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AN OVERVIEW OF AERO-ACOUSTIC EXPERIMENTAL TECHNOLOGY IN AVIC FL-10 WIND TUNNEL

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Abstract: In order to meet the technical requirement for wind tunnel experiments posed by civil aircraft, high speed train and ground vehicles, a large scale low speed aero-acoustic wind tunnel(FL-10 wind tunnel) was built in AVIC Aerodynamics Research Institute(ARI), which is the first 8mX6m scale aero-acoustic wind tunnel in China, the experimental technology includes airframe noise, rotor noise, high speed train noise measurement, etc. FL-10 wind tunnel is equipped with multi-channel acoustic data acquisition system, besides, a series of arrays such as microphone phased array, ground line array, hemispherical array are available to meet the measurement needs of different testing subjects. In terms of support system, FL-10 wind tunnel has scaled aircraft model support system, landing gear support system, high lift device support system and rotor test stand, which can satisfy the experimental requirement of civil aircraft, rotorcraft and high speed train. In this article, a general introduction of the anechoic chamber, noise measurement system, aero-acoustic experimental system and some typical test results are presented.

Keywords: aero-acoustic; wind tunnel experiment; airframe noise; rotor noise; high speed train noise

0 Introduction

Aerodynamic noise is one of the main noise sources of civil aircraft. The engine noise and airframe noise of civil aircraft are both closed related to aerodynamic noise.[1]-[2]. Wind tunnel experiment is the most direct and reliable method to study aerodynamic noise. Carrying out aero-acoustic measurement of real size or scaled model in the aero-acoustic wind tunnel provides detailed and necessary acoustic data for preliminary design, which guarantees the acoustic level meet the design goal. Wind tunnel experiment is the most direct and effective way to study aerodynamic noise. In order to carry out aero-acoustic experiment, a low background noise and non-reflective test environment is essential, usually these tests are carried out in specific aero-acoustic wind tunnel. Some loss of details and change of flow characteristics are often inevitable when performing aero-acoustic experiment using scaled model, which leads to some deviations from the real situation, for the above reason, carrying out aero-acoustic experiment in large scale aero-acoustic wind tunnel is the optimal solution for the time being[3].

Since 1970s, lots of aero-acoustic wind tunnels were built ether by improvement or new-built. Among which the LLF wind tunnel of DNW and the 40×80 feet NASA Ames research center are the most representative. DNW LLF wind tunnel is a low speed closed circuit wind tunnel with a test section of 8X6 m, LLF achieved its first acoustic renovation in 1981 and became an aero-acoustic wind tunnel ever since, in 2014, a second renovation was made to further bring down its background noise level. The 40X80 feet wind tunnel of NASA Ames center finished its aero-acoustic upgrading in 1994 and gained aero-acoustic capability, the size of its aero-acoustic test section is 24×12m. Besides, European countries also constructed a series of 3~4m level aero-acoustic wind tunnels, such as DNW NWB[7], Boeing LSAF[8], ONERA CEPRA 19[9], etc, these aero-acoustic wind tunnels made great contributions to the development of civil aircraft.

The construction of aero-acoustic wind tunnel in China started relatively late, in 2013, FL-17 aero-acoustic wind tunnel of China Aerodynamics Research and Development Center(CARDC) came into being, FL-17 is a closed circuit low speed wind tunnel with a test section of 5.5×4.5m, the affiliated anechoic chamber size is 28m(L) ×26m(W) ×20m(H)[9]. In 2016, AVIC ARI finished the first period of construction of FL-10 wind tunnel, FL-10 is also a closed circuit low speed wind tunnel, the dimension of the test section is 8m(W) ×6m(H). In the first period of construction, noise control methods were applied to the wind tunnel body, it wasn't until 2019 that acoustic environment and instruments were completed in the second period of construction, making it the first 8m level aero-acoustic wind tunnel of China. In the past few years, a series of aero-acoustic experiments such as scaled whole aircraft noise experiment, landing gear noise experiment, high lift device noise experiment, rotor noise experiment, etc, were conducted in FL-10 wind tunnel, meanwhile, the aero-acoustic measurement system and equipment were successfully implemented in the experiments, which indicates that FL-10 wind tunnel has comprehensive experimental capabilities.

Regarding experimental technology, a general introduction of FL-10 wind tunnel and its anechoic chamber, acoustic measurement system, and experimental system of airframe noise, landing gear noise, high speed train noise, rotor noise and application is included in this paper.

1 General information of FL-10 wind tunnel

FL-10 wind tunnel is a low speed close circuit wind tunnel, the general layout is shown in Fig 1. The circuit is about 145m long and 47m wide, the wind tunnel is equipped with a testing hall of 49 m(L)×33 m(W)×26 m(H). FL-10 wind tunnel has two test sections: open jet test section and closed test section, different test sections serve for different requirements. The open jet test section dimension is 8 m(W)×6 m(H)×20 m(L). The center of the test section is 10m above the ground, and 7m downstream of the nozzle. The wind tunnel is powered by an axial-fan driven by high power motor, the maximum wind speed is 85m/s for open jet test section and 110m/s for closed test section, the maximum Reynolds number corresponding to 110m/s is 6.3×10^6(reference length 0.69282 m)

At the design phase, FL-10 has taken the future aero-acoustic experimental need into consideration, a series of noise reduction design was applied to the wind tunnel body, such as:

(1) Low noise fan design, blade and stator number optimization to reduce fan noise;

(2) Acoustic treatment using resistive acoustic liner to absorb fan noise;

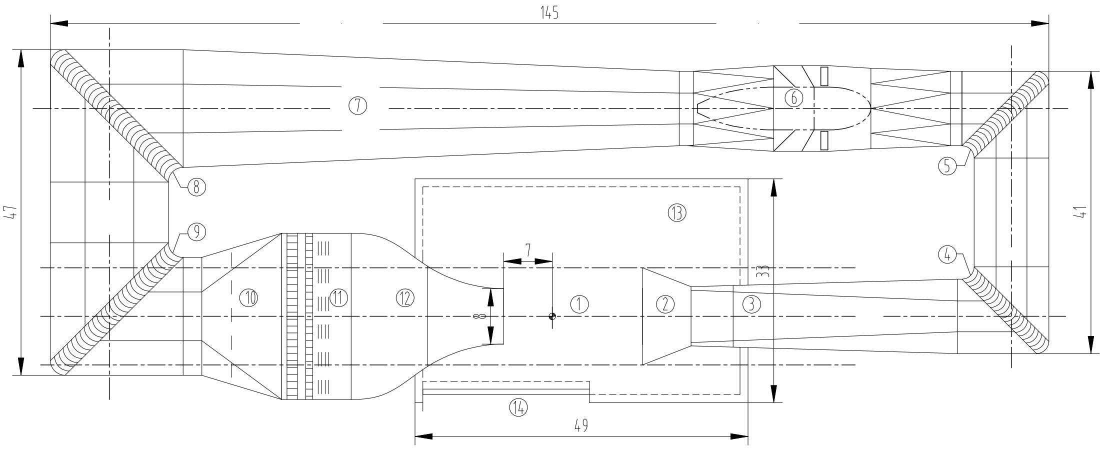
(3) Acoustic treatment applied to the turning vanes to reduce noise and turn the flow;

(4) Optimization of the collector angle, the collector is made of porous noise reduction structure and covered by soft materials to reduce the noise caused by collector;

(5) Optimum design of the pressure balance window size to mitigate low frequency flutter of open jet test section;

(6) Large sound insulation door driven by floatation can achieve an average of 60 dB sound insulation;

All above methods guarantee that FL-10 wind tunnel has a relatively low background noise level and satisfy the need of aero-acoustic experiment.



1.-open jet test section; 2.-collector; 3.first diffusor section; 4.-first corner; 5.-second corner; 6.-powe section 7.-second diffusor section; 8.-third corner; 9.-fourth corner; 10.-large angle diffusor section; 11.-stablizing section; 12.-contraction section; 13.-anechoic chamber; 14.-sound insulation door

Fig.1 Sketch of FL-10 wind tunnel

2 Anechoic chamber of FL-10 wind tunnel

The anechoic chamber should meet the requirement of far field non-reflection condition during aero-acoustic experiment and also satisfy the aerodynamics loading requirement during wind tunnel operation. The anechoic chamber is designed according to the above standards.

(1) The anechoic chamber is fully anechoic, the walls, ceiling and ground are all covered by sound absorber. In order to control the cost, sound absorbing plate is applied to the area beneath and behind the collector, the rest part is covered by acoustic wedges;

(2) In order to improve the sound insulation of the ceiling and guarantee structural safety, a combination of sound barrier and acoustic wedge is adopted to block sound from outside and reduce sound reflection;

(3) Acoustic treatment is applied to the steel tunnel body to avoid reflection;

(4)Muffler is installed on the pressure balance window to suppress noise from outside;

(5) Sound absorbing and insulation is applied to the hydraulic tail support system to mitigate noise from hydraulic pipeline and reflection from the surface of the support system;

Fig2 gives inner view of the anechoic chamber, the net dimension is 47 m(L)×31 m(W)×22 m(H), it is the largest anechoic chamber domestic so far.

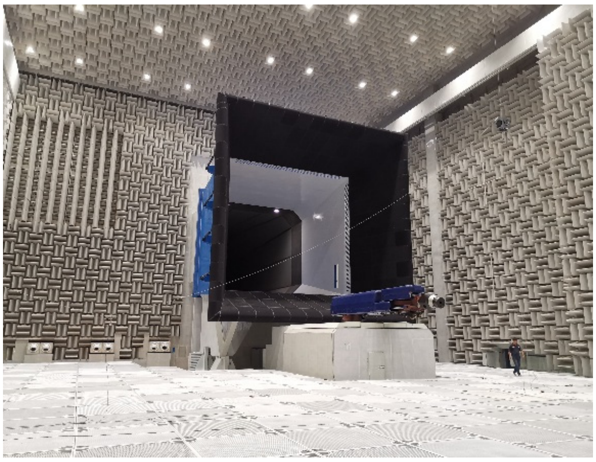


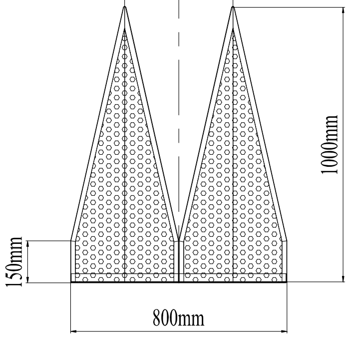
Fig.2 Anechoic chamber of FL-10 wind tunnel

Sound absorbing plate and acoustic wedge is adopted in the anechoic chamber of FL-10 wind tunnel. The acoustic wedge is covered by metallic wire-mesh mask, metallic mask wedge more durable, bearable and deformation resistant, it has certain advantages when switch of test section, acoustic wedge and measurement equipment movement often happens.

The total height of the wedge is 1000m, the base part is 150mm high and the tip part is 850mm high, the bottom size is 800 mm×800 mm, twin wedge arrangement is adopted as shown in Fig 3. The acoustic wedge is filled by environment-friendly superfine glass fiber cotton with a density of 32 kg/m^3, metallic perforation plate serves as covering of the wedge, the perforation plate is 0.8mm thick, the hole diameter is 3mm and the porosity is 32%, the surface is plastic painted.

The acoustic wedge is installed on the rack anchored to the wall, the spacing between the wall and wedge bottom is 150mm. The ground wedge is placed in the wedge frame, each frame has 4 wedges, the frame is installed on wheels and pedestrian expanded metal mesh on top of the wedge, which makes it convenient to move during the experiment and deposit during vacancy.

According to the overall design of the anechoic chamber, sound absorbing plate is placed in the secondary reflection area. The sound absorbing plate dimension is 1600mm(w) ×1600mm(L) ×200mm(H) as shown in Fig 4. The sound absorbing plate is filled by environment-friendly superfine glass fiber cotton, the cavity depth is 150mm.



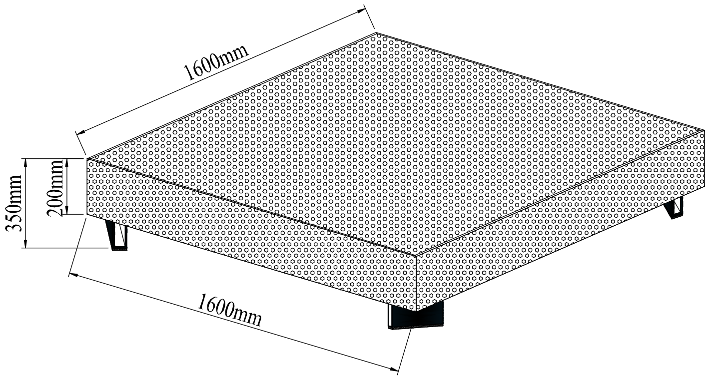


Fig.3 Sketch of acoustic wedge Fig.4 Sketch of acoustic panel

In order to minimize sound reflection from the wind tunnel body, acoustic treatment is applied to the contraction section and the collector. The acoustic treatment is 200mm thick superfine glass fiber cotton and covered by porous metallic plate (as shown in Fig 6). Since the ribbed slab on the tunnel body is usually higher than 200mm, the acoustic treatment is installed on the steel tube welded to the rib, on one hand saves the acoustic material, on the other hand, the cavity beneath the acoustic material can mitigate the low frequency noise.

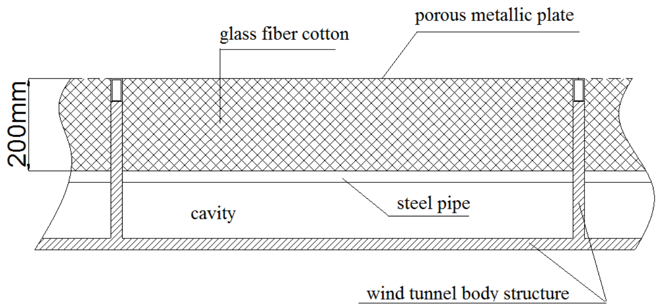
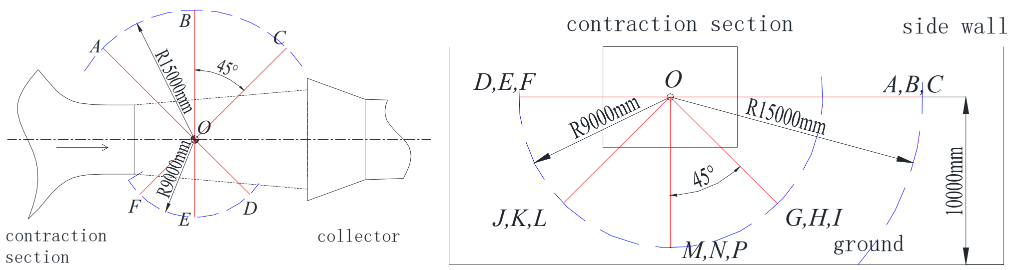


Fig.5 Outside acoustic treatment of wind tunnel

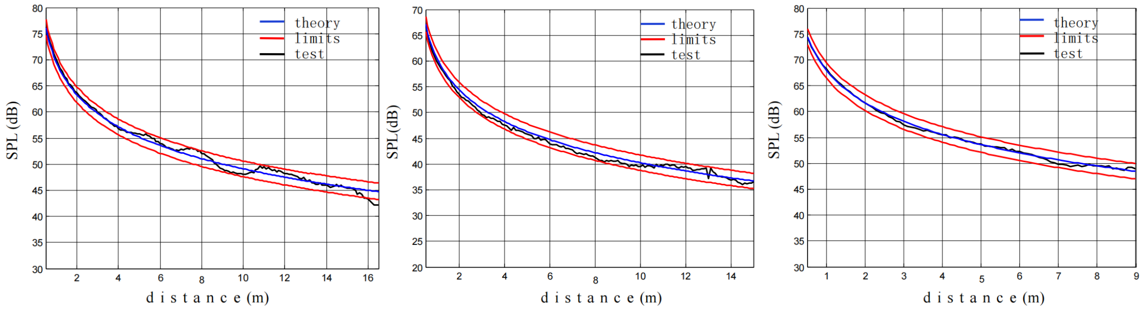
A free field calibration of the anechoic chamber is carried out after the completion of building. A omnidirectional sound source is placed in the center of the test section (Fig 6), the calibration path is shown in Fig 7, a moving measurement track is used to measure the sound pressure distribution from the source to the wedge. The calibration frequency range is 80~40kHz. Fig 8 gives the calibration result along OA, OB and OC path in the range of 80~40kHz[11]. As can be seen in Fig 8, the SPL decay cure falls within the national standard requirement. Since OA path is close to the nozzle and OC path points to the collector, the sound reflected from the nozzle and collector leads to some oscillation on the SPL curve.

Fig.6 Arrangement of calibration sound source

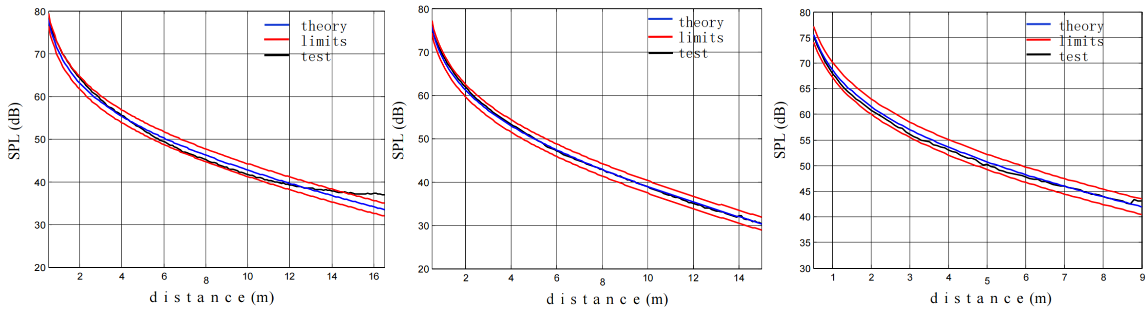


(a) plan view (b) vertical view

Fig.6 Free field calibration path of anechoic chamber



(a) *OA* path，80 Hz (b) *OB* path，80 Hz (c) *OC* path，80 Hz



(d) *OA* path，40 kHz (e) *OB* path，40 kHz (f) *OC* path，40 kHz

Fig.7 Sound pressure level attenuation curve of *OA*, *OB*, *OC* calibration path[12]

3 Noise measurement system of FL-10 wind tunnel

In order to serve for different measurement requirement pose by different testing subjects, FL-10 wind tunnel facilitates ground line array, horizontal phased array, vertical phased array, 1/3 polar directivity to measure flyover noise, sideline noise and sound source distribution. Fig 8 gives a sketch of array layout in scaled airframe noise experiment.

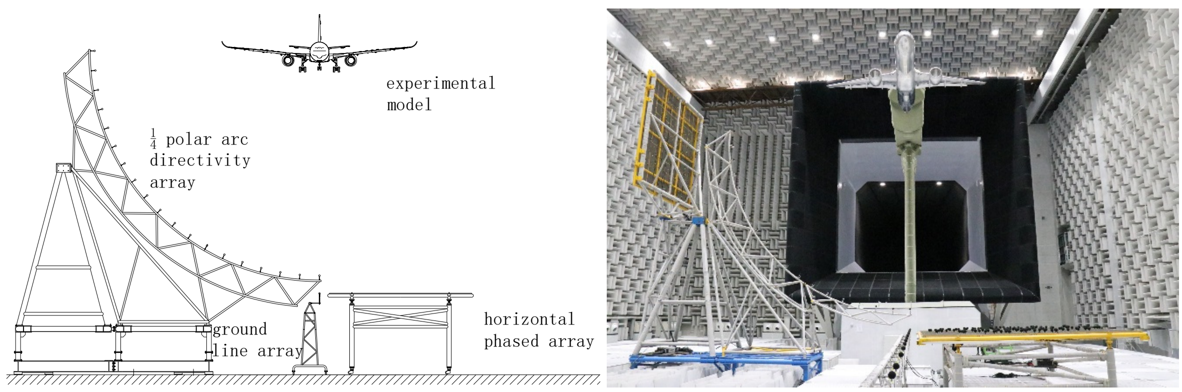


Fig 8 Array lay out for the scaled a/c model noise experiment

3.1 Microphone and data acquisition system

More than 400 B&K 4954A type microphones are equipped on phased array and far-field arrays of FL-10 wind tunnel. B&K 4954A microphone has wide frequency and dynamic range, detailed performance parameter is as follows:

- Microphone diameter: 1/4 inch

- Sensitivity: 2.8 mV/Pa;
- Frequency range: 16Hz~80kHz
- Dynamic range: 40~160dB(A).

The data acquisition system is PXIe high speed parallel data acquisition system of National Instrument company, FL-10 wind tunnel is equipped with 432 channel high speed data acquisition system to serve for multi-array simultaneous use. The performance parameter of the system is as follows:

- Sampling rate: lower than 204.8kHz
- Filtering: Pre anti-aliasing filter, IEPE(4mA) current supply.

3.2 Ground line array

The ground line array is designed to measure flyover noise, the ground line array is placed on the centerline of the wind tunnel beneath the model 2.5m above the ground, the ground line array is 7.5m to the center of model. As shown in Fig 9, the ground line array has 19 channels and covers the range of 40°~130° against the flow, the angular interval is 5°, each microphone points to the center of wind tunnel during experiment. The 11th channel is right below the model. All the microphones on the ground line array is covered by wind screen to minimize the influence of reverse flow on acoustic measurement. Meanwhile, the ground line array is wrapped by sound absorbing foam to reduce sound reflection.

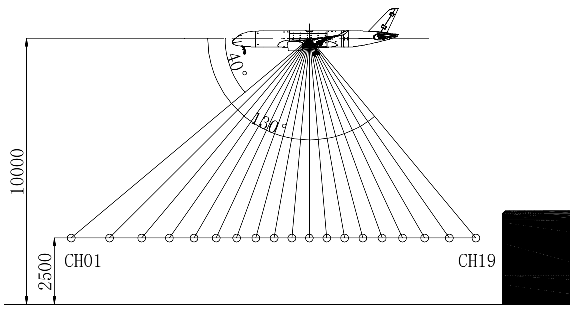


Fig 9 Sensor distribution on the ground line array

3.3 Horizontal phased array

The horizontal phased array is placed horizontally to localize sources of airframe and rotor. The horizontal phased array is pluggable grid type, sensor position on the array can be altered as demanded. The size of the array is 4.4mX4.4m, grid spacing is 20mm. The most usual used phased array is 143-channel muti-spiral array of 4m in diameter, there are 13 arms, each arm has 11 microphones(see Fig 12). When doing source localization for rotor noise, the array can be extended to 10m in diameter by the extending arm along the diagonal of the array, 5 microphones are placed on each extending arm, which makes the array 163-channel cross and muti-spiral mixed array, the mixed array has better resolution at low frequency.

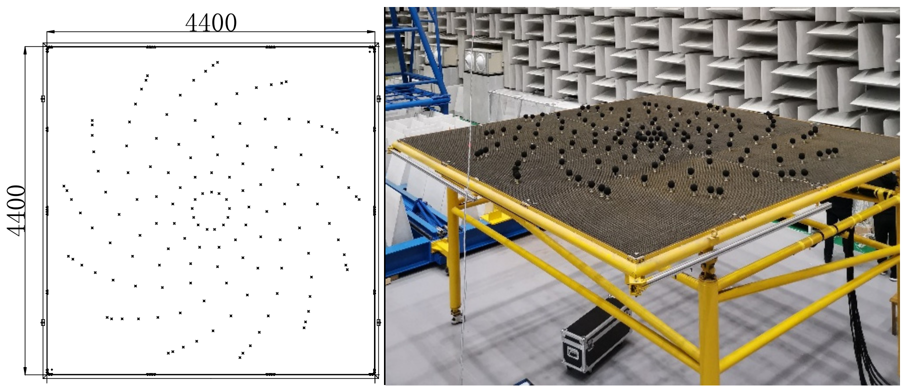


Fig 10 Sensor distribution of the array and real subject

3.4 Vertical phased array

The vertical phased array is designed for the source localization of high lift device and high speed train, the size and parameter is the same as the horizontal array. The center of the vertical array is 10m to the ground, same as the center of the test section.

Fig 11 Vertical phased array (ground commissioning)

3.5 1/4 polar arc directivity array

The 1/4 polar directivity array is designed to measure the sideline noise of model, the array is installed on a transfer track which moves in the flow direction, acoustic characteristic on the scanning surface can be obtained. The polar array diameter is 7m, measurement range is 90° with angular interval of 5°,19 microphones are installed on the polar array. The transfer track base is 14m long and the moving range is 12m, the polar array is also wrapped with acoustic foam to minimize sound reflection.

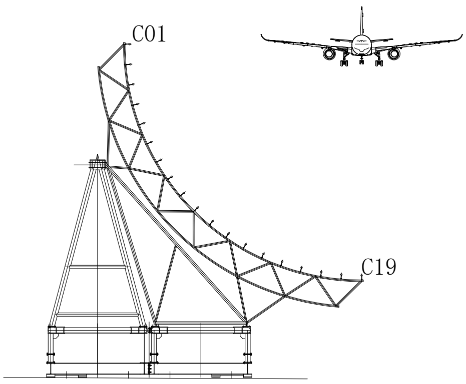


Fig 12 1/4 polar arc array (front view)

3.6 Hemispherical array

The hemispherical array is designed for the measurement of helicopter noise propagating towards the ground, the array is hemispheric , the top of the array is flush with the rotor disk, the total height is 11m. The yaw angle range is 20°~90°, angular spacing is 10°; the azimuthal angle range is 0°~360°, the azimuthal angle spacing is 15°. Affected by the wind tunnel flow, some of the microphones located in the wind tunnel airflow are removed. The entire array has a total of 160 microphones.

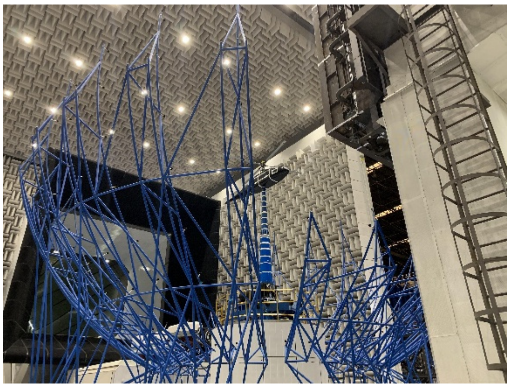


Fig 13 Hemispherical array

3.7 Inflow microphone array

The inflow microphone array is used to measure the near-field sound directivity of rotor, propeller and engine fan noise. The inflow array is U shape and divided into two parts so that it can transverse through the rotor test stand to measure the upstream and downstream noise. The inflow array is 2.3m high and 5.67m wide, it is completely within the flow of the open jet test section. In order to reduce the self noise of the support frame, the cross-section of the support is made of NACA 0028 airfoil. 11 microphones are evenly distributed on each side of the array, the yaw angle range is 0°~-80°, Fig 14 shows the picture of inflow array measuring rotor noise during the test.

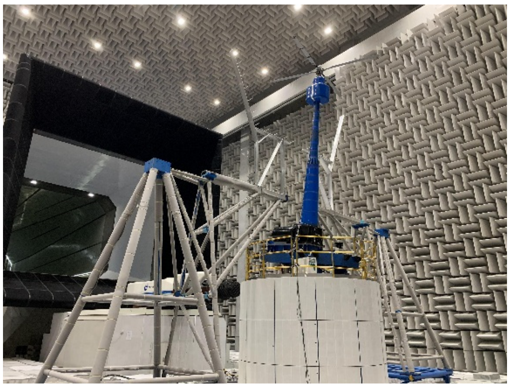


Fig 14 Inflow microphone array

4 FL-10 aero-acoustic experimental system

By adopting different support and measurement system, FL-10 wind tunnel has been capable of performing comprehensive aero-acoustic experiment such as scaled a/c noise experiment, landing gear noise experiment, high lift device noise experiment, high speed train noise experiment, rotor noise experiment, the experimental capability has been fully proved by the experimental results.

4.1 Scaled airframe noise experiment

The hydraulic tail support system is used for scaled aircraft noise experiment, during the test, the scaled a/c model kept in the center of test section by an airfoil strut on the back of the model, back support can minimize the influence of strut on acoustic result. The hydraulic tail support system is equipped with an acoustic fairing to protect the complex structures of the support system from the flow, besides, the acoustic fairing is covered by soft material to reduce the flow induced noise by the fairing. The angle range after installing acoustic fairing is -2°~12°.

As for the scaled airframe noise measurement, the flyover noise, sideline noise and source localization result of a civil aircraft is measured, the influence of wind speed, angle of attack, and configuration on acoustic characteristic is obtained (Fig 15). According to the experimental result, the signal-to-noise ratio of scaled airframe noise experiment in FL-10 is higher than 10dB, and the OASPL repeatability is within 0.5dB. Fig 16(a) shows the spectrum repeatability and signal-to-noise ratio of take-off configuration, Fig 16(b) shows the influence of wind speed on the spectrum of approach configuration.

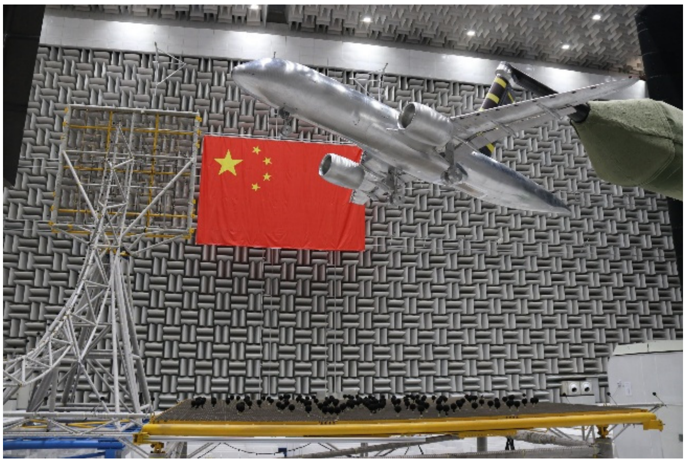
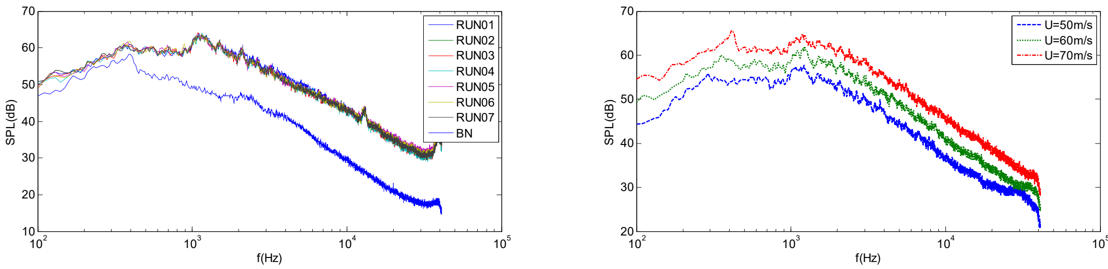
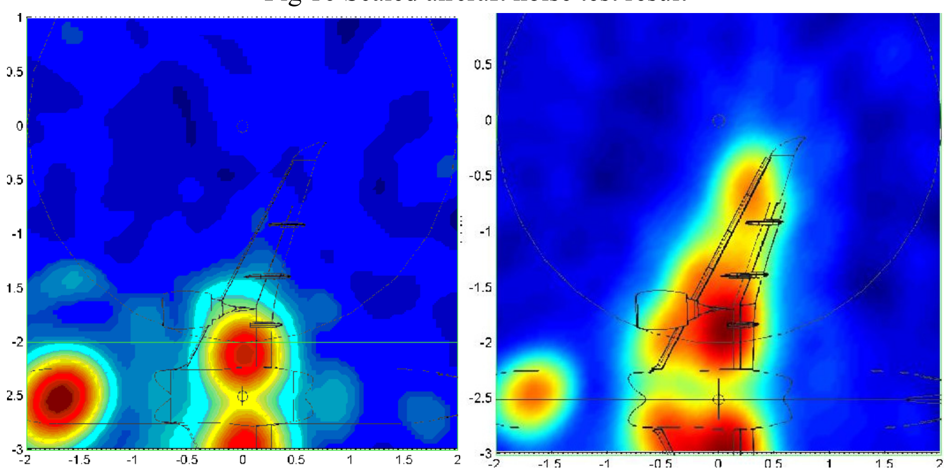


Fig.15 Airframe noise test in FL-10 WT



（a）Spectrum repeatability of takeoff configuration （b）Influence of wind speed on approach configuration spectrum

Fig 16 Scaled aircraft noise test result



(a) Landing gear noise source localization result (b)Landing gear and high lift device noise source localization result

Fig 17 Source localization result of scaled a/c

4.2 Landing gear noise experiment

Landing gear noise experiment is carried out by side plate support system. The landing gear support system is made up by side plate support frame, baffle plate, landing gear connection system and landing gear cavity simulator. The baffle plate is 8m wide and 7m long with metal and Kevlar plate which correspond to hard wall and acoustic transparent wall. There are two landing gear installation positions on the support system, the two installation positions are designed for nose landing gear and main landing gear installation.

A simplified full scale 4-wheel landing gear model based on a typical civil aircraft main landing gear is experimentally measured in FL-10, the landing gear model maintains the key feature of the original landing gear. The landing gear model is made up of wheel, main strut, side bar, wheel axle linkage, etc. The diameter of the wheel is 1270mm and total height of the model is 4089mm. Static pressure ports and dynamic pressure ports are placed on the surface of the model. Horizontal and vertical phased array is adopted to perform source localization, 1/4 polar arc directivity array and far-field wall array is used to measure the far-field acoustic result. Fig 19 shows the influence of wind speed on noise spectrum.

Fig 18 Full scale 4-wheel landing gear model

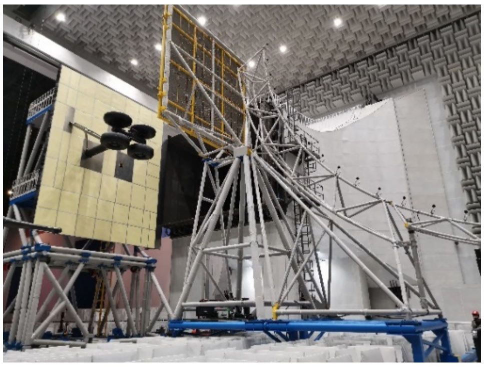


Fig.19 Landing gear noise test in FL-10 WT

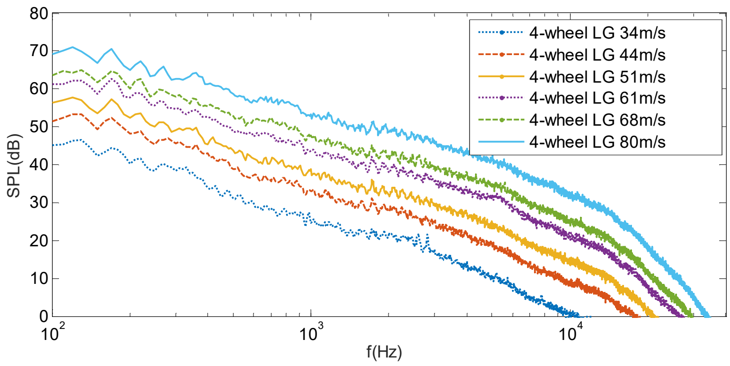


Fig.20 Landing gear noise spectrum curve under different wind speed

4.3 High lift device noise measurement platform

High lift device noise measurement platform is deigned for half model and high speed train noise experiment. The platform is 20m long, 16m wide and 7m from the ground. The upper surface is flush with the nozzle lower surface, together with the collector and contraction section, consists of the 3/4 open jet test section. The platform has two kinds of surfaces, the solid surface is designed for high speed train and truck noise experiment; the sound absorption surface with a 400mm sound absorbing layer to eliminate sound reflection is designed for high lift device noise experiment.

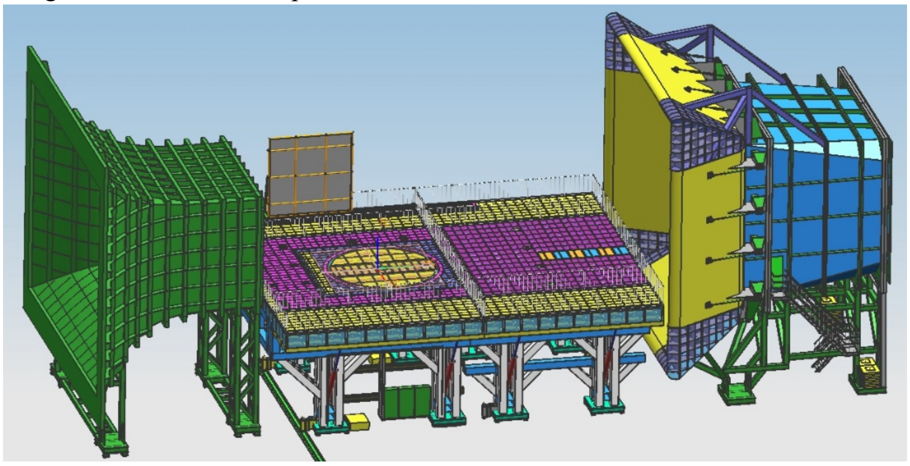


Fig 21 High lift device noise measurement platform

A 1:8 scaled 3-group high speed train noise experiment was carried out on the high lift device experiment platform, aero-acoustic data including far-field noise, source map and surface acoustic loading result was obtained, the influence of pantograph and bogie truck on high speed train noise spectrum was experimentally studied. The signal-to-noise ratio of high speed train noise experiment is 5-10dB, the OASPL repeatability is less than 0.5dB. Fig 22 shows the influence of pantograph on far-field noise.

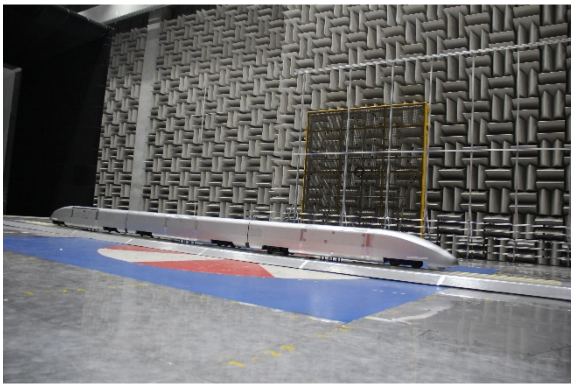


Fig 22 High speed train noise test in FL-10 WT

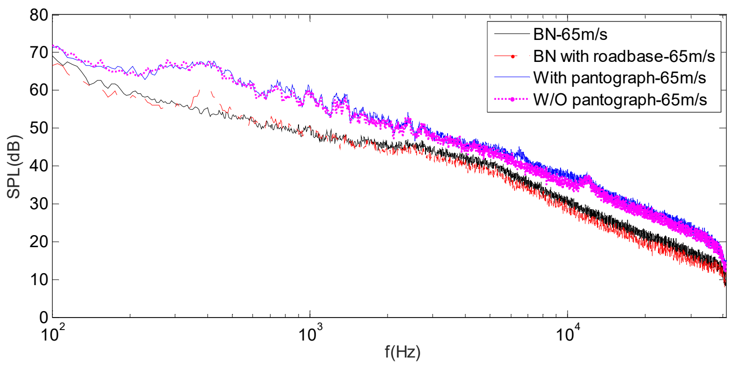


Fig.23 Noise spectrum w/o pantograph at 65m/s

4.4 Rotor noise experiment

The rotor noise test bench can carry out aerodynamic and aero-acoustic test of rotor up to 4m in diameter.

The main performance parameter of the test bench is listed as follows:

1) Rated rotation speed: 1050 rpm;

2) Maximum rotation speed:1300rpm;

3) Total pitch angle range: -4°～+16° (angular precision ±0.1°)

4) Rotor cyclic pitch range: ±10°(angular precision ±0.1°)

5) Rotor main shaft inclination angle range: -25°～15°(angular precision ±3′)

A 4m BO-105 rotor model experiment is carried out in FL-10 (Fig 23), hemispherical array, inflow array is adopted to measure the far-field noise, near field noise and surface acoustic loading of hover and forward flight configuration. Fig 24 shows the far-field spectrum of BO-105 rotor, as can be seen in the spectrum, discrete tonal noise is the main content.

Fig 24 Helicopter noise experiment in FL-10 wind tunnel

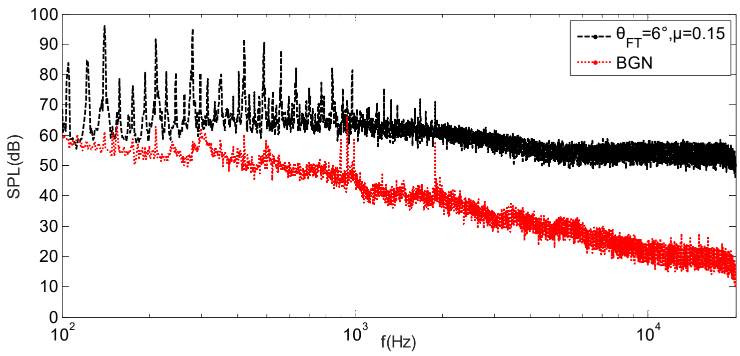


Fig.25 Helicopter noise test result in FL-10 WT

5 Conclusion

In terms of the aero-acoustic experimental capability of AVIC ARI FL-10 wind tunnel, basic information, noise measurement system and experimental system is introduced, some characteristic test results are also shown. FL-10 wind tunnel has good aerodynamic and aero-acoustic quality, combining the support and measurement system, experimental capability of airframe noise, rotor noise, high speed train noise, etc has been formed and fully validated. The repeatability and precision of test result is remarkable, which guarantees a high quality experimental result for civil aircraft and high speed train development.

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