Constructing Progress of the Low Speed Pressurized Wind Tunnel in China

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Abstract: In this paper, the necessity of building Low Speed Pressurized Wind Tunnel (LPW) in China is discussed, and the development of low speed high Reynolds number wind tunnel at abroad is introduced. It is put forward the performance criterion for modern productive wind tunnel. The primary technical performance as well as key points of designing and constructing LPW at China is given, and the up to date progress of constructing FL-9 low speed pressurized wind tunnel is introduced.

Key words: pressurized wind tunnel; high Reynolds number; wind tunnel constructing

0. Introduction

The low speed pressurized wind tunnel (FL-9) of China was put in for in March 1996, the argumentation conference of the item was hold in June 1996 in Harbin, and the demonstrability conference was hold in January 1998 in Beijing. It was list on the important aeronautic science and technology lab of the 9th Five Years Plan in February 1999, and was warranted in October 1999. The structure design of the tunnel was finished in July, 2002, and the construction was started on. The whole work of the pressurized wind tunnel has been finished this year and the flow field calibration is carrying through now.

1. The necessity of constructing a low speed pressurized wind tunnel

It is known that Reynolds number can affect lift characteristics of high aspect ratio civil aircrafts, especially near the maximal lift point, and the parameter being affected includes C_{Lmax}, C_{cr}, $C_{L\alpha}$, and so on. It can affect drag characteristics too, especially to C_{Dmin}. Reynolds number can also affect longitudinal and lateral-directional stability uncertainly. Reynolds number has a more serious, more complicated and worse regular effect on modern civil aircrafts with supercritical Wing. So, it is important to carry through high Reynolds number wind tunnel test.

Statistical results show that the lift measure results are credible to high aspect ratio and low swept angle civil aircrafts, when the Reynolds number is not lower than 6×10^6. The experience of Boeing Company shows that, to measure lift with low speed high-lift devices, the test Reynolds number must be morn than 6×10^6, and to measure drag, more than 4×10^6. So, it is generally taken for that the test results are basically credible when the test Reynolds number reaches 6×10^6 for low speed wind tunnel models.

To low aspect ratio, high swept and sharp leading edge aircrafts with shedding vortex and separated flow style, maneuverability and agility need credible wind tunnel test results with angle of attack arriving at 90-deg and angle of sideslip arriving at ± 45-deg, and the influence of Reynolds number will be more serious and worse regular. It is necessary to be tested in high Reynolds number wind tunnel for qualification.

Low speed wind tunnel tests in China are all operating at normal pressure, the highest Reynolds number has a big difference to 6×10^6 and can't meet the needs. It is not a good choice to constructing a low temperature high Reynolds number wind tunnel like NTF of America and ETW of Europe at present, but constructing a 4 meters level low speed pressure wind tunnel is possible. The construction of LPW will upgrade our wind tunnel test capabilities, and meet the needs of the design and manufacture of aircrafts with low speed wind tunnel Reynolds number simulation tests.

2. Aiming at advanced technique

At present, there are three kinds of low speed high Reynolds number wind tunnel. The first is full-scale wind tunnel built in 40 decades in the 20th century, represented by TSAGI T101 wind tunnel of Russia and NASA Ames 24 m × 36 m wind tunnel of America. The second is pressure wind tunnel, represented by NASA 3.4 m pressurized wind tunnel of America, ONERA F1 wind tunnel of France and RAE 5m pressure wind tunnel of UK. The last is low temperature wind tunnel, represented by DLR KKK wind tunnel of Germany. Table 1 gives the main low speed high Reynolds number wind tunnel of the world.

Table 1 Main low speed high Reynolds number wind tunnel of the world

Items / Wind tunnel	Size of test section (meter, width × height)	Nationality	Highest Re number × 10^{-6} (reference length is $0.1\sqrt{A}$)	Running style	Time of constructing and reconstructing
T101	24 × 12 (ellipse)	TSAGI of Russia	8	Atmosphere pressure	Constructed in 1939
24m × 36m wind tunnel	36 × 24	NASA of America	10.8	Atmosphere pressure	Constructed in 1944 Reconstructed in 1982
3.4m pressure wind tunnel	5.5 × 3.4	NASA of America	10	Pressurized	Constructed in 1946 Reconstructed in 1990
KKK wind tunnel	2.4 × 2.4	DLR of Germany	7.7	Low temperature	Constructed in 1984
F1 wind tunnel	4.5 × 3.5	ONERA of France	7.5	Pressurized	Constructed in 1977
5m pressure wind tunnel	5.0 × 4.2	RAE of UK	7.2	Pressurized	Constructed in 1978

Construction upsurge of low temperature high Reynolds number wind tunnels in 80 decades in the 20th century has passed. Low temperature wind tunnels run with high test cost (NTF of America, 12000 US dollars per polar curve) and with low efficiency because of the complicated test systems. An advanced productive wind tunnel must have three requirements contemporarily: high simulation capacities, high productivity and low price. To low speed wind tunnel, the target is that Reynolds number 3×10^7 (at least 6×10^6), 5 polar curves per hour, low tests price, and ensuring excellent flow field quality.

According to the criterions mentioned above, FL-9 wind tunnel chooses the pressurization style to obtain high Reynolds number. Although It can not reach the flight Reynolds number of full-scale aircrafts, but can meets the need of test Reynolds number (the Reynolds number with the reference length of mean aerodynamic chord length, to the 1:14 Air Bus 320 model is 10.2×10^6) and can obtain high productivity and low cost.

3. The pressure wind tunnel (FL-9) design proposal

To obtain high Reynolds number, the tunnel (FL-9) utilizes the compressor to press the air, aiming at F1 wind tunnel of France ONERA, and the simulation capability, wind tunnel performance, flow field quality, productivity must be good, and the cost should be acceptable.

Fig. 1 gives the aerodynamic contour of FL-9 wind tunnel. The axes of FL-9 is 78m (length) × 18m (width), with the biggest diameter 16m (plenum chamber), the cubage is 13000 m^3, and the total mass is over 4000 tons. The laboratory construction area is 11100 m^2.

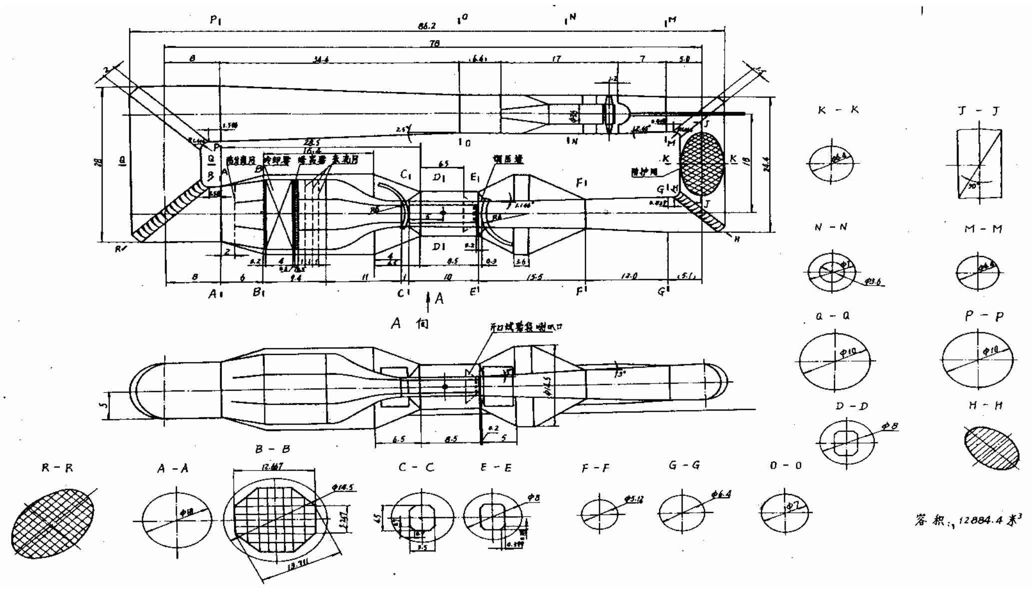


Fig. 1 Aerodynamic contour of FL-9 wind tunnel

Main capabilities of FL-9 are listed as following:

(1) Size of test section: 4.5 m (width) × 3.5 m (height) × 11 m (length).

(2) Highest wind speed: 130 m/s.

(3) Pressure range: from 0 to 0.4 MPa.

(4) Power: 9500 KW.

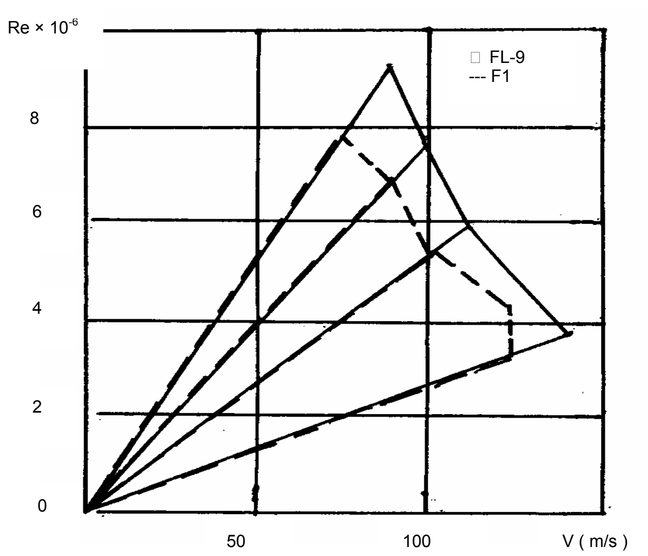


Fig. 2 Work envelopes for FL-9 and F1 wind tunnels

(5) Highest Reynolds number: 8.5×10^6 (reference length is $0.1\sqrt{A}$, A

refers the area of test section). Fig. 2 gives the work envelopes for FL-9 and F1 wind tunnel.

(6) Flow fields quality: see table 2.

Table 2 Flow fields quality comparison between FL-9 and F1 wind tunnel

Wind Tunnel Items	FL-9 (4.5 M × 3.5 M)	F1 (4.5 M × 3.5 M)	National Military Criterion (Advanced Index)
Velocity Pressure Distribution Δμ	≤0.1%	≤0.1%	≤0.2%
Direction Field Δα, Δβ	≤0.1°	≤0.2°	≤0.2°
Local Temperature Departure	≤0.5□	≤0.5□	
Axile Static Pressure Grads	≤0.002	0	≤0.005
Flow Turbulence	≤0.1	≤0.1	≤0.2
Speed Pressure Stability	≤0.002	≤0.002	≤0.002
Highest Temperature	≤40□	≤40□	≤45□

(7) Test capabilities:

□ Conventional load and pressure measurements test (ventral supports and rear supports).

□ Half model test.

□ Large amplitude of angle of attack test (angle of attack: from 0-deg to 110-deg, angle of sideslip: ± 45-deg).

□ Ground effect test.

□ Flow visualization and measurement test.

□ Reynolds number effect test (range from 1×10^6 to 8.5×10^6).

(8) Productivity: 5 polar curves per hour.

(9) Price: reasonable

Table 3 gives the performance comparison between FL-9 and F1 wind tunnel. From the table, we can see that the capability of FL-9 wind tunnel has arrived at the advanced level of the world.

Table 3 Performance compared between FL-9 and F1 wind tunnel

Wind Tunnel Items	FL-9	F1
The size of the test section (m, width × height × length)	4.5 × 3.5 × 11	4.5 × 3.5 × 11
Highest wind speed (m/s)	130	125
Highest pressure (Pa)	4×10^5	4×10^5
The power of the fan (KW)	9500	9500
Highest Reynolds number (reference length is $0.1\sqrt{A}$)	8.5×10^6	7.5×10^6
Flow quality	See table 2	See table 2
Test ability	Multifunctional, Powerful test capabilities	Powerful test capabilities
productivity	5 polar curves per hour	5 polar curves per hour

4. Characteristics and key techniques in the construction of FL-9 wind tunnel

4.1 Characteristics in the construction of FL-9

(1) The body of the wind tunnel is a large pipeline pressure vessel with flow air, which has the characteristics of wind tunnel pipeline and large pressured vessel.

(2) The wind tunnel is pressurized when working. So, sealing must be considered especially.

(3) Wind tunnel often works at high dynamic pressure (atmosphere pressure q = 1.05×10^5 Pa, pressurized q = 2.025×10^5 Pa), which makes the loads of the body and model bigger than usual.

(4) The fan with the power of 9500 KW, will heat up the air inside, which must be cool down to keep the temperature ranging of 40 ± 1 □.

(5) To save energy, when changing model or components, the pressure would not be decompressed totally. Only the pressure in the test section should be decompressed.

(6) To improve efficiency, the test preparation should not be done in

wind tunnel, and the mobile test sections (including plenum chamber) are adopted. The preparation works can all be done outside the tunnel to save time.

4.2 key techniques

(1) aerodynamic design :

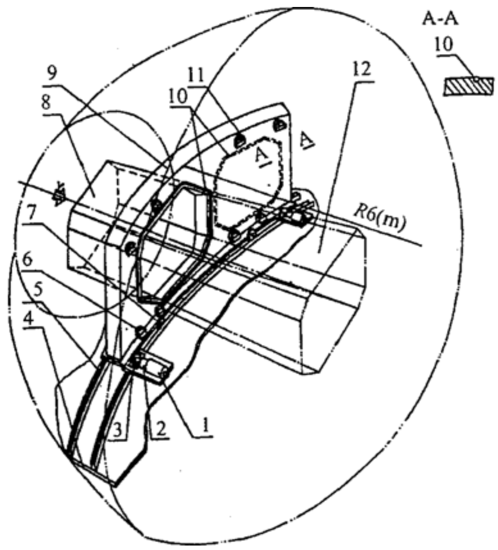
To get good flow field quality, every parameter of the components of the wind tunnel must meets the need of referenced criterion, and must be optimized.

Compared with F1, FL-9 wind tunnel has three obvious changes in aerodynamic design.

- Contraction ratio changes (from 7.2 to 9).
- High angle of diffusing is adopted at the entrance of the plenum chamber (the largest angle of diffusing is 17.2-deg).
- The cooler is placed in the plenum chamber to reduce flow loss and to straighten the flow.

(2) Airproofing is an very important problem.

Aired rubber loops are placed in the seal between the movable section and fixed section, and there is special air source to supply the aired loops. Furthermore, there are two important facilities: one is the sealed door of the test section (Fig. 3), which is hard to control and seal for sake of the volume (The radius is 6 meters.) and the weight (Each weights 27 tons.) ; the other is the seal of long axis of the drive system (10 meters) and body of the wind tunnel, which needs special airproof structure.



1. motor; 2. retarder; 3. active wheel; 4. wall; 5. oriented orbit;
6. nether tectorial wheel (double sides); 7. driven wheel;
8. test section; 9. arc sealed door; 10. sealed loop;
11. upper tectorial wheel (double sides); 12. diffuser

Fig. 3 Work principle of sealed door

(3) Mobile test sections.

Mobile test sections and plenum chambers are special facilities of FL-9 wind tunnel. The length is 8.5 meters. The bottom plate is coupled with mobile cart, and each mobile cart owns its own bottom plate which can be moved in or out of the test section. The inner diameter of the mobile plenum chambers is 8 meters, and the thickness is 30 millimeters. Plenum chambers can move along the oriented orbit, and the speed is 14 meters per minute.

(4) Mobile carts -- kernel facility of the wind tunnel.

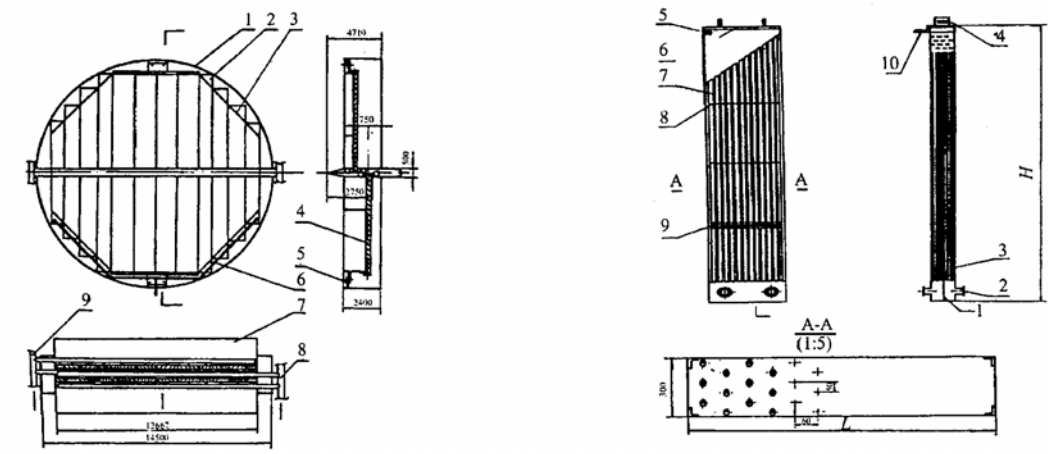
To improve productivity, different styles of mobile carts are used to make the models change quickly. Mobile carts are composed of model bracket, angle-changing setup, bottom plate (The wall underside of the test section), mobile vehicle along the oriented orbit, and so on. There are 3 mobile carts in FL-9 wind tunnel: the fist one is rear supports double rotary axes mobile cart, which is applied to conventional middle and low angle of attack test, with the range of angle of attack being negative 19-deg to 35-deg and angle of sideslip being negative 45-deg to 45-deg. The second one is ventral supports and high angle of attack mobile cart, which is applied to ventral supports model wind tunnel test, and high angle of attack test, with the range of angle of attack being negative 180-deg to 180-deg and angle of sideslip being negative 45-deg to 45-deg. The third one is half model supports mobile cart, with the range of angle of attack being negative 10-deg to 90-deg.

(5) Pressure testing

According to the national standardization GB150-89 "steel pressure vessel", the pressurized wall of wind tunnel must carry through pressure testing. Usually, pressure test includes water pressure test and air pressure test. The advantage of water pressure test is safety, but it brings much more loads to the foundation of the wind tunnel. The cubage of FL-9 is 13000 m^3. If water pressure test is adopted, 13000 tons accessional loads will make the cost of the foundation more expensive. For this reason, air pressure test is adopted in FL-9. Moreover, the highest pressure of FL-9 is in the range of 0.1 MPa to 0.4 MPa, belongs to low pressure vessel (0.1 MPa to 1.6 MPa). Relief valve is used to reduce the pressure when leaking.

(6) The design of driving system and the high efficient lower noise fan.

There are two kinds of proposals about the driving system: one is fixed rotate speed of the fan, changing wind speed by adjusting the pitch of blades. It was adopted by F1 wind tunnel. And the other is driving fan with AC electromotor, and changing the frequency of electromotor with transducer to change the speed of fan and wind speed. It is usually adopted by modern wind tunnel such as DNW. The excellence of this one is simple configuration, credible running, convenient operation, but it needs more investment. The latter is adopted by FL-9 wind tunnel.



1. crust of plenum chamber; 2. upper cooling bar;
3. settling chamber; 4. nether cooling bar;
5. coupling board of cooler; 6. drainage pipes;
7. rectifier; 8. general water-in pipe;
9. general backwater pipe.

(a) Arrangement of the cooler

1. clapboard of passage; 2. pipe of passage;
3. crust; 4. stationary ring; 5. drainage pipes;
6. coping; 7. 17 × 34 elliptic cupreous pipes;
8. supporting boards; 9. heat scattering slices;
10. fixing angle irons.

(b) Configuration of the cooler

Fig. 4 Arrangement and configuration of the cooler in FL-9

High efficiency and lower noise are two main targets of fan design, but they are antinomies and must be optimized. Many techniques are introduced to raise the fan efficiency up to 90% and reduce noise, such as the adjustment of design parameters, the debasement of loads of fan blades and speed of wingtips, increasing the performance of aerofoil at about 0-deg of the angle of attack (Drag is minimum, lift coefficient is about 0.5, and the flow near the blade is laminar and separation is avoided), properly choosing the lift-drag-ratio of blades (≥ 40) and the advannce ratio of fans (from 0.6 to 1.2), adjusting the number of blades and flow deflector to be matched, and so on.

(7) Cooling system.

Cooling system is used to keep the temperature of the test section of FL-9 in 40 ± 1 degree Celsius. Water-cooling is adopted to ensure the test section running at invariable temperature.

Fig. 4 shows the configuration of the cooler. The cooler has 24 cooling water pipes with tendon outside, the section of which is ellipse of 17 mm × 34 mm and the thickness of the wall is 1 mm. The general heat scattering area is 13127 m^2, and it weights about 80 tons.

5. Up to date progresses

The construction of the Low Speed Pressurized Wind Tunnel (LPW) began in 2001, and now all construction projects have been finished. The integration of all systems and flow field calibrations have been on since April 2007. And now, manufacturing of standard model and related balance, has finished, debugging of ventral support system, measurement and adjustment of axial static pressure gradient have finished. Other flow calibration projects are expected be accomplished and the Low Speed Pressurized Wind Tunnel (LPW) come to use by the end of this year.

6. Conclusions

The establishment of large low speed pressurized wind tunnel is a systems engineering, which needs excellent design, organization and construction. With optimum design, exquisite construction, and excellent flow field calibration, FL-9 low speed pressure wind tunnel will reach or exceed the advanced level of the world.

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