of racks. It is interesting to note that a store with an internally spinning fly wheel, if dropped in the free fall mode, would not spin appreciably because the store and fly wheel fall at the same rate. Consequently, the torque due to friction coupling could not act efficiently. It is conceivable that the spin of the store could be optimized for stability by using fin cant or roll tabs.

Frick[1] of the Naval Weapons Laboratory has derived the equations of motion for two rigid bodies coupled by a bearing. In a body fixed reference frame (rolling with the outer body) the six-degree-of-freedom equations are:

$$\begin{bmatrix} \dot{u} \\ \dot{v} \\ \dot{w} \end{bmatrix} = (1/m)\begin{bmatrix} F(x_B) \\ F(y_B) \\ F(z_B) \end{bmatrix} + \begin{bmatrix} rv - qw \\ p_1 w - ru \\ qu - p_1 v \end{bmatrix} \tag{3}$$

$$M_{x_B} = I_{x_1}\dot{p}_1 + I_{x_2}\dot{p}_2$$

$$M_{y_B} = \tilde{I}\dot{q} - (\tilde{I} - I_{x_1}p_1 r + I_{x_2}p_2 r \tag{4}$$

$$M_{z_B} = \tilde{I}\dot{r} + (\tilde{I} - I_{x_1}p_1 q - I_{x_2}p_2 r$$

where

$$\tilde{I} = I_{y_1} + I_{y_2} + m_1 x_1^2 + m_2 x_2^2 \tag{5}$$

For aeroballistic axes: (do not spin with outer body):

$$\begin{bmatrix} \dot{u} \\ \dot{v} \\ \dot{w} \end{bmatrix} = (1/m)\begin{bmatrix} F_{xA} \\ F_{yA} \\ F_{zA} \end{bmatrix} + \begin{bmatrix} rv - qw \\ -ru \\ qu \end{bmatrix} \tag{6}$$

$$M_{xA} = I(x_1\dot{p}_1 + I_{x_2}\dot{p}_2$$

$$M_{y_A} = \tilde{I}\dot{q} + (I_{x_1}p_1 + I_{x_2}p_2)r \tag{7}$$

$$M_{z_A} = \tilde{I}\dot{r} - (I_{x_1}p_1 + I_{x_2}p_2)q$$

It can be shown that, for linear aerodynamics, an approximate solution for the angle of attack is

$$\boldsymbol{\alpha} = \sum_{j=1}^{2} K_J\, e^{\phi_j t} \tag{8}$$

where

$$\phi_j = \lambda_j + i\omega_j \tag{9}$$

$$\omega_{1,2} = [p_1 I_{x_1} + p_2 I_{x_2}][1 \pm 1/\tau]/2\tilde{I} \tag{10}$$

$$\tau = 1/(1 - 1/s)^{1/2} \tag{11}$$

$$s = [p_1 I_{x_1} + p_2 I_{x_2}]^2 / 4\tilde{I}M_\alpha \tag{12}$$

$$\lambda_{1,2} = Z_\alpha(1 \mp \tau)/2mv + (M_q + M_{\dot{\alpha}})(1 \pm \tau)/2\tilde{I} \pm M_{p\alpha}p_1\tau/[p_1 I_{x_1} + p_2 I_{x_2}] \tag{13}$$

The necessary and sufficient conditions for stability are:

$$\begin{matrix} s > 1, \\ \text{or} \\ s < 0 \end{matrix} \qquad \lambda_{1,2} < 0 \tag{14}$$

The maximum angle of attack due to an angular rate now becomes:

$$|\boldsymbol{\alpha}_{MAX}| = 2|\dot{\boldsymbol{\alpha}}_0| / [p_1 I_{x_1} + p_2 I_{x_2}]^2/\tilde{I}^2 - 4M_\alpha/\tilde{I}]^{1/2} \tag{15}$$

Consequently, the maximum angle of attack due to an angular rate is reduced by increasing the angular momentum of either the inner or outer bodies and the stability of the store depends on Eqs. (13–15).

Discussion

The fly wheel complicates the design of an external store. However, folding fins, parachutes, etc. also complicate the design and are not always effective in improving its over-all performance. The over-all performance of a store would be improved according to Eqs. (12–15) if a properly designed fly wheel were inserted.

The fly wheel concept might be employed successfully to reduce the launch disturbance of low density stores, which have always been troublesome, or of high density stores at supersonic speeds. It could also be useful to improve the stability of marginally stable stores or to gyroscopically stabilize stores which are statically unstable.

References

[1]Frick, C. H., "Equations of Motion for Two Rigid Bodies Coupled by a Bearing," Rept. 1630, Nov. 25, 1958, Naval Proving Ground, Dahlgren, Va.

Errata

Reduction of ILS Errors Caused by Building Reflections

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ON p. 171, the figure numbers referred to as "4A," "4B," and "4C" in the paragraph immediately preceding the Conclusion section should read as "5A," "5B," and "5C."

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