MODELING AIRCRAFT CABIN NOISE WITH STATISTICAL ENERGY ANALYSIS (SEA)

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1. INTRODUCTION

Designing aircraft for lower passenger cabin noise and reduced weight is a considerable challenge that requires sophisticated prediction tools. Statistical Energy Analysis (SEA) is widely used in the aerospace industry to predict aircraft cabin interior noise in the mid-high frequency range. Bombardier Aerospace uses SEA as the primary tool to design optimized noise treatments at reduced weight. This paper is a summary of the work conducted by Bombardier to develop and validate SEA modeling methodologies for aircraft structures.

SEA is preferred over deterministic Finite Element (FE) methods to model the vibro-acoustic behaviour of aircraft structures[1]. Aircraft structures typically exhibit high modal densities in the mid-high frequency range, which are very sensitive to perturbations. Furthermore, the dominant noise sources in flight at cruise conditions are broadband, random, and appropriate for SEA modeling. Another advantage of SEA is that a path contribution analysis can be obtained from a solution, which is a valuable result that can be used to optimize the location of noise treatments.

2. SEA MODELING

The Statistical Energy Analysis (SEA) method[2] has been applied to model aircraft cabin noise in flight cruise conditions[3]. The aircraft modeling methodology has been developed from a progression of simple Transmission Loss (TL) models to more complex aircraft cabin noise models. Tests have been conducted to validate the SEA models. AutoSEA2 software is used for all SEA modeling.

2.1 Transmission Loss

Transmission loss of the fuselage cross-section has been modeled and validated with TL measurements conducted at the University of Sherbrooke. The TL model combines SEA and, independently, a transfer matrix approach to determine the insertion loss and absorption of the insulation blankets. The transfer matrix modeling is accomplished with Nova – a software code developed by the University of Sherbrooke and Mecanum Inc. – and models wave propagation through homogenous layers of solid, shells, fluid and porous media. The fuselage panel and trim are modeled as SEA subsystems – the ribbed panel property is used for the aluminum skin and frames, the sandwich or general laminate property is used for the trim panel.

2.2 Aircraft Cabin

The modeling technique developed and validated for TL provided the confidence to model the interior noise in a full aircraft with diffuse acoustic sources. SEA models of a green and completed aircraft were developed to predict the cabin average Sound-Pressure Level (SPL). These models consist of subsystems for the green aircraft structure, interior components, and acoustic cavities (cabin and below floor). Each subsystem must satisfy the SEA requirements – minimum 5 modes per band and a high modal overlap (>0.5). The models were validated from ground tests conducted with loudspeakers emitting pink noise surrounding the airplane in a hanger (a diffuse acoustic source was approximated).

After successful validation of the aircraft cabin model from ground test, the models were modified to predict the in-flight cabin average SPL at standard cruise condition. The diffuse acoustic field excitation was replaced with a Turbulent Boundary Layer (TBL) source, the dominant noise source for jets with fuselage aft mounted engines, in cruise flight condition. The Corcoss[4] and Efimtsov[5] models to estimate the modal power input to a structure excited by TBL were considered. Noise from the air supply and re-circulation in the cabin from the Environment Control System (ECS) was implemented as a direct user-defined power input source. Sound power levels were obtained from sound-intensity probe scans over the ECS registers. Noise from other systems such as pumps and fans are usually insignificant in cruise flight conditions. Structure-borne noise, originating from the fan and turbine tones through the engine mounts, is present but usually not significant in flight. Furthermore this excitation is lower in frequency, more deterministic and, hence, not well represented in an SEA model.

3. MODEL VALIDATION

Three TL configurations are considered – the bare fuselage panel (aluminum skin and frames), fuselage panel with insulation bags, and the fuselage panel with insulation and interior trim panel (double-wall system). The 1/3-octave band TL spectrum for each configuration is predicted and measured. Results for the double-wall system are shown in Figure 1.

Three aircraft cabin configurations are considered – green (bare fuselage structure, no insulation or interior), green with insulation blankets, completed aircraft (full interior installed). Cabin average 1/3-octave band SPL spectrum was predicted and measured from ground tests for the three configurations. Results for the completed aircraft case are shown in Figure 2.

The completed aircraft cabin model was modified to predict average SPL for in-flight cruise conditions. The TBL source model available in the software was used with default wavenumber and correlation decay coefficient constants (Corcoss model), and with wavenumber and correlation decay coefficient spectra calculated using the Efimtsov empirical equations[5]. Predicted cabin average SPL was compared to the average SPL from in-flight noise surveys on 5 aircraft with a similar interior. Average octave-band SPL spectra are shown in Figure 3, comparing SEA predictions (Corcoss and Efimtsov TBL models) with measurements.

4. DISCUSSION

Overall there was good agreement between SEA predictions and measurement for TL and cabin average SPL. The TL predictions correlate well with measurement for the fuselage panel with insulation and trim panel, yielding confidence in the modeling of noise transmission through the fuselage cross-section. In the aircraft cabin model with full interior, the SEA predictions compare well to the measurement, but under predict in the mid frequency range. This discrepancy is attributed to crude approximations in the modeling of the interior mounting and the damping of the trimmed fuselage. This could be improved with measured coupling loss factors for the interior mounts, and better damping models for the treated fuselage.

Good agreement in the cabin average SPL prediction vs. measurement for in-flight cruise condition was observed. The Efimtsov TBL model yielded better correlation to measurement. This model could also be improved with better coupling loss factors for the interior trim mounts and damping loss factors for the trimmed fuselage.

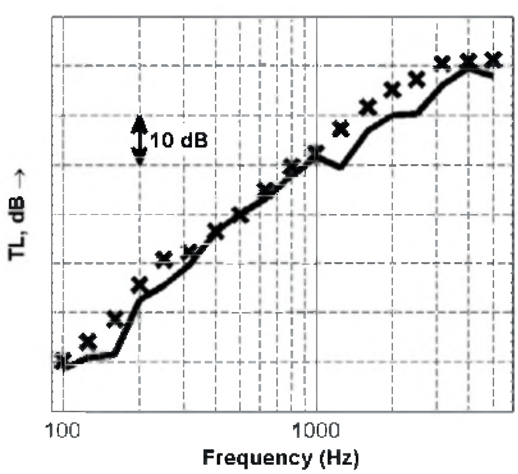

Figure 1. Third-octave band TL of the fuselage panel + insulation + trim panel. Measurement: X. SEA prediction: ▬

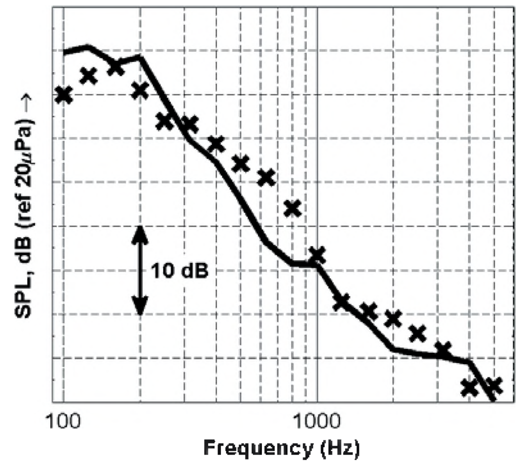

Figure 2. Cabin average 1/3-octave band SPL from ground test, diffuse acoustic exterior source. Measurement: X. SEA prediction: ▬

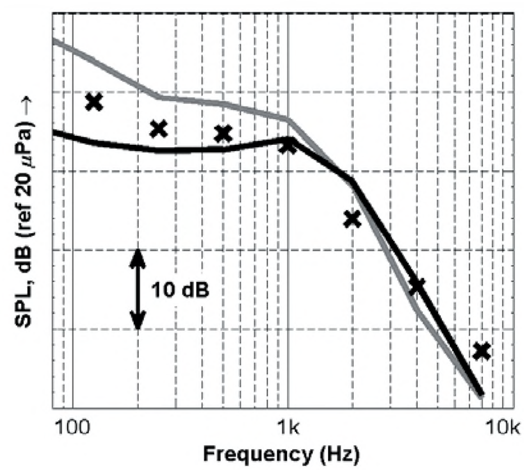

Figure 3. Cabin average octave-band SPL in flight cruise condition. Measurement: X. SEA prediction with Efimtsov TBL parameters: ▬ . Sea prediction with Corcoss TBL parameters: ▬

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