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Aerodynamic Noise Simulation of Civil Aircraft Landing Gears Based on LES-Smargorinsky Model

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Abstract

Landing gears is one of the important sound sources for aerodynamic noise of civil aircraft components. In order to better evaluate sound levels of civil aircraft components at various design phase, accurately prediction of propagation characteristics of landing gears aerodynamic noise is very necessary, for supporting incoming civil aircraft noise reduction technologies development. China domestic four-wheel landing gear model designed independently and international landing gear common model LAGOON are taken as research subjects. This thesis illustrates aerodynamic noise simulation of civil aircraft landing gears using LES-Smargorinsky turbulent model. A hybrid simulation method of unsteady LES flow simulation and FWH solution for far-field acoustics propagation is applied. In inflow condition that flow velocity is 80m/s, CFD module in commercial software is applied to simulate unsteady flow around landing gears. Acoustics solution module in commercial software is applied to calculate far field sound propagation. Acoustics propagation characteristics such as sound power spectra density and directivity of civil aircraft landing gears is investigated. By aero acoustics solver computation, the sound power spectra density PSD on model probe points and sound pressure level in far region as well as directivity effect is analyzed. The computation results of PSD on near field probe points by CAE are compared with that calculated by other aviation institutions. Sound pressure level at microphone array in anechoic chamber is compared with experiment datas tested in low velocity wind tunnels. It can be concluded that acoustics computation results are in good accordance with wind tunnel datas. This accordance validates the reliability and accuracy of commercial software calculations.

Keywords: aerodynamic noise; civil aircraft; landing gears; LES-Smargorinsky model; commercial software

1. Current research status introduction

With the application of advanced aero engine noise control technology, airframe noise has become the main sound source during civil aircraft approach. For airframe, the aerodynamics noise of the landing gear during the process of approach and takeoff is one of the strongest sound sources of airframe. Hence accurate prediction of aerodynamic noise has become the focus of aviation industry and furthermore it has been taken as an important basis for low noise design of civil aircraft. In recent years, China civil aircraft industry has developed rapidly. China independently designed own four wheels landing gears model by domestic civil aviation standards. This model and the international benchmark research model LAGOON are taken as objects of research and computation. This paper presents aerodynamic noise simulation of civil aircraft landing gears using hybrid method of LES-Smargorinsky viscous model and FWH equation solution for far-field acoustics propagation. The acoustics propagation characteristics of landing gears aerodynamic noise is analyzed and compared with wind tunnel experiment. It is of great significance to the low noise design of civil aircraft.

1.1 Research models description

The international benchmark research model LAGOON is one standard model from BANC2 Workshop (Benchmark problems for Airframe Noise Computation), which is held by AIAA and CEAS European research council in 2012. LAGOON model is designed by ONERA and Airbus as 1:2.5 scale model of real Airbus320 airplane landing gear. All boundary of computation domain and simplified LAGOON two wheel landing gear model are introduced by Fig.1. Sideline and flyover arrays of 24 microphones are described as following picture Fig.2.

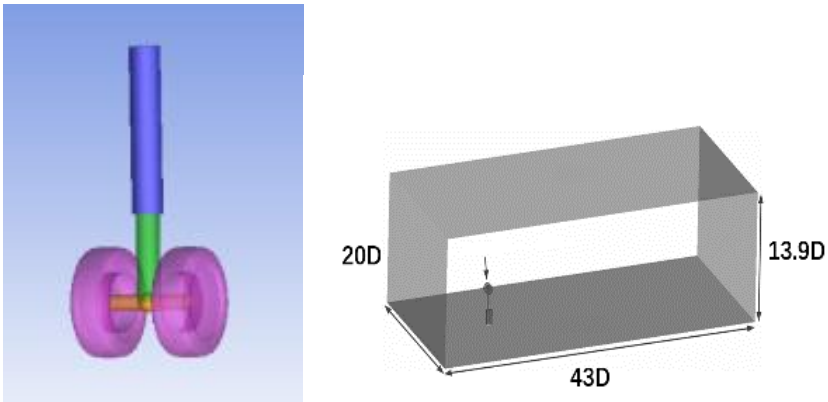

Fig1. LAGOON model and computation domain

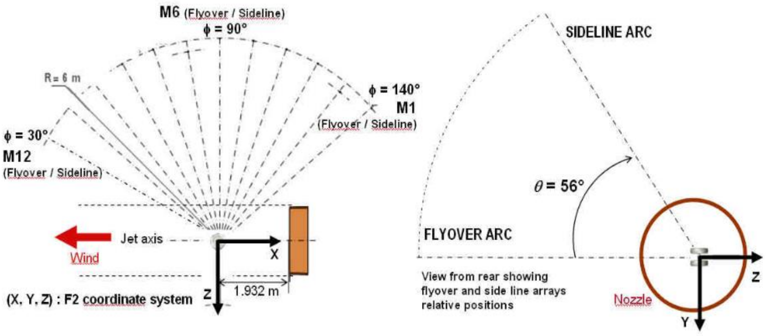

Fig2. Two arcs of far field microphones disposition

China domestic four-wheel landing gear research model is designed independently, taking real landing gears of Boeing747 and China commercial wide body passenger aircraft as reference. Its components include wheels, main stick, shock absorbers stick, axel connecting rod and so on. As it is known, inlet flow velocity in X direction is 80m/s and flow Mach is about 0.23. The sideslip angle is set as 0° and the attack angle is set as 0°. The wind tunnel experiment environment is simplified as a cuboid with landing gears model installed in center position. In Fig.3 one horizontal quarter-arc microphone array with a radius of seven meter and a linear muffling chamber wall array in one range of 110° are installed in the anechoic chamber. Acoustic propagation characteristic and directivity effect of four-wheel landing gear in far field are computed and investigated by typical commercial software.

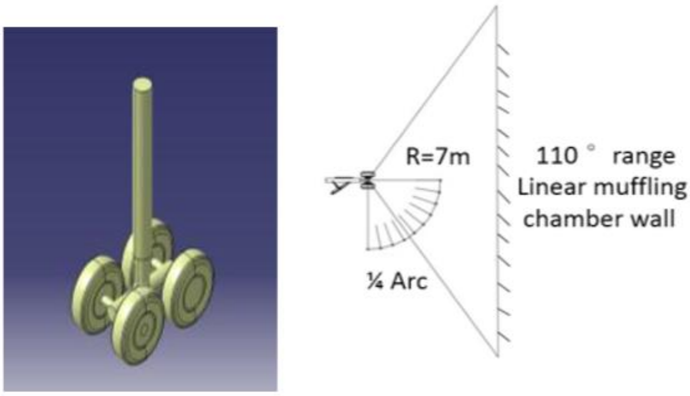

Fig.3 China four-wheel landing gear model and microphone array in anechoic chamber

1.1 Model grid description

The surface grid of four wheel landing gear and lagoon landing gear research models are in a grid topology of unstructured grid as in Fig.4 in computation. According to the geometry the surface grid is generated firstly, secondly the cartesian spatial grid is generated. The total grid vertex number of four wheel civil airplane landing gear model is about 55 million. The volume grid type is tetrahedral. X axis in three dimensional coordinate is the same as the flow direction. The model feature length which is the same as research model diameter and noted as D is 1.27 meter. The size of whole computational domain around landing gear research model is 20D in length,12D in width and 9D in height.

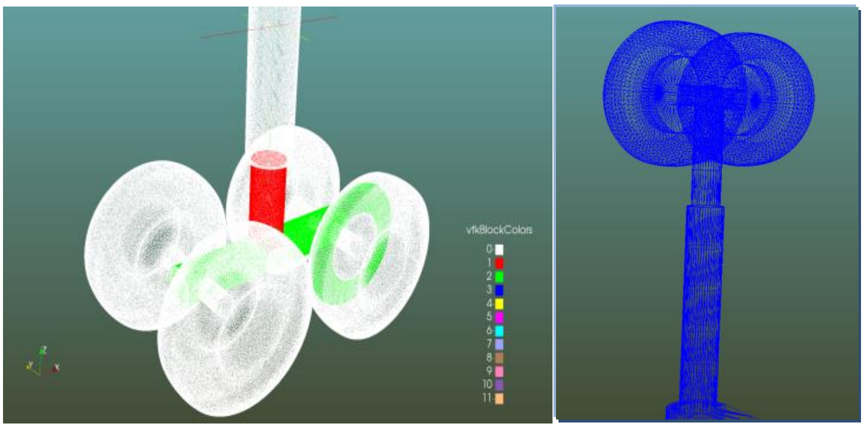

Fig.4 unstructured grid of four wheel landing gear model and lagoon

1.2 Boundary condition description

The boundary condition on four wheel landing gear model surfaces are velocity inlet surface, pressure outlet surface, wall condition of landing gear model body part, free stream flow conditions in far field. The computation boundary around the four wheel landing gear research model is shown in Fig.5.

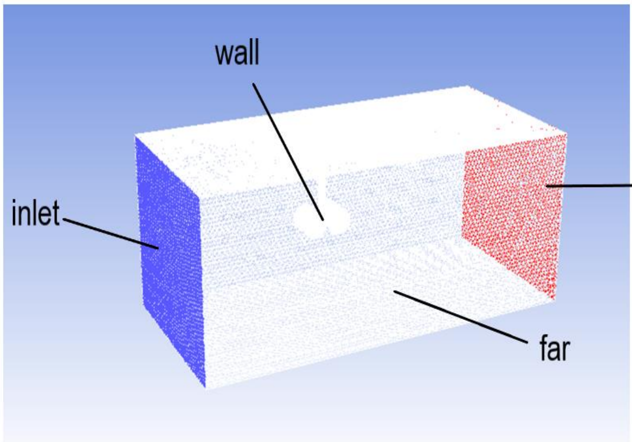

Fig.5 computation boundary around the four wheels landing gear model

2. Simulation Method

2.1 Viscous model description

In pressured based initial steady flow computation, standard k-epsilon model is chosen as the viscous model to simulate steady flow around landing gears model. By steady flow simulation, the source of sound, perturbation pressure in fluid flow which has been fully developed can be captured and .In pressured based transient flow computation, LES-Smargorinsky viscous model is chosen and defined in commercial software to simulate unsteady state air flow. In the time domain, since the flow state of sound source has been developed fully by steady flow simulation, then in the computation of the unsteady flow field it is required that continuous flow field feature samplings is prepared in advance and reliable for further acoustics propagation computation.

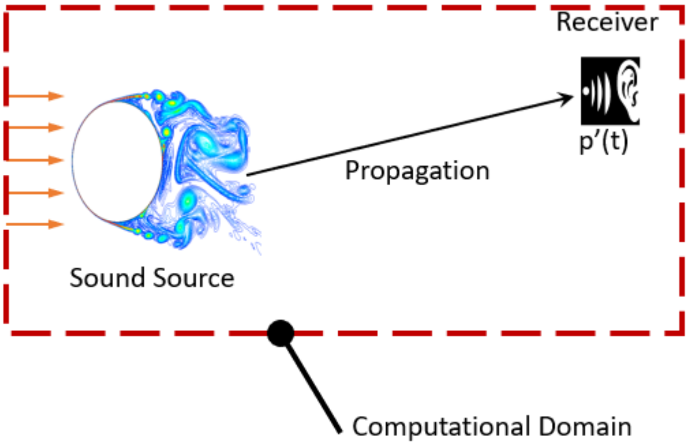

Fig.6 sound spurce propagation process digram

2.2 Turbulent RANS and LES model

Turbulence flow is a kind of complex and nonlinear fluid motion which is chaotic in space and time. Turbulent flow motion has been very complex in manifestation. The kind of complexity lies in randomness, spinnability, statistics characteristics of flow. In traditional CFD, the basis of describing turbulence is Navier-Stokes equation. Numerical simulation is the main mean to turbulence research. According to the computation scale of turbulence flow by Navier-Stokes equation, the existing numerical simulation of turbulence includes mainly three kinds of method. Direct numerical simulation, Reynolds averaged Navier Stokes simulation and large eddy simulation noted as LES are the existing turbulence numerical simulation methods. Direct numerical simulation can calculate accurate turbulent flow information but DNS computation requires very large memory capacity and time consumption. Reynolds averaged Navier Stokes simulation can be applied to compute complex flow of high Reynolds number, however the computation results are time averaged flow results and the details of flow field turbulence can not be calculated. LES simulation model is based on turbulent kinetics energy transmission mechanism and can directly compute the large-scale vortex motion. LES simulation model described the large-scale vortex motion of turbulence by low-pass small-scale vortex filtering of Navier- Stokes equation. The effect of small scale vortex on large scale vortex is reflected by a build of simulation model LES. This kind of turbulent simulation above can be applied to compute the structure and feature of large scale vortex, whereas the computation efficiency is better than that of direct numerical simulation, hence LES has been widely applied and developed in industry.

2.3 Aeroacoustics computation method

In essence, sound is a mechanical vibration in a gas, liquid, and solid elastic medium through which the traveling sound waves transmit the sound energy from the sound source.

According to the general steps of aeroacoustics computation, unsteady flow CFD simulation around landing gears should be carried out before aeroacoustics simulation starts. Flow CFD simulation results are important for accuracy of acoustics source propagation computation and estimation in far field. In order to capture accurate turbulence information in the flow field, LES turbulent model is applied in unsteady CFD simulation, which is proven to be efficient in parallel computation and can accurately capture the flow vortex evolution, meanwhile the computation grid number does not have to be so great. Hence large eddy simulation model is one reasonable turbulent model for steady and unsteady flow simulation as well as the acoustics computation that is about to begin.

Making a premise that letters f and ΔT represent frequency and unsteady flow simulation time step in aeroacoustics computation, letters P' and Pref represent air perturbation pressure and reference sound pressure. The value of is reference sound pressure is 2E-5Pa generally. Ambient atmosphere pressure is 101325 Pa and sound speed is 340m/s, atmosphere density is 1.125kg/m^3.

The computation results of aeroacoustics propagation in far field include sound pressure and sound pressure level and overall sound pressure level OASPL. Two types of acoustic integration equation Curle and FWH can be applied to compute propagation effect from sound source. If solid wall boundary is defined as sound source, then Curle acoustic integration equation is applied and solved. Otherwise if penetrating face or interface is defined as acoustics sound source, then FWH acoustic integration equation is applied and solved.

All aeroacoustics computation result datas are output automatically by specific aero acoustic simulation software with sound frequency change. The computation results include acoustics Power Spectra Density change due to pressure perturbation at specific near field points on research model surface, and sound pressure level at microphone place in far field. The acoustics frequency band width computation formula is as formula(2) in below, which seriously depends on the discrete time step value of unsteady flow field CFD computation for civil aircraft landing gears model.

$$f=1/(2\Delta T) \quad (1)$$

The sound pressure level computation formula is as below.

$$SPL=10\log(P'/P_{ref})^2 \quad (2)$$

And overall sound pressure level OASPL computation formula is as formula (3) in below. The overall sound pressure level OASPL can be thought of as an overlay of all valid sound pressure level SPL at total frequency bandwidth, including SPL of all landing gear model components. The unit of sound pressure level noted as SPL is dB and the unit of sound pressure is Pascal.

$$OASPL=10\log\Sigma 10^{(SPL/10)} \quad (3)$$

3. Experiment content in wind tunnel

The test contents of the wind tunnel experiment for research model contains five parts, including aeroacoustics directivity measurements, aeroacoustics positioning measurements, the landing gears surface static pressure distribution measurement, the landing gear surface perturbation pressure measurement. Hence the surface of the landing gears model is installed with perturbation pressure sensors for perturbation pressure measurement. Far field microphone is applied to measure landing gears directivity effect, while vertical and horizontal microphones arranged in far field phase array are used for aeroacoustics positioning measurements. Static pressure distribution on the front and rear wheels are measured by pressure sweep valve. As in Fig.7 flow separation on landing gear wheels surface can be measured by PIV testing technique.

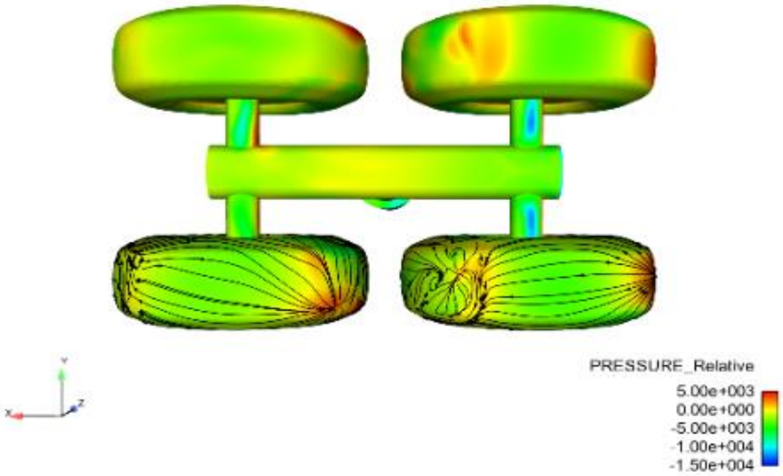

Fig.7 Flow separation on landing gear wheels surface by PIV technique test

4. Computation Results analysis

4.1 Unsteady flow CFD simulation results

The total physics computation time is 0.33s and the initial unsteady flow computation time is 0.1s, while after 0.1s the sampling time of flow parameters starts. The whole flow parameters sampling time of landing gears model lasts for 0.23s, in which some flow field parameters such as perturbation pressure, static pressure coefficient, transient velocity, mean flow field velocity and so on.

Commercial software Fluent and fully transient aerodynamics computation software Aries are applied to simulate unsteady flow change during the total unsteady flow computation time period of 0.33s. One single physics time step is set as 1.3E-4s.

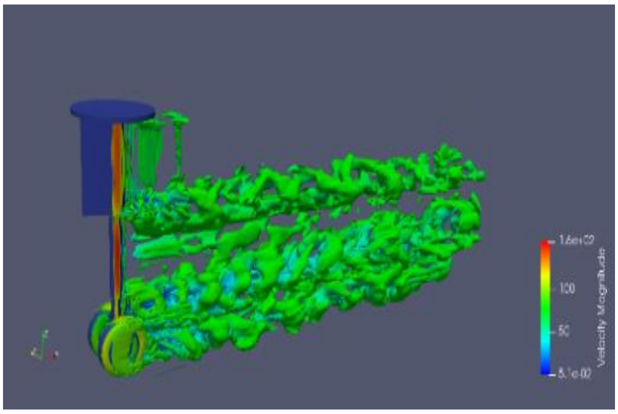

Fig.8 Vortex isosurface identified by Lamda2 criteria

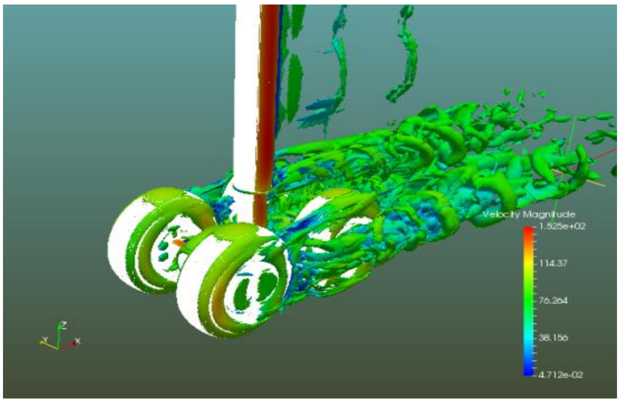

Fig.9 four wheel landing gears unsteady tail flow

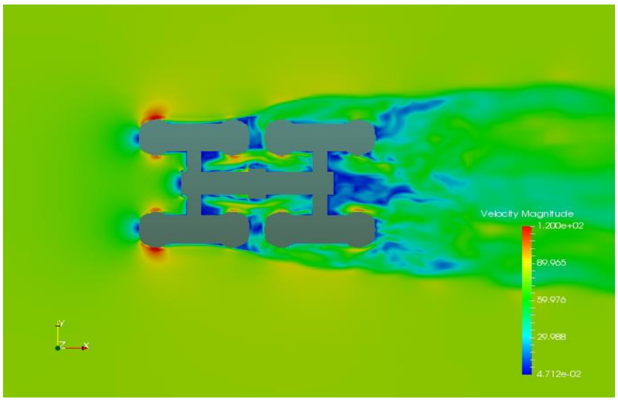

Fig.10 transient flow change in Z direction from four wheel landing gears unsteady tail flow

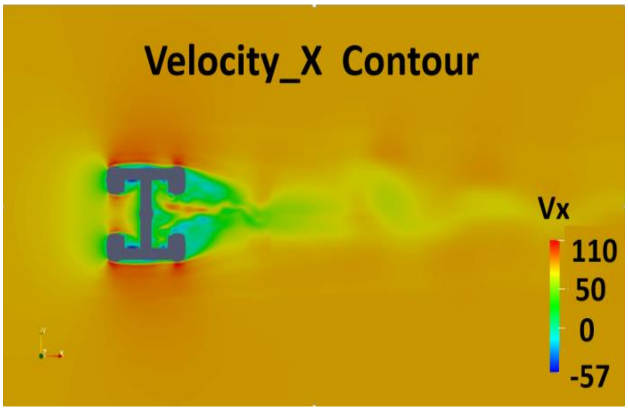

Fig.11 velocity magnitude in unsteady flow field in Z direction view

In Fig.8 and Fig.9 as above flow visualization pictures, the vortex isosurfaces around two wheels and four wheels landing gears in flow field are identified by Lamda2 numerical criteria. From Fig.10 and Fig.11 it can be observed that the vortex in flow trailing areas are shedding gradually.

4.2 Steady flow CFD simulation results

Before unsteady flow CFD computation of the below two research model, in order to get flow field features in one steady state, the steady flow simulation is carried on by commercial computation software ANSYS. As shown in Fig.13 the computation result of static pressure coefficient is in good consistency with wind tunnel experiment test datas.This consistent results with experiment test datas indicates that flow state gradually tends to stable in one initial incoming flow condition of 80m/s velocity in steady flow simulation.The results consistency with experiment test datas performs a validation study and examines ANSYS Fluent software accuracy.

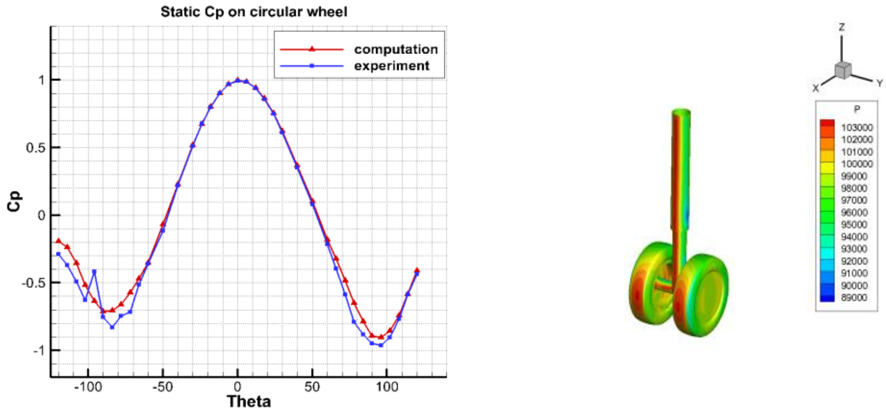

Fig.13 Static pressure coefficient on circular wheel surface compared with experiment

4.3 Near field acoustics Power Spectral Density analysis

In the concept of physics signals normally exist in form of wave, such as sound waves and electromagnetic waves, random vibrations. When the power spectral density of some kind of wave is multiplied by an appropriate coefficient, the power carried per unit of frequency wave is obtained, which is defined and identified as the power spectral density of the acoustics signal and also referred as PSD. The unit of PSD is dB generally.

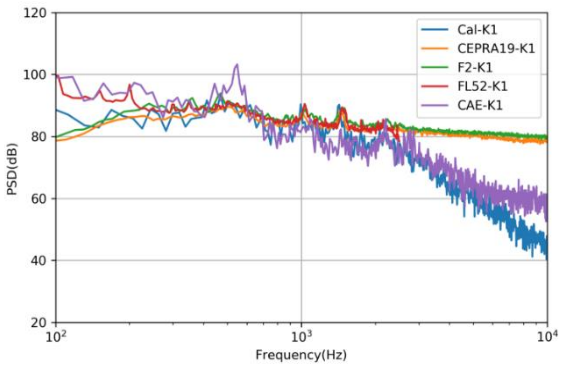

Fig. 14 PSD computation contrast of K1 point on lagoon wheel

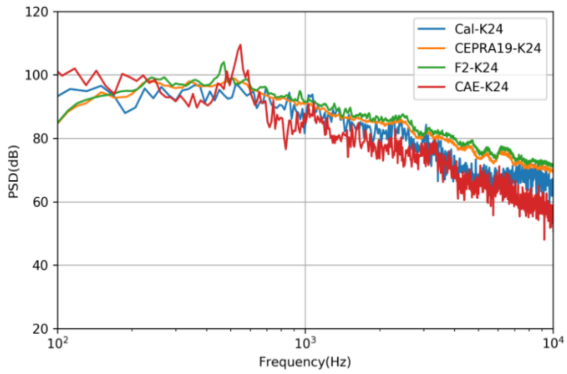

Fig.15 PSD computation contrast of K24 point on lagoon wheel

PSD results on lagoon landing gears surface in near field which are computed by commercial software, are compared with wind tunnel test datas. In wind tunnel experiment PSD test datas are measured by pressure sensors. As Fig.14 and Fig.15 shown, the curves trend of PSD to frequency is same as that measured from acoustics experiment in FL52 in China Aerodynamics Research Institute and France ONERA CEPRA19. The frequency at the maximum peak PSD value exactly refits that frequency and maximum peak PSD value tested in wind tunnels FL52 and CEPRA19.

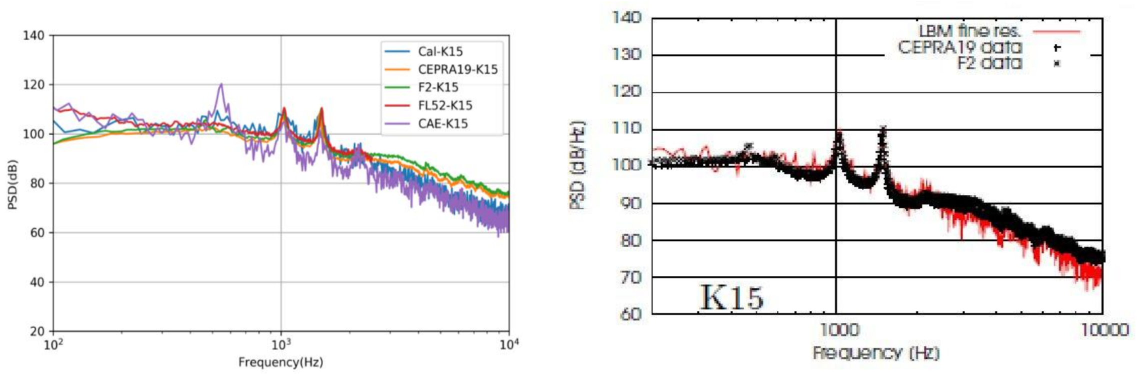

Fig.16 PSD computation contrast of K15 point on lagoon wheel with AIAA BANC II

The right second picture in Fig.16 shows the PSD curves computed based on Lattice Boltzmann model by software Powerflow in AIAA/CEAS second workshop on Benchmark Problems for Airframe Noise Computation in 2012. By comparison of above two pictures of Fig.16, the maximum peak PSD values in high frequency range for point K15 in left picture of Fig.16 are exactly the same as that in high frequency range in right picture of Fig.16. Hence the PSD computation results are comparable to accuracy and reliability level of international main aerodynamics computation software.

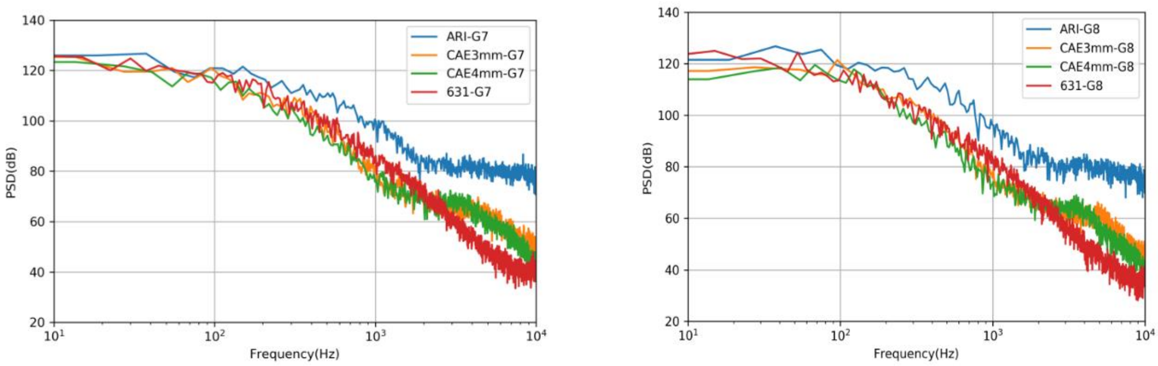

Fig.17 PSD computation contrast of points G7 and G8 on four wheel landing gears

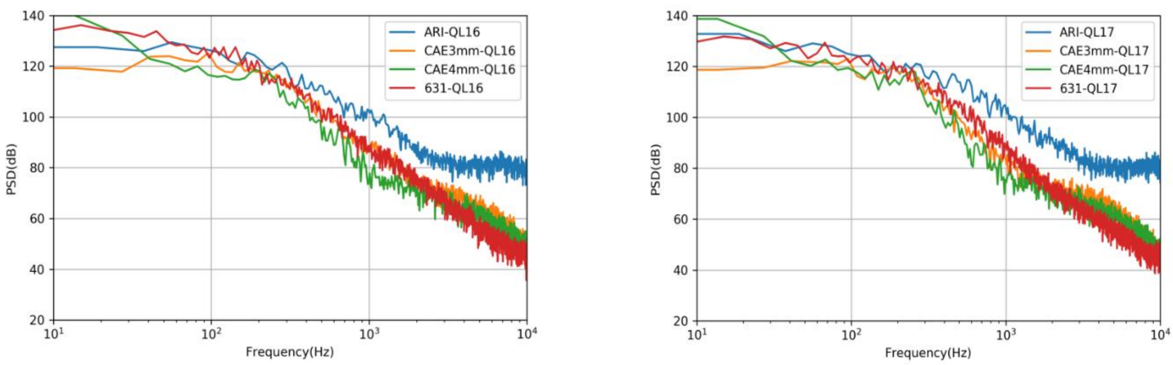

Fig.18 PSD computation contrast of points QL16 and QL17 on four wheel landing gears

By Fourier transformation the flow field solution datas within time domain are converted to the power spetrum density signals in frequency domain. In Fig.17 and Fig.18, the PSD computation results of two probe points on landing gears model support stick surfaces and two probe points on landing gears model front wheel are compared with that provided by other research institutes of China Aviation industry. In Fig.19 the PSD computation results of points HL13 and HL17 on landing gears model back wheels are coherent well with that from Aeronautics Computing Technology Research

Institute in a fequency range of 10000Hz.This consistency in between by cross-validation verifies computation software accuracy and reliability.

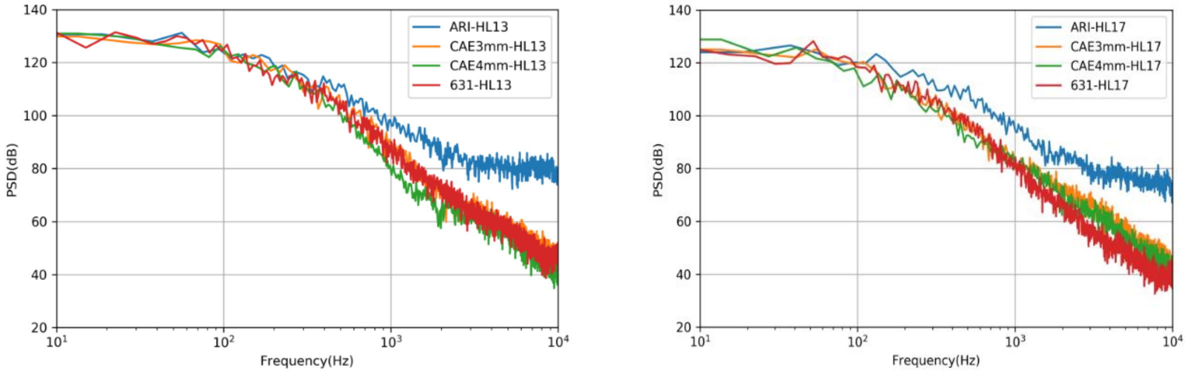

Fig.19 PSD computation contrast of points HL13 and HL17 on four wheel landing gears

5. Acoustics propagation computation analysis

5.1 SPL analysis of four wheel landing gear standard model

After the computation of PSD is finished, the Sound Pressure Level marked as SPL is computed and output by commercial software ANSYS and Aries automatically. From Fig.20 to Fig.23 the Sound Pressure Level of four probe points U7, d7, d19, U8 in far field are compared with wind tunnel experiment datas and shown as below. The As Fig.20 to Fig.23 shown, the curves trend of SPL to frequency is same as that measured from wind tunnel experiment which is noted by orange color curves. It can be concluded that the difference between the landing gears model acoustics propagation computation results and the wind tunnel experiment datas is not more than 4dB. The far field Sound Pressure Level spectrum curve has the characteristics of narrow frequency SPL peak.

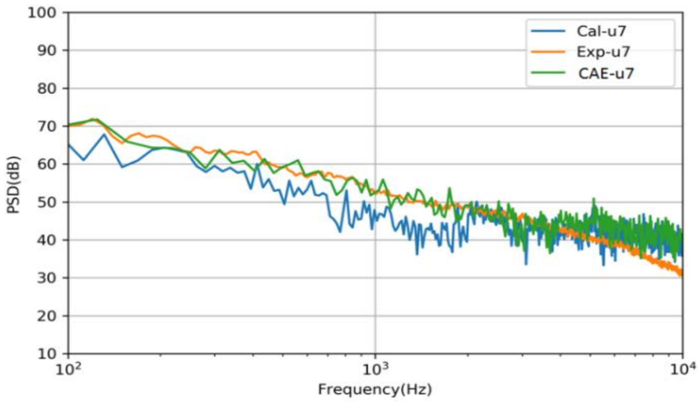

Fig.20 Sound Pressure Level computation result of far field point U7

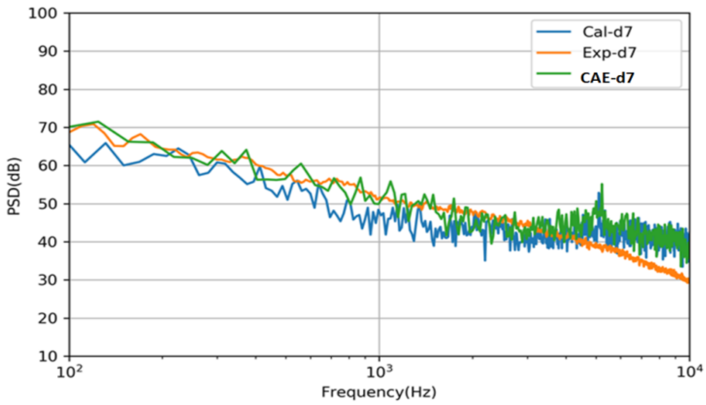

Fig.21 Sound Pressure Level computation result of far field point d7

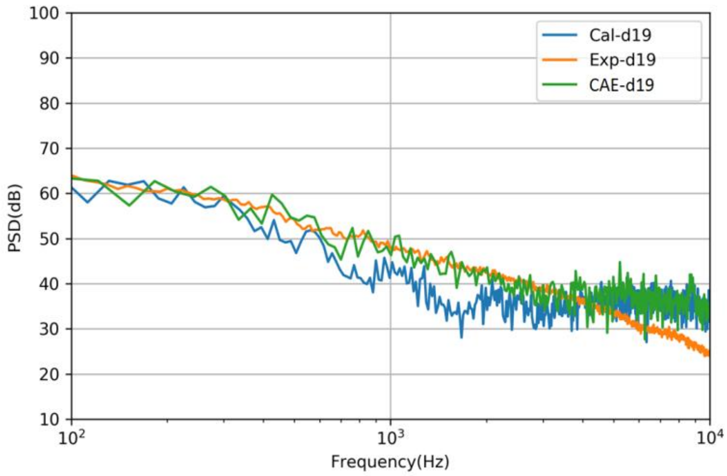

Fig.22 Sound Pressure Level computation result of far field point d19

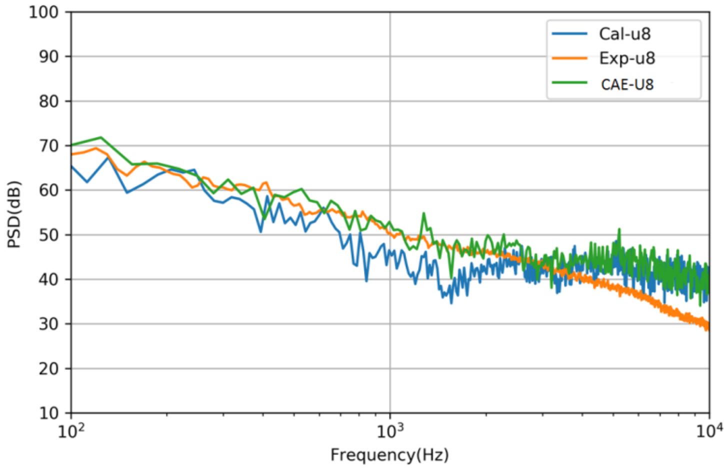

Fig.23 Sound Pressure Level computation result of far field point U8

6. Conclusion

Through unsteady flow computation and aeroacoustics sound propagation simulation for large civil aircraft four wheel landing gears model and international lagoon research model, the focus of this thesis is on aeroacoustics sound propagation impact in the near flow field and far flow field of landing gears standard model. The computation results of PSD on near field probe points by Chinese Aeronautical Establishment are compared with that calculated by other China aviation institutions. By comparison it can be concluded that the computation results trend are consistent, and PSD computing datas within 10,000 Hz are very close. The results of Sound Pressure Level spectrum calculation and wind tunnel experiment test datas for probe point in linear far field microphone array are comparable, and the computation error of Sound Pressure Level amplitude at peak frequency is not more than 4 dB. This accordance validates the accuracy of commercial software computations.

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