Force Measurement System of a Low-Speed Wind Tunnel

Yan Li Xingzhi Ding Yankui Wang
(School of Aeronautic Science and Engineering, Beijing University of Aeronautics and Astronautics, Beijing 100191, China)
E-mail: liyuyan@*buaa.edu.cn*

Abstract *–Wind tunnel is a basic experimental facility, in which a variety of aerodynamic research can be conducted by measuring force acted on the test model, pressure distribution on the model surface, as well as by visualizing the flow around the model. The force measurement test is conventional and especially important for the aircraft and other vehicle design to predict their performance. The force measurement system of D-4 wind tunnel in Beijing University of Aeronautics and Astronautics is introduced together with a force measurement test as an instance.*
Key words *–force measurement system, wind tunnel, strain gauge balance, data acquisition and processing.*

I. INTRODUCTION

Wind tunnel is the basic research facility in fluid mechanics and aerodynamics. D-4 low-speed wind tunnel in Beijing University of Aeronautics and Astronautics (BUAA) was built in 2003, which is characterized by high quality of flow field in the test section. It is powerful in test capacity, including force and pressure measurements and flow visualization, and equipped by some modern devices such as 6-component force balance, PSI9816 static pressure measurement system, fluctuating pressure measurement system based on Agilent VXI, HyScan2000 data acquisition system and 3D Particle Image Velocimetry (PIV) system. Not only static but also dynamic tests can be conducted in this tunnel.

Force measurement is the basic and conventional function for a wind tunnel, and is essentially important for new high-speed vehicle design in air, on ground or on/in water. For instance, Force measurement test of an aircraft model in wind tunnel is to measure the aerodynamic forces and moments for evaluating the aerodynamic characteristics of the aircraft [1].The force-measurement system of D-4 wind tunnel is based on six-component strain-gauge balance. The corresponding data acquirement/processing system require real-time sampling and processing, friendly communication interfaces and multiple display and output format. The realization and functions of the system are described in this paper in company with a force-measurement test conducted by using this system.

II. D-4 WIND TUNNEL IN BUAA

The structure of D-4 wind tunnel in Beijing University of Aeronautics and Astronautics is shown in Figure 1. It is a circular low-speed wind tunnel characterized by high quality of flow field with turbulent level of 0.08% in the test section. The test section is 1.5m×1.5m×3.5m (width × height × length). The highest speed of the flow in the test section is 60m/s and 80m/s with the test section open and closed respectively. The test section was open in this test.

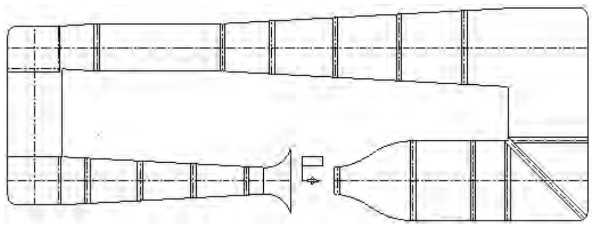

Figure 1. Sketch of D-4 low-speed wind tunnel in BUAA

III. TEST MODEL AND SETUP

The test model was an aircraft model with scale of 1:20. The model was fixed in the model support system, by which the angle of attack can be changed from -10° to 85° and slip angle is free from limit [2], as shown in Figure 2. The force balance was installed inner the model and fixed to the support system by a sting.

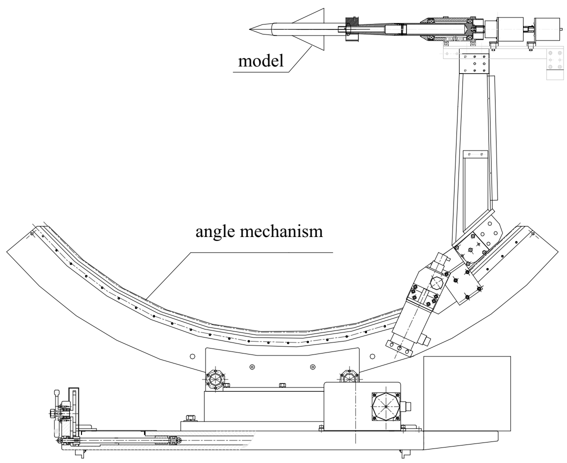

Figure 2. Model and support system

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Ⅳ. FORCE MEASUREMENT SYSTEM

The force measurement system includes force-balance, signal amplifier, data acquisition card and the corresponding data acquisition and processing software [3], as shown in Figure 3.

Figure 3. Force measurement system diagram

A. Force-balance

The force-balance is of six-component sting-type strain ganged balance, by which the axial force X, normal force Z, side force Y, as well as rolling moment Mx_b, pitching moment My_b and yawing moment Mz_b of the model are measured based on the body coordinate system[4], as shown in Figure 4.

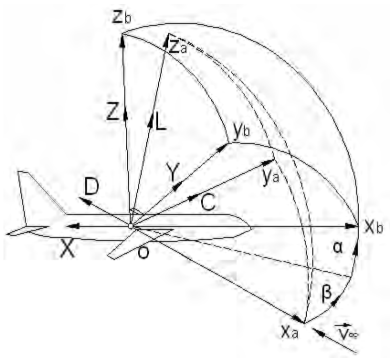

Figure 4. Six components of forces and moments in body coordinate system (x_b, y_b, z_b) and in wind coordinate system (x_a, y_a, z_a)

In the test, the aerodynamic forces acted on the model were transferred to the balance, deformed the sense components of the balance, and then the strain, which is proportional to the force, was converted into voltage increment [5]. Such voltage increment was too small to be measured accurately, so it must be amplified by the signal-amplifier before it was transmitted to A/D card in the computer for sampling [3]. The performance parameters of the balance are shown in Table 1. The bridge resistance of the balance must be checked before test in order to ensure the balance in the normal status.

Table 1. Balance performance parameters

	X	Y	Z	Mx_b	My_b	Mz_b
Design loads	60 N	50 N	300 N	2 N • m	9 N • m	6 N • m
Bridge resistance	1200Ω	600Ω	600Ω	1200Ω	600Ω	600Ω
Precision（‰）	2.8	1.2	1.3	2.5	1.6	3.0
Accuracy（‰）	3.0	2.1	1.5	3.6	2.1	2.5

B. Data amplifier and terminal board

A Preston data amplifier was involved in the force measurement system. It has sixteen channels, of which six channels were used in this test to measure the six components of forces and moments acted on the test model. Each channel independently has its own signal conditioner and low-pass filter. The system gain was decided according to the output magnitude of the balance. The gain and the cut-off frequency of low-pass filter in this test are shown in table 2. The amplifier output are transmitted to the PCI2003 Data Acquisition card through a terminal board, which has a filter circuit to filter the surrounding disturbances [3]. The output voltage signal of wind-speed sensor was also connected to the terminal board and sampled simultaneously to monitor the wind speed in the test section.

Table 2. Channel magnification

	X	Y	Z	Mx_b	My_b	Mz_b
Gain	1000	500	500	500	500	1000
Cut-off frequency (HZ)	10	10	10	10	10	10

C. Data Acquisition

PCI2003 card is a data acquisition card based on PCI bus, which is inserted into the computer's PCI slot directly. It has acquisition, display, saving and playback functions, and is widely used in not only data acquisition but also waveform analysis and processing system. PCI2003 card has its own attached data-acquisition software, and makes it easy to meet our demands for the force measurement by some simple choice and adjustment. The data acquisition interface of the force measurement system is shown in Figure 5.

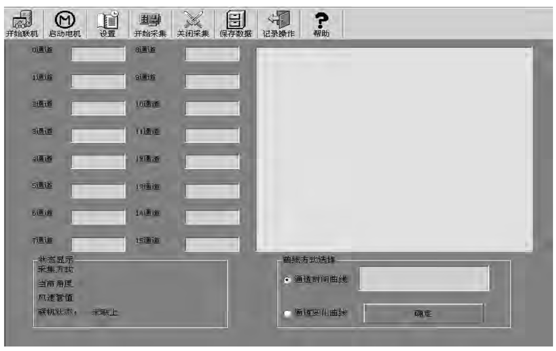

Figure 5. Data acquisition interface of the force measurement system

Acquisition process:
(1) Initializing

Before the data acquisition begins, it is necessary to initialize the settings, such as the channel gain, sampling frequency, data storage path etc.

(2) On-line

After initialization of the settings, the data acquisition computer should be turned to the status of communicating with the angle control computer by clicking the function icon of 'on-line' in the interface, as shown Figure 5, to ensure the data sampled is at the correct angle of attack and slip angle.

(3) zero-load readings

When the wind speed in the test section was zero, there is no aerodynamic force acted on the model, but the balance output is not zero due to the weight of the model. The gravity center of the model usually doesn't coincide with the centre of balance, thus the force and moment components acted on the model will change with the angle of attack. Thus, the zero-load readings should be read and eliminated from the test data sampled under the test condition in the data processing to get the pure aerodynamic forces and moments acted on the model [6].

(4) Aerodynamic load acquisition

In this test, the test angle of attack changed from 30^{o} to 65^{o} with the step of 5^{o} to explore the aerodynamic characteristics of the aircraft, and the free stream velocity was 20 m/s. The test angles should be set previously in the angle control computer. After a test angle is reached and ready, an instruction will be sent to the data acquisition computer to start the acquisition procedure. When acquisition is completed, a corresponding instruction will be returned back to the angle control computer for changing to the next angle [2]. The real-time voltage values of balance output can be displayed on the interface in the data acquisition computer.

D. Data Processing

The data from acquisition are collected, analyzed and calculated to extract corresponding physical parameters required and shown in multiple ways, such as in text and chart, etc. the procedure is easy to work. All the setting parameters needed in the calculation can be input directly in the dialog box on the interface without modifying the source code, and these parameters could be saved automatically for a series of test data reduction with the same parameter setting. The interface is shown in Figure 6.

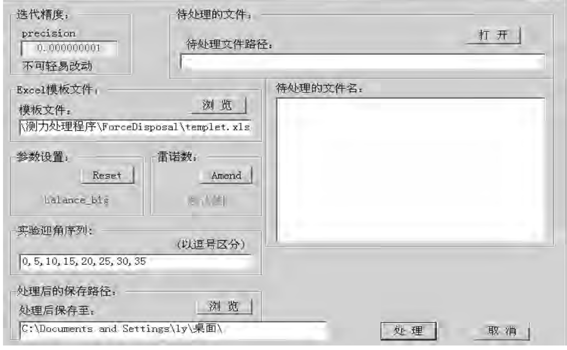

Figure 6 Data processing interfaces

The parameters needed to set on the interface are as follows:

Model reference area;

Spanwise reference length of the model _ wing span;

Longitudinal reference length of the model _ average aerodynamic chord length;

Dx — distance between balance center and model reference center in x_b axis;

Dy — distance between balance center and model reference center in y_b axis;

Dz — distance between balance center and model reference center in z_b axis.

The forces and moments measured by the balance correspond to the body coordinate system, and they should be transformed into those corresponding to the wind coordinate system in the data processing, to obtain the conventional aerodynamic parameters, such as lift, drag, side force, pitching moment, rolling moment and yaw moment, as well as their corresponding coefficients. The forces and moments corresponding to the body and wind coordinate system respectively are assembled in table 3 and shown in Figure 4. The graphic results generated automatically by the data processing procedure are presented in Figure 7 and Figure 8.

Table 3 forces and moments as well as aerodynamic coefficients in the two coordinate systems

Force in the body coordinate system	Force in the wind coordinate system	Aerodynamic coefficient
X - Axial force（along negative x_b direction）	D – Drag（along negative x_a negative direction）	CD- Axial force coefficient
Y – Side force（along y_b direction）	C - Side force（along y_a direction）	CL- Normal force coefficient
Z - Normal force（along z_b direction）	L – Lift（along z_a-axis direction）	CC -Side force coefficient
Mx_b – Rolling moment (around x_b -axis)	Mx_a - Rolling moment (around x_a-axis)	C_{Mxa}- Rolling moment coefficient
My_b– Pitching moment (around y_b -axis)	My_a - Pitching moment (around y_a-axis)	C_{Mya} - Yaw moment coefficient
Mz_b - Yawing moment (around z_b -axis)	Mz_a - Yawing moment (around z_a-axis)	C_{Mza} - Pitching moment coefficient

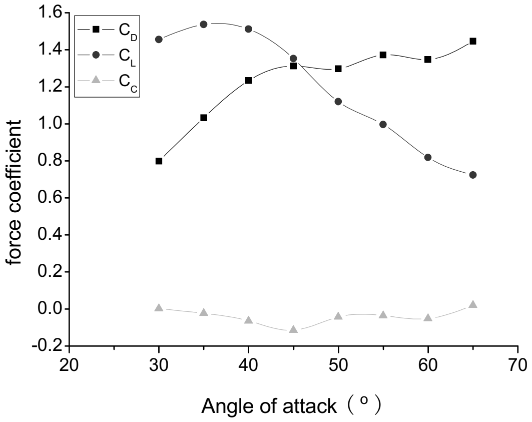

Figure 7. Measured C_D, C_L and C_C versus angle of attack

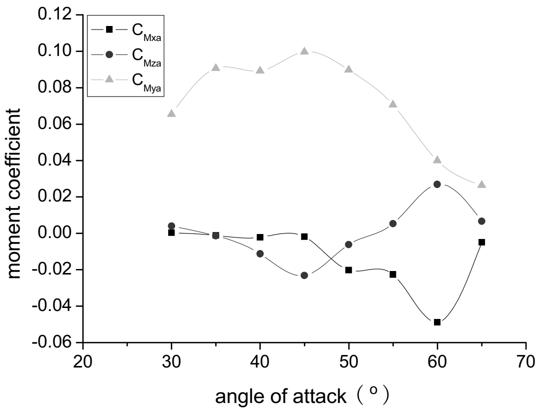

Figure 8. Measured C_{Mxa}, C_{Mya}, C_{Mza} versus angle of attack

Ⅳ. CONCLUSION

A force measurement system was designed and fulfilled in D-4 wind tunnel at BUAA. Its structure and functions were described, including hardware and software, accompanying a force measurement test as an instance. The measurement accuracy and its function all meet the design requirement, and the interface is very friendly to make it be easy to use.

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