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Hybrid Active-passive Systems for Control of Aircraft Interior Noise

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Previous work has demonstrated the large potential for hybrid active-passive systems for attenuating interior noise in aircraft fuselages. The main advantage of an active-passive system is, by utilizing the natural dynamics of the actuator system, the control actuator power and weight is markedly reduced and stability/robustness is enhanced. Three different active-passive approaches were studied in the past year.

The first technique utilizes multiple tunable vibration absorbers (ATVA) for reducing narrow band sound radiated from panels and transmitted through fuselage structures. The focus is on reducing interior noise due to propeller or turbo fan harmonic excitation. Two types of tunable vibration absorbers were investigated; a solid state system based upon a piezoelectric mechanical exciter and an electromechanical system based upon a Motran shaker. Both of these systems utilize a mass-spring dynamic effect to maximize the output force near resonance of the shaker system and so can also be used as vibration absorbers. The dynamic properties of the absorbers (i.e. resonance frequency) were modified using a feedback signal from an accelerometer mounted on the active mass, passed through a compensator and fed into the drive component of the shaker system (piezoelectric element or voice coil respectively). The feedback loop consisted of a two coefficient FIR filter, implemented on a DSP, where the input is acceleration of the ATVA mass and the output is a force acting in parallel with the stiffness of the absorber. By separating the feedback signal into real and imaginary components, the effective natural frequency and damping of the ATVA can be altered independently. This approach gave control of the resonance frequencies while also allowing the simultaneous removal of damping from the ATVA , thus increasing the ease of controllability and effectiveness. In order to obtain a "tuned" vibration absorber the chosen resonant frequency was set to the excitation frequency. In order to minimize sound radiation a gradient descent algorithm was developed which globally adapted the resonance frequencies of multiple ATVA's while minimizing a cost based upon the radiated sound power or sound energy obtained from an array of microphones.

The performance of the ATVA's was investigated theoretically and experimentally. Simulations of the ATVA's with the local feedback laws and global detuning demonstrated its potential. Five sets of experiments were carried out. In the first, the use of both types of ATVA's and the local feedback tuning laws were studied and demonstrated on a SDOF large shaker base. In the second, multiple solid state piezoelectric and Motran based ATVA's were applied to large steel plate located in the VAL-VPI anechoic chamber. The experiments demonstrated that global detuning leads to improved sound reduction over local perfect tuning. The Motran based ATVA's were then applied to the composite fuselage test rig at NASA LaRC and demonstrated that the tuning laws can work on a real structure. The Motran ATVA's were the applied to the VAL-VPI Cessna fuselage test rig and new global detuning control laws were developed and successfully demonstrated. Finally the Motran ATVA's were applied to a flight test of a Beech propeller aircraft. The flight test demonstrated sound reduction when the ATVA's were tuned to the propeller fundamental frequency. However due to a software modification error it was not possible to demonstrate the global detuning technique in flight. The experimental results have demonstrated the large potential of tunable ATVA's for reducing interior noise with a low weight, low power system. The proposed research will build upon this work for further development and demonstration of the ATVA techniques.

The second active-passive technique utilizes the smart foam system to control broadband interior noise due to boundary layer excitation. The smart foam elements consist of standard acoustic blown polyurethane foam (the passive component) with embedded curved PVDF elements (the active component). Much work was carried out studying the most effective smart foam configuration and manufacturing technique in order to increase the control output. Three main tests were carried out to demonstrate the use of the smart foam. In the first test an experimental rig was constructed on a small wind tunnel at VPI. An aluminum panel , surrounded by an anechoic box, was positioned flush in the side of the tunnel. Six smart foam elements were used to cover the exterior side of the panel. The smart foam elements were glued directly to the plate. A feedforward control approach was used to minimize the radiated sound at an array of microphones positioned in the anechoic box. Four accelerometers located on the panel were used to provide reference signals. The LMS filtered -x controller resident on a C40 DSP system was thus 4 by 6 by 6. The system demonstrated good control of boundary layer noise from 300 to 800Hz with a flow rate of M=0.15. The smart foam system was then applied to a real aircraft panel located in a low speed wind tunnel at NASA LaRC. Again high attenuations of boundary layer noise in the 300 to 1000Hz band were demonstrated for flow speeds of M=0.1. Finally the smart foam system was applied to an advanced aircraft Titanium panel located in the high speed wind tunnel at AEDC, Tennessee. Test were performed at M=0.8 and 1.5. Both tests gave good attenuation of boundary layer radiated sound with the M=0.8 providing excellent control. A surprising result of all of the above tests was the amount of passive structural damping achieved with the smart foam at low frequencies. The above series of tests have demonstrated a number of key aspects of the smart foam. Firstly the smart foam has enough control output to be used on real aircraft panels at real flow speeds. Secondly, the feedforward control approach can be utilized in real applications with structural reference sensors. Thirdly the smart foam provides both high passive structural and acoustic damping and good active reduction giving a very lightweight, effective noise reduction treatment. Further work is planned in order to investigate and develop more effective smart foam elements and associated control approaches as discussed below.

The third active-passive approach was focussed on developing active trim panels for reducing cabin noise. The focus application is interior noise due to a localized flow excitation due to vortex separation over the crown of the aircraft. This part of the project completed work initiated in the previous year. The speaker excitation source on the exterior of the Cessna fuselage was modified to include multiple uncorrelated noise sources which is more representative of the real application. Tests were performed using two uncorrelated noise sources and two different types of reference sensors; an array of fuselage mounted accelerometers and an array of exterior pressure sensors mounted flush with the fuselage. The controller was a MIMO Filtered-x resident on a TMS C40 DSP system. The tests showed large improvements in control performance (amount of attenuation, global nature of the control field reduction and control bandwidth) when the pressure sensors were used as reference sensors due to decreasing the latency through the control path. This suggests that a realistic control system for reducing flow noise due to vortex separation would consist of an array of exterior flush mounted pressure sensors whose outputs are directly summed to provide a single reference signal. The work also demonstrated that the active trim panel will also work for realistic disturbance levels and form.