An Improved Noise Reduction Modelling Approach For Wire Screens Applied To Aircraft Landing Gears

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Summary
Recent attempts have been aimed at the reduction of noise emissions from aircraft landing gears. These attempts have resulted in the application of low noise treatments on aircraft landing gears such as air curtains, porous fairings, wire screens, etc. However, from a computational aeroacoustics (CAA) implementation point of view, the complex nature of landing gears often results in a highly expensive computational process, particularly when numerically simulating the effect of low noise treatments as add-ons within the landing gears. This paper therefore presents a novel and less computational expensive method for numerically simulating the effect of a physical woven wire screen upstream or wrapped around the complicated geometry of landing gears. Within this paper, an improved Volume Averaged Method (VAM) is employed within a CFD code for a half scale main landing gear and numerical results are validated with an EU project results: ALLEGRA. The results comparison demonstrates potentials for future work within this application. This improved VAM approach is carried out by the inclusion of a turbulence suppression term specific to wire screens within the original VAM methodology. Therefore, this paper aims to show that the implementation of this modified modeling approach for wire screens presents a viable alternative to more expensive means of fully resolving the effect of wire screens upstream or wrapped around landing gear models within a CFD flow domain.

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1. Introduction

Aerodynamic induced noise from aircraft landing gears are a primary concern to aeroacoustic engineers, industry experts and policy makers. This is primarily because landing gears of commercial aircrafts contribute a major percentage to its overall noise emission at approach-phase [1, 2].

Recent co-ordinated test programs have investigated noise reduction potentials from aircraft landing gears when making use of add-on low noise treatments such as wire mesh screens, perforated fairings, hub caps, air-curtains (single and double jet) and they achieved varying degree of success [3, 4, 5, 6, 7, 8, 9].

Within the framework of the ALLEGRA program, wind tunnel tests were carried out in Pininfarina wind tunnel, Turin, Italy, on regional aircraft landing gear models [10, 11, 12]. Within the test campaign, various low noise treatments were tested for the landing gears noise reduction, and the application of woven wire mesh screen on the MLG was one of these
low noise treatments. Acoustic noise reductions of up to 5dB centered at 4000 Hz 1/3 octave band were achieved with the implementation of the woven wire mesh screen as a low noise treatment for the MLG [13].

The aim of this paper is to perform CFD-Acoustic analogy coupled computational studies for the realistic regional main landing gear geometry utilized within the ALLEGRA program, in order to test the woven wire screen noise reduction modeling approach as proposed [14], which was applied to a simplified landing gear strut represented by a H-strut unit. This current paper will apply this technique to a more advanced and realistic representation of an aircraft main landing gear (MLG). This paper therefore presents a first attempt at testing this noise reduction modeling approach on a realistic regional main landing gear geometry.

2. Modeling Approach

The modeling approach utilized within this paper is carried out by modeling the wire screen as a porous zone comprising of cell layers within the CFD computational domain as shown in Figure 1, where a physical wire screen is approximated and replaced by an alternative porous zone possessing pressure drop effect \( \Delta P_e \) and turbulence suppression effect \( T_e \) of a realistic wire screen [15, 16].

2.1. Pressure Drop Effect \( \Delta P_e \)

The wire screen pressure drop effect \( \Delta P_e \) is modeled by using the Volume Averaged Method (VAM), with the loss coefficient relation of Idelchik [17] implemented within a re-written Navier-Stokes equation. The empirical correlated relationship for flow loss coefficient as documented by Idelchik [17] for woven wire screens was found to be Reynolds number independent for all \( Re_D \geq 400 \) and is given by Equation 1.

\[
K = \frac{2\Delta P}{\rho U^2} = K_{mesh} K_{Re} (1 - \beta) + \left( \frac{1 - \beta}{\beta} \right)^2 \quad (1)
\]

Where wire constant \( K_{mesh} = 1 \) for new screens and wire Reynolds number factor \( K_{Re} = 1 \) for \( Re_D \geq 400 \).

2.2. Turbulence Alteration Effect

Various models exist for which the turbulence suppression effect \( T_e \) of a woven wire screen could be accounted for. These models include the Prandtl[18], Collar[19], Taylor and Bachelor [20] and the Dryden and Schubauer[21] models.

For the implementation of woven wire screens turbulence suppression within the porous zone of a CFD domain, the model of Dryden and Schubauer[21] is proposed for this implementation. This model is as shown in Equation 2, where \( f_u \) is the axial component of turbulence reduction factor, and is utilized as a sink term for turbulence quantities within the Navier Stokes equations of the CFD domain.

\[
f_u = \frac{1}{\sqrt{1 + K}} \quad (2)
\]

3. ALLEGRA Test Set-up

The ALLEGRA project conducted coordinated experimental acoustics tests on a MLG and NLG model installed at the Pininfarina wind tunnel, Turin, Italy as shown in Figure 2. Test section dimensions are 8.0m × 9.6m × 4.2m. Microphone arrays installed within the tunnel facility include a top array, side array, linear far-field array and front arrays.
3.1. MLG Model Dimensions

Figure 3 presents the MLG model installed within the Pininfarina wind tunnel, while Figure 4 shows the MLG model dimensions.

4. Computational Set-up

4.1. MLG Geometry Modification

The original and modified MLG model utilized are as shown in Figure 5. MLG dressings were deemed unnecessary for the CFD analysis, therefore, all tiny holes, including bolts and nuts were closed or removed. A closer look at the remodeled wheels are presented in Figure 6, where the wheels section meant for brakes are completely closed.

4.2. Computational Domain

The nomenclature showed in Table I is utilized for simulation cases carried out within this paper.

Table I. MLG Nomenclature Utilized

<table>
<thead>
<tr>
<th>MLG-1</th>
<th>MLG-No Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLG-2</td>
<td>MLG-Mesh Treatment</td>
</tr>
</tbody>
</table>

Computational domain utilized for the CFD-FW-H analysis is as shown in Figure 7, with the final utilized domain dimensions presented in Table II, where $D_w$ represents MLG wheel diameter, $L_x$ the x-direction domain extent, $L_y$ the y-direction domain extent, and $L_z$ the z-direction domain extent.

The unsteady IDDES used for this simulations utilizes a criteria for switching between LES and URANS solver. If the grid size within a zone of interest is less than $0.05D_w$, the solver switches to an LES, but for cell sizes greater than this value, a URANS approach is utilized [22].

For both cases of MLG-1 and MLG-2 computational analysis, unstructured grids were utilized, with a maximum cell grid count of 6.5 million cells utilized. For utilized boundary conditions, the inlet was a uniform inlet flow velocity with turbulence intensities of 2%. Inlet velocity of $40m/s$ was utilized to match the flow speeds used within the ALLEGRA test campaign. Pressure outlet conditions were utilized for the computational domain exit, while symmetry conditions were utilized for domain side walls, as these walls were placed sufficiently far away from the MLG geometry so to introduce negligible effect on the fluid flow within the landing gear geometry region.

5. MLG-1 Steady Results

MLG-1 results from the steady flow simulations carried out by utilizing the $k-\omega$ turbulence model are presented within this section. Results for MLG-1 wall
Table II. MLG Domain Dimensions and Features

<table>
<thead>
<tr>
<th>Domain</th>
<th>$L_x$</th>
<th>$L_y$</th>
<th>$L_z$</th>
<th>Max cell size (m)</th>
<th>Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Omega_1$</td>
<td>$2.5D_w$</td>
<td>$4D_w$</td>
<td>$2.3D_w$</td>
<td>0.02</td>
<td>LES zone</td>
</tr>
<tr>
<td>$\Omega_2$</td>
<td>$18.5D_w$</td>
<td>$5D_w$</td>
<td>$5D_w$</td>
<td>0.10</td>
<td>LES/URANS zone</td>
</tr>
<tr>
<td>$\Omega_3$</td>
<td>$23D_w$</td>
<td>$8D_w$</td>
<td>$8D_w$</td>
<td>0.17</td>
<td>URANS zone</td>
</tr>
</tbody>
</table>

Figure 8. MLG-1 steady surface results

Figure 9. MLG-1 steady state velocity field contours. $U_\infty = 40\text{ m/s}$, $0^\circ$ Yaw

5.1. MLG-1 Surface Results

Figure 8(a) presents $y+$ values across the MLG-1 model configuration. Maximum wall $y+$ on MLG-1
Table III. Plane locations (y=0 at center of wheel)

<table>
<thead>
<tr>
<th>Plane</th>
<th>y</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.2044 m</td>
</tr>
<tr>
<td>2</td>
<td>0 m</td>
</tr>
<tr>
<td>3</td>
<td>-0.2525 m</td>
</tr>
<tr>
<td>4</td>
<td>-0.8132 m</td>
</tr>
</tbody>
</table>

is 1.1. The nature and value of surface pressures on the MLG-1 model is as presented in Figure 8(b). Surface pressure across the entire MLG-1 as well as values across strut components and wheels are highlighted. Maximum values of surface pressures are observable on the frontal area section of the strut. The distribution of wall shear stress on the MLG-1 model is as presented in Figure 8(c). Maximum values of wall shear stress are located at the sides of the strut components.

5.2. MLG-1 Velocity Field

For presentation of flow speeds, field contours are extracted at four different planes as identified in Table III.

Steady flow field contours of velocity flow past the MLG-1 configuration are as presented in Figure 9. Results presented here are for a uniform inlet velocity value of $U_\infty = 40 m/s$. For plane 1, maximum flow speed results from flow deflection at the wheels, and this maximum values are well within the wheel geometry.

6. MLG-2 Steady Results

It is worth noting at this point that the modeled wire screen utilized possessed a porosity of 65%, as this was chosen to match wire screen porosity utilized during the ALLEGRA test campaign. For the CFD-VAM modeling approach carried out here, the wire screen porous zone was located 10mm upstream of the MLG-2 wheels outer diameter. The wire screen porous zone streamwise thickness was 2mm, and its y and z dimensions were chosen so as to extend beyond the MLG-2 wheels and strut by $1/4D_w$.

Wall $y+$ distribution across MLG-2 is as presented in Figure 10(a). A quick observation on the effect of flow speeds reduction as a result of the upstream wire mesh screen is immediately noticed, where the maximum $y+$ value across MLG-2 is 0.7, compared to MLG-1 where maximum $y+$ values of 1.1 were obtained.

Results of surface pressure across MLG-2 is presented in Figure 10(b). An observation of surface pressure reductions on MLG-2 compared to MLG-1 is made, where maximum surface forces on MLG-2 are reduced by roughly 4% compared to MLG-1.

Walls shear distribution across MLG-2 is presented in Figure 10(c). Compared to MLG-1, a reduction in shear forces are observable in MLG-2, with maximum shear forces acting on MLG-2 reduced by roughly 58%.

6.1. MLG-2 Velocity Field

Similar to the presentation of MLG-1, contours are extracted at four different planes as previously identified in Table III.

Field contours of velocity flow past MLG-2 configuration is as presented in Figure 11. Results presented here are for a similar uniform inlet velocity value of $U_\infty = 40m/s$ as utilized for MLG-1.

For plane 1, the flow speeds deflection as a result of the wire screen causes a shift in the maximum flow speeds from the MLG-2 proximity to the edges of the screen, thereby resulting in reduced flow speeds impinging on MLG-2. Similar effects are observable on planes 2 to 4.

7. MLG Unsteady IDDES Results

MLG-1 and MLG2 results from the unsteady flow analysis using the IDDES approach are presented within this section by presenting unsteady plots of vortex core regions.

7.1. Unsteady Velocity Field

The IDDES utilized a $k-\omega$ URANS model at the MLG near-wall so as to save computational cost. A time step of $3.2 \times 10^{-6}$ was sufficient enough to ensure domain average CFL number of less than one was maintained throughout the unsteady simulation process. Unsteady results of vortex core region for Q-criterion colored by $U_x$ magnitude after 1.05 secs is as shown Figure 12.

From this result the effect of wire screen implementation is noticed, as the impinging flow speeds on MLG-2 wheels are much lower than the impinging speeds on MLG-1. Therefore, as expected, the woven wire screens modeling implementation produced a flow speed reduction on the downstream MLG-2 geometry, and because aerodynamic noise scales with flow speeds to within the sixth power from landing gear components, we therefore expect noise reduction as a result of the wire screen modeled implementation.

7.2. Unsteady Turbulent Kinetic Energy

Unsteady results of vortex core region for Q-criterion colored by turbulent kinetic energy values after 1.05 secs is presented in Figure 13. From the plot, we observe that the turbulent kinetic energy of flows impinging on and within the MLG-2 near-field region are substantially reduced compared to the impinging flows turbulent kinetic energy on MLG-1. This turbulent kinetic energy reduction is not only as a result of flow speeds reduction, but also as a result of the turbulence suppression sink terms implemented within the porous zone mimicking the wire screen.
8. MLG FW-H Results

For all acoustic cases presented, the numerical FW-H microphone receiver location corresponds to a specific microphone position within the ALLEGRA linear far-field array, viz. 90° at a horizontal distance of 2.92m. Results in Figure 14 of SPL are presented against 1/3 octave bands. From this plot, SPL peaks are seen to exist at 1/3 octave band values of 16 Hz, 160 Hz and 1250 Hz, with SPL values of 29.5 dB, 32.5 dB and 33.2 dB respectively. For the MLG-2 model, sound pressure level plots produces peak SPL values of 26.2 dB, 30.3 dB and 30.5dB at 1/3 octave bands of 20 Hz, 125 Hz and 1250 Hz. Therefore, comparison of acoustic results obtained from MLG-1 and MLG-2 shows that the peak values of MLG-1 were reduced by 3.8 dB, 3.1 dB and 3 dB at the 1/3 octave bands of 16 Hz, 160 Hz and 1250 Hz respectively. Therefore, the potentials of wire screens modeling application is hereby evident.
9. Comparison With ALLEGRA

CFD-VAM predicted noise reduction effect obtained as a result of wire screen modeling is compared with experimental noise reduction effect as a result of wire screen introduction as obtained within the ALLEGRA test campaign. This comparison is presented in Figure 15. The ALLEGRA screen effect $\Delta SPL$ results were obtained by subtracting the acoustic results obtained when the woven wire screen was introduced from the acoustic results obtained without the woven wire mesh screen, this is presented in Figure 15(a). The CFD-VAM screen effect as shown in Figure 15(b), and is obtained by subtracting IDDES-FW-H acoustic result of MLG-1 from MLG-2. From this result, we observation that the experimental noise increase within the low 1/3 octave band frequency range was not detected by the numerical modeling approach. However, from 315 Hz, comparable noise reduction results were obtained. From the ALLEGRA experiments, maximum noise reduction of 5 dB occurred at 4000 Hz, while the equivalent reduction obtained utilizing the CFD-VAM modeling approach was 3.5 dB at that same frequency, but a noise reduction of 4.8 dB at 5000 Hz 1/3 octave band.

10. Conclusions

This paper presents a novel implementation of an improved Volume Averaged Method for woven wire mesh screens as a noise reduction technology for realistic main landing gears. Whilst the numerical results are compared to experimental test results from an EU Collaborative Research project, it must be noted that this comparison is only rudimentary given the fundamental difference in test set-up. From comparisons of MLG-1 and MLG-2 acoustic results, we observe that the modeling of woven wire screens potentially reduces peak SPL by up to -3.8 dB. When comparisons between CFD-VAM approach and experimental tests are made, noise reductions from the ALLEGRA test resulted in a maximum $\Delta SPL$ value of -5 dB centered at 4000 Hz of 1/3 octave band, while a maximum noise reduction $\Delta SPL$ value of -4.8 dB centered at 5000 Hz of 1/3 octave band was obtained for the CFD-VAM screen modeling approach. Therefore, aerodynamic noise reductions achieved by using the CFD-VAM approach proposed and utilized in this paper shows promising signs and potentials, with room for further improvements.

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References

Figure 15. ALLEGRA vs CFD-VAM Comparison $\Delta SPL$ vs 1/3 Octave Band.


