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Experimental Investigation of the CHN-T1 Model in FL-13 Wind Tunnel of CARDC and DNW-LLF Facility

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Abstract

Experimental aerodynamic investigation of the China Transport Calibration Model (CHN-T1) with wingspan of 4.667m and MAC of 0.582m designed and manufactured by China Aerodynamics and Development Center(CARDC) have been conducted in FL-13 Wind Tunnel of CARDC and DNW-LLF Facility. Data have been obtained at chord Reynolds numbers from 1.5 million to 3.4 million for the same configuration at both wind tunnels. Force and moment data were obtained in both facilities and are presented herein. CHN-T1 was mounted on a TG1801A six-component stain-gauge internal balance connected to the large AOA support mechanism in FL-13 wind tunnel and a W616 internal balance connected to a sting support in DNW-LLF facility. Tunnel to tunnel variations including Reynolds numbers effect and aerodynamic characteristics have been assessed. Reynolds numbers effect on CHN-T1 aerodynamic characteristics follows the expected trends. Results comparison shows that the $C_{L\alpha}$ varies very little to be neglected and the minimum C_D is of a difference of 0.0001, C_{m0} shows a difference of 0.033. This difference may be due to the variation in the sting mounting systems at the two tunnels.

Keywords: CHN-T1, calibration model, large low speed wind tunnel, force measurement

1. General Introduction

High aerodynamic efficient large aspect ratio wing is the ideal choice for long-range and long-endurance transport airplane design, also widely applied in low speed general aviation aircraft and slow maneuver UAV. To obtain higher performance and reduce development risk, reliable prediction of aircraft aerodynamic characteristics is necessary in design phase.

Large low speed wind tunnel is the effective facility to acquire low speed aerodynamic characteristics of large aspect ratio aircraft. For the same aircraft, different wind tunnels will generate test result variation for flow quality, model strut, measurement equipment and correction method difference. It is necessary to investigate the large aspect ratio aircraft test result relevance between different large low speed wind tunnels.

FL-13 wind tunnel is the main facility for large aspect ratio aircraft aerodynamic characteristics research in China. DNW-LLF wind tunnel has the similar test section(Table 1), which is well recognized for its strong capability and skilful technique. In recent years, many institutes have conducted comparison tests to investigate the result agreement between the two wind tunnels. China Aerodynamics Research and Development Center(CARDC) carried out systematic and overall force tests in the two wind tunnels on the self-developed CHN-T1(1:6.4 model)[1,2], and made guidance for the correlation analysis of the two wind tunnels.

Table 1 FL-13 wind tunnel and DNW-LLF wind tunnel specification

Wind Tunnel	Test section	Max Wind Speed	Dynamic pressure field coefficient	Angle of flow field	Turbulence
FL-13	15m(L)×6m(H)×8m(W),closed	100m/s	0.5%	±0.5°	0.1%
DNW-LLF	20(L)×6m(H)×8m(W),closed	115m/s	0.3%	±0.3°	0.1%

2. Test Facility

2.1 Wind tunnel

FL-13 wind tunnel is an open circuit wind tunnel with two closed tandem test sections. The calibration model tests are performed in the second test section with 47.4m^2 cross area and wind range of 20m/s to 80m/s.

LLF wind tunnel is a return circuit wind tunnel with two changeable closed test sections. The overall changeable section length is 45m, including contraction, test and diffuser section. The calibration model tests are carried out in the 8m×6m test section.

2.2 Model support system

The calibration model is supported by the Large AOA support system(Figure 1) in FL-13 and sting support system(Figure 2) in DNW-LLF. The two systems can provide ventral and dorsal support during the test period.

Figure 1 Large AOA system in FL-13

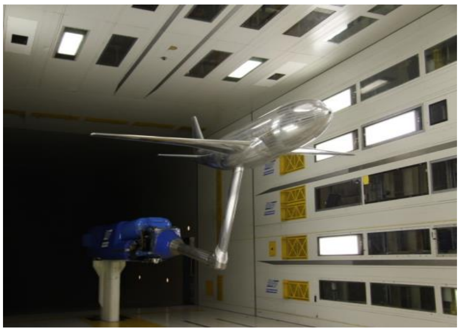

Figure 2 sting support system in DNW-LLF

2.3 Balance

The calibration model load in FL-13 is measured by the CARDC self-developed TG1801A balance[3]. Table 2 shows the balance performance.

Table 2 TG1801A balance specification

	Y	X	Mz	Z	My	Mx
Design Load（N, N • m）	40000	12000	12000	7000	7000	8000
Accuracy（%）	0.06	0.17	0.13	0.09	0.11	0.14

The inner six-component strain gauge W616 balance[4](Table 3) and TG1801A balance are employed for model load measurement in DNW-LLF.

Table 3 W616 balance specification

	Y	X	Mz	Z	My	Mx
Design Load（N, N • m）	20000	6000	7500	10000	3000	4500
Accuracy（%）	0.05	0.09	0.08	0.05	0.13	0.11

2.4 Measurement and control system

FL-13 wind tunnel measurement and control system mainly includes data acquisition system, model attitude control system, dynamic pressure control system, data processing system, test dispatch system and data analysis system. The real time dynamic pressure control precision is 0.3%. The model pose measurement precision is better than 0.01°.

The DNW-LLF wind tunnel flow reference system(FRS) provides data about the conditions in the tunnel setting chamber and the contraction. With the information from the FRS flow conditions in the test section are calculated. The output of all measurement equipment is acquired by various DNW-LLF data acquisition subsystems. The readings from the main balance strain gauges and the model attitude system are measured and stored on the DNW static data acquisition subsystem for each data point. The information from the flow reference system is acquired by a different subsystem. All subsystems are triggered by the DNW main Supervisor computer, SPV. Upon triggering data is acquired and stored in a so-called data point.

3. Test Model

The 1:6.4 aluminum alloy calibration model is a lower single wing with supercritical airfoil, low-located horizontal tail transport aircraft model(Figure 3). There are no nacelles and control surfaces for model storage stability and mounting repeatability. Table 4 presents the dimensions of the model.

Figure 3 3D drawing of CHN-T1

Table 4 Dimensions of CHN-T1

Model part	Length	4.782m
Fuselage	Length	4.731m
	Diameter	0.589m
Wing	Area	2.328m^2
	MAC	0.582m
	Wing span	4.667m
H.T.	Area	0.191m^2
	Span	1.557
V.T.	Height	0.745m
	Area	0.315m^2

Flow transition is fixed by using zigzag tape on the fuselage nose, wing, horizontal tail and vertical tail. An overview of the size and locations of the strips is listed in Table 5.

Table 5 Size and locations of the strips

Model part	Strip position	Strip thickness
Wing upper surface	5% chord relative to LE	0.25mm
Wing lower surface	5% chord relative to LE	0.25mm
H.T. upper surface	8% chord relative to LE	0.40mm
H.T. lower surface	8% chord relative to LE	0.40mm
V.T. (both sides)	8% chord relative to LE	0.40mm
Fuselage nose	70mm from nose LE	0.40mm

4. Test Method

4.1 FL-13 wind tunnel

The model is mounted in the second test section on the TG1801A internal main balance connected to the large AOA support system. A ventral sting configuration is used for the main longitudinal and lateral investigations, and the dorsal sting set-up is used for support interference investigations. The model MAC is about 1m ahead of the second test section center. The model attitude is measured by two inclinometers in real time. The aerodynamic load is measured by the TG1801A internal main balance. During the test, FL-13 wind tunnel is performed in 'stable dynamic pressure' mode, data acquired after dynamic pressure reaching the target value and keeping stable. Data is acquired in 'step-by-step' testing mode.

4.2 DNW-LLF

The model is supported by the sting support system in DNW-LLF. Ventral sting configuration and dorsal sting configuration are used separately for force measurement and interference investigation.

Data acquisition is realized in ‘step-by-step’ testing mode. Model AOA angle are measured by the electronic inclinometer on the zero reference plane. Zero yaw position was checked by a laser light sheet, which was beamed from the test section ceiling.

5. Data Processing

Unless otherwise stated, all the results in this paper are corrected for support interference and wall interference. Longitudinal data are presented in air-path axis system, and lateral data are presented in body axis system.

FL-13 wind tunnel interference corrections are derived from the differences in aerodynamic coefficients between two sting set-up configurations, dorsal and dorsal + dummy ventral(④ and ② in Figure 4), while the two sting set-up configurations for interference corrections in DNW-LLF are ventral + dummy dorsal and dorsal[5](③ and ② in Figure 4).

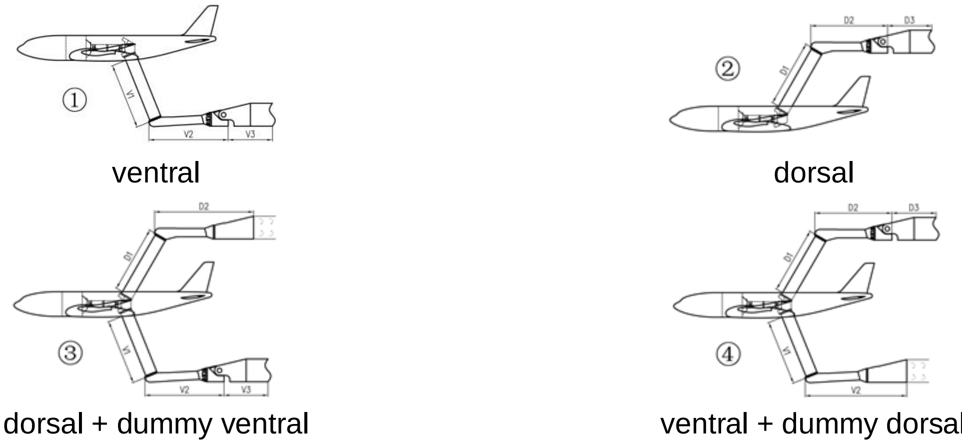

Figure 4 Support interference correction

6. Test results and correlation analysis

6.1 Longitudinal test

The longitudinal aerodynamic characteristics curve and parameters are shown in Figure 5 and Table 6. All the data are average values from repeatable tests.

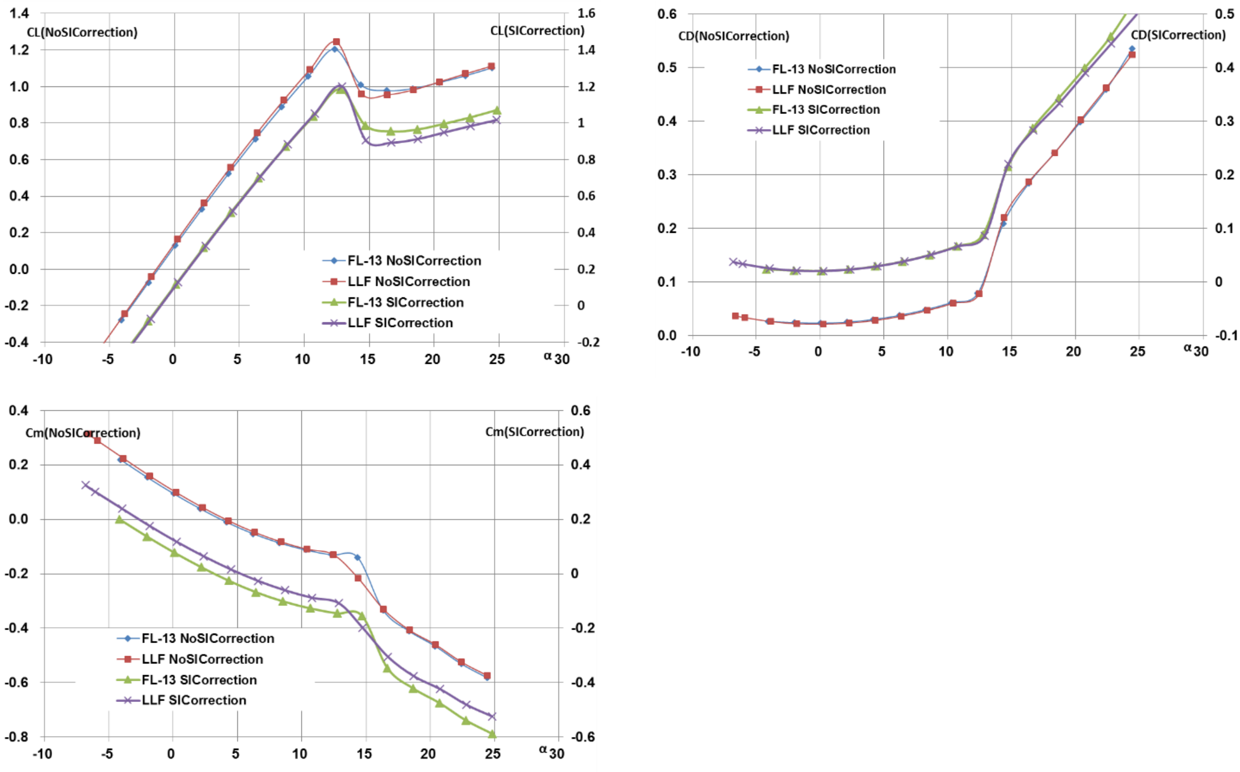

Figure 5 Comparison of longitudinal aerodynamic coefficients from two wind tunnels

Table 6 Longitudinal aerodynamic characteristics of CHN-T1

	$C_{L\alpha}$	C_{Lmax}	α_0	α_{cr}	C_{Dmin}	C_{D0}	C_{mCL}	C_{m0}
FL-13	0.0923	1.2	-1.15	12.5	0.0204	0.0209	-0.26	0.11
LLF	0.0924	1.2	-1.08	12.5	0.0203	0.0204	-0.26	0.15

Test results indicate the good agreement between the longitudinal aerodynamic coefficients from two wind tunnels except C_{m0}. There is a C_{m0} difference in the order of 0.04.

6.2 Lateral test

The lateral aerodynamic characteristics curve and parameters are shown in Figure 6 and Table 7. All the data are average values from repeatable tests. The results show that the trends of the lateral results are very similar.

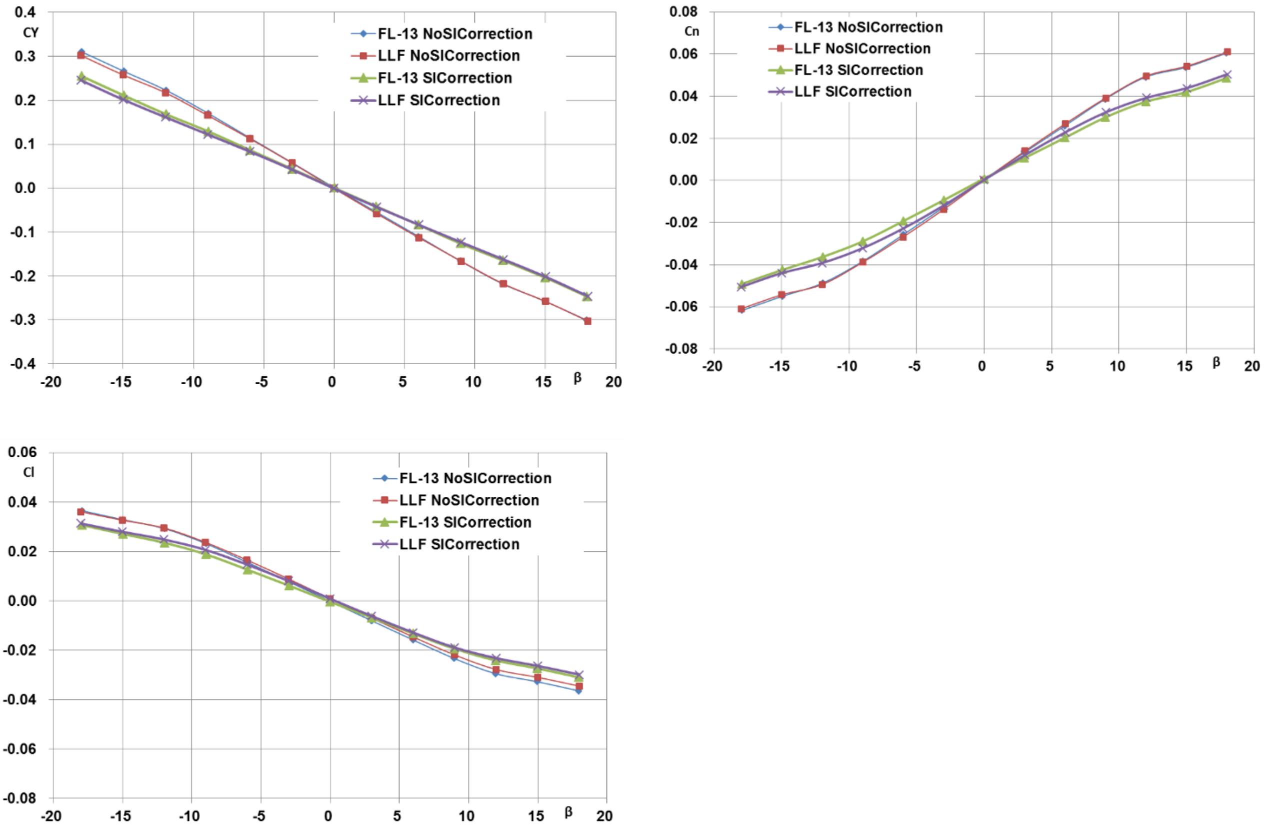

Figure 6 Comparison of lateral aerodynamic coefficients from two wind tunnels

Table 7 Longitudinal aerodynamic characteristics of CHN-T1

	$C_{Y\beta}$	$C_{n\beta}$	$C_{l\beta}$
FL-13	-0.0142	0.00329	-0.00214
LLF	-0.0137	0.00367	-0.00224

6.3 Wind speed variation test

Figure 7 presents the flow speed variation effect on the CHN-T1 aerodynamic characteristics. Test results indicate that the similar trends in CHN-T1 aerodynamic characteristics with wind speed. The critical AOA and C_{Lmax} almost keep constant as the wind speed reaches 80m/s($Re=3.0\times10^6$) from 50m/s($Re=1.9\times10^6$).

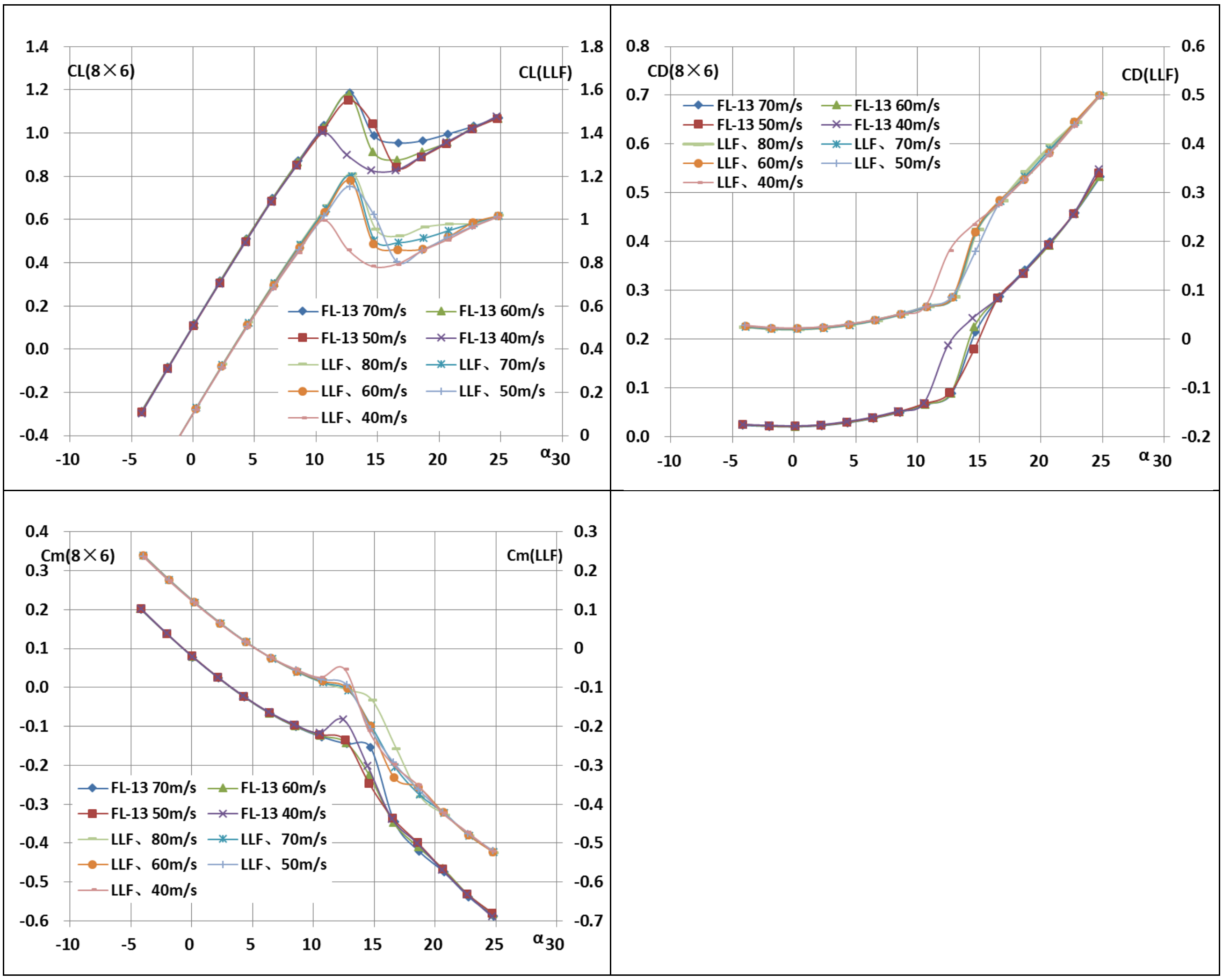

Figure 7 Test results of wind speed variation

6.4 Support interference investigation

The similar ventral support system is used both in FL-13 and DNW-LLF, which results in support interference mainly from the rear part of CHN-T1. Therefore the model tail aerodynamic characteristics, especially the moment characteristics, are more sensitive to the support interference. C_{m0} and $C_{n\beta}$ from the two tunnels are almost same respectively before support interference correction(Figure 5 and Figure 6). After support interference correction, C_L is almost same for small tail effect, while pitch moment and sideslip moment results show obvious deviation close to the tail. It can be inferred that the final result difference originates from the support interference test distortion.

It can be seen from Figure 4 that FL-13 and DNW-LLF use short dummy horizontal strut to deal with support interference problem. Longer horizontal strut is difficult to install, and theoretically the volume effect can be simulated partly with dead air zone from the end cross section of dummy strut horizontal part. However, this section cannot simulate the lift or side force characteristics of the real strut. That is to say, if there is wash flow near the strut, this support interference processing method will bring flow simulation distortion and a deviation for support interference determination. The distortion is related to the wash flow and distance from the model.

Support interference correction in Figure 5 can be presented as

$$F_{vsi}=\Delta F_{vs,f}+\Delta F_{vs,r}+\dots \qquad (1)$$

F_{vsi} is the ventral support interference, $\Delta F_{vs,f}$ and $\Delta F_{vs,r}$ are the model aerodynamic load variation separately from the front part and the rear part of the ventral strut located in the wash flow because of the model, and the last term means higher order quantity.

The model aerodynamic loads for dorsal configuration in LLF can be formulated as

$$F_{DAL}=F_{AL,f}+\Delta F_{ds,f}+\Delta F_{ds,r}\dots \qquad (2)$$

F_{DAL} is the aerodynamic loads of the model in the wind tunnel, $F_{AL,f}$ is the aerodynamic loads of the model in free airflow, and $\Delta F_{ds,f}$ and $\Delta F_{ds,r}$ are the model aerodynamic load variation separately from the front part and the rear part of the dorsal strut located in the wash flow because of the model.

The model aerodynamic loads for ventral + dummy dorsal configuration can be described as

$$F_{VDAL}=F_{AL,f}+\Delta F_{ds,f}+\Delta F_{vs,f}+\Delta F_{vs,r}\ldots \quad (3)$$

The measured support interference value in LLF can be presented as

$$F_{sim,LLF}=\Delta F_{vs,f}+\Delta F_{vs,r}-\Delta F_{ds,r} \quad (4)$$

The measured support interference value in FL-13 can be expressed as

$$F_{sim,FL\text{-}13}=\Delta F_{vs,f} \quad (5)$$

From the view of wash flow investigation on support interference, the correction methods in the two tunnels are inaccurate. FL-13 neglects $\Delta F_{vs,r}$ and LLF corrects $-\Delta F_{ds,r}$ additionally. When $\Delta F_{vs,r}>\Delta F_{ds,r}$, the support interference correction in FL-13 is less accurate than in LLF, and vice versa. FL-13 method will result in a smaller C_{m0} and LLF method will enlarge C_{m0}. Figure 8 shows the support interference correction results using different methods in FL-13. An obvious difference in C_{m0} can be observed. To investigate the horizontal strut simulation distortion effect on support interference correction, a real dummy cantilever is used in FL-13 to simulate the rear ventral part effect (Figure 9). C_{m0} becomes smaller, following the theoretical expectation.

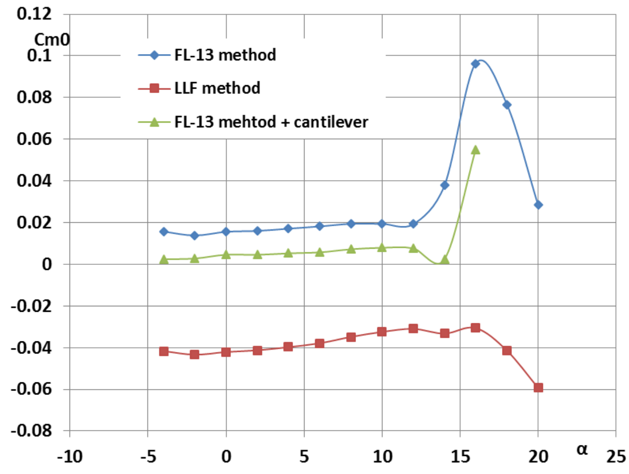

Figure 8 Different support interference correction method effect on C_{m0}

Figure 9 Real dummy cantilever simulation test

7. Conclusion

Comparison tests on CHN-T1 developed by CARDC in FL-13 and LLF indicate that the results from two tunnels agrees well. Some aerodynamic parameters related to the tail vary little for the difference support interference method. The test result reliability can be enhanced through test technique improvement.

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9. Copyright Statement

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