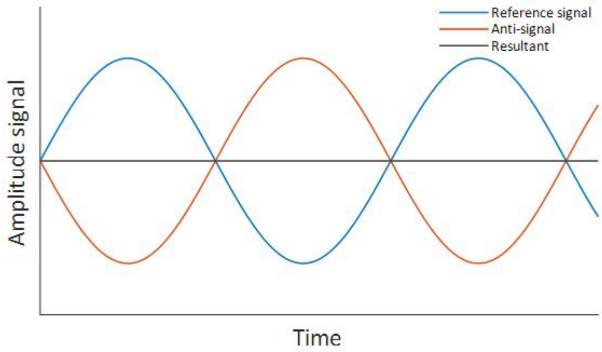

Figure 2; Working principle of a wave active control.

The anti-noise signal is ideally of equal amplitude and 180 degrees out-of-phase with the noise signal any time and along all the controlled space environment[1-2]. Consequently, the combination of the anti-noise signal with the existing noise signal at an acoustical summing junction results in the cancellation (or, more realistically) attenuation of both signals and hence a reduction in noise. The ANC system concept is an old idea but the realistic application was limited in the past by the impossibility to generate an anti-noise signal variable in time and within the space as required to control the noise source environmental signal. As soon the computer speed has become enough high to generate an adequate variable signal the control system has been developed; this has become during the '80 years. The application was first of all tried within the transport systems: cars, aircraft, etc., where the necessity of improved environmental conditions for the passenger comfort was very required and the commercial concurrence has helped the development of applicable system[3-4]. Today several car automobiles are installing very efficient systems as well some aircraft. Specifically the noise within any turboprop aircraft cabin has a significant contribution generated by the rotation of the propellers. The air-fluid motion activated by this propeller rotation creates pressure waves, which impinging on the aircraft fuselage, cause vibrations in the structure of the aircraft that generate noise signals transmitted all along the cabin volume, normally known as cabin noise levels. In an exemplary application, propeller noise-generating vibrations were dampened at their source, by a set of vibration actuators properly driven by a control system capable to reduce fuselage vibrations so that most of the noise normally generated never enters within the passenger cabin. The cabin environmental result is a dramatic reduction of both the noise and vibration levels within the cabin. As the system is fully active, it continuously adapts to changes in flight condition, therefore the passenger comfort is high improved.

3. Passive Damping solutions

The Dynamic Vibration Absorber (simple DVA in the following) is a passive device which when vibrate has one principal degree of freedom. A certain number of them are applied on the frame webs to reduce the radial frame/fuselage vibration at the tuning frequency (the propeller BPF) in order to control the propeller blade fundamental noise component transmitted in the cabin, and on the floor beams to reduce the floor vibration so controlling the vibration passenger comfort. A similar concept has and has had a large use on the propeller driven aircraft to improve the comfort on board. It is a full passive device useful to reduce the vibration of the main structure[5]. The peculiarity of a new possible design is that it is a full mass/spring device with only the structural damping, therefore too simple and also useful to implement an active control system. The device in this case shall be very similar adding an electromagnetic component around the moving mass, then having the potential to become a component of an active control system. Another "passive" solution is provided by dissipating materials. A typical aircraft composite fuselage skin is made by carbon fiber / epoxy resin pre-preg laminate. A possible way to increase the skin panel damping, without adding any additional damping treatment on its surface, consists in the addition of a viscoelastic layer into the laminate itself. In this way the functionality exploited by the constrained layer is substituted by the skin layers. This new design of skin gives a weight reduction to the overall damping treatments, because only the weight of the viscoelastic must be taken into account. As can be noticed, the viscoelastic layer is put just in the middle of the lamination sequence. When the structure is excited by flexural waves and bends, the two sides of composite work as a constrained layer each other, while the viscoelastic is subjected to shear strains and dissipates energy. The maximum energy dissipation is obtained when the viscoelastic layer is positioned in the middle plane of the skin section, where the shear strength generated by the bending moment is maximum. A series of experiments has been conducted in order to assure a good bonding of the viscoelastic layer with the epoxy resin, and verify that the mechanical properties of the skin itself are maintained. The damping treatment, if it is an add-on part or inserted in the skin itself, must not necessarily cover all the skin surface, but usually only the free bay between two stringers and two frames is treated. An innovative approach in manufacturing fuselage skin panels has been evaluated, where a thin layer of viscoelastic material has been added to the lamination sequence of the skin, in the middle plane. This allows to increase panel damping performance with a very neglectable added weight. The increase in damping performance of fuselage skin, if opportunely optimized and improved, can lead to the condition to avoid add-on damping treatments installation at all on the fuselage skin. This will mean a significant weight saving on an entire fuselage, and a more significant cost saving in terms of reduced part numbers to manage, completely cancelled working hours for the manual installation of these add-on damping patches on the internal skin[6-8].

4. Conclusions

The prediction and reduction of aircraft interior noise are important considerations for conventional propeller aircraft now entering the commercial market as well as for aircraft currently being developed, such as the advanced turboprop. Consequently, the interior noise problem is receiving attention even during the first stages of the aircraft design process. Vibrations topic is central in current engineering field, especially addressed to find optimized solution to reduce the noise impact in the aircraft sector. In aeronautical sector active-control technologies for noise and vibrations reduction can have different applications whose aim is improve quality of structure and making flight condition more comfortable. With the passive control techniques, it can proceed to work directly on the structure by making improvements that can reduce both structural vibration and noise. The presence of external control unit is not necessary, but it works directly on the mass, stiffness and damping matrices of the structure. On the other side, active control techniques have been developed in the last decades thanks to a great progress in the electronics and in control logics that have made possible the development of more and more efficient systems. The vibrations are controlled through the use of sensors and actuators “intelligent” network.

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