Chapter 7

Conclusions and recommendations

An advanced model of active control of fan noise for turbofan engines has been developed. This model was developed by implementing active noise control into the ducted fan noise prediction code TBIEM3D. As such, the model simulates the generation and control of fan noise radiating from the openings of a finite length, infinitesimally thin circular cylinder in a uniform flow field.

Two new fan models were developed to simulate fan loading noise. The first model uses spinning line sources, with radially distributed strength, to model the loading force that the fan blades apply to the medium. The second model uses radial arrays of spinning point dipoles to simulate the generation of fan modes of specific modal amplitudes. The accuracy of these fan models was tested via comparison to experimental data. Good agreement was observed between numerical and experimental results, showing that these fan models can provide a reasonable approximation of actual engine fan noise in the instance when the modal amplitude of the propagating modes, or the loading force distribution on the fan blades, is known.

The control sources required by the active control system were modeled as point monopoles placed along the duct inner wall. Different system configurations and feedforward control algorithms were modeled. The control systems modeled comprised one or two control source array(s) and error sensors placed in the acoustic far field, or along the aircraft fuselage, or along the duct inner wall. The duct inner wall was assumed to be either lined or rigid.

Several cases of active control of ducted fan noise were performed in order to demonstrate the feasibility of the model and to investigate the potential that active noise control techniques have in reducing fan noise on a ultra high bypass turbofan engine. Regarding the capabilities of the model, the results obtained indicates that:

1) The model is conducive to more realistic studies of active control of fan noise on ultra high bypass turbofan engines because it accounts for the presence of evanescent modes generated by the fan and control sources, and for interference between inlet and outlet radiation. These two factors, which are not included in current models, were shown to have significant impact on the performance of the active noise control system for ducts of geometry representative of ultra high bypass turbofan engines.

2) This model is very useful because it allows monitoring of any region of the acoustic field. For example, it provides information on the behavior of the pressure field downstream of the outlet and around the duct when active noise control of inlet noise is performed.

3) The model is versatile because it can model purely passive, purely active or hybrid noise control techniques.

4) The model is computationally fast, and therefore suitable for conducting multi-variable parametric studies on practical computers.

Regarding active control of the fan noise radiating from an ultra high bypass turbofan engine, the results obtained indicate that:

1) Active noise control has the potential to reduce substantially, over a relatively large sector, the fan noise radiated by an ultra high bypass turbofan engine. With a lined engine duct, two control source arrays and seven fuselage-mounted error sensors, a reduction in sound power level of up to 10.2 dB could be achieved within the 40° to 155° sector (sector measured from the inlet opening, with respect to the axis of the duct).

2) A hybrid control system can achieve significantly better levels of noise reduction as compared to a pure passive or pure active control system; also, its optimum solution is more robust than the one achieved with a pure active control system.

3) The fuselage error sensor technique performs better than the in-duct wavenumber sensor technique. The former has a more robust optimum solution and is easier to optimize.

4) An increase in the mean flow Mach number can result in a larger number of modes propagating in the duct, hence increasing the number of degrees of freedom of the problem to solve and diminishing the performance of the control system. An increase in the flow Mach number would particularly affect the performance of the in-duct wavenumber sensors technique since it would diminish the spacing between consecutive axial wavenumbers, making it more difficult for the control system to accurately detect the propagating modes.

5) When controlling the noise radiating within a 40 to 155 degree sector (sector that is believed to strongly affect the EPNL), radiation from both the inlet and outlet influence the optimum solution. Simultaneous control of inlet and outlet radiation

increases the robustness of the optimum solution with respect to the location of the control source arrays.

6) The presence of evanescent modes can not be neglected. Due to the short length of the duct, the modes that are close to being cut-on do not completely decay before reaching the duct openings and thus radiate into the far field. The phase and amplitude of each of these modes are detected by the error sensors, increasing the number of degrees of freedom of the problem to solve and hence affecting the performance of the control system.

Recommendations for future work are:

- Extend the fan model to include the thickness component of fan noise. This process already been initiated. Derivations of an analytical expression for thickness noise for the spinning line source fan model are presented in Appendix B.

- Control of multiple tones, i.e., blade passing frequency and harmonics, should be investigated. This model can be easily used to study the performance that a purely active or hybrid control system can achieve when multiple tones are targeted for control. For example, it would be interesting to study the performance that a hybrid control system can achieve if the liner could be tuned to control a given tone, while the active control system targets a different one.

- Use this model to try to uncover the mechanics behind a hybrid control approach, including:
  - Effect of the presence of the control modes in the duct on the behavior of the liner.
  - Effect of the presence of the liner on the output of the active control system.

- Optimization of combined passive/active control.
- Effect of axially segmented liners on hybrid control system performance.

- Use the model to study the influence of engine geometry on the control of fan noise radiation.

- Include reflection from stator vanes.

- Include reflection from the fan.