Optimisation and Adaptive Control of Aircraft Propeller Synchrophase Angles

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For my father
Richard Mark Blunt
24 April 1924 – 24 October 2009

Abstract

This thesis provides a new and detailed examination of how the optimum propeller synchrophase angles for minimum cabin noise and vibration vary with different flight conditions, particularly altitude and airspeed, and how, based on these observations, adaptive control techniques could best be employed to further improve the noise-reducing potential of synchrophasing. This has been done through experimental investigations in one AP-3C Orion and two C-130J-30 Super Hercules aircraft.

It is shown, using propeller signature theory, that synchrophasing has significant effects on the average cabin floor vibration and the average cabin sound pressure levels. In the trial aircraft, these effects range between 4 dB and 12 dB at the blade-pass frequency, depending on the flight condition and the aircraft. The effects at individual sensors locations can, however, sometimes exceed 20 dB.

It is also shown that the effects of altitude and airspeed on the optimum synchrophase angles are significant, and that a fixed set of synchrophase angles cannot be optimal for more than a limited range of flight conditions. For example, over the range of altitudes and airspeeds considered in this investigation, a fixed set of angles is shown to produce results that can vary by more than half of the range from the lowest to the highest predicted average sound pressure level at the blade-pass frequency.

Adaptive control of the synchrophase angles using pre-defined look-up tables or active control algorithms are considered, and the latter recommended for their ability to compensate for unknown and variable influencing factors.

Two ranking strategies are developed and employed to identify the number and placement of error sensors for an active control system. Significantly, both strategies identify that the predicted average sound pressure levels at the blade-pass frequency in the trial aircraft could be maintained within 2 dB of the optimum across all considered flight conditions using as few as 3 to 6 well-placed microphones.

A single-input (master propeller tachometer) multi-output (slave propeller synchrophase angles) feed-forward active control system with multiple error sensors (microphones or accelerometers) is developed using propeller signature theory and the Filtered-x LMS algorithm.

Recommendations for further work are also made.

Acknowledgment

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Thesis Declaration

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