CLOSE PROXIMITY DYNAMIC DERIVATIVES

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Abstract

An exploratory experimental test programme investigating the dynamic derivative interference effects of a parent airframe on a store revealed changes in the pitch dynamic derivatives dependent on the relative position of the store with respect to the parent airframe, and the parent angle of attack. The tests were performed on 1/12th scale models at free-stream velocities varying from 30 m/s to 43 m/s and the Low Speed Wind Tunnel of the CSIR . The changes in the combined pitch dynamic derivatives for the chosen store parent airframe combination were relatively small (a maximum change of 28%) with the interference derivatives generally showing an increase over that the free-stream values.

List of Symbols

C_{m_q}	Moment coefficient about the store y body axis due to pitch velocity, $\frac{\partial C_m}{\partial \frac{qc}{2V}}$, rad^{-1}
$C_{m_{\dot{\alpha}}}$	Moment coefficient about the store y body axis due to time rate change of angle of attack, $\frac{\partial C_m}{\partial \frac{\dot{\alpha} c}{2V}}$, rad^{-1}
l	reference length, m
q	Angular time rate of change about the store y body axis, rad/sec
Red Freq	Reduced frequency, $\frac{\omega l}{2V}$
V	Free-stream velocity m/s
α	Angle of attack, degrees

Nomenclature

LSWT	Low Speed Wind Tunnel
CTS	Captive Trajectory System

1 Introduction

Of particular interest to aircraft designers is the requirement to simulate the behaviour of the air vehicle under all design conditions. One of the greatest difficulties in the modelling process is the determination of the loads that are imposed by the air flow on the aircraft structure. The classic representation of the aerodynamic loads was devised by Bryan [1] in 1911, where the loads are assumed to be a first order Taylor algebraic summation of various time independent parameters. While the model has served the aerospace community well for almost a century a number of alternative models have been proposed to overcome, in particular the limitation of the time independence of parameters [1]. This is particularly relevant for separated flow and high angles of attack [1, 2].

A number of various techniques have in the past been used to simulate the separation of weapons or stores from parent airframes. During the 1960's the experimental captive trajectory method (CTS) was developed. This method is still widely used today, both of production programmes and as validation for computational methodologies. The captive trajectory technique, in contrast to the free fall techniques, moves the store in a captive manner (the store is usually mounted on a sting via a five or six component balance) depending on the loads measured by the store balance. The technique is thus a static technique as no dynamic motion effects are measured directly. The dynamic motion effects such as damping are normally included as constants, and using the classic Bryan first order Taylor model the three orthogonal forces and moments are determined so that the trajectory can be simulated.

Even though the CTS technique is relatively successful, its inherent limitations have resulted in computational techniques being invested in to overcome these difficulties. While the CTS technique suffers from limitations, an area which could be improved is the modelling of the dynamic derivatives that are used to build the store loads. Normally, these loads are obtained from the store or weapons supplier when the integration programme is initiated. These dynamic derivatives may be determined experimentally or analytically, and normally for the store or weapon in free-stream. The interference effect of the parent airframe on the store is indeterminate and assumed to negligible.

The effect of the parent airframe on the dynamic derivatives of a store being released has not been readily published in the literature. In determining the safety of release changes in the dynamic derivatives, especially when the derivative could result in a possible collision, is of particular interest to weapons integration engineers. Experiments have, however, been performed on the separation of the Space Shuttle orbiter from the Shuttle booster [3, 4]. These tests determined the static and dynamic interference effects of the booster on the orbiter and vice versa. The static interference tests were defined by only oscillating the body of interest (eg. booster) and keeping the other body (eg. orbiter) stationary. Dynamic interference tests involved oscillating both bodies at various amplitudes and phases. A significant dynamic interference effect was observed where divergence in oscillation of the orbiter may be experienced due to the oscillating booster. For the static interference tests a relatively small effect was observed, this being a maximum of 27% with respect to the interference free value.

For stores being released from parent airframes, the store is normally smaller than the parent airframe, such that the static interference case is more of interest than the dynamic interference case. Of particular interest in the study was the interference effects on the store when the store was of significantly different size to the parent airframe. This is typical of weapons store release, where the weapon is normally not of appreciable size compared to the parent airframe.

This paper presents exploratory experimental research to determine the static interference effects of a parent airframe on a store. Both the parent airframe and store geometries are representative and are thus not simplified.

The tests were performed using the small amplitude free oscillation test technique. The dynamic derivatives of interest are the combined pitch derivatives $C_{m_q} + C_{m_{\dot{\alpha}}}$. This option was chosen over measuring each pitch derivative separately due to the simplicity of the experimental equipment; this is contrast to what is required for measuring C_{m_q} to $C_{m_{\dot{\alpha}}}$ separately. Future tests that will isolate the changes of each individual component will need to be performed.

2 Experimental Setup

The following experimental setup was used.

- 1/12th scale Cheetah parent aircraft
- 1/12th scale fuel tank
- Solenoid trigger mechanism
- Two component flexure strain-gauge balance mounted at the model center-of-gravity
- HBM strain gauge signal conditioners
- PC based data acquisition system, running LabView

The tests were performed in the Low Speed Wind Tunnel (LSWT) of the CSIR. The tunnel is an atmospheric tunnel capable of speeds up to 120m/s depending on the size of the models. It has a 7’ x 5’ test section with corner fillets resulting a test section area of 2.25 m^2.

Figures 1 to 2 show the Cheetah model and the fuel tank in the carriage position. The Cheetah model also has two short range air to air missile mounted.

3 Experimental Methodology

To determine the interference effects of the parent aircraft on the stability derivatives of the store, the combined dynamic derivatives in pitch ($C_{m_q} + C_{m_{\dot{\alpha}}}$) were first determined in free-stream. The same tests were then repeated with the store in close proximity to the parent aircraft at relative positions (linear and angular) of interest.

The effect of reduced frequency was also ascertained by performing tests at different velocities, assuming that there were no Mach or Reynolds number effects because the tests were conducted at low subsonic speeds.

For the free oscillation tests, the store was oscillated about the store center-of-gravity and triggered by an electro-mechanical mechanism. The maximum amplitude of oscillation was 0.5°.

3.1 Test Programme

The following test programme was followed. Free oscillation data were collected for the store at the free-stream velocities of 30, 35, 40 and 43 m/s. This was to vary the reduced frequency and thus determine the effect of the combined dynamic derivatives on reduced frequency. The store was kept at the same relative angle of attack to the parent aircraft namely carriage position or 0°, and the following linear displacement positions for the store were tested namely carriage, $1.0m$ and $2.5m$ full scale aft of the carriage position. The carriage position configuration represents the store as it is release from the captive carriage position.

The angle of attack of the parent airframe was pitched to the following angle namely, 0°, 3°, 6° and 9° respectively.

4 Results and Discussion

4.1 Results

Figures 3 to 6 show the interference effect of the parent airframe on the store for the three store positions. Position 1 refers to the store being $1.0m$ aft of the store carriage position, while position 2 is when the store is $2.5m$ aft. The uncertainty of the combined pitch damping derivatives ($C_{m_q} + C_{m_{\dot{\alpha}}}$) varies depending on the angle of attack. The uncertainty of the results varies from 10 rad^{-1} to 15 rad^{-1}.

4.2 Free-stream Derivatives

The free-stream derivatives are both angle of attack and reduced frequency dependent. No obvious trends can be extracted from the results.

4.3 Interference Derivatives

No obvious trends can be extracted from the results because the dynamic derivatives are angle of attack and reduced frequency parameter dependent. The interference effect is, however, evident. For most angles of attack and configurations, the interference effects show an increase in the pitch damping derivative. Only at the parent airframe angle of attack of 0° does the pitch damping derivative show a decrease for the carriage configuration. The largest change was 28%.

4.4 Sting Oscillations

The effect of sting oscillations were not accounted for. The effect on the results may be significant [5]. Subsequent data processing will need to be performed on the results presented in this paper. As can be seen from the results, the changes are relatively small. This implies that the accounting for sting deflections will probably results in absolute changes in the values of pitch damping derivatives, but smaller changes in the differences between the free-stream derivatives and interference flow field derivatives.

4.5 Implications for Weapons Release

The results generally show an increase in the damping derivative values for all three relative store positions. This, from a safety and clearance perspective, normally implies that the amplitude of store oscillations will be smaller than that predicted using the free-stream derivatives, thus initially indicating that the trajectories predicted by current CTS would be slightly conservative. These results are, however, both store and parent airframe configuration dependent, because results from [3] show different trends to the results obtained in this test programme.

With respect to the studies performed in [3] and [4], this study seems to indicate that the dynamic derivatives, for stores being released from larger parent airframes, also change. This implies that the dynamic interference effects is of interest because the parent airframe could feed significant energy into the motion of a store possibly resulting in a collision or divergence. This effect could be exacerbated compared to references [3] and [4] due to the relative sizes of the parent airframe and store in weapons release programmes.

5 Conclusions and Recommendations

The following conclusions can be drawn from the test programme:

- Dynamic stability derivatives for stores being released from larger parent airframes change.
- The changes for the chosen store parent airframe combination were, however, relatively small (a maximum change of 28%)
- For the parent airframe store configuration tested the combined pitch dynamic derivatives showed a general increase for the chosen parent airframe angles of attack.

5.1 Recommendations

The following are recommended for further investigation:

- Further processing of the results to account for sting oscillations
- Dynamic derivative tests isolating the interference effects of each individual derivative component i.e. C_{m_q} and $C_{m_{\dot{\alpha}}}$ could be performed to give insight into the contribution of each component to the combined effect.
- With reference to [3] an investigation into the dynamic interference effects of a parent airframe on a store would be of interest because the parent airframe could feed significant energy into the motion of the store possibly resulting in a collision or divergence.

References

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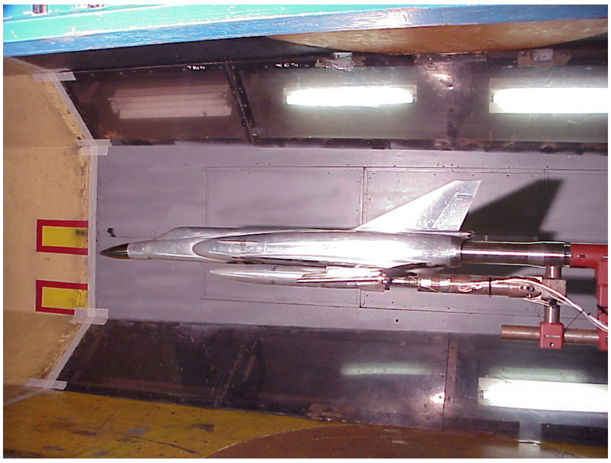

Fig. 1 Experimental Setup, Overview

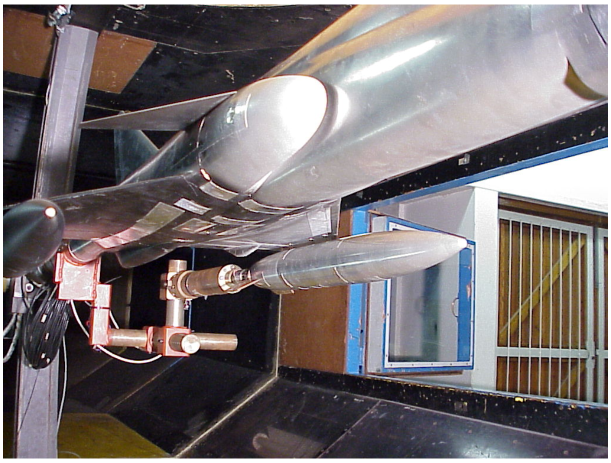

Fig. 2 Experimental Setup, Fuel Tank in Carriage Position

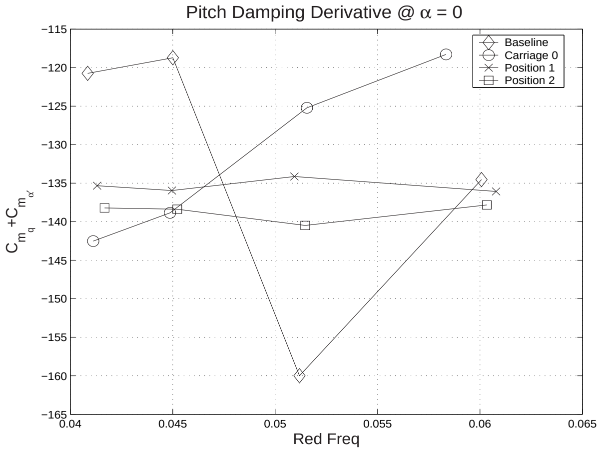

Fig. 3 Variation of $C_{m_q} + C_{m_{\dot{\alpha}}}$ at $\alpha = 0°$

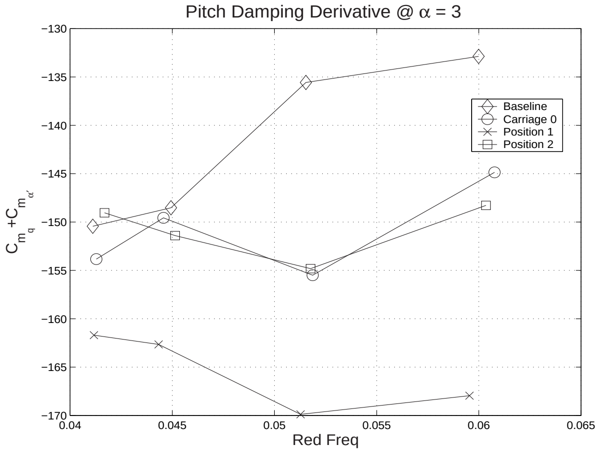

Fig. 4 Variation of $C_{m_q} + C_{m_{\dot{\alpha}}}$ at $\alpha = 3°$

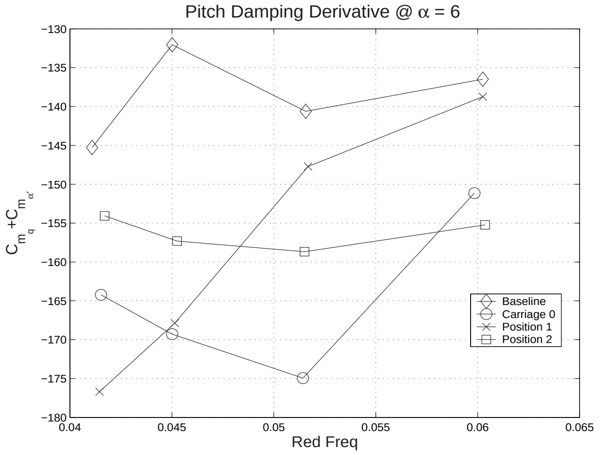

Fig. 5 Variation of $C_{m_q} + C_{m_{\dot{\alpha}}}$ at $\alpha = 6°$

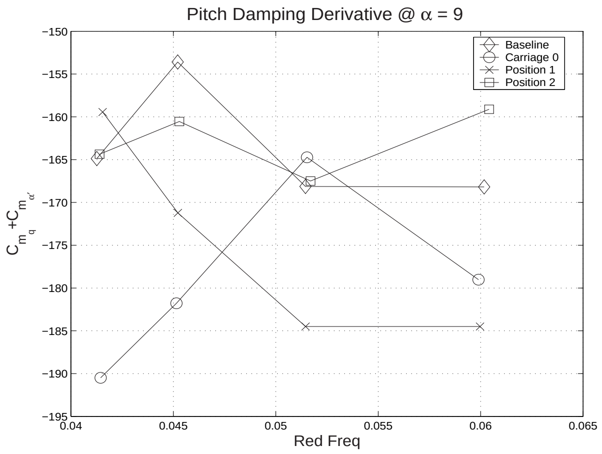

Fig. 6 Variation of $C_{m_q}+C_{m_{\dot{\alpha}}}$ at $\alpha = 9^\circ$