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Passengers’ seat vibration exposure on turboprop aircraft flights

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THE WORK IN CONTEXT

Turboprop aircraft offer the possibility of lower emissions for regional travel in comparison to jet aircraft. Future low-carbon aircraft concepts include propeller-generated thrust powered from fuel cells, hydrogen, biofuel, battery or hybrid power. The noise and vibration experienced in a turboprop cabin is different to that experienced in a jet, with signals characterised by tonal components related to the blade pass frequency of the propellers. These components have been associated with more noise and vibration discomfort. There are few published studies of aircraft cabin vibration measured on the seat cushion surface according to ISO2631-1. This paper gives data from two turboprop aircraft flights with measurements made in three different seats. It shows how the vibration is highly tonal, and is affected by position and flight phase.

KEYWORDS

Turboprop, comfort, ISO2631-1, vibration, ComfDemo

Introduction

Demand for passenger air travel is expected to continue to grow despite the shift in working patterns and communication norms triggered by the global pandemic (International Air Transport Association, 2021). Regional passenger transport usually occurs on single aisle aircraft, including those powered by turbojet engines (‘jets’ such as Boeing 737 or Airbus A320 series) or turboprops (such as ATR 42/72 or Bombardier Q400/Dash 8). Turboprops generate power through rotation of the propeller, the wake from which interacts with the wing resulting in the tonal component related to the blade pass frequency. Future aircraft may use alternative power sources such as electric or hybrid systems also likely to use propellers. Passengers perceive propeller aircraft as being uncomfortable due the noise and vibration (Mansfield et al., 2021).

A review of the literature showed that there have been very few published studies of the vibration experienced by passengers in aircraft cabins (Mansfield & Aggarwal, 2022). Studies rarely conducted vibration measurements according to ISO261-1 or measured the entire flight from gate-to-gate.

This paper reports vibration data measured on the surface of seats in an ATR72 turboprop aircraft. Two fully occupied test flights were conducted as part of the ComfDemo project (Vink, et al., 2022).

Method

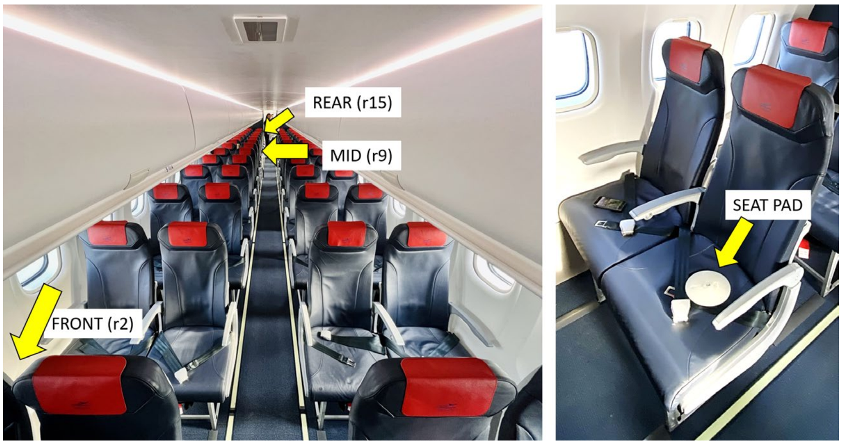

Figure 1. Position of accelerometers in the ATR aircraft.

Data was collected on two flights of 70 minutes duration reaching a cruising altitude of 17,000 feet. Data was also collected during taxi. The aircraft was an ATR72-500 with a capacity of 60. The aircraft was configured in a 2x2 layout with 35” seat pitch.

Whole body vibration was measured on the surface of three occupied seats in the aircraft cabin. The seats were located on different rows representing front (p1), middle (p2) and rear (p3) positions. Measurements were made using Axivity AX3 triaxial accelerometer and data loggers which were mounted inside a seat pad (Figure 1). Calibration was checked before each flight (ATR01 and ATR02). The AX3s were configured to sample at 800 Hz with a range of 2 g. Measurements were conducted for the full duration of the flights. Data segments were extracted from the measurements for full analysis. The data segments were selected to represent the different flight phases.

Data analysis was conducted in MATLAB and included frequency weighted signals, in accordance with ISO2631-1, and the use of unweighted band limited signals.

Results

Samples of data were extracted based on the flight phase. Five-minute data samples were extracted for taxi, climb, cruise and approach/landing. Runway/take-off comprised a shorter sample (approximately 40s) starting from initial acceleration to take-off.

For most phases of the flight, the vibration was dominated by the main engine rotation and harmonics related to the blade-pass frequency (Figure 2). The first peak during the climb and cruise phase occurred at 16.5 Hz, with additional components at 35, 49 and 98 Hz. During landing the 16.5 Hz component is reduced but blade-pass harmonics are still present. Lower frequency components were increased due to air turbulence.

Frequency weighted vibration data showed that the highest vibration was experienced on the runway / takeoff phase, and the least during the cruise phase (Figure 3). Whilst the vibration was greatest during runway/takeoff, this was the shortest element of the flight with measurements lasting less than a minute. There was a greater variation with flight phase than with position on the aircraft. However, p3 at the rear of the aircraft showed a higher magnitude of vibration than p1 or p2 during takeoff and landing. During flight 2, there was more cloud cover and therefore more turbulence during the landing phase, as observed in the data comparing flights ATR01 and ATR02 ‘land’ data.

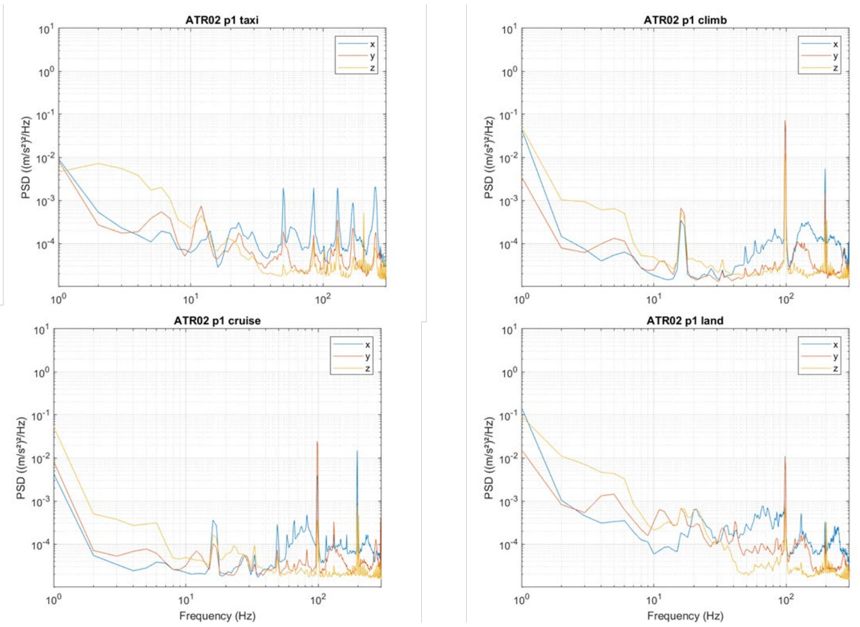

Figure 2. Power Spectral Density of vibration measured on the surface of an aircraft seat during four flight phases; flight 2.

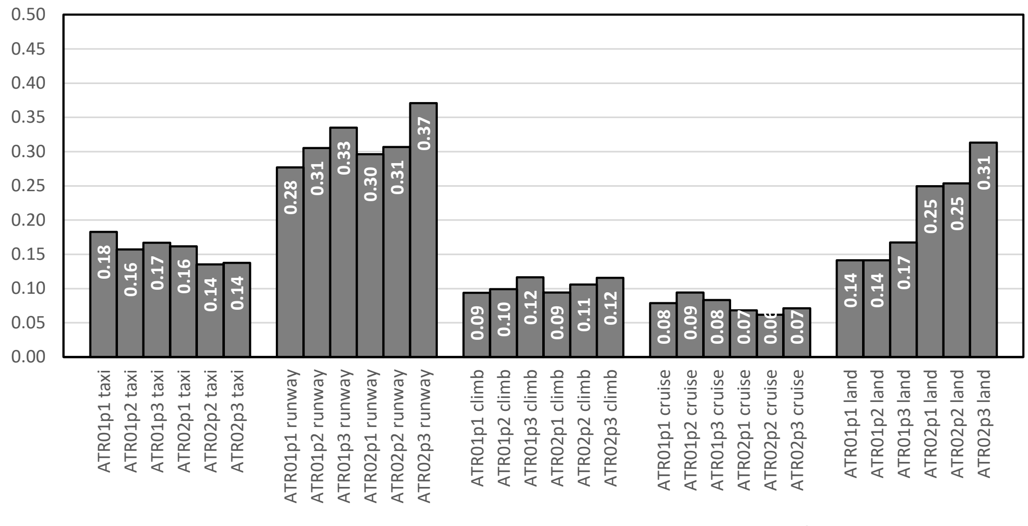

Figure 3. Frequency weighted vibration magnitude measured at each of three seat positions over two flights. Data show r.s.s. vibration including axis multipliers.

Turboprop aircraft have a reputation for exposing passengers to uncomfortable vibration that is not clearly supported by the frequency weighted vibration results. Some studies have shown that vibration that is highly attenuated by frequency weighting filters can be important for perception (Morioka & Griffin, 2006). Spectral analysis showed that there was significant vibration with high levels of tonality (e.g. Figure 2). To consider higher frequency vibration components in an overall analysis it is possible to use ISO 2631-1 band-limiting filters at 0.4 and 100 Hz. However, Figure 2 illustrates that there are several components of vibration that would be attenuated by a 100 Hz filter. To

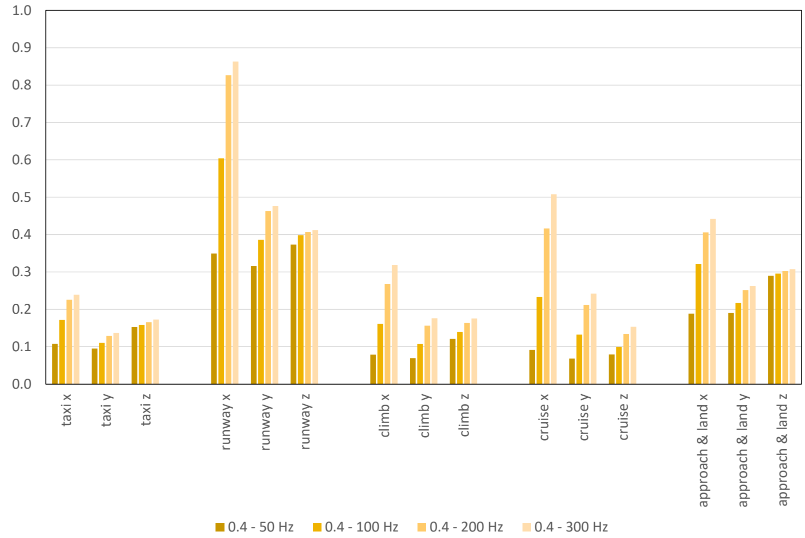

Figure 4. Effect of low-pass band limiting filter on r.m.s. vibration across all flight phases (ATR02p2).

investigate this effect, band-limiting filters were applied at the ISO 2631-1 frequencies, and also with a low-pass filter set to 50 Hz, 200 Hz, and 300 Hz. These data show that the dominant axis of vibration changes with selection of the band-limiting filter.

If the low pass filter is set to 50 Hz vertical vibration is dominant for most flight phases (Fig 4). As the filter frequency increases, fore-aft vibration becomes dominant. Therefore prioritization of the aircraft optimization strategy will be dictated by the selection of the filter. High pass filtering can also affect the overall assessment of vibration exposure. The greatest effect occurred for vibration in the vertical direction. This is what would be expected considering the spectral data in Figure 2.

Conclusion

Measurements of seat vibration according to ISO2631-1 have been successfully made from gate-to-gate on passenger seats on an ATR72 aircraft. Vibration was dominated by tonal components that are attenuated using the ISO2631-1 filters. Indications of the magnitude experienced by turboprop passengers is affected by the choice of digital filters applied to the signal. Studies of human perception of aircraft vibration should include frequency components up to 300 Hz.

Acknowledgement

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