SUMMARY OF THE DYNAMIC TEST CAPABILITIES AT CARIA LOW SPEED WIND TUNNEL

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Abstract

The summary of the dynamic test capabilities at CARIA low speed wind tunnel is presented. Four sets of dynamic test apparatus have been built which are rotary balance, forced oscillation balance, large amplitude pitch and descent coupling motion rig and multi-axis test system. Dynamic stability, stall, departure and spin characters of an airplane at a large range of angle of attack could be obtained and the aerodynamic characteristics of an aircraft on behavior of high–performance maneuver could be studied in CARIA low speed wind tunnel by these dynamic test apparatus.

1 Introduction

Modern high performance aircraft often flight at extreme flight conditions such as high angle of attack and large angular rate. Unsteady and nonlinear aerodynamics which may have significant effects on characteristics of aircraft motion are encountered in these conditions. Various countries in the world have developed their dynamic wind tunnel test techniques and associated experimental apparatus to study the aerodynamics characteristics of the aircraft in unsteady flow fields and to support the aircraft designers with reliable dynamic test data. The data should be used to analyze the flight dynamic characteristics such as characters of control, stability and safety and to calculate the structural loads for validation and verification of computational dynamic codes and to simulate some complex and realistic aircraft maneuvers.

China Aerodynamics Research Institute of Aeronautics (CARIA) began to develop dynamic wind tunnel test techniques from 1980s’. Firstly, a rotary balance apparatus which was designed from 1985 and was accomplished in 1992. Tens of aircraft model spin test programs have been done in CARIA’s low speed wind tunnel named FL-8. Secondly, a forced oscillation balance apparatus was designed and manufactured from 1995 to 1999. The third apparatus which called Large Amplitude Pitch and Descent Coupling Motion Rig was set up for FL-8 wind tunnel in order to study the unsteady aerodynamics characteristics of an aircraft in its longitudinal maneuver and to measure the pitch damping derivatives. The developing programs of a multi-axis dynamic test system began at 1998 should be completed this year after the process of the wind tunnel verify test is over. The details of these four apparatuses will be presented in the below sections.

2 Wind Tunnel Facilities

The CARIA FL-8 is an Low-Speed Wind Tunnel with a closed return circuit. The test section which has a octagonal cross section is 2.5 meters high, 3.5 meters wide, and 5 meters long. The maximum velocity of 72 meters per second could be reached. The Reynolds number per meter ranges from 0 to 4.96 x10^6. Test section airflow is produced by a fan driven by a 1000 KW electric DC motor. This main drive motor was installed in 2004.

3 Rotary Balance

The rotary-balance testing technique was developed to provide information on the effect of angular rates on the overall aerodynamic forces and moments acting on aircraft in flight and to predict aircraft spin behaviors under representative similarity conditions. Certain motions, such as the developed spin, generate large differences in local flow angles for various airframe components, and the separated airflow characteristics experienced in spins are extremely difficult to predict or analyze using other techniques.[1][2]

A rotary-balance apparatus has been developed in CARIA's FL-8 low speed wind tunnel in 1992. The primary purpose of the apparatus is to produce a coning motion, that is, a continuous rolling motion of the vehicle about the free-stream velocity vector. Model mass is kept within 15kg because of rig and balance load limits and to avoid severe vibrations. The maximum wing span of model is 1.2 meter. The angle of attack can be varied from -36° to 128° using three different sting mounts, and sideslip angle can be changed between $\pm 36^\circ$ by manually rotating the front portion of the sting about its axis. The attitude angle is constant during the rotational cycle. The maximum angle rate is 300 rpm. Reynolds numbers up to 1.5×10^6 based on reference chord can be achieved at the maximum tunnel speed of 45m/s. The apparatus provides for no spin radius.

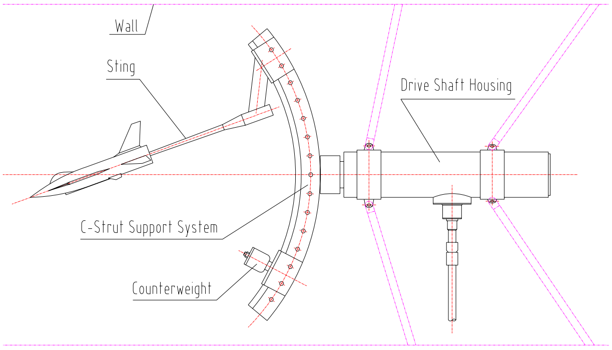

Figure.1. Sketch of rotary balance

In the testing, a model was mounted on the rotary balance apparatus through a six component strain-gauge balance. The apparatuses are driven by a servo-motor, and the balance is sting-mounted on a C-strut support system as shown in figure 1. The mounting arrangement rotates the model about the reference center of aircraft model. [3]

4 Forced-Oscillation Apparatuses

Modern aircrafts are often exposed to strong unsteady flow conditions, for instance asymmetric vortex shedding on slender configurations at sideslip, flow separation at high angle of attack and maneuver in the wake flow of large transport aircraft. A precise prediction of dynamic aircraft motions under such adverse flight conditions has become essential for a successful advanced aircraft design.

In the past, at low angles of attack, most of the dynamic stability derivatives were relatively easy to predict analytically and had only a relatively insignificant or at least a relatively constant effect on the resulting flight characteristics of the aircraft. With the advent of flight at high angles of attack at high speed, all that has drastically changed. The dynamic stability derivatives are now found to depend strongly on non-linear effects and can no longer be calculated using relatively simple linear analytical methods as in the past. [4][5]

The small amplitude forced-oscillation apparatuses as shown in figure 2 and figure 3 has been built in CARIA's FL-8 low speed wind tunnel in 1999. The primary purpose of the facilities is to measure the dynamic stability derivatives of an aircraft. Three separate experiments could be done for angular oscillations in pitch, roll, and yaw, and two other separate experiments could be done for model's sideslip and descent motion which are employed to research the effect of $\dot{\alpha}$ and $\dot{\beta}$. The apparatuses are driven by an electric servo-motor.

In the angular oscillation testing, the angle of attack ranged from 0° to $\pm 120^\circ$ are changed automatically. The angle of sideslip ranged from 0° to $\pm 30^\circ$ can be changed manually. The majority of the forced oscillatory amplitude was held constant ($\pm 5^\circ$ for all three body-axis oscillations) while varying the oscillatory frequency to obtain the desired non-dimensional angular rate values corresponding to the range seen in flight. The relationship between the frequencies, *f* (Hz), and the reduced frequencies,

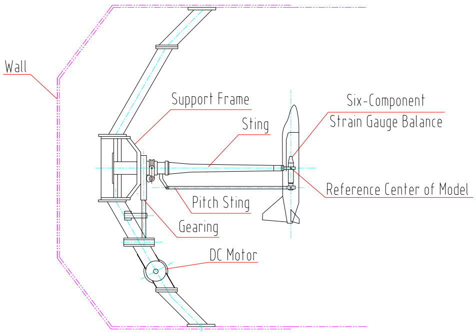

Figure.2. Sketch of forced angular oscillation apparatus

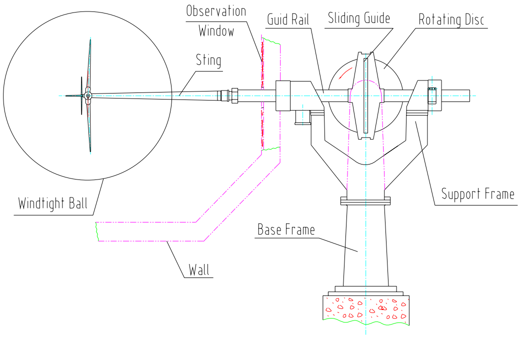

Figure.3. Sketch of translational oscillation apparatus

k, is given by the equation followed:

$$k = \frac{\omega l}{V} = 2\pi f \frac{l}{V}$$

where l is the reference length, V is the flow velocity. For the longitudinal case, the reference length is the mean aerodynamic chord of the wing. For the lateral case, the reference length is the semi-span of the wing, *b*/2.

In the translational oscillation testing, the angle of attack is ranged from 0° to $\pm 120^\circ$ and the angle of sideslip is ranged from 0° to $\pm 30^\circ$, both are changed manually. The angle of attack or the angle of sideslip of the model undergo sinusoidal vibration with zero body axis angular rate in the testing, and the angular amplitude of oscillation is set equal to the amplitude of angular oscillation testing for considering the effect of damping derivatives c_m^q or c_n^r. A windtight ball shown in figure 3 was made for minimizing the damping effect in a wind-off condition in the sideslip or descent oscillatory testing. [6]

5 Large Amplitude Descent and Pitch Coupling Motion Rig

General, when an aircraft is flight in a real maneuver, the time rate of changing in the angle of attack $\dot{\alpha}(t)$ is not equal to the pitch angular rate $\omega_z(t)$. There were no equipments which could simulate this relation in CARIA until 2003 since the pitching oscillation apparatus simulate the motion of $\dot{\alpha}(t) = \omega_z(t)$ and the descent motion apparatus realized the motion $\omega_z(t) = 0$. In order to investigate the aerodynamic characteristics of an aircraft in a maneuver when $\dot{\alpha}(t) \neq \omega_z(t)$, a new apparatus was developed for FL-8 wind tunnel in 2003. The apparatus as shown in figure 4 is composed of two shafts, which realized pitching motion and descent motion respectively. The motion described above can be achieved by a coupling motion of the two shafts.

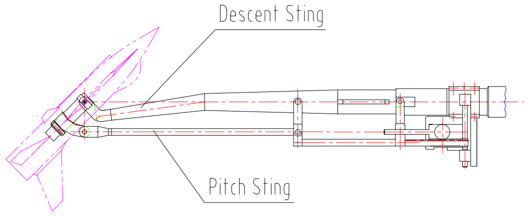

Figure.4. Sketch of descent and pith coupling forced oscillation apparatus

The special case of the motion is pure pitch motion ($\omega_z(t) \neq 0, \quad \dot{\alpha}(t) = 0$) when descent motion and pitch motion fit some special conditions. For the pure pith motion, the data results are given by means of derivatives which show the effect of ω_z separately. Generally, the damping derivatives are obtained in the method of subtracting the time delay derivatives from the combined derivatives, in which the time delay derivatives are measured from the descent oscillatory test, and the combined derivatives are measured from the pitch oscillation test. Whereas, it is obviously that non-linear coupling effect between damping derivative and time delay derivative is strong when the aircraft is flying with middle or high angle of attack and high angular rate. Thus the result is not exact. The large amplitude descent-pitch coupling forced oscillation apparatus can produce pure-pitching motion, and measure the damping derivatives directly. [7]

6 Multi-Axis Dynamic Test System

At high angle of attack, unsteady aerodynamic effects may have a major impact on the maneuverability and controllability of an airplane. Currently, some modern fighters are capable of performing transient maneuvers involving high pitch rates to extreme angles of attack. The advent of innovative high-α control effectors such as thrust vectoring and forebody controls will enable even greater capability to effectively exploit a substantially enlarged envelope for air combat. The impact of unsteady aerodynamic effects on airplane flight dynamics and a practical means of utilizing these unsteady effects need to be addressed. [8]

With recent efforts to expand flight envelope, and ordinary dynamic performance beyond conventional regimes, the need for studying the truly unsteady, high excursion and high Reynolds number flows thus encountered has increased. Standard stability and control derivative techniques fail to capture the non-linearity in such flows and CFD techniques cannot accurately compute the highly complex, separated flow fields of full vehicle geometries in steady conditions, let alone unsteady ones. Such methods are deficient because they lack physical models on which to base their computations that accurately describe the complexities of a time-dependent, turbulent, separated flow field. These models can only be developed with suitable experimental flow field data from sufficiently realistic flows [9].

For better understanding of aerodynamic characteristics of an aircraft in large amplitude maneuvers, a new apparatus, the dynamic multi-axis test system as shown in figure 5, was accomplished and installed in CARIA's FL-8 wind tunnel to provide the capability of simulating truly time-dependent, high-excursion motion. The capabilities of the rig include carrying out large amplitude harmonic motions, ramp motions and some combined motions.

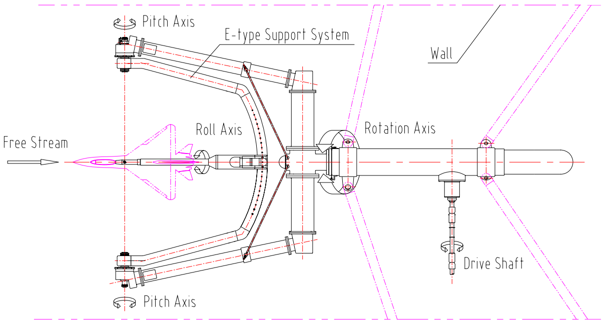

Figure.5. Sketch of dynamic multi-axis test system

The system is composed of three (pitch, roll and rotation) rotary shafts driven by three electric servo-motors respectively. Three types of motion are realized by three shafts' respective or coupled running. Some character motions of the system are summarized in Table1.

Ramp motion means to change the model's attitude rapidly. The mode is designed to realize some maneuvers like constant rate pitching up in the wind tunnel. In the testing, one or two rotary shafts driven by their servo-motors individually run the model according to the time dependent motion prearranged. The time history effect on aerodynamic characteristics should be gained in the testing.

Large amplitude harmonic motion mode is used to research some parameter's effect on unsteady aerodynamic characteristics of an aircraft. Amplitude, frequency, phase of the oscillation and the offset angle can be changed in the testing and the measured data should be compared each other to descript the effect respectively. Further more, some periodic modes like wing rock and dutch roll could be achieved.

Combined motions are generated by superpositioning body-axis forced oscillation cycles over a steady velocity vector rotation.

The resulting motion allows the aerodynamic characteristics to be acquired under motions that are significantly more representative of flight motion like oscillation spin than the traditional single body-axis forced oscillation testing or rotary balance testing. So far, superpositioning roll oscillatory motion over steady rotations has been realized in FL-8 tunnel, and the forced oscillation derivatives in rotational flow field of an aircraft model have been measured. [10]

Table 1: The detailed categories of the dynamic multi-axis test system's capability

Motion mode	Single freedom	Coupling motion
Ramp	Pitch Roll yaw	1. Pitch and roll 2. Yaw and roll
Harmonic oscillation	Pitch Roll Yaw	1. Pitch and roll 2. Yaw and roll
Combined motion		1. Pitch oscillation and wind vector rotation 2. Roll oscillation and wind vector rotation coupling 3. Yaw oscillation and wind vector rotation coupling

7 Summary and future works

CARIA's dynamic test capabilities have been presented in this paper. The details of the test facilities which are forced oscillation rig, rotary balance, large amplitude pitch and descent coupling motion rig and multi-axis test system are described too. Some techniques should be developed to improve the precision of the dynamic data in the next few years such as model positioning, support interference correction, tunnel wall interference correction and so on.

References

[1] Ericsson L. E. Rotary-balance techniques, *AGARD-AR-265*, No. 1, pp 1-21, 1990.

[2] Bihrle W. Use of rotary-balance data in the prediction of aircraft dynamic. *AGARD-AR-265*, No. 9, pp 188-208, 1990.

[3] Wang xue-jian. RB-1 rotational balance system in the FL-8 wind tunnel. HJB941262, 1994.

[4] Orlik-Rückemann K. J. Techniques for dynamic stability testing in wind tunnel. *AGARD-CP-235*, No. 1, pp 1-24, 1978.

[5] Orlik-Rückemann K. J and Hanff. E. S. Experiments on cross-coupling and translational acceleration derivatives. *AGARD-CP-235*, No. 8, pp 1-8, 1978.

[6] Wang Xue-jian. The oscillation balance system of FL-8 wind tunnel. CARIA, 1999.

[7] Wang Xue-jian. The development of large amplitude descent and pitching coupling forced oscillation test system, CARIA, 2003

[8] Orlik-Rückemann K. J. Aerodynamic aspects of aircraft dynamics at high angle of attack. *J. Aircraft*, Vol. 20, No. 9, pp 737-752, 1983.

[9] Kay J. Acquiring & modeling unsteady aerodynamic characteristic. AIAA-2000-3907.

[10] DU Xi-qi. Investigation of roll oscillation dynamical stability derivative in rotational flow field, CARIA, 2004.