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A NEW APPARATUS OF DYNAMIC STABILITY DERIVATIVE MEASUREMENT IN 1.2M WIND TUNNEL

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Abstract. A new apparatus of dynamic stability derivative measurement has been developed recently in CARIA (China Aerodynamics Research Institute of Aeronautics). The new apparatus consists of a balance of new type, an oscillation drive mechanism, data acquisition and reduction system. The apparatus has a capability of measuring direct derivatives due to roll, pitch and yaw as well as cross derivatives on a civil aircraft. A series of tests of the new apparatus with a civil aircraft model was conducted in a 1.2m×1.2m trisonic wind tunnel at M numbers of 0.4 0.7 0.78 0.82 0.89 and oscillation frequencies of 4, 8, 12Hz. This paper presents a detailed description of the apparatus and the test data analysis.

NOMENCLATURE

M	Free-stream Mach number
f	Frequency
b	Wing span
C_A	Mean aerodynamic chord
V	Flow velocity
q_∞	Free-stream dynamic pressure
$C_{lp} + C_{l\dot{\beta}} \sin\alpha$	$\partial C_l / \partial(pb/2V) + \left[\partial C_l / \partial(\dot{\beta} b/2V)\right] \sin\alpha$
$C_{mq} + C_{m\dot{\alpha}}$	$\partial C_m / \partial(pC_A/2V) + \partial C_m / \partial(\dot{\alpha} C_A/2V)$
$C_{nr} - C_{n\dot{\beta}} \cos\alpha$	$\partial C_n / \partial(rb/2V) - \left[\partial C_n / \partial(\dot{\beta} b/2V)\right] \cos\alpha$
C_l	$L/(q_\infty sb)$
C_m	$M/(q_\infty sC_A)$
C_n	$N/(q_\infty sb)$

L	Rolling moment
M	Pitching moment
N	Yawing moment
p	Rolling velocity
q	Pitching velocity
r	Yawing velocity

1. INTRODUCTION

In high-speed wind tunnels, it has been difficult to make accurate measurement of dynamic stability derivatives. With the development of new flight vehicles, the demand for accurate measurement of derivatives has been greatly increased not only for the expansion of flight envelop of new-generation fighter aircraft, but also for the derivatives demand during the processing of designing civil airplanes. Excellent flight quality and flight control system must be focused on for civil airplanes. Dynamic derivatives are necessary aerodynamic data to the design of flight quality and flight control system. The derivatives are related directly to the dynamic process of an airplanes returning to equilibrium, which will affect the passengers' feelings of comfort. so accurate measurement of dynamic stability derivatives are especially important to civil aircrafts.

For the measurement of high-speed stability derivatives on a civil aircraft, a new forced-oscillation measurement system has been recently developed in CARIA. A big effort was made to increase the measurement accuracy. A new type of balance with high signal output was designed, so the signal-to-noise ratio could be improved. A new oscillation drive instrument and a new data acquisition and reduction system were used. This measurement system can measure the dynamic stability derivatives due to roll, pitch and yaw oscillation. The apparatus was used to conduct a wind tunnel test on a civil aircraft configuration. The dynamic stability derivatives due to pitch, yaw and roll oscillation were obtained. The direct derivatives $C_{lp} + C_{l\dot{\beta}} \sin\alpha$, $C_{mq} + C_{m\dot{\alpha}}$ and $C_{nr} - C_{n\dot{\beta}} \cos\alpha$ are discussed here.

2. APPARATUS

2.1. Mechanism

The oscillation mechanism has two sets, one for the pitching and yawing tests, the other for rolling tests. In the pitching and yawing mechanism as shown in Fig.1, the balance is attached to a pair of cross-flexure pivots which are capable of deflecting about the pivot center. A rotary flange driven by a servo electromotor forces the balance to oscillate at a fixed amplitude ± 1 degree. The balance has five components (no axial force) with provisions of high stiffness and high signal output. The cross-flexure pivots are instrumented with strain gauges to measure the angular displacement. The same mechanism is used to measure the pitch and yaw derivatives. The only difference is that the model can be rotated 90 degrees with respect to the balance to change from pitch to yaw oscillation.

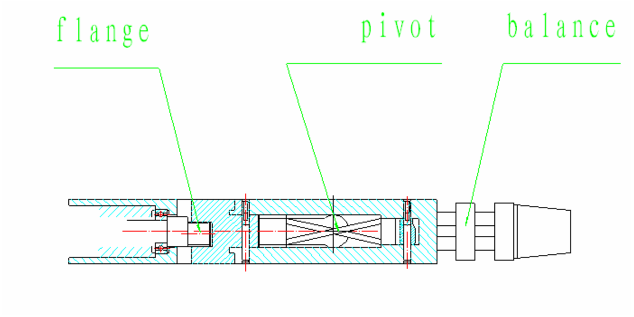

Figure 1. Pitch/yaw mechanism

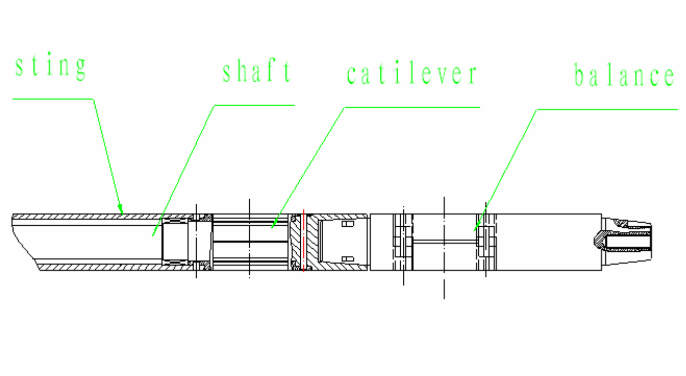

Figure 2. Roll mechanism

The rolling mechanism as shown in Fig.2 is designed with a roll shaft which drives the balance to oscillate and supports a model. The model is mounted on the five-component balance attached to 8 axially oriented cantilever springs which are instrumented strain gages to measure angular displacement. The roll amplitude is ± 0.8 degree. The two balances limits are listed in table 1.

Balance	N(N)	Y(N)	L(N.m)	M(N.m)	N(N.m)
Pitch/yaw	1200	50	18	230	14
Roll	1200	30	30	230	14

Table 1. Balance limits

The two sets of the mechanism are generated by one servo DC motor with little interference to balance signal. The motor drives an internal shaft converting rotary shaft motion to pitch/yaw or roll oscillation. The motor can provide a constant rolling velocity and arbitrary oscillation frequency below 20Hz.

2.2. Data acquisition and reduction systeme

For dynamic test, the response of a model can be corrupted by noise due to unsteady flow and support mechanism vibration, especially in dynamic stability derivative test, the noise has a dramatic effect on low dynamic signals. So how to filter the noise signal is a fatal technique.

PXI dynamic data acquisition and reduction system is operated at a sample rate 5K/s and low-pass cutoff frequency 20Hz. The dynamic signals are amplified, filtered and digitalized. According to the wind tunnel test data, PXI can effectively get rid of noise effect.

The dynamic derivative data processing software was developed with VB language, which has functions of data acquisition, display and reduction, serves the raw data with a desirable analysis and judgment to delete false points and select correct numerical integration range. It can provide reasonable and reliable data results. Also it can be used to make calculations and analyses of static derivatives and unsteady aerodynamics of an aircraft model

3. WIND TUNNEL TEST

The test model is a civil aircraft configuration with high aspect ratio and T-shaped tails. The balance pivot center and model moment reference point were located at the same point. The model is made of aluminum with a steel adaptor mounting on the balance, which can decrease the mass moments of inertia. The model has a set of removable wings, nacelles and a combination of horizontal and vertical tails. Four model configurations were tested. Configuration A is a complete aircraft model, with fusalage+wings+nacelles+tails; B: fusalage+wings+nacelles; C: fusalage+wings; D: fusalage+taisl; The free oscillation frequency of the mechanism including the model (configuration A) is 20Hz in pitch, 21 Hz in yaw and 22 Hz in roll respectively.

The test was conducted in the CARIA 1.2m trisonic wind tunnel which is an open-circuit blow-down wind tunnel with a 1.2 meter square test section. Pitch, yaw and roll oscillation data were taken at Mach numbers of 0.4 0.7 0.78 0.82 0.89. The angle of attack ranged from –2 to 4 degree. Data were taken at pitching/yawing oscillation amplitude of 1 deg and rolling oscillation amplitude of 0.8 deg. All data were obtained at nominal oscillation frequency of 4, 8 and 12 Hz respectively.

The pitch oscillation repeatability tests were conducted on configuration A at Mach number 0.78, oscillation frequency 12 Hz, the test was done three times. The precision of pitch damping derivatives are presented in the table 2.

α	-2	-1	0	1	2	3	4
σ%	6.74	0.85	6.2	8.45	2.09	4.83	9.39

Table 2. Pitch test precision

The comparison of wind tunnel test data and reference data are shown in Fig.3. The reference data was obtained from an in-flight simulator. The two results are similar in trend and magnitude. Fig.4 shows damping derivatives for different configurations or at different oscillation frequencies. Fig. 4a shows that derivatives for configuration C and D are smaller than configuration A and B in magnitude, which is due to the pitch damping derivatives being caused mainly by horizontal tails. Fig.4b demonstrates that the pitching damping derivatives value is dependent on the oscillation frequency, derivatives being bigger in magnitude with the increase of oscillation frequency.

For configuration A and D the Yaw damping derivatives shown in Fig.5 are similar, but much larger than configuration C, which is because yaw damping derivatives are caused mainly by a vertical tail.

Roll damping derivatives as shown in Fig.6 are similar for configuration A and B. Oscillation frequency has no effect on derivatives.

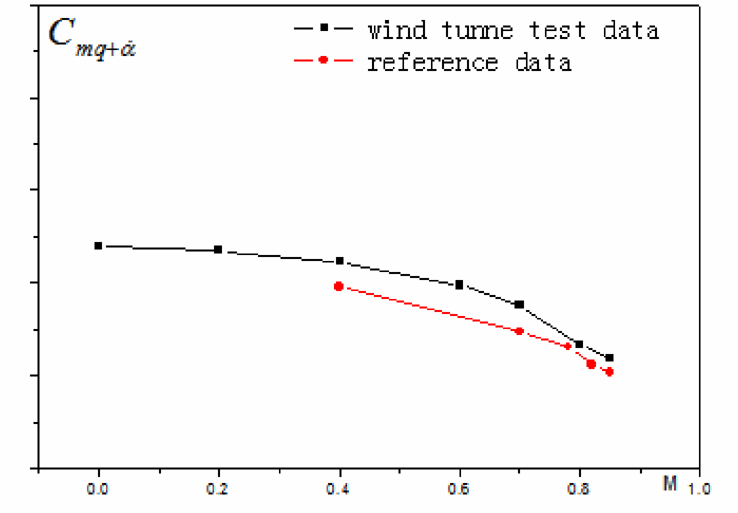

Figure 3. M=0.82

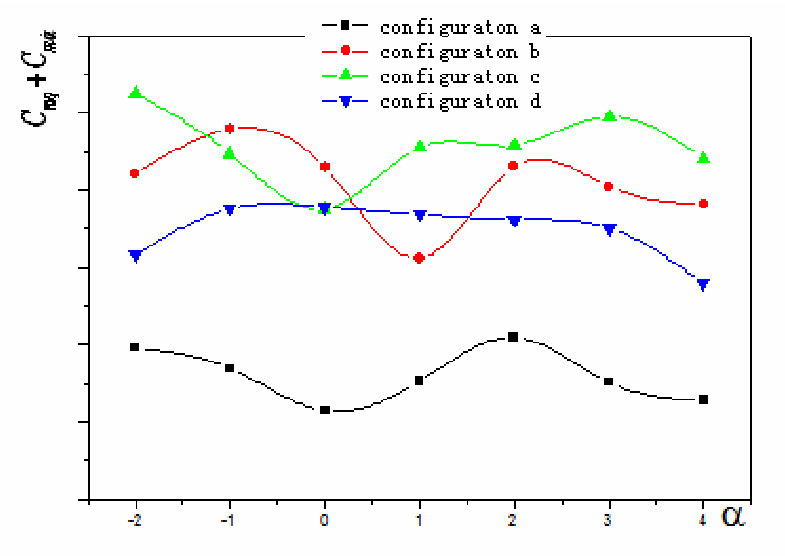

Figure 4a. M=0.78

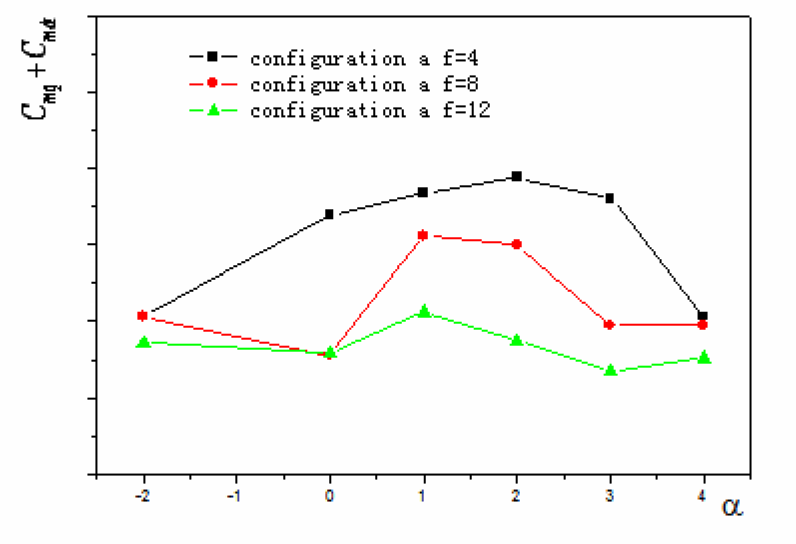

Figure 4b. M=0.7

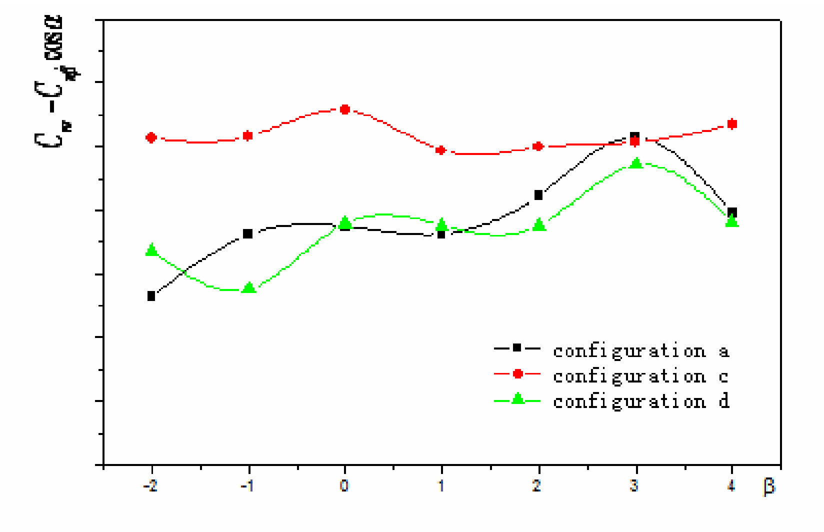

Figure 5. M=0.78

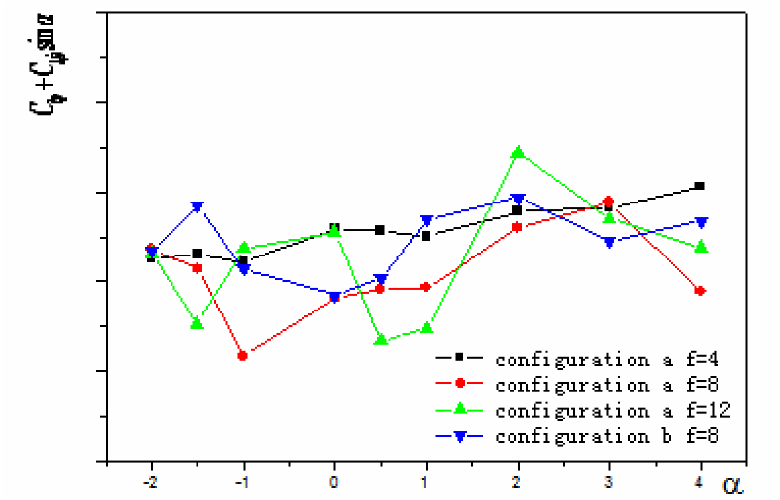

Figure 6a. M=0.7

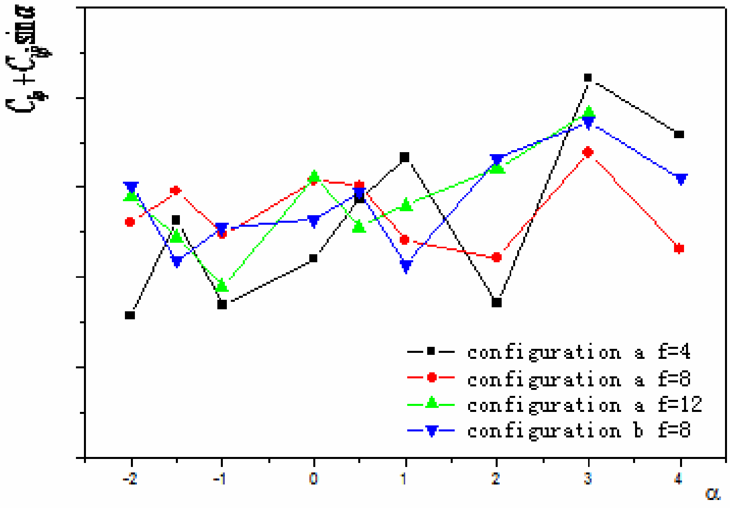

Figure 6b. M=0.89

5. CONCLUSION

The new apparatus was developed to measure forced-oscillation dynamic stability derivatives of a civil aircraft configuration. A series of wind tunnel tests was carried out with the apparatus. The test results verify that the apparatus has a good feasibility. The successful development of the new apparatus is attributive to the followings:

1).The oscillation mechanism is rigid enough for test model to oscillate at a fixed amplitude.

2).Both the pitch/yaw and roll balances have high stiffness as well as high signal output with high interference resistance.

3).The drive motor can support enough torque and its interference to balance signal can be neglected.

4).The dynamic data acquisition and reduction system PXI has a high sample rate and strong function of data processing.