

886. Aeroacoustic noise reduction design of a landing gear structure based on wind tunnel experiment and simulation

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Abstract. In the process of aircraft landing, the aerodynamic noise of the landing gear constitutes an appreciable part of the airframe noise. Therefore it is important to dedicate research efforts to study of aerodynamic noise of landing gear and its structural parts. Acoustic wind tunnel test on landing gear is designed to measure aerodynamic noise of structural parts of landing gear such as pillar and torque arm. Aerodynamic noise spectrum characteristic and radiation directive characteristic of structural parts in different velocities are established. The effect of flow velocity to noise is analyzed. Two noise reduction designs are proposed in the paper. The effect of the relative position of pillar and torque arm to structural noise is considered based on simulations and testing. Simulation method to assess the noise reduction effect of torque arm shape modification is adopted. The results demonstrate that structural noise can be appreciably reduced by placing torque arm behind the pillar as well as by modifying the shape of the torque arm. In total, the study holds reference value to the ongoing research activities on aerodynamic noise of landing gear and design method for low noise operation of the gear.

Keywords: acoustic measurement, computational aeroacoustics, landing gear structure noise, acoustic analogy.

1. Introduction

As the living environment is more concerned, aircraft noise has been attracting a lot of attention in recent years. During landing, when the engines are operating at reduced power, the noise from airframe is equal to the engine noise, among of which landing gear is in large proportion [1]. The structure radiating noise of landing gear mainly includes strut and torque links, therefore they are of great significance in studying the noise of the structure.

But, due to the complex geometry of landing gear, it is difficult to build meshes in the computational domain before simulation. So the existing studies are generally numerical simulation for simple or simplified landing gears. Hedge calculated the flow field around a simplified four-wheel landing gear by Detached Eddy Simulation (DES) and unsteady Reynolds Averaged Navier-Stokes (URANS) simulation [2]. Murayama simulated the noise field of G550 simplified landing gear using CFD method combining with CAA method [3]. Dobrzynski studied the noise characteristics of A320 scaled model and A340 full scale model via wind tunnel tests. The results show that strut and torque links are important contributors to landing gear noise [4-5]. Patricio tested the noise radiated from the 26 % scaled main landing gear of Boeing 777 in the wind tunnel and obtained the noise spectra of some components, including strut and torque links [6]. And, Huang reduced the noise radiated from the structure including strut and torque links in the wind tunnel by plasma [7]. After that, the research on noise from landing gear was started. Characteristics and prediction methods of landing gear noise were discussed by Long [8].

The paper presents numerical analysis using DES with FW-H method to calculate flow field around the simplified structure including strut and torque links and noise field radiated from the

structure. Compared to the results of the wind tunnel test, it is demonstrated that the simulation method is feasible and reliable.

2. Noise reduction design based on acoustic wind tunnel test

2.1 Noise reduction scheme

On the basis of the results of simulation and wind tunnel tests, two schemes are designed to reduce the noise of landing gear structure:

1. make the torque arm behind pillar;
2. based on the first schemes, make both sides of the torque arm arc.

Assess the effects of the both noise reduction schemes through the wind tunnel test and numerical simulation methods.

2.2 Comparison between the settings of working condition

By adjusting the relative position of torque arm and pillar, compare the noise spectrum acquired before and after change, analyze the effect of relative position of torque arm and pillar on structure noise. We can assess the noise of improved design through wind tunnel tests, but it is difficult to analyze the generating mechanism of noise source on different structural elements and the contribution of a single component to the noise only contrast spectrums of the two working conditions. Therefore, we must design different experiments to perform more in-depth study. The contrast tests also set up a wind tunnel of a single pillar, and then perform more in-depth study on noise characteristics through the spectrum curve obtained in various working conditions. Table 1 provides a set of test conditions.

Table 1. Test working conditions

Method	Condition	Flow velocity (m/s)	Model
Experiment	exp BJ	30, 40, 50, 60, 70, 80	Empty wind tunnel
	exp 1 (scheme 0)	30, 40, 50, 60, 70, 80	Torque arm in front of pillar
	exp 2 (scheme 1)	50, 70	Torque arm behind pillar
	exp 3	50, 70	Pillar

2.3 Analysis of the contrastive tests

Table 2 provides sound pressure level for various working conditions. At the condition of 50 m/s and 70 m/s, the difference between working conditions is almost the same. When the torque arm is in front of the pillar, the noise level is about 3.1 dB higher than that when the torque arm is behind the pillar. If torque arm is removed, the noise level will reduce about 4.8 dB in comparison to working condition exp 1. Therefore, the torque arm and its position have a great impact on aerodynamic noise of a landing gear.

Table 2. Sound pressure level in different conditions and their difference

Velocity (m/s)	OASPL (dBA)			Difference1 (dBA)	Difference2 (dBA)	Difference3 (dBA)
	exp 1	exp 2	exp 3	exp 1-exp 2	exp 1-exp 3	exp 2-exp 3
50	81.36	78.25	76.61	3.11	4.75	1.64
70	91.43	88.33	86.67	3.10	4.76	1.66

When the velocity is 70 m/s, working condition exp 1, exp 2 and exp 3, the measured 1/3 octave spectrum characteristic curve of point 16 is shown in Fig. 1. Contrasting the 1/3 octave spectrum characteristic curve of condition exp 2 and exp 3, a large difference is detected at

500 Hz. At the frequency of 500 Hz, the noise level of working condition exp 2 is 55 dB higher than that of exp 3. The structural difference between exp 2 and exp 3 is that there is a pair of torque arm behind pillar in exp 2. It can be inferred that the peak at the frequency of 500 Hz in working condition exp 1 contain the flow around noise, which is generated when airflow bypasses the pillar and separate through the torque arm, and the interference noise of them. Comparing the spectrum of condition exp 1 and exp 2, we detected that at a frequency larger than 700 Hz, the frequency range of $St > 0.44$, the amplitude of sound pressure level dropped 4-6 dB. The relative position of components has a significant impact on its aerodynamic noise. The noise reduction scheme is an effective measure to reduce noise.

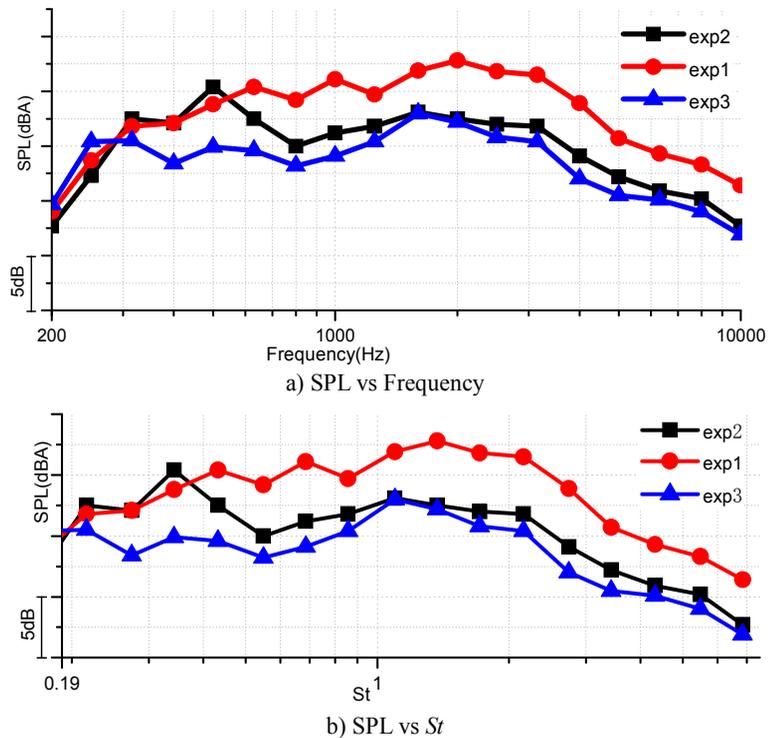


Fig. 1. 1/3 octave spectrum characteristic curve of point 16 in different conditions when velocity is 70 m/s

3. Noise reduction design based on aerodynamic noise simulation

3. 1 Assessment on the effect of noise reduction design scheme 1

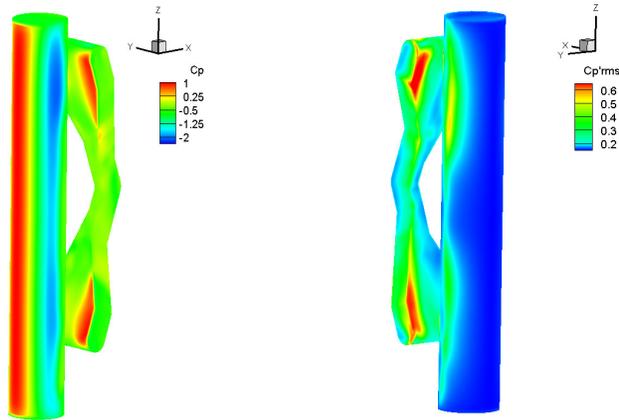
(1) Geometry model, grid generation and simulation setting

Change the position of torque arm from being located in front of the pillar to the case when it is located behind pillar, set the condition as simulation 2, and the primitive condition as simulation 1.

(2) Simulation results of the flow field under design scheme 1

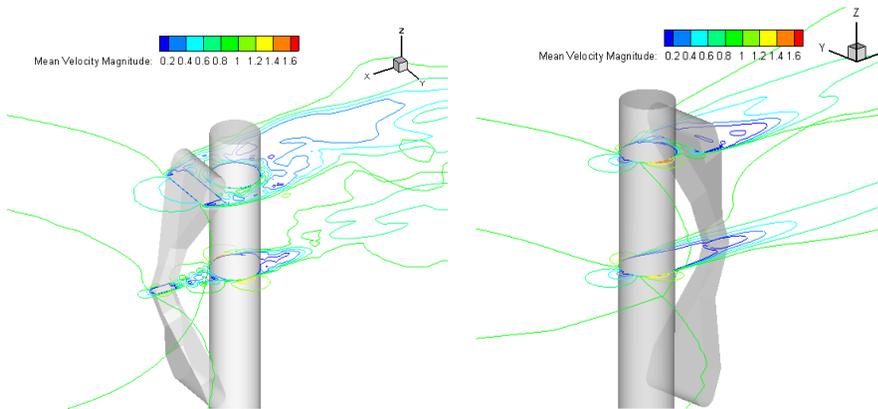
Instantaneous static pressure coefficient and the pulsatility index of the model surface is normalized according to equation (2-47) and (2-49). The normalized pressure coefficient distribution is presented in Fig. 2. The figure reveals that at the windward side of the model, including the front of the pillar and both sides of the ends of torque arm that is not sheltered by pillar, the instantaneous pressure coefficient is the maximum and the fluctuating pressure is the minimum. At both sides of the pillar and the center of the ends of torque arm, the amplitude of

low-pressure and fluctuating pressure is maximum. Comparing to the result of primitive design, we found that after improvement the maximum of fluctuating pressure amplitude has increased, but the fluctuating pressure presence area on model is reduced.



a) Instantaneous pressure coefficient b) Fluctuating pressure coefficient
Fig. 2. Normalized pressure coefficient distribution on the model surface in scheme 1

Non-dimensional average velocity amplitude of the model is shown in Fig. 3. The figure indicates that when air flow through the noise reduction scheme 1 (working condition simulation 1), the air on both sides of pillar is accelerated and that on both sides of torque arm is decelerated. Besides, there is deceleration phenomenon in obtuse angle area of the triangle that constituted by torque arms and pillar. But the change of average speed of the air around model is less than primitive model, shows that the improved configuration has reduced the possibility of flow separation.



a) Working condition Simulation 1 b) Working condition Simulation 2
Fig. 3. Velocity characteristics in the flow field near model in scheme 1 and primitive scheme

(3) Simulation results of the sound field under design scheme 1

Time-frequency transform the result of acoustic simulation the same as the primitive scheme. For example, the measured point R_1 (0, 0, -9660 mm) of far field, analyze the noise characteristics of the pillar and torque arm and structure total noise, the sound pressure level in R_1 of the two schemes is compared in Fig. 4. The figure indicates that compared with the primitive scheme 0 (simulation 1), total noise sound pressure of the scheme after noise

reduction design is reduced by 3.28 dB, while that of pillar - 17.86 dB and that of torque arm - 1.34 dB. Because there is no change in shapes of torque arm and pillar after modification, we just change their relative position. It indicates that the relative position of torque arm and pillar has a great influence on the structure total sound pressure, and selecting a suitable position can significantly reduce total noise of a structure. From the contribution of component noise to the total noise, in the primitive design scheme 0, the contribution of pillar is larger than torque arm, and it is contrary in the noise reduction design scheme 1. The change in contribution indicates that the sound source radiated by pillar and torque arm includes noise related to their position. It is called interference noise.

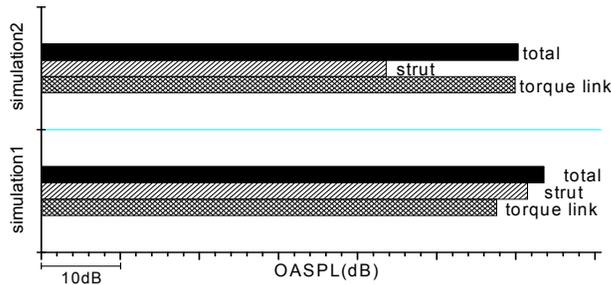


Fig. 4. Comparison of sound pressure level in scheme 1 with scheme 2

Fig. 5 provides power spectral density curve and 1/3 octave spectrum curve of the pillar, torque arm and total structure noise in noise reduction design (simulation 2) and the primitive design (simulation 1). The figure reveals that each of the spectrum curves in scheme 1 is broadband and contains regular periodic variations, but each of them contains only one considerable energy peak, which corresponds to $f = 300$ Hz and $St = 0.29$. Comparing with the corresponding spectrum in scheme 0, we found that the spectrums of total sound pressure level in the two schemes are in good agreement, the difference between them is 1-2 dB when $f < 300$ Hz. When $f > 300$ Hz, there are two energy peaks in the spectrum of scheme 0, but there is no energy peak in scheme 1 because the amplitude of spectrum is reduced with frequency increase. Besides, the sound pressure level amplitude corresponding to spectrum in scheme 1 is less than that in scheme 0. After noise reduction design, the spectrum amplitude of pillar is reduced by 10-20 dB in the entire frequency range. The maximum frequency in spectrum is changed from 600 Hz (scheme 0) to 300 Hz (scheme 1). It indicates the significant reduction of pillar noise. Besides, the change in relative position of torque arm and pillar also reduces the interference noise. The spectrum amplitude of torque arm is increased by 3-10 dB in the frequency range of $St < 1.2$, and reduced by 3-10 dB in the frequency range of $St > 1.2$, which indicates that by changing the relative position of torque arm and pillar, the torque arm blunt body flow around noise is increased, but the interference noise is reduced.

Therefore, it follows that the interference noise between components can be induced by just changing the relative position of the pillar and torque arm, without changing component shape. The noise reduction design scheme 1 is feasible.

Fig. 6 presents the directive characteristic in the plane $xo'y$, $xo'z$ and $yo'z$ contrast curve of the model on the two conditions. It can be observed from Fig. 6a that there is an obvious dipole characteristic on the plane $xo'y$ in scheme 1 (working condition simulation 2), while there is no obvious dipole characteristic in the primitive scheme 0 (working condition simulation 1). In the direction of y -axis, the total noise in scheme 1 is 8 dB larger than that in scheme 0; in the direction of x -axis, the total noise in scheme 1 is 9 dB larger than that in scheme 0. It can be observed from Figs. 6b-c that there are obvious dipole characteristics on plane $xo'z$ and plane $yo'z$ in both scheme 1 and scheme 0.

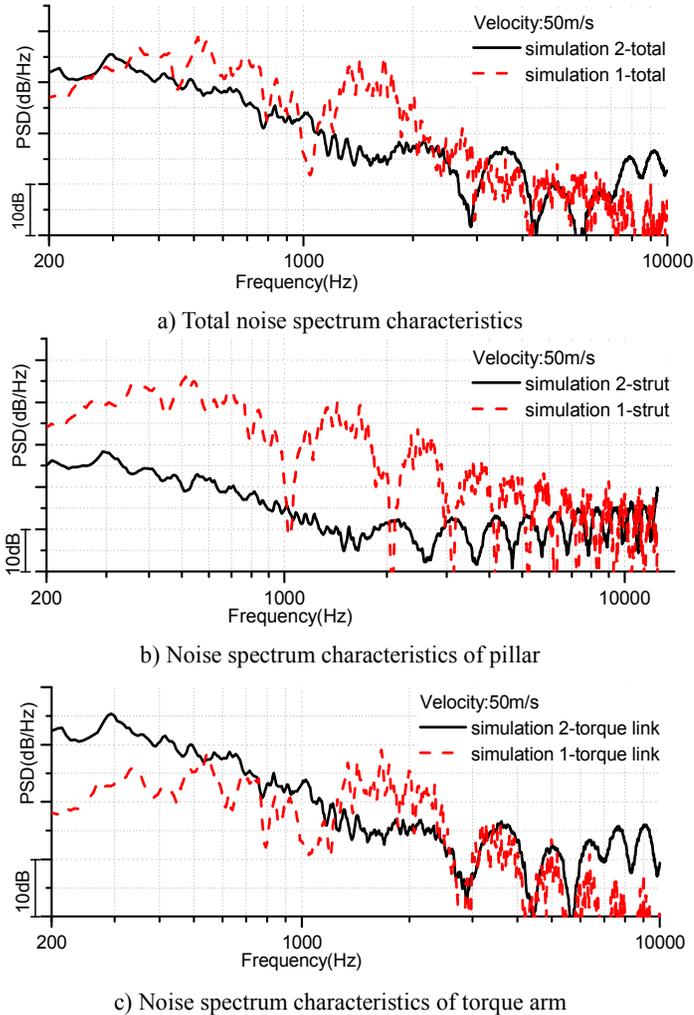


Fig. 5. Noise spectrum of components and total in different conditions when velocity is 50 m/s

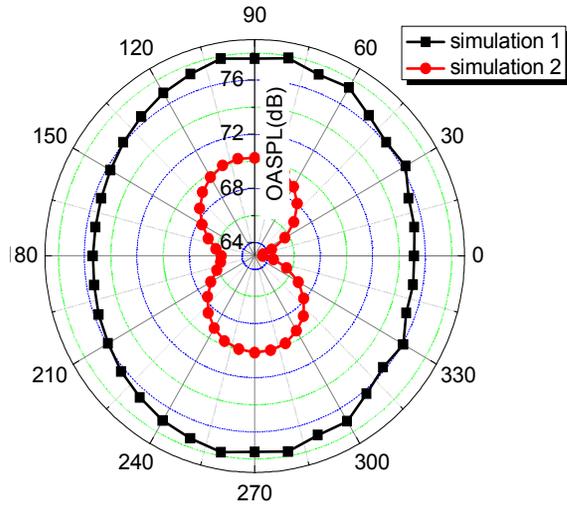
Assessing the noise reduction effect of the noise reduction design 1, it can be concluded that the scheme 1 is feasible. Next, we can modify the shape of components based on the scheme 1 to design a scheme 2 and assess its noise reduction effect.

3. 2 Assessment on noise reduction effect of scheme 2

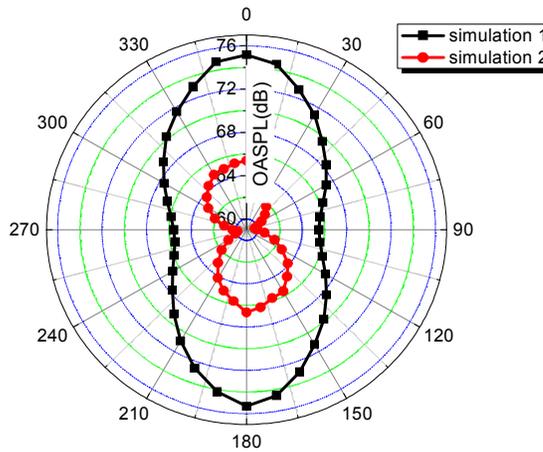
(1) Simulation model and setting

Select plane $z = 114$ mm of which the acoustic pulsating quantity is larger in the scheme 1, the shape and relative position of components are shown in Fig. 7a, where $R = 24$ mm, $L/D = 1$, $a = 20$ mm, $b = 64$ mm. The cross-section of torque arm that behind the pillar is inversed in the corner, the rest of geometric dimensions remain unchanged, as shown in Fig. 7b.

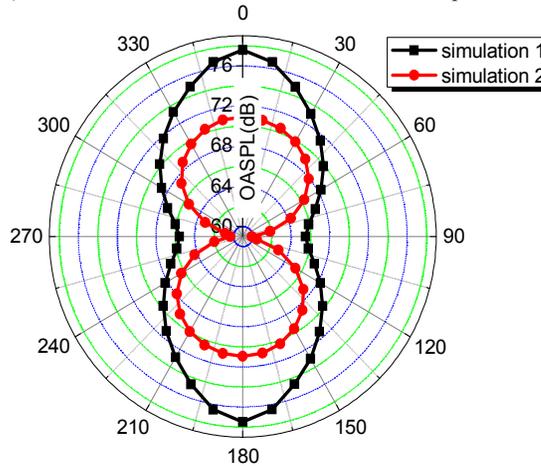
The computational domain is presented in Fig. 8. The positive x -direction is the flow direction. The distance of entrance and wall to the center is $5D$. Distance of exports to the right edge of rectangle is $15D$. D is the feature size, diameter of the circle. The grid of model used structured grid.



a) Directive characteristic of noise radiation in plane $x'o'y'$



b) Directive characteristic of noise radiation in plane $x'o'z'$



c) Directive characteristic of noise radiation in plane $y'o'z'$

Fig. 6. Comparison of radiation directive characteristics in scheme 1 and primitive design (velocity is 50 m/s)

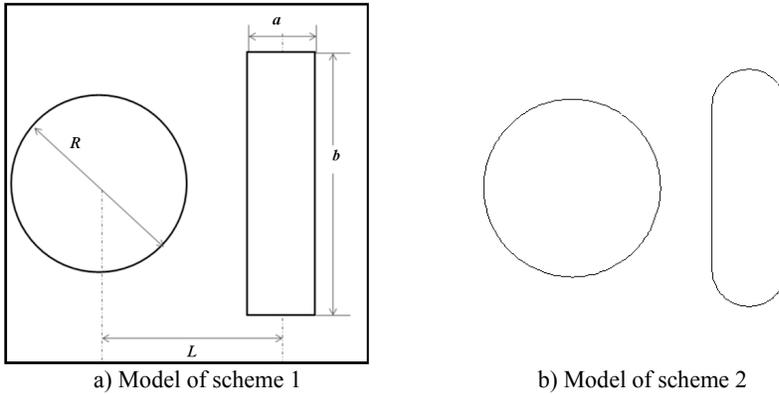


Fig. 7. 2-D geometrical model of the structure before and after modification of torque arm

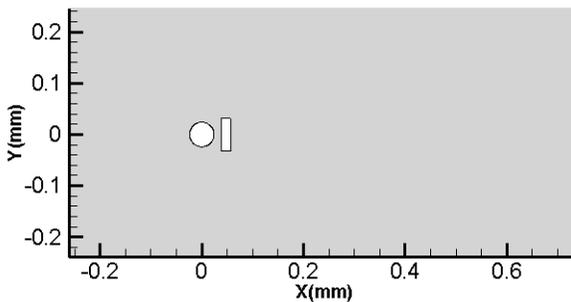


Fig. 8. Computational domain of 2-D model before modification

(2) Simulation results of the flow field under design scheme 2

Fig. 9 demonstrates fluctuating pressure coefficient distribution of the flow field near the model in scheme 1 and scheme 2. These results indicate that in scheme 1 there is a considerable area, in where the fluctuating pressure coefficient is greater than 2, behind the torque arm, but that area in scheme 2 is very small, which means the pneumatic separation on both sides of the torque arm in scheme has been obviously weakened.

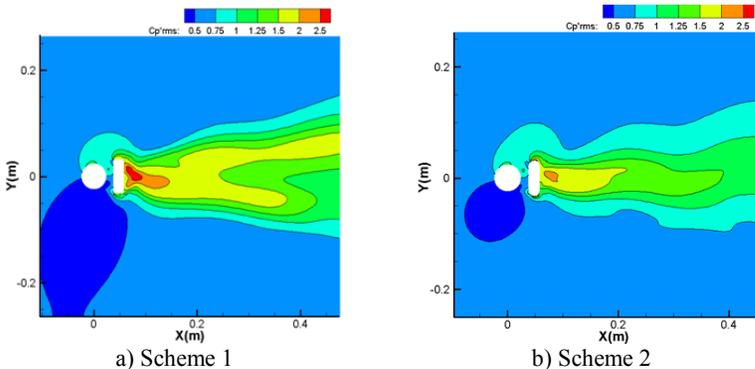


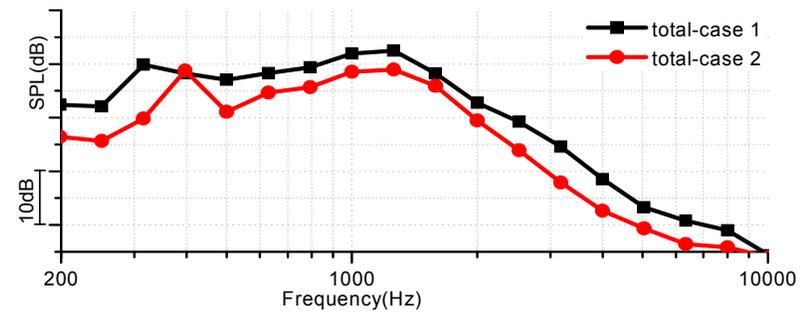
Fig. 9. Fluctuating pressure coefficient of the flow field near the model after and before modifying

(3) Simulation results of the sound field under design scheme 2

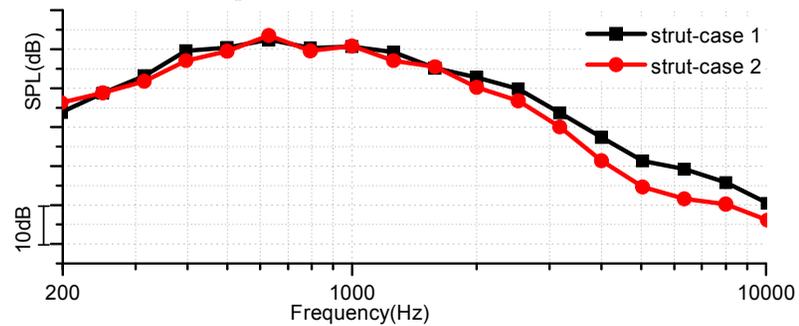
Use the same method of computation of a 3-D model to compute the sound field. Set a measured point R_2 at the coordinate $(-2\text{ m}, 0)$, where time-frequency transform the acoustic

fluctuating quantity. Analyze the noise characteristics of the pillar and torque arm and the total noise characteristics.

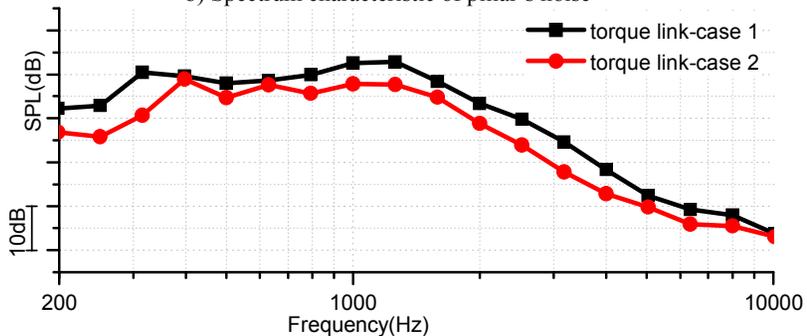
Fig. 10 provides power spectral density curve and 1/3 octave spectrum curve of the pillar, torque arm and total structure noise in the design 1 and 2. The figure reveals that the sound pressure level in scheme 2 is 2-10 dB less than that in scheme 1 except that they are equal at the frequency of 400 Hz. The sound pressure level of pillar noise spectrum curve in scheme 1 and scheme 2 are approximately equal because pillar noise is mainly blunt body turbulence noise related to the shape, and the shape does not change. The sound pressure level amplitude of the torque arm noise spectrum in scheme 2 is 5-10 dB less than that in scheme 1 except they are approximately equal at the frequency of 400 Hz and 600 Hz. It means that the noise of torque arm is obviously reduced after shape modification. Because the vortex shedding frequency is changed after modification, the frequency peak of the spectrum in scheme 1 is increased from 315 Hz to 400 Hz.



a) Spectrum characteristic of total noise



b) Spectrum characteristic of pillar's noise



c) Spectrum characteristic of torque arm's noise

Fig. 10. Spectrum characteristics of the total noise and structural noise before and after modification

4. Conclusion

The paper presented two design schemes for noise reduction in landing gear structure. Assessment of the two noise reduction schemes was performed based on acoustic wind tunnel test and numerical simulations. The effect of the relative position of pillar and torque arm to structural noise based on simulation and test was analyzed. The following conclusions are obtained:

(1) Structural noise can be obviously reduced by placing torque arm behind pillar and can be reduced by modifying the shape of the torque arm.

(2) In comparison to the primitive design, the noise reduction scheme 1 does not change the shape of pillar and torque arm, thus their blunt body turbulence noise is remained. And the structural noise total sound pressure level is reduced by 3 dB. Thus, the noise reduction scheme 1 can diminish the interference noise between pillar and torque arm, and constitutes an effective measure to reduce noise.

(3) Based on the noise reduction scheme 1, the noise reduction scheme 2 inverted the corner of the torque arms sides. Simulation results indicate that the structural noise total sound pressure level is reduced except for 400 Hz, and the frequency peak is increased from 315 Hz to 400 Hz.

Acknowledgements

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