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The noise generated by a landing gear wheel with hub and rim cavities

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ABSTRACT

Wheels are one of the major noise sources of landing gears. Accurate numerical predictions of wheel noise can provide an insight into the physical mechanism of landing gear noise generation and can aid in the design of noise control devices. The major noise sources of a 33% scaled isolated landing gear wheel are investigated by simulating three different wheel configurations using high-order numerical simulations to compute the flow field and the FW-H equation to obtain the far-field acoustic pressures. The baseline configuration is a wheel with a hub cavity and two rim cavities. Two additional simulations are performed; one with the hub cavity covered (NHC) and the other with both the hub cavity and rim cavities covered (NHCRC). These simulations isolate the effects of the hub cavity and rim cavities on the overall wheel noise. The surface flow patterns are visualised by shear stress lines and show that the flow separations and attachments on the side of the wheel, in both the baseline and the configuration with only the hub cavity covered, are significantly reduced by covering both the hub and rim cavities. A frequency-domain FW-H equation is used to identify the noise source regions on the surface of the wheel. The tyre is the main low frequency noise source and shows a lift dipole and side force dipole pattern depending on the frequency. The hub cavity is identified as the dominant middle frequency noise source and radiates in a frequency range centered around the first and second depth modes of the cylindrical hub cavity. The rim cavities are the main high-frequency noise sources. With the hub cavity and rim cavities covered, the largest reduction in Overall Sound Pressure Level (OASPL) is achieved in the hub side direction. In the other directivities, there is also a reduction in the radiated sound.

1. Introduction

Landing gears are recognized as one of the most significant contributors to airframe noise for commercial aircraft in the approach configuration [1]. A landing gear is an assembly of a large number of components with different sizes and shapes. Wheels are one of the major large-scale landing gear components, which can be considered as the most significant noise sources for simplified two-wheel nose landing gears [2] and important noise contributors for four-wheel main landing gears [3]. Numerical studies of wheel noise can provide a useful insight into the landing gear noise generation mechanisms and can aid in the design of noise reduction treatments.

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A simplified landing gear wheel can be considered as a short aspect ratio circular cylinder. Zdravkovich et al. [4] performed experiments to investigate the flow features past free-end circular cylinders of spanwise length to diameter ratio W/D between 1 and 10. They found two counter-rotating streamwise vortices formed by the flow separation at the cylinder ends. The vortices convect downstream as a streamwise vortex pair. The highly three dimensional flow near the ends of the cylinders was found to interrupt the vortex shedding resulting in more broadband noise compared to the tonal noise observed in the case of cylinders with large aspect ratios ($W/D \gg 10$).

Several experimental and numerical tests have been performed to study the flow features and far-field acoustics of landing gear wheels. Lazos [5,6] analysed the mean flow features around the wheels of a simplified four-wheel landing gear. The flow separation and attachment regions on the wheel surface were considered to be potential sources of noise [6]. Neuhart et al. [7] performed aerodynamic experiments of a Gulfstream G550 nose landing gear. They reported that the hub area on the wheels might be one of the stronger noise sources due to the high levels of turbulent kinetic energy and pressure perturbations found around the hub area. Yokokawa et al. [8] measured the far-field acoustics generated from a two-wheel main landing gear. They found that the dominant noise sources were the tyre and the sidebrace, compared to the cylinder, the axle, the torque link and the landing gear door. In a four-wheel Rudimentary Landing Gear (RLG) test, complex flow interactions were found between the upstream and downstream wheels [9,10], which might be a significant noise source. Liu et al. [2] performed high-order simulations of a two-wheel nose landing gear and found that the wheel noise dominated the strut noise and the axle noise. They observed that more wheel noise radiated towards the sideline direction.

Cylindrical cavities are present on realistic landing gear wheels. These cylindrical cavities can generate tonal and broadband noise. An experimental aeroacoustic study of a high-fidelity six-wheel landing gear performed by Jaeger et al. [11] showed that a reduction of 3 dB in the far-field acoustic SPL can be achieved by covering the hub cavity with a flat plate [11]. In the experiments performed as part of the LAnding Gear nOise database for CAA validatiON (LAGOON) project, two tonal peaks were found in the sideline direction for a generic two-wheel landing gear with two facing rim cavities on the wheels, and they are also confirmed by numerical simulations [12]. The tones are generated by the interaction of the shear layer between the wheels with the acoustic resonance of the rim cavities. These two tones were further investigated numerically by Casalino et al. [13], who found that the first tone was related to a plane wave corresponding to the floor-to-floor cavity distance, while the second tone was from an azimuthal mode of the wheel cavities [13]. Zhang et al. [14] performed aerodynamic and aeroacoustic experiments of an isolated high-fidelity landing gear wheel including a tyre, a sidewall, a hub, a hub cavity and rim cavities. They found that the wheel noise is characterized by broadband middle frequency noise centred around 630 Hz and 1250 Hz, which are fixed by the geometry dimensions and does not scale with flow velocities. Wang et al. [15] conducted numerical simulations with the same geometry used by Zhang et al. [14] and found that the noise at 630 Hz and 1250 Hz is generated by the first and second depth modes of the hub cavity and the OASPL of the noise at the hub side is 4 dB higher than the other sideline direction. The opposite facing rim cavities in the numerical simulations by Casalino et al. [13] and the hub cavity in the experiments by Jaeger et al. [11], Zhang et al. [14] and numerical simulation by Wang et al. [15] share shallow cylindrical cavity geometries. It has been shown by Marsden et al. [16] that the dominant mechanism driving the flow around relatively deep cylindrical cavities is the interaction of aerodynamic flow with the cavity resonance of the depth modes, which is different from the acoustic feedback in the Rossiter's mode [17]. However, for shallow cylindrical cavities, which is the case of the hub cavity in this work, they reported that tones are not as distinguishable compared to deep cylindrical cavities, and the far-field acoustics are generally more broadband [18]. Thus, the sound generated by a hub cavity on a landing gear wheel is expected to be broadband rather than tonal.

The baseline geometry used in the simulations is the same as the one used in the experiments by Zhang et al. [14]. The validation of the numerical methodology against experimental data for the baseline configuration was presented by Wang et al. [15]. The validation is not repeated in this paper. In this current work, the effects of the hub cavity and the rim cavities on the wheel noise are isolated by covering them in two different simulations and comparing them to the baseline simulation. The results from the baseline configuration are also analysed to give an insight into the sound generation mechanisms and their radiation characteristics. The wheel geometry and details of the grid generation are provided in Section 2. Section 3 describes the numerical methodology and the computational setup in the simulations. The aerodynamic and acoustic simulation results are presented in Section 4, focussing on the effects of the hub cavity and rim cavities on the near-field flows and far-field acoustics.

2. Model detail and computational grids

A 33% scaled isolated landing gear wheel from the Technology Strategy Board CADWIE (Control of Approach Drag Without Impact on the Environment) project [14] is used in this study and the model is illustrated in Fig. 1. The diameter and the width of the wheel are $D=0.48$ m and $W=0.186$ m, respectively. The isolated wheel contains a sidewall and a hub on opposite sides. A large shallow cylindrical cavity with a diameter-to-depth ratio of approximately 0.3 is located around the hub. Surrounding the sidewall and the hub cavity are two rim cavities, which are small-scale features, relative to the wheel size, with a depth of approximately $0.045D$. Three different configurations have been simulated. The unmodified CADWIE wheel is the baseline configuration. A cross section through the baseline configuration is shown in Fig. 2(a). The second configuration, **N**o **H**ub **C**avity (NHC), is shown in Fig. 2(b), with the hub cavity covered. The geometry in this configuration is symmetrical with respect to $z/D = 0$ plane. The simulation of the NHC configuration aims to determine the