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COMMISSIONING THE NEW PITCH DAMPING RIG AT THE CSIR WIND TUNNEL FACILITIES

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ABSTRACT

The first phase in the establishment of a pitch damping capability was presented at the 22nd ISB (reference 1). Following functionality checks and analysis of the acquired data from tests performed at M0.3 it was decided to re-evaluate some aspects of the rig design. This paper describes the commissioning of the first rig at the CSIR's wind tunnel facilities. In addition, the aspects for re-evaluation are discussed with some basic design criteria required for follow-up work by a second rig.

DESCRIPTION OF EXPERIMENTAL DESIGN

In order to respect the requirement for performing pitch damping tests at nominal incidence angles of up to 10°, test rig development focused on the concept of an oscillating frame, fitted with a sting and balance such as to provide a controlled, sinusoidal rotation of the model in the pitch plane. Motion was effected via a wing, mounted on this frame, controlled from an external hydraulic actuator through a drive train system.

The main technical parameters describing the pitch damping test rig are as follows:

- Maximum Dynamic pressure = 15 kPa
- Typical Reynolds number = 1.0×10^6
- Mach number limit, M ≤ 0.9
- Commanded frequency ≤ 4 Hz (limited by rig natural frequency)
- Commanded amplitude = ± 2.0° (structural limits)
- Rig natural frequency = 7.2 Hz
- Model mass ≤ 15 kg
- Maximum offset incidence ≤ 10°

CALIBRATION

Sensors

Data from three measurement sensors was acquired: a reference gyro-on-chip (calibration shown in **Figure 1**), a 4-component load balance (calibration shown in Figure 2) and an accelerometer with a nominal sensitivity of 250mV/g.

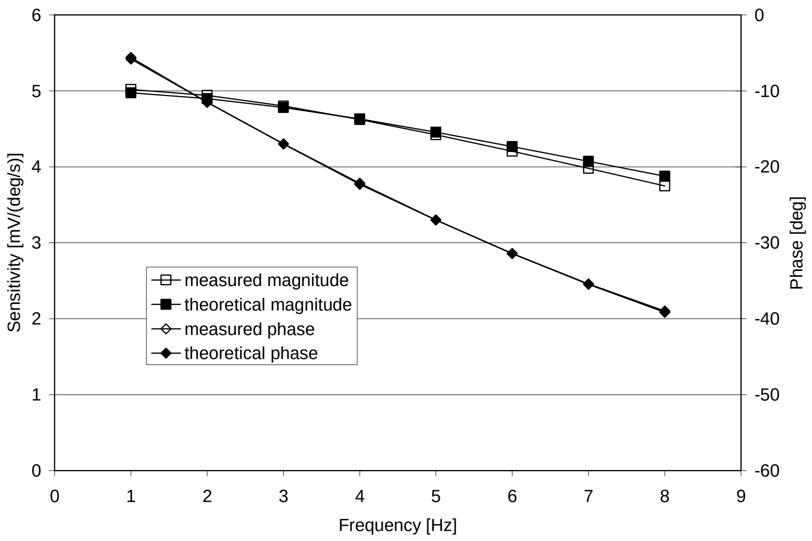

Figure 1: ADXRS300EB gyro-on-chip calibration

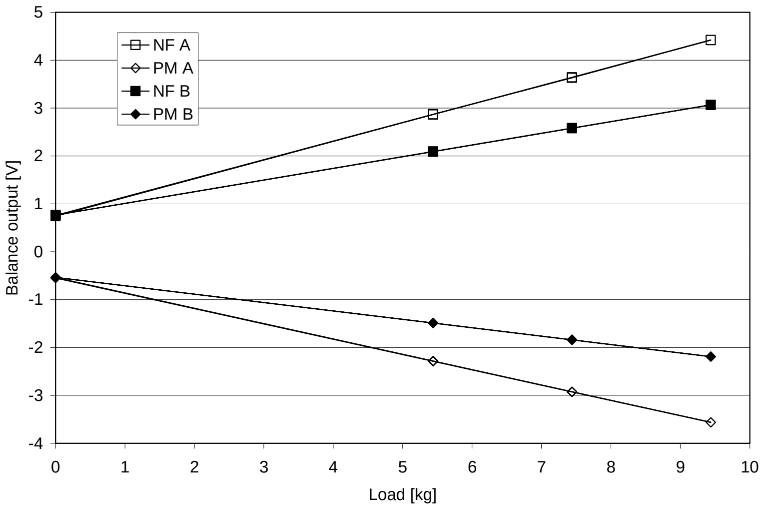

Figure 2: Load balance calibration

Inertial characterization

The basic assumption used in processing the data was that the inertial loads could be described by a constant relationship:

$$\begin{Bmatrix} NF \\ PM \end{Bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{Bmatrix} gyro \\ accel \end{Bmatrix}$$

The elements of the matrix are transfer functions. The matrix was determined by oscillating the model in two independent motions with air-off. With these results one could define:

$$\begin{bmatrix} NF_1 & NF_2 \\ PM_1 & PM_2 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} gyro_1 & gyro_2 \\ accel_1 & accel_2 \end{bmatrix}$$

or

$$\begin{bmatrix} NF_1 & NF_2 \\ PM_1 & PM_2 \end{bmatrix} \begin{bmatrix} gyro_1 & gyro_2 \\ accel_1 & accel_2 \end{bmatrix}^{-1} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$$

Without loss of generality, all the measurements were normalised by the gyro output. The results were recorded as transfer functions for the output signals of the measurement sensors. The data was then processed by subtracting the inertial loads, applying the sensor transfer functions and converting the balance output to loads.

The first motion analyzed was the sting vertical bending mode while the second was the pitching mode. The frequency of the sting bending mode obtained was 7.5 Hz, which made it impossible to obtain sufficiently pure pitching motion above 6 Hz.

TEST DATA ACQUISITION AND DATA REDUCTION

To check the full functionality of the rig, a low speed test campaign was first performed at M0.3 in the Low Speed Wind Tunnel facility (LSWT) (see **Figure 3**).

Figure 3. Pitch Damping Rig in the LSWT using the Standard Dynamic Model (SDM)

Test results

The pitch damping derivative results for three testing frequencies are shown in Table 1. These represent the aerodynamic pitch damping moment at the instant of maximum angular velocity and minimum (or mean) incidence.

Table 1. Pitch damping, Nm/(rad/s)

Frequency	Repetition 1	Repetition 2	Average
2	-3.30	-3.16	-3.23
3	-1.43	-2.11	-1.77
4	-1.02	-1.44	-1.23

One would expect a reasonably constant value of pitch damping moment over the frequency range of 2 to 4 Hz (k=0.02 to 0.04), which is not the case. This is likely due to a combination of poor data quality, particularly from the built-in inertial sensors, high model mass and low dynamic pressure. The pitch damping coefficient approaches the experimentally determined value as the frequency, and therefore the signal levels, increase.

RE-EVALUATION OF THE DESIGN

The wing-driven oscillating frame potentially provides an elegant solution to the challenge of acquiring dynamic derivative data at significant angles of incidence. The design did, however, pose the following problems during implementation in the Low Speed Wind Tunnel and design review.

Model inertia

The model mounting to the balance is designed for multi-functionality, allowing axial position adjustment and controlled roll motion. A large mass penalty is incurred by the bearings, actuators and structures required to provide this functionality.

The high model inertia negatively impacts the accuracy of the data reduction result, because the balance readings are dominated by the inertial forces.

Rig stiffness

A relatively low natural frequency is achieved, approximately 7.5 Hz. The first mode consists of the model mass pitching against the stiffness of the sting in bending, the cross-beam in torsion and the two side-arms in bending. This value is difficult to improve upon without significantly reducing the model mass and thereby removing the multi-functionality.

Another design restriction with respect to rig stiffness is the cross-beam running through the wing. The wing size, internal structure and bearings, limit the maximum cross-beam diameter, resulting in excessive flexibility.

Similarly, the presence of the wing behind the model determines an adequate clearance distance. Increasing length of the sting and side-arms decreases the inherent stiffness of the frame. These factors present inherent design limitations, that link achievable stiffness to wing size.

Aerodynamic pitching moment natural frequency

An aerodynamic pitch plane frequency is identified by considering the natural frequency of the rig inertia about the centre of oscillation with the wing aerodynamic restoring moment as the spring factor:

$$f_n \quad = \quad (1/2\pi)\,(d.q.S.\,C_{N\alpha}\,/I)^{½}$$

where $C_{N\alpha}$ (= 6.3) is the wing normal force slope with respect to incidence, in radians, d is the distance between the wing aerodynamic centre and the rig centre of oscillation and I ($\approx$ 15 kg m^2) is the inertia of the rig about the centre of oscillation. It follows that the term ($d.q.S.C_{N\alpha}$) yields the aerodynamic 'stiffness' resisting rotation of the rig inertia (I).

The high values for characteristic length (d = 0.8 m) and surface area (S = 0.455 m^2) results in uncommonly high values for f_n, when compared to typical values for ballistic rockets, for instance. At dynamic pressures approaching 15 kPa, values for $f_n \approx$ 7.5 Hz, the aerodynamic and structural first modes converge and resonance occurs. This potential failure scenario cannot be tolerated. In addition the potential dynamic pressure allowable for testing would also be seriously limited.

Flutter potential

The combination of a large wing and low frequency structural modes poses the awkward possibility of flutter.

With most of the frame flexibility residing in the sting, there is also the possibility of the SDM / sting system approaching a flutter mode.

GENERAL SAFETY CONSIDERATIONS

The high potential energy associated with the large wing leads to a situation where it is difficult to guarantee safety. Potentially critical scenarios include controller runaway, wing instability and aero-mechanical resonance.

Conclusion of review

It is concluded that the design, although inherently promising, should be modified to address safety concerns and, if possible, extend the currently limiting parameters of operating frequency, dynamic pressure and model inertia.

DESIGN CRITERIA FOR SECOND RIG

The oscillating frame is still regarded as the answer to achieving pitch damping testing at significant angles of incidence.

A redesign of the frame and actuation method is being conducted with the following in view:

- Investigate direct actuation, possibly hydraulic or electrical, to eliminate the need for a large wing inside the test section.
- Increase the frame natural frequency by optimising with respect to frame member stiffness, frame shape, frame mass and model mass.
- Achievement of a pure sinusoidal motion is a priority. It is an important criterion in the selection of an actuation method and / or peripheral systems to facilitate this function. One option under consideration is to implement a mechanical spring resistance, to make use of the natural sinusoidal motion resulting from a spring-and-inertial system.
- Due to the poor quality of acquired data from the build in sensors, laser measurement techniques are going to be investigated.

- Decrease model and balance block mass to the fullest extent, as limited by structural safety and manufacturability. The design aim is for a mass of less than 4 kg.
- The structural design goal is to achieve 8 Hz operating frequency and 30 kPa dynamic pressure (double the current test limits, for both parameters).
- The offset incidence requirement is 10°, with an oscillation about the nominal of ±3°.

Preliminary design results indicate a fair level of feasibility. The frame inertia, actuated at the stated frequency and amplitude levels, become a driver design parameter. With the wing-driven design, the aerodynamic force is available at such an excess that it was not a concern. The frame needs to be optimised for low mass (inertia) and drag (frontal size) on the one hand and stiffness on the other, in order to converge on a solution that satisfies the contradicting requirements.

REFERENCES

1. F Dionisio, Establishing a Pitch Damping Testing Capability at CSIR Defencetek. *22nd International Symposium on Ballistics,* 14-18 November 2005, Vancouver Canada