PASSENGER CABIN NOISE COMFORT EVOLUTION OF THE DASH-8Q

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1.0 INTRODUCTION

The Dash-8 Q Series are considered today the quietest turbo-prop aircraft in their category. This success is mainly attributed to the increased passenger comfort, provided by the reduction of the low frequency noise and vibration tones generated in the passenger cabin by the propellers.

This achievement is the result of more than a decade of development work on this field by Bombardier Aerospace deHavilland with specialised partners and consulting experts.

The purpose of this paper is to present the different development activities, including the design and implementation of the Active Noise and Vibration Suppression™ (ANVS) system with ULTRA Electronics N&V System division, which is being installed today on all new Dash-8 models, Q100/Q200/Q300 and Q400.

In parallel, a series of improvements introduced in the interior design of the aircraft has contributed to the enhancement of the passenger cabin noise and vibration environment. A brief overview of those changes is also presented in the paper.

2.0 NOISE AND VIBRATION SOURCES IN THE CABIN

The major sources of noise and vibration in the passenger cabin of the cabin are listed below. It is important to note that while some of those sources do not contribute directly to the overall cabin noise and vibration levels, they can be significantly annoying to passengers, and need to be addressed in the design of the cabin environment.

a. Boundary layer noise.
b. Systems noise from the air distribution system, the cooling fans, the hydraulic pumps, and the galley and lavatory drains.
c. Propeller induced tones: which arise at the blade pass frequency (RPM x No. of blades), and its harmonics.
d. Propeller imbalance, which generates vibration at the propeller rotating frequency.
e. Buzz and rattles, and interior component resonance.
f. Propeller modulation noise and vibration caused by a slight difference in RPM between the two propellers.

In order to provide a "jet-like" quiet environment in a turbo-prop aircraft, sources "c", "d", "e" and "f" needed to be addressed specifically. Baseline surveys on the aircraft showed that the propeller induced tones were required to be reduced significantly to increase comfort.

3.0 PASSIVE TUNED VIBRATION ABSORBERS (TVAS)

The first step in cabin comfort improvement was launched in the early 90's, with the introduction of Passive TVAs of the production Dash-8 Series 100 and 300. An exhaustive test program, utilising a Series 300, was conducted with Anatrol Corp. to design the units and to determine their locations.

The in-flight measurements of the operating deflection shapes at the blade pass frequency (BPF) and harmonics were used to define the optimum positioning of the Passive TVAs.

The program lead to the definition of production kits that were to be installed on five frames of the fuselage in the propeller plane area. Two sets of TVAs were required, one to attenuate the BPF and the other to attenuate its first harmonic, 2BPF. Figure 1.0 shows the in-flight operating deflection shape of the frames at the BPF with and without the Passive TVAs.

The advantages of such a system was a reduction of 4 dB(A) in the SPL at the worst seat, and a cabin average noise reduction of around 2 dB(A) in cruise condition. However, the residual propeller tones were still dominant in some area of the cabin, and the Passive TVAs were efficient only at the cruise RPM condition of 910 RPM, there was no real benefit at the take-off and climb RPMs of 1200 and 1050 RPM respectively.

4.0 ACTIVE NOISE CANCELLATION (ANC) SYSTEM

In parallel, the use of speaker based ANC system was considered by the company. In 1992, a technology demonstrator program was conducted on a Dash-8 Series 100. The trial system provided by Noise Cancellation Technologies consisted of one controller, 48 microphones and 23 speakers temporarily installed inside the passenger cabin.

The net advantages of such a system were its ability to reduce the BPF and its first 3 harmonics, and its capacity to operate at the different propeller RPMs. An overall noise reduction up to 6 dB(A) at the worst seat was measured in-flight, while the cabin average noise level was reduced by up to 5 dB(A) in the loudest cruise RPM condition. However, such a system provided no reduction in cabin vibration.

The main problem associated with the implementation of an ANC system on production aircraft is the installation of the speakers and their enclosures. These units interfere directly with the interior trim panels, the aircraft structure and system components. As a result, a number of favourable speaker locations for noise reduction could be eliminated, thus reducing the system performance.

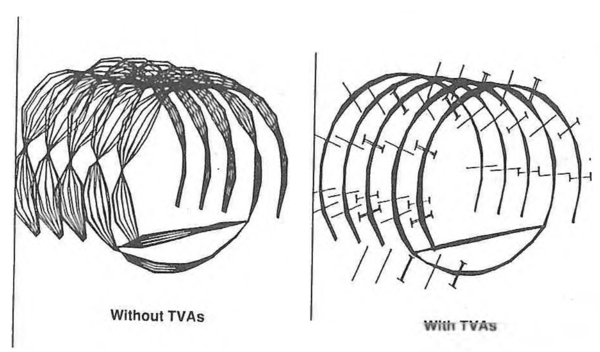

Fig 1. Operation deflection shape at the BPF with and without passive TVAs.

5. ACTIVE NOISE AND VIBRATION SUPPRESSION (ANVS) SYSTEM

The advantages of both the Passive TVAs and the speaker based ANC system needed to be combined in order to achieve major noise and vibration reductions in the cabin. Between 1994 and 1996, an intense development program was jointly conducted by Bombardier Aerospace and Ultra Electronics N&V System division.

The actuators designed for this system are Active Tuned Vibration Absorbers (ATVAs), which are installed with their power amplifier directly on the fuselage frames to control the vibration field of the fuselage.

In addition to the ATVAs, the system includes a central controller and a large set of microphones which are mounted behind the interior trim panels, leaving only a tiny hole seen from the inside for the cabin noise to be measured. The system on the Q400 Series also includes accelerometers as sensors to increase vibration reduction performance.

The system also utilises inputs from aircraft systems, such as tachometer signals to track the frequency, and the cabin differential pressure to account for the dynamic structural change of the fuselage with pressurisation.

The definition of the location of the sensors and actuators, and the system implementation were completed through specific development phases:

Identification of all possible sensor and actuator locations: this stage required drawing reviews and aircraft surveys.
Transfer Functions (FRF) measurements for all possible sensor and actuator locations with externally mounted ATVA on a furnished aircraft.
In-flight baseline cabin noise and vibration measurements at the various conditions throughout the whole cabin.
System layout definition: performance predictions and optimisation calculations.
Component design for light weight, high reliability, and stringent certification requirements.
Trial installation and system optimisation test flights.
System calibration and functional test procedures before entry into service.

6.0 RESULTS

The net result is a significant reduction of both noise and vibration in the passenger cabin. Both the BPF and the harmonics are reduced significantly throughout the cabin, for any of the operating propeller RPMs of the aircraft.

Figure 2.0 shows a typical noise spectra in the propeller plane area with the ANVS system both ON and OFF. On some seats, the combined induced tones are reduced by more than 12 dB(A). On cruise condition, the loudest seat is reduced by over 8 dB(A) in SPL, and the cabin average is improved by a reduction up to 5 dB(A) in SPL, which provides a cabin noise level equal or below the level of some commercial jets of same capacity.

The first production version of the ANVS system was incorporated on a production Dash-8 in 1996. Since then, the ANVS system is an integral part of the production aircraft built for all models, and over 125 Dash-8 aircraft have been delivered to date with the system installed.

7.0 INTERIOR DESIGN FEATURES

A series of additional improvement in the interior design was also introduced to enhance cabin comfort. Right at the design stage of the interior, specific guidelines were followed and passive treatment solutions were implemented, these includes :

The soft mounting of the trim panels and bins.
The sealing of joints and gaps between trim panels and bins.
The optimisation of the insulation package for noise absorption and maintainability.
The avoidance of the natural frequencies for interior components (panels, meal trays, seats, light lens, etc.) at the BPF and propeller shaft RPM.
The elimination of buzz and rattles.

8.0 SYNCHROPHASER AND PROPELLER BALANCING

Two other valuable systems are integrated in the aircraft for passenger comfort, the synchophaser and the propeller balance monitoring system.

The purpose of the synchrophaser is to maintain the two propellers at the exact same speed and with a constant relative angle between them. The main benefit of such a system is the elimination of the propeller modulation or beating noise. The programmable angle capability of the unit also allows to select the optimum angle to reduce the combined noise and vibration contribution of each propeller in the cabin.

The propeller balance monitoring system installed on the aircraft allows the continuous monitoring of the propeller balance condition. After a flight, the operator can read the balance status, calculate and install the required single plane mass balance solution to avoid any imbalance vibration. In case of imbalance, low frequency vibration at the propeller shaft RPM could be an annoyance to passengers due to the shaking of the seats, floors or interior components.

9.0 CONCLUSION

The Dash-8Q aircraft has achieved a new level in turbo-prop cabin comfort. The introduction of its ANVS system and additional features are providing comfortable cabin environment to both passengers and crew. The experimental approach and advance developments were the keys to this success. Through continuing test programs, new findings have also been made, which could lead to further advancements in cabin comfort in the near future of the Dash-8Q aircraft.

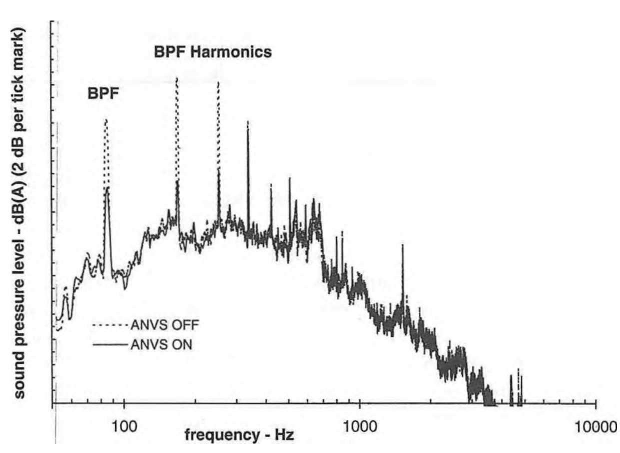

Fig 2. Typical Dash-8 noise spectra in the passenger cabin, propeller plane area.