OVERVIEW OF DYNAMIC TEST TECHNIQUES AT LOW SPEED AERODYNAMICS INSTITUTE, CARDC

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Abstract

This paper reviews dynamic test techniques developed in the past 30 years in Low Speed Aerodynamics Institute (LSAI), CARDC. Forced oscillation, wing rock, and spin fight test techniques are stressed. These techniques offer aerodynamics/flight/control integration study an important tool.

1 Introduction

The dynamic aerodynamic characteristics study starts in 1960s. The main topic is to resolve single-freedom dynamic derivative test technique problem within small angle of attack (AOA) range till 1980s. To fulfill the requirements of new generation aircraft development for high maneuver, LSAI develops high AOA dynamic derivative, large amplitude oscillation, multi-freedom maneuver simulation, wing rock, and rotary balance test techniques in 4m×3m wind tunnel and Φ3.2m wind tunnel to improve test capabilities. These facilities are utilized to study dynamic aerodynamics characteristics for low aspect ratio aircraft model and develop flow control techniques. In recent years, a dynamic test system is established in 8m×6m wind tunnel to meet the requirements of study on dynamic aerodynamic characteristics for large scale model. This system can be used to carry out small amplitude dynamic derivative test and large amplitude unsteady aerodynamic force measurement test. Compared with real flight tests, there are many advantages for wind tunnel tests such as controllable environment, more accurate and convenient measurement, shorter test period and lower cost. Flight test in wind tunnel can be considered as an important complementary tool for real flight test. LSAI develops spin test techniques, virtual flight and free flight test techniques for aerodynamics/flight/control integration study.

2 Forced Oscillation Test Techniques

The dynamic derivative test system (Fig. 1) was established in 4m×3m wind tunnel in 1996 and capable of roll, yaw, pitch, heave and translation movement for damp derivative, cross derivative and cross coupled derivative measurement [1]. The system consists of longitudinal and lateral facilities, using eccentric mechanism to amplitude step-less adjusted [2].

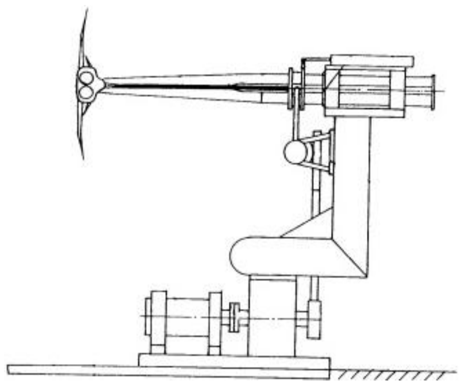


Fig. 1. Dynamic Test Rig in 4m×3m W.T.(Pitch Motion)

The later development of dynamic test systems was transferred to Φ3.2m wind tunnel to employ its open test section to reduce wall interference after 2000. Φ3.2m wind tunnel is suitable for unsteady aerodynamic characteristics and flow field characteristics study during high AOA and large amplitude maneuver. In 2009, a fully new dynamic test system (Fig. 2) was developed. The usage of electronic CAM reduces transmission links and improves test efficiency. This system can be used for dynamic derivative and large amplitude oscillation tests. Table 1 shows the main specifications of the system.

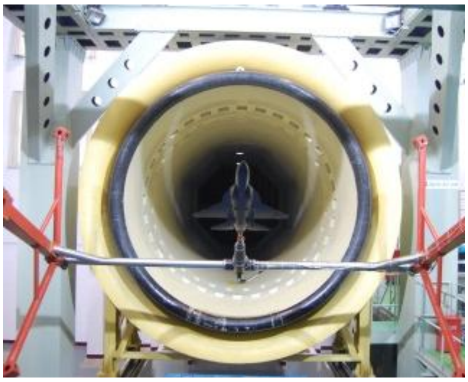


Fig. 2. Single DOF Dynamic Test Rig in Φ3.2m W.T

Table.1 Performance Parameter of One DOF Dynamic Test Rig

angle of attack	-90° ～90°
sideslip angle	-45° ～45°
frequency	0～4Hz
max amplitude	40°

Fig. 3 presents some test results of a delta wing aircraft, including amplitude and reduced frequency effect on large amplitude oscillation dynamic aerodynamic characteristics. The test data indicate good patterns.

The two-freedom dynamic test system (Fig. 4) was developed based on the above-mentioned system. Fig. 5 shows the sketch of roll movement part. Main specifications can be found in Table 2. This system can achieve pith/roll, pitch/yaw, yaw/roll coupled movement. Besides that, with the help of a sting strut, the system can support the model to carry out pitch, yaw and roll movement. Test data prove good agreement.

PIV technique was developed based on the two-freedom dynamic test system for wing vortex study (Fig. 6). The laser and the camera are fixed on the support system, and the sync between movement control and PIV system is a key technique. A embedded computer CompactRIO can check angle position and direction within 10μs period using FPGA programming function through the signal source provided by a potentiometer angle sensor to accomplish high accuracy measurement.

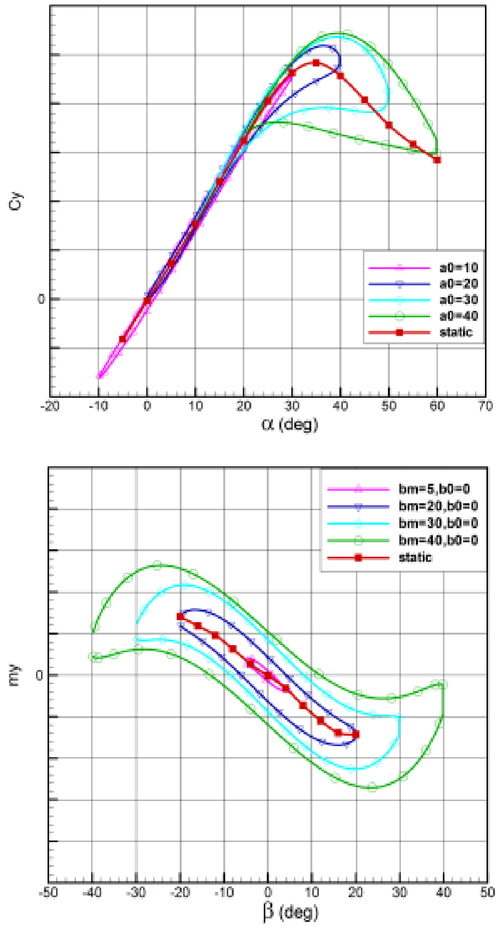


Fig. 3. Effect of Mean Angle on Unsteady Aerodynamics

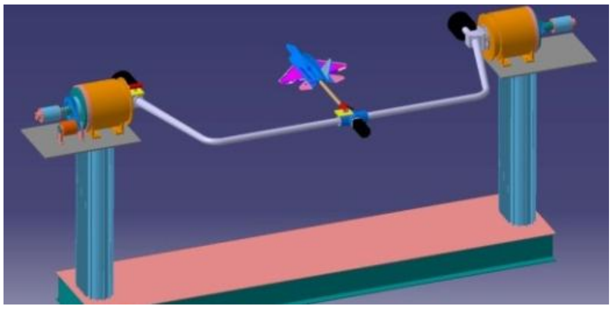
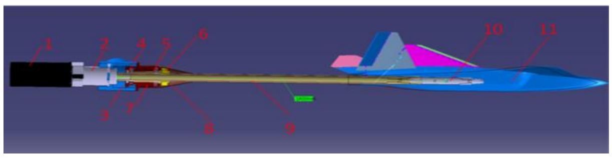


Fig. 4. Two DOF Dynamic Test Rig in Φ 3.2m W.T.



1.motor 2.reducer 3.coupling head 4.baering-1 5.bearing-2 6.GL500 7.bearing block 8.cowling 9.sting 10.balance 11.model

Fig. 5. Sketch of Roll Motion Sting

Table 2. Performance Parameter of Two DOF Dynamic Test Rig

motion coupling	amplitude（°）	frequency（Hz）
pitch/roll	45/40	1/2
pitch/yaw	45/40	1/2
yaw/roll	40/40	1/2

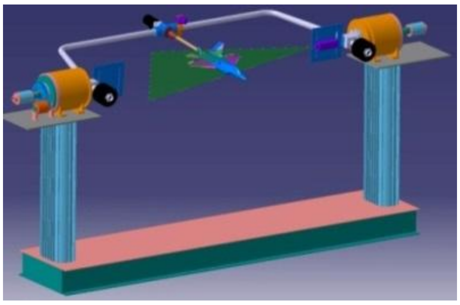


Fig. 6. Sketch of PIV Measurement Test

A six-freedom wind tunnel dynamic test system (Fig. 7) was developed based on parallel robot principles for high maneuver aircrafts in Φ3.2m wind tunnel [3]. A model will be driven by six linear motors for three directional angle displacement movement, three directional linear displacement movement and coupled movement among them. The model attitude will be measured by an optical system. Table 3 presents some main specifications of this system.

Fig. 7. Multi-DOF Dynamic Test Rig

Table 3. Performance Parameter of Six DOF Dynamic Test Rig

Motion	pitch, yaw, roll, heave, sway and their combination
angle of attack	-35° ～70°
sideslip angle	-20° ～20°
Roll angle	-15° ～15°
frequency	0～2Hz

Fig. 8 shows a specific use of this system. The traditional method to acquire pitch damp derivative is to get $C_{mq} + C_{m\dot{\alpha}}$ through pitch oscillation movement, and get $C_{m\dot{\alpha}}$ through heave oscillation movement at first. C_{mq} can be directly acquired using this system by designing pure pitch oscillation movement using the angle movement and linear movement coupled character. This method can reduce test error and enhance test efficiency.

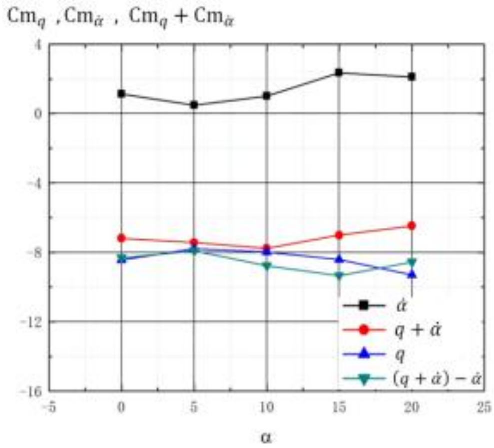


Fig. 8. Direct Measurement for Dmping derivatives

For large aircraft, large model is necessary for dynamic aerodynamic characteristics study to reduce scale effect and Reynolds number effect. For this purpose, LSAI developed a dynamic test system (Fig. 9) in 8m×6m wind tunnel, capable of pitch, roll and yaw movement to carry out small amplitude dynamic derivative test and large amplitude unsteady force measurement test. Table 4. lists some main specifications. Fig. 10 presents side force characteristics of a transporter during pitch oscillation [4].

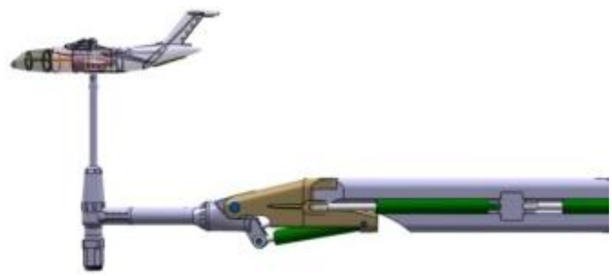


Fig. 9. Dynamic test rig in 8m× 6m W.T.（yaw motion）

Table 4. Performance Parameter of Dynamic Test Rig in 8m× 6m W.T.

Motion	pitch, yaw, roll
angle of attack	-10° ～45°
sideslip angle	-30° ～30°
amplitude	0° ～20°
frequency	0.3～2Hz

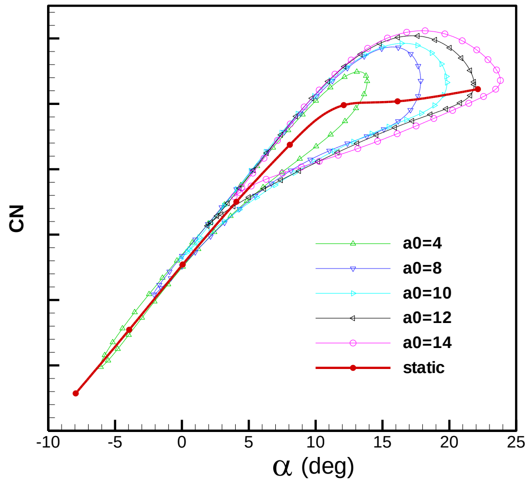


Fig. 10. C_N for a transport aircraft

3 Free to Roll Test Technique

Wing rock is a non controllable roll limit cycle oscillation movement on the delta wing which will affect flight safety. Free to roll test technique was developed in 4m × 3m wind tunnel in 1990s based on ball bearings (Fig. 11) to investigate rock characteristics and aerodynamic measures to restrict rock for specific layout fighter. Fig. 12 presents original roll angle effect on wing rock [5].

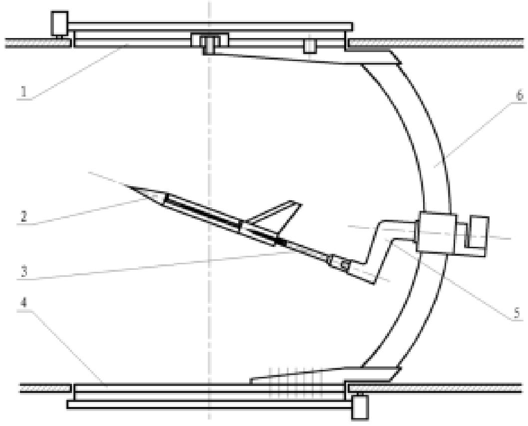


Fig. 11. Free to roll test rig in 4m×3m W.T.

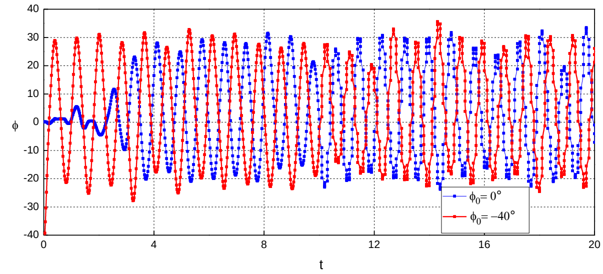


Fig. 12. Effect of initial roll angle on wing rock characteristics

Free to roll technique (Fig. 13) was developed in 2010 in Φ3.2m wind tunnel based on liquid-floated bearings to reduce friction. However, it is found that the liquid-floated bearing structure is complicated and hard to maintain. LSAI will develop free to roll technique based on magnetic bearings.

Fig. 13. Free to Roll Test for a Double Delta Wing

4 Spin Study Wind Tunnel Test Technique

Spin is a dangerous critical flight state. Rotary balance equipment (Fig. 14) was developed in Φ5m vertical wind tunnel to achieve rotation oscillation movement, rotation movement around wind axis and coupled oscillation movement around body axis to investigate model aerodynamic characteristics under stable spin and oscillation spin [6]. Compared with a longitudinal wind tunnel, a vertical wind tunnel can reduce model gravity effect on test result. A air damp ball (Fig. 15) was developed to resolve zero reading correction problem. Different correction methods under rotation movement, rotation coupled with small amplitude oscillation, and rotation coupled with large amplitude oscillation. It is found that traditional correction method clockwise rotation coupled with anticlockwise rotation has its limitation under certain circumstance and results in larger error.

Fig. 14. Rotary balance test rig

Fig. 15. Damping Ball for Rotary Balance Test

Spin test technique in the Φ5m vertical wind tunnel was developed in 2000s [7]. Fig. 16 is a spin test photo of C919 aircraft. Model movement measurement is a key technology for spin test. Two cameras and multi cameras were used to develop model attitude and position measurement based on computer image analysis. Sometimes the model will fly out of the CCD view, and the data processing is not real time, so a attitude measurement method based on MEMS sensors was developed (Fig. 17).

Fig. 16. Spin Test in Vertical W.T.

Fig. 17. Model Attitude Measurement

5 Wind Tunnel Model Flight Technique

Wind tunnel model flight is an efficient method to verify flight control law and investigate the dynamics characteristics of an aircraft. Fig. 18 is the virtual flight system developed in Φ 3.2m wind tunnel [8]. The system is compose of support rig, instrument and hardware of FCS, host computer and database computer.

Virtual flight has no power, and linear displacement is restricted. To validate flight control law more accurately, a powered model flight test rig (Fig. 19) was developed in 8m× 6m wind tunnel [9]. A model can be driven by pressurized air or small turbojet engines. This system can be used for stall and departure study. Fig. 20 shows wind tunnel free-flight test and prototype simulation test comparison result of dual square wave response [10].

Fig. 18. Virtual Flight Test

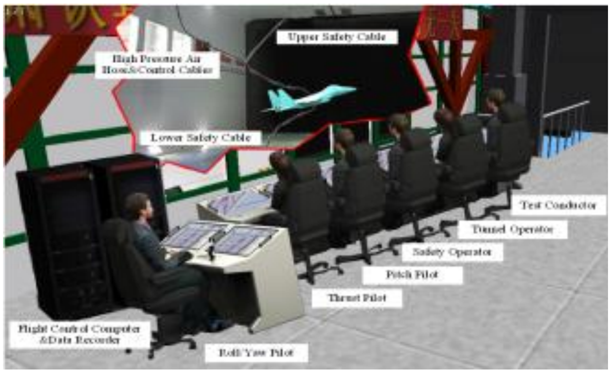


Fig. 19. Free Flight Test with Power

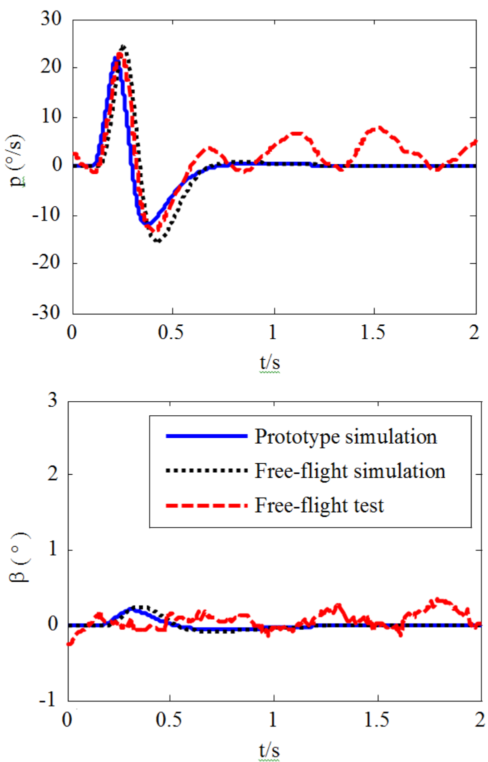


Fig. 20. The Response of the Aircraft under Free-Flight Test and Dynamic-scale Prototype Simulation with Doublet Square Input

6 Conclusion

With the increasing demand for flight performance and flight quality of the aircraft, the new aerodynamic layout, new structural materials, new dynamic distribution methods and new flow control measures have been widely used in the design of aircraft. The research method of aerodynamics/flight/control integration is an important tool. In the next step, we will further improve this method by combining numerical calculation with atmospheric model flight test. We are also looking forward to conducting extensive joint research with researchers with common interests to get more meaningful research results.

References

[1]SUN H S. The development of 96 test system for measuring dynamic derivatives at high angle of attack[J]. Experiments and Measurements In Fluid Mechanics, 1999, 13(1):31-37 (in Chinese) .

[2] SUN H S. A measurement technique for derivatives of aircraft due to acceleration in heave and sideslip at high angle of attack[J]. Experiments and Measurements In Fluid Mechanics, 2001, 15(4):15-19 (in Chinese) .

[3] XIE Z J, SUN X Y, SUN H S, ZHANG J. Mechanism design and dynamics analysis of high speed parallel robot for dynamic test in low speed wind tunnel[J]. Acta Aeronautica et Astronautica Sinica, 2013, 34(3):487-494 (in Chinese) .

[4] LIU Z T, SUN H S. A model attitude control and measurement technique for improving quality of wind tunnel dynamic test data[J]. Acta Aeronautica et Astronautica Sinica, 2016, 37(8):2427-2435 (in Chinese) .

[5] SUN H S, JIANG Y B. Investigation on wing rock in low speed wind tunnel for a fighter configuration[J]. Experiments and Measurements In Fluid Mechanics, 2000, 14(4):32-40 (in Chinese) .

[6] WU J H, SUN H S, SHEN Z H, JIANG Y B. Investigation of test technique of oscillatory dynamic derivative in rotational flow field[J]. Journal of Experiments in Fluid Mechanics, 2014, 28(4):54-58 (in Chinese) .

[7] ZHU M H, YANG H S, WANG X N, et al. Improvements and validation of spin test techniques in vertical wind-tunnel[J]. Journal of Experiments in Fluid Mechanics, 2011, 25(5):94-98 (in Chinese) .

[8] GUO L L, ZHU M H, Kong P, NIE B W, ZHONG C W. Analysis of dynamic characteristics between prototype aircraft and scaled-model of virtual flight test in wind tunnel[J]. Acta Aeronautica et Astronautica Sinica, 2016, 37(8):2583-2592 (in Chinese) .

[9] SUN H S, CEN F, NIE B W, et al. Present research status and prospective application of wind tunnel free-flight test technique[J]. Journal of Experiments in Fluid Mechanics, 2011, 25(4):103-108 (in Chinese) .
[10] LIU Z T, CEN F, NIE B W, FAN L T, SUN H S. Similarity criteria and simulation method for flight control system of free-flight test in low speed wind tunnel[J]. Acta Aerodynamica Sinica, 2017, 35(5):693-699 (in Chinese) .

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