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EQUATIONS FOR A STUDY OF A ROLL-OUT CLAMSHELL EJECTION CONCEPT FOR SPINNING ROCKET VEHICLES

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16. Abstract

Equations for estimating the motion, forces, and couples applicable to the design of clamshell systems utilizing a new roll-out ejection concept are presented. Both the deployment and the free flight phases of the clamshell ejection are considered. No attempt is made to answer the thermal, vibratory, and structural detail problems of these clamshells.

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EQUATIONS FOR A STUDY OF A ROLL-OUT CLAMSHELL EJECTION CONCEPT FOR SPINNING ROCKET VEHICLES

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INTRODUCTION

A clamshell system is flown on a sounding rocket to protect its payload from the generated flight environment and to expose the payload when this protection is no longer needed. It therefore performs the same tasks as an ejectable nose cone system. The clamshell system is preferable, however, as it does have a number of desirable advantages. From the experimenter's viewpoint, it does not disturb the environment—and affect the readings taken—as is done by impelling ejected bodies ahead of the payload. The clamshells may be ejected sooner and thus permit the recording of measurements from lower altitudes, where booster thrust or mass-drag differences preclude nose cone ejection. Significantly improved rocket system performance capability is also achieved with ejection under booster thrust. Unfortunately, the design of sounding rocket clamshell systems has not received the attention it should have. In this situation, it is not sufficient to apply the lessons learned from other applications.

Developed successfully for non-spinning rocket vehicles, the pitch-out clamshell systems tend to be marginal if not unacceptable for sounding rocket use. As a consequence of vehicle spin, the ejecting clamshells exhibit a notable tendency to rotate into collision with the payload. This tendency may be offset (at the expense of overall system efficiency) by rigid structuring, massive hinging, and guides and rollers, or their equivalents. Since the rocket vehicle will rarely be completely despun by clamshell ejection, the collision tendency will be transmitted to the free flight of the ejected bodies. Thus it is additionally necessary to retain the clamshells until they have swept through sufficiently large pitch-out angles to clear the payload before releasing them. This retention requirement means that the rocket vehicle will be subject to despinning and to disturbances arising from clamshell dynamic mismatch or vehicular coning motion for a longer and perhaps significant period of time. It also means that the intervals between successive releases of such clamshells will be stretched out. If these intervals are unduly lengthened at this time of lessening rocket vehicle stability, the rocket mission could be seriously compromised by the increased "yo-effect."

The roll-out clamshell concept advocated in this report is expected to provide a reasonable solution to the sounding rocket clamshell ejection problem. In this concept, each of the ejecting clamshells is made to pivot, i.e. roll out essentially like a door, about that one of its edges which trails with respect to vehicle spin. In this manner, the moving parts of the ejecting bodies are directed away from the payload. The positioning of the pivot permits the available forces to carry out this movement. It will be seen that an essential ingredient of this concept is the development of a "reasonable" clamshell roll-out rate. Under the conditions occurring at clamshell ejection time, it is expected that this roll-out rate will be readily attained. Since this rate is in opposition to the rocket vehicle spin, the effect of the latter on the rotational motion of the clamshells will be lessened if not eliminated. That is, clamshell ejection under this concept implies both clamshell despinning and c.m. (center-of-mass) translation away from the payload. Hence it should not be necessary to retain the ejecting clamshells until they have swept through a large roll-out angle. The time over which the rocket vehicle must be subject to despinning and to unbalanced forces may therefore be greatly reduced by the use of this system.

SYMBOLS

A, B, C, D - inertial parameters (slug ft^2).

$\vec{a}$ - clamshell c.m. acceleration (ft sec^{-2}).

$C_{y_1}, C_{y_2}, C_{y_3}$ - hinge couple components about axes parallel to the clamshell body—fixed y_1, y_2, and y_3 axes, respectively (ft lb).

$c\psi, c\theta, c\phi$ - cosines of the Eulerian angles ψ, θ, and ϕ, respectively (-).

d_1 - clamshell hinge axis displacement from the x_1 axis, i.e. the rocket vehicle system longitudinal axis (ft).

d_2 - clamshell c.m. displacement from the $x_1 - x_2$ plane, i.e. the clamshell system bisection plane, before clamshell deployment (ft).

d_3 - clamshell c.m. displacement from the clamshell system base plane (ft).

d_5 - clamshell c.m. displacement from its hinge axis (ft).

d_6 - clamshell c.m. displacement from the $x_2 - x_3$ plane, i.e. the rocket vehicle system transverse plane containing the rocket vehicle system c.m. (ft).

d_7 - clamshell c.m. displacement from the x_1 axis, i.e. the rocket vehicle system longitudinal axis, during clamshell deployment (ft).

d_{7f} - terminal d_7 (ft).

$\vec{e}_1, \vec{e}_2, \vec{e}_3$ - unit vectors directed along the rocket vehicle body—fixed x_1, x_2, and x_3 axes, respectively (-).

$F_{x_1}, F_{x_2}, F_{x_3}$ - hinge force components directed along axes parallel to the rocket vehicle body—fixed x_1, x_2, and x_3 axes, respectively (lb).

$F_{y_1}, F_{y_2}, F_{y_3}$ - hinge force components directed along axes parallel to the clamshell body—fixed y_1, y_2, and y_3 axes, respectively (lb).

F_1, F_2, F_3, F_4, F_5 - inertial forces (lb).

J - clamshell moment of inertia about an arbitrary axis which passes through its c.m. and lies in its plane of mass symmetry defined by the y_1 and y_3 axes (slug ft²).

$$\left.\begin{aligned}
J_{cy1} &= \int_m \left(y_2^2 + y_3^2\right) dm \\
J_{cy2} &= \int_m \left(y_1^2 + y_3^2\right) dm \\
J_{cy3} &= \int_m \left(y_1^2 + y_2^2\right) dm \\
J_{cy4} &= \int_m y_1 y_2 \, dm \\
J_{cy5} &= \int_m y_1 y_3 \, dm \\
J_{cy6} &= \int_m y_2 y_3 \, dm
\end{aligned}\right\}$$

- elements of the clamshell inertia matrix defined in terms of the clamshell body—fixed geometric frame centered at its c.m., i.e. the y-frame (slug ft²).

J_{vx_1} - rocket vehicle (payload and motor) spin moment of inertia, i.e. moment of inertia about the x_1 axis (slug ft²).

$J_{z_1}, J_{z_2}, J_{z_3}$ - clamshell principal moments of inertia about the z_1, z_2, and z_3 axes centered at its c.m., respectively (slug ft²).

K - direction cosine matrix (-).

M - rocket vehicle (payload and motor) mass (slug).

$M_{y_1}, M_{y_2}, M_{y_3}$ - moments about the clamshell body—fixed y_1, y_2, and y_3 axes, respectively (ft lb).

$M_{z_1}, M_{z_2}, M_{z_3}$ - moments about the clamshell z_1, z_2, and z_3 axes, respectively (ft lb).

m - clamshell mass (slug).

$\vec{p}$ - position vector from the origin of the rocket vehicle body—fixed geometric frame centered at the c.m. of the total vehicle system, i.e. the origin of the x-frame, to the clamshell c.m. (ft).

$(\dot{\vec{p}})_r$ - time derivative of the position vector, $\vec{p}$, as noted from the x-frame (ft sec^{-1}).

p_{Ω_1}, p_η - generalized angular momenta associated with the Ω_1 and η coordinates, respectively (slug ft^2 sec^{-1}).

Q_{Ω_1}, Q_η - external moments doing work with respect to the Ω_1 and η coordinates, respectively (ft lb).

$\vec{R}$ - position vector from an inertial frame origin to the rocket vehicle body—fixed x-frame origin (ft).

$\vec{r}$ - position vector from an inertial frame origin to the clamshell c.m. (ft).

$s\psi$, $s\theta$, $s\phi$ - sines of the Eulerian angles ψ, θ, and ϕ, respectively (-).

T - kinetic energy of the total vehicle system (ft lb).

t - elapsed time (sec).

t_f - time denoting the end of the clamshell deployment phase and the beginning of the free flight phase (sec).

U, V - momental parameters (ft lb).

$\vec{v}$ - clamshell c.m. velocity (ft sec^{-1}).

W_1, W_2, W_3 - clamshell free flight rotational rate components about the z_1, z_2, and z_3 axes, respectively (sec^{-1}).

$\{X_j\}$ - displacement vector for the j-th point on the clamshell defined in terms of the X-frame, i.e. the inertial frame which is coincident with the x-frame at the instant of clamshell release and translates at the velocity established by the rocket vehicle at this instant in time (ft).

$\{X_{cm}\}$ - displacement vector for the clamshell c.m. defined in terms of the inertial X-frame (ft).

$\{z_j\}$ - displacement vector for the j-th point on the clamshell defined in terms of the z-frame, i.e. the clamshell principal axis frame centered at its c.m. (ft).

α - angle developed during clamshell deployment between the $x_1 - x_2$ plane and the plane defined by the x_1 axis and the position vector $\vec{p}$ (-).

β - angle in the clamshell mass symmetry plane between the clamshell body-fixed y-frame and the clamshell principal axis set centered at the clamshell c.m. (-).

γ - clamshell roll-out angle, i.e. the angle developed between the $x_1 - x_2$ plane and the $y_1 - y_2$ plane (-).

η - angle developed during clamshell deployment between the $x_1 - x_2$ plane and the plane which contains both the clamshell hinge axis and clamshell c.m. (-).

λ - angle between the clamshell body fixed y_1 axis and an arbitrary axis lying within the $y_1 - y_3$ plane (-).

η_0 - initial η (-).

$\alpha_f, \gamma_f, \eta_f$ - terminal α, γ, and η, respectively (-).

ψ, θ, ϕ - Eulerian angles—see Figure 2 (-).

Ω_1 - component of $\vec{\omega}$ (sec^{-1}).

Ω_{1f} - terminal Ω_1 (sec^{-1}).

$\vec{\omega}$ - angular velocity of the x-frame (sec^{-1}).

CLAMSHELL EJECTION EQUATIONS

The following equations are applicable to a study of the deployment and the free flight phases of roll-out clamshell ejection. The principal items of interest in these equations are the motion of the system components, the forces and couples at the clamshell hinges, and the free flight displacements of selected points on the clamshell.

In order to facilitate problem resolution, it is assumed that the clamshells are dynamically matched rigid bodies attached to an axially symmetric, spinning rocket vehicle which exhibits negligible coning motion during clamshell ejection. For convenience, it is also assumed that the aerodynamic and frictional forces are not significant in comparison to the inertial forces. From the first assumption, we can devise a problem symmetry which will allow us to characterize the system dynamics by those of an individual clamshell.

Three coordinate frames will be used in the analysis of the deployment phase dynamics. One of these is the x-frame which is centered at the total vehicle system c.m. with its x_1 axis coincident with the rocket vehicle longitudinal axis and its x_2 axis directed so that the clamshell bisection plane is the $x_1 - x_2$ plane. The clamshell body-fixed y-frame is centered at the clamshell c.m. with its y_1, y_2, and y_3 axes, respectively, paralleling the x_1, x_2, and x_3 axes of the x-frame before clamshell deployment. The clamshell is hinged so that only the parallelism between the x_1 and y_1 axes is maintained during deployment. The clamshell body-fixed z-frame is the clamshell principal axis set centered at the clamshell c.m. with its z_3 axis coincident with the y_3 axis of the y-frame.

Equations of Body Angular Motion

Utilizing the preceding assumptions and Figure 1, it can be shown that the kinetic energy of the total vehicle system may be expressed as

$$T = 0.5\left(J_{vx_1}\Omega_1^2 + M\dot{R}_1^2\right) + J_{cy1}\left(\Omega_1 - \dot{\eta}\right)^2 + mv^2 ,$$

where (according to Appendix A)

$$v^2 = \dot{R}_1^2 + \dot{\eta}^2 d_5^2 + \Omega_1^2 d_7^2 - 2\Omega_1 \dot{\eta} d_5\left(d_5 - d_1 \cos\eta\right) .$$

Noting that

$$d_7^2 = d_1^2 + d_5^2 - 2d_1 d_5 \cos\eta ,$$

we get

$$p_{\Omega_1} = \frac{\partial T}{\partial \Omega_1}$$

$$= J_{vx_1}\Omega_1 + 2J_{cy1}\left(\Omega_1 - \dot{\eta}\right) + 2m\left[\Omega_1 d_7^2 - \dot{\eta} d_5\left(d_5 - d_1\cos\eta\right)\right] ,$$

$$\dot{p}_{\Omega_1} = Q_{\Omega_1}$$

$$= J_{vx_1}\dot{\Omega}_1 + 2J_{cy1}\left(\dot{\Omega}_1 - \ddot{\eta}\right)$$

$$+ 2m\left[\dot{\Omega}_1 d_7^2 + 2\Omega_1 \dot{\eta} d_5 d_1 \sin\eta\right.$$

$$\left.- \ddot{\eta} d_5\left(d_5 - d_1\cos\eta\right) - \dot{\eta}^2 d_5 d_1 \sin\eta\right] ,$$

and

$$Q_{\Omega_1} = \left[J_{vx_1} + 2\left(J_{cy1} + md_7^2\right)\right]\dot{\Omega}_1 - 2\left(J_{cy1} + md_5^2\right)\ddot{\eta}$$

$$+ 2\left(2m\Omega_1 \dot{\eta} d_5 - m\dot{\eta}^2 d_5\right) d_1 \sin\eta$$

$$+ 2\left(m\ddot{\eta} d_5\right) d_1 \cos\eta \quad . \qquad (1)$$

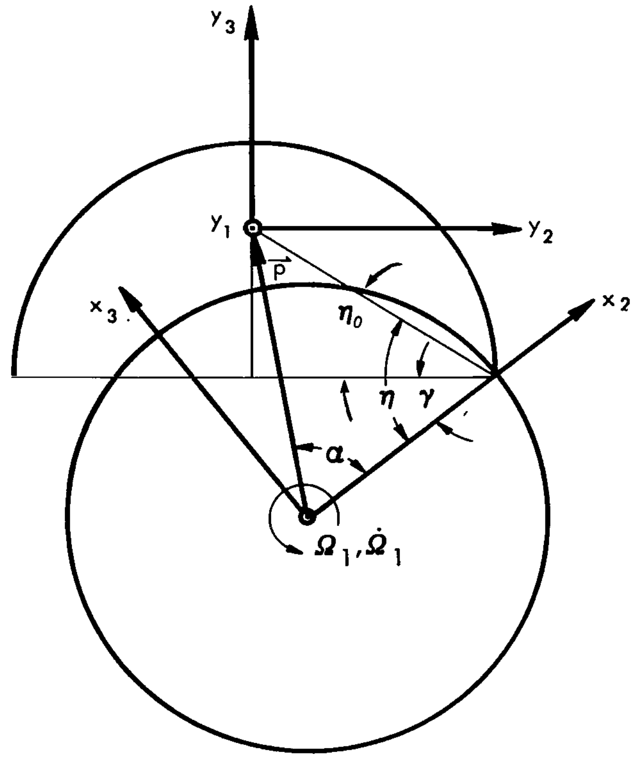

Figure 1—Trailing edge pivot roll-out clamshell system.

Likewise,

$$\frac{\partial T}{\partial \eta} = 2m\left(\Omega_1^2 d_5 d_1 \sin\eta - \Omega_1 \dot{\eta} d_5 d_1 \sin\eta\right) ,$$

$$p_{\dot{\eta}} = \frac{\partial T}{\partial \dot{\eta}}$$

$$= 2m\left[\dot{\eta} d_5^2 - \Omega_1 d_5\left(d_5 - d_1\cos\eta\right)\right] - 2J_{cy1}\left(\Omega_1 - \dot{\eta}\right) ,$$

and

$$Q_\eta = \dot{p}_{\dot{\eta}} - \frac{\partial T}{\partial \eta}$$

$$= 2\left(J_{cy1} + md_5^2\right)\ddot{\eta} - 2\left(J_{cy1} + md_5^2\right)\dot{\Omega}_1$$

$$+ 2\left(m\dot{\Omega}_1 d_5\right) d_1 \cos\eta - 2\left(m\Omega_1^2 d_5\right) d_1 \sin\eta .$$

Letting

$$A = J_{vx_1} + 2\left(J_{cy1} + md_7^2\right) ,$$

$$B = -2\left(J_{cy1} + md_5^2\right) + 2md_5 d_1 \cos\eta ,$$

$$C = B ,$$

$$D = 2\left(J_{cy1} + md_5^2\right) ,$$

$$U = Q_{\Omega_1} - 2\left(2m\Omega_1 \dot{\eta} d_5 - m\dot{\eta}^2 d_5\right) d_1 \sin\eta ,$$

and

$$V = Q_\eta + 2\left(m\Omega_1^2 d_5\right) d_1 \sin\eta ,$$

we can rewrite the angular motion equations as follows:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{Bmatrix} \dot{\Omega}_1 \\ \ddot{\eta} \end{Bmatrix} = \begin{Bmatrix} U \\ V \end{Bmatrix} .$$

It is therefore evident that

$$\dot{\Omega}_1 = \frac{DU - BV}{AD - BC}$$

and

$$\ddot{\eta} = \frac{AV - CU}{AD - BC} ,$$

where:

$$AD - BC = 2J_{vx_1}\left(J_{cy_1} + md_5^2\right) + 4md_1^2\left[J_{cy_1} + md_5^2 \left(1 - \cos^2 7\right)\right] \neq 0 .$$

Equations for Hinge Force Components

The requisite forces may be obtained from a force balance based on a knowledge of the acceleration of the clamshell mass center. The acceleration may be expressed as

$$\vec{a} = \ddot{\vec{R}} + (\ddot{\vec{p}})_r + 2\vec{\omega} \times (\dot{\vec{p}})_r + \dot{\vec{\omega}} \times \vec{p} + \vec{\omega} \times (\vec{\omega} \times \vec{p}) ,$$

where

$$\ddot{\vec{R}} = \vec{e}_1 \ddot{R}_1 ,$$

$$\vec{p} = \vec{e}_1 d_6 + \vec{e}_2 \left(d_1 - d_5 \cos\eta\right) + \vec{e}_3 \left(d_5 \sin\eta\right) ,$$

$$(\dot{\vec{p}})_r = \vec{e}_2 \left(\dot{\eta} d_5 \sin\eta\right) + \vec{e}_3 \left(\dot{\eta} d_5 \cos\eta\right) ,$$

$$(\ddot{\vec{p}})_r = \vec{e}_2 \left(\ddot{\eta} d_5 \sin\eta + \dot{\eta}^2 d_5 \cos\eta\right) + \vec{e}_3 \left(\ddot{\eta} d_5 \cos\eta - \dot{\eta}^2 d_5 \sin\eta\right) ,$$

$$\vec{\omega} = \vec{e}_1 \Omega_1 ,$$

$$\dot{\vec{\omega}} = \vec{e}_1 \dot{\Omega}_1 ,$$

and

$$d_5 = \sqrt{d_1^2 + d_2^2} .$$

Noting that

$$d_7 \cos\alpha = d_1 - d_5 \cos\eta ,$$

$$d_7 \sin\alpha = d_5 \sin\eta ,$$

$$Q_\eta = Q_{\Omega_1} = 0 ,$$

and

$$m\vec{a} = \vec{e}_1 F_{x_1} + \vec{e}_2 F_{x_2} + \vec{e}_3 F_{x_3} ,$$

we get

$$F_{x_1} = m\ddot{R}_1 ,$$

$$F_{x_2} = F_1 \sin\eta + \left(F_2 - F_3\right) \cos\eta - F_4 \sin\alpha - F_5 \cos\alpha ,$$

and

$$F_{x_3} = F_1 \cos\eta - \left(F_2 - F_3\right) \sin\eta + F_4 \cos\alpha - F_5 \sin\alpha ,$$

where

$$F_1 = m\ddot{\eta}d_5 \ ,$$

$$F_2 = m\dot{\eta}^2 d_5 \ ,$$

$$F_3 = 2m\Omega_1 \dot{\eta}d_5 \ ,$$

$$F_4 = m\dot{\Omega}_1 d_7 \ ,$$

and

$$F_5 = m\Omega_1^2 d_7 \ .$$

Equations for Hinge Couple Components

The required couples may now be readily determined by the application of Euler's equations of motion to the problem. Noting that (according to Appendix B):

$$\beta = 0.5 \tan^{-1}\left(\frac{2J_{cy5}}{J_{cy3} - J_{cy1}}\right) ,$$

$$J_{z_1} = J_{cy1} \cos^2\beta + J_{cy3} \sin^2\beta - 2J_{cy5} \cos\beta \sin\beta \ ,$$

$$J_{z_2} = J_{cy2} \ ,$$

and

$$J_{z_3} = J_{cy1} \sin^2\beta + J_{cy3} \cos^2\beta + 2J_{cy5} \cos\beta \sin\beta \ ,$$

we get

$$M_{z_1} = J_{z_1}\left(\dot{\Omega}_1 - \ddot{\eta}\right)\cos\beta \ ,$$

$$M_{z_2} = \left(J_{z_3} - J_{z_1}\right)\left(\Omega_1 - \dot{\eta}\right)^2 \sin\beta\cos\beta \ ,$$

and

$$M_{z_3} = -J_{z_3}\left(\dot{\Omega}_1 - \ddot{\eta}\right)\sin\beta \ .$$

From Figure 1, it can be shown that

$$M_{z_1} = M_{y_1}\cos\beta + M_{y_3}\sin\beta \ ,$$

$$M_{z_2} = M_{y_2} \ ,$$

and

$$M_{z_3} = M_{y_3}\cos\beta - M_{y_1}\sin\beta \ .$$

Likewise,

$$M_{y_1} = C_{y_1} + F_{y_2}d_2 + F_{y_3}d_1 \ ,$$

$$M_{y_2} = C_{y_2} - F_{y_1}d_2 + F_{y_3}d_3 \ ,$$

and

$$M_{y_3} = C_{y_3} - F_{y_1}d_1 - F_{y_2}d_3 \ ,$$

where

$$F_{y_1} = F_{x_1} \ ,$$

$$F_{y_2} = F_{x_2}\cos\gamma - F_{x_3}\sin\gamma \ ,$$

$$F_{y_3} = F_{x_3}\cos\gamma + F_{x_2}\sin\gamma \ ,$$

and

$$\gamma = \eta - \eta_0 \ .$$

Equations for Free Flight

The free flight displacements of the j-th point on the ejected clamshell may be expressed as follows:

$$\{X_j\} = K\{z_j\} + \{X_{cm}\} ,$$

where

$$K = \begin{bmatrix} c\theta\, c\phi & -s\theta & c\theta\, s\phi \\ c\psi\, s\theta\, c\phi + s\psi\, s\phi & c\psi\, c\theta & c\psi\, s\theta\, s\phi - s\psi\, c\phi \\ s\psi\, s\theta\, c\phi - c\psi\, s\phi & s\psi\, c\theta & s\psi\, s\theta\, s\phi + c\psi\, c\phi \end{bmatrix}$$

and

$$\{X_{cm}\} = (t - t_f) \begin{Bmatrix} 0 \\ \dot{\eta}_f\, d_5 \sin \eta_f - \Omega_{1_f}\, d_{7_f} \sin \alpha_f \\ \dot{\eta}_f\, d_5 \cos \eta_f + \Omega_{1_f}\, d_{7_f} \cos \alpha_f \end{Bmatrix} + \begin{Bmatrix} d_6 \\ d_{7_f} \cos \alpha_f \\ d_{7_f} \sin \alpha_f \end{Bmatrix} .$$

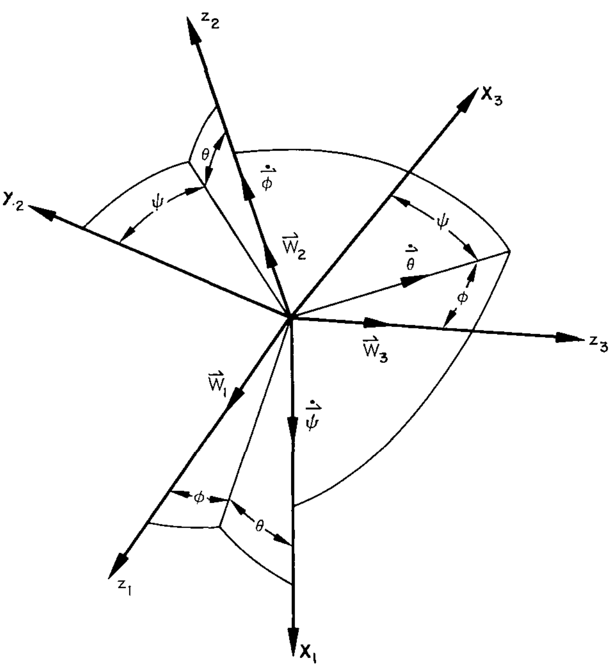

Figure 2—Euler angle system.

The K-matrix is based on the Euler angle system illustrated by Figure 2. This angular system is a variant of a system widely used by aeronautical engineers. It was adopted to simplify the determination of the initial Euler angles. From the construction in Figure 2, it can be shown that

$$\dot{\psi} = \frac{(W_3 \sin\phi + W_1 \cos\phi)}{\cos\theta} ,$$

$$\dot{\theta} = W_3 \cos\phi - W_1 \sin\phi ,$$

$$\dot{\phi} = W_2 + \dot{\psi} \sin\theta ,$$

and

$$\psi = \int^t \dot{\psi}\, dt - \gamma_f ,$$

$$\theta = \int^{t} \dot{\theta}\, dt ,$$

$$\phi = \int^{t} \dot{\phi}\, dt - \beta .$$

The z-frame components of the clamshell rotational rate may be obtained from Euler's equations of motion for the free flight, thus:

$$\dot{W}_1 = \frac{W_2 W_3 \left(J_{z_2} - J_{z_3}\right)}{J_{z_1}} ,$$

$$\dot{W}_2 = \frac{W_3 W_1 \left(J_{z_3} - J_{z_1}\right)}{J_{z_2}} ,$$

$$\dot{W}_3 = \frac{W_1 W_2 \left(J_{z_1} - J_{z_2}\right)}{J_{z_3}} ,$$

and

$$W_1 = \int^{t} \dot{W}_1\, dt + \left(\Omega_{1_f} - \dot{\eta}_f\right) \cos\beta ,$$

$$W_2 = \int^{t} \dot{W}_2\, dt ,$$

$$W_3 = \int^{t} \dot{W}_3\, dt - \left(\Omega_{1_f} - \dot{\eta}_f\right) \sin\beta .$$

REMARKS

The preceding equations are sufficient for estimating the motion, forces, and couples affecting the design of roll-out clamshell systems. Although derived primarily for the trailing edge pivot type of system, these equations may be used to compute the magnitudes of the equivalent items of interest for the leading edge pivot type of system.

It should be noted that, even under the simplifying assumptions used, the equations are complex and not amenable to hand computation. Indeed, very little if any quantitative information can be conveniently obtained from them without the aid of either a digital or an analog computer. This complexity is indicative of the nature of the sounding rocket clamshell design problem. Since there is really no great store of meaningful experience in this design area, there can be no placement of confidence in a largely empirical approach to this problem.

Qualitatively, a number of interesting features of roll-out clamshell systems can be demonstrated. According to Equation 1, it is expected that the despinning of the rocket vehicle due to clamshell ejection will be less if each clamshell is made to pivot about its trailing edge instead of its leading edge. The basis for this belief resides in the fact that this equation shows the clamshell roll-out acceleration contributing to positive rocket vehicle spin-up. In this same equation, it will also be noted that the normal force due to the clamshell roll-out rate is in opposition to the rocket vehicle despinning Coriolis force. The equivalent equation for the leading edge pivot type of system (contained in Appendix C) shows the clamshell roll-out acceleration to be a rocket vehicle despinning factor and the normal force augmenting the Coriolis force. Since spin is essential to sounding rocket vehicle stability at the altitudes where clamshell ejection may occur, it is expected that a roll-out clamshell system with trailing edge pivoting would be preferable to one with leading edge pivoting. This selection may well be crucial where clamshell ejection is also to take place under rocket booster thrust.

The roll-out clamshell system flown on the Shotput rocket vehicle is a unique example of the type with leading edge pivoting. The despinning effects of clamshell ejection on the rocket vehicle are minimized, if not eliminated, by allowing each pivot axis to move on a Teflon roller in a grooved track which is interrupted about halfway around the circumference of the vehicle. Other rollers and guides are used to prevent the upper parts of the clamshells from rotating into the payload. This system and its analog with the trailing edge pivot can be studied by means of the preceding equations. It is expected that a comparative study will show that the clamshells for the analogous systems may be released at considerably smaller roll-out angles than those of the Shotput type systems. The possibility thereby exists that these systems can be made simpler than the Shotput system. That is, the various devices provided to meet the longer Shotput clamshell retention requirement may well be eliminated in the design of the analogous systems.

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Appendix A

The Velocity of an Ejecting Clamshell

In order to derive the kinetic energy of an ejecting clamshell, it is necessary to know its velocity. Referring back to Figure 1, it can be seen that

$$d_7 \cos\alpha = d_1 - d_5 \cos\eta$$

and

$$d_7 \sin\alpha = d_5 \sin\eta ,$$

so that

$$d_7^2 = d_1^2 + d_5^2 - 2d_1 d_5 \cos\eta .$$

Noting that

$$\dot{\vec{R}} = \vec{e}_1 \dot{R}_1 ,$$

$$\vec{\omega} = \vec{e}_1 \Omega_1 ,$$

$$\vec{p} = \vec{e}_1 d_6 + \vec{e}_2 \left(d_1 - d_5 \cos\eta\right) + \vec{e}_3 \left(d_5 \sin\eta\right) ,$$

$$(\dot{\vec{p}})_r = \vec{e}_2 \left(\dot{\eta} d_5 \sin\eta\right) + \vec{e}_3 \left(\dot{\eta} d_5 \cos\eta\right) ,$$

$$\vec{\omega} \times \vec{p} = - \vec{e}_2 \left(\Omega_1 d_7 \sin\alpha\right) + \vec{e}_3 \left(\Omega_1 d_7 \cos\alpha\right) ,$$

and

$$\vec{r} = \vec{R} + \vec{p} ,$$

we get

$$
\begin{aligned}
\vec{v} &= \dot{\vec{r}} \\
&= \dot{\vec{R}} + (\dot{\vec{p}})_r + \vec{\omega} \times \vec{p} \\
&= \vec{e}_1 \dot{R}_1 + \vec{e}_2 \left(\dot{\eta} d_5 \sin\eta - \Omega_1 d_7 \sin\alpha\right) + \vec{e}_3 \left(\dot{\eta} d_5 \cos\eta + \Omega_1 d_7 \cos\alpha\right) .
\end{aligned}
$$

Therefore,

$$
\begin{aligned}
v^2 &= |\vec{v}|^2 \\
&= \dot{R}_1^2 + \dot{\eta}^2 d_5^2 + \Omega_1^2 d_7^2 - 2\Omega_1 \dot{\eta}\left[d_5^2 \sin^2\eta - d_5 \cos\eta\left(d_1 - d_5 \cos\eta\right)\right] \\
&= \dot{R}_1^2 + \dot{\eta}^2 d_5^2 + \Omega_1^2 d_7^2 - 2\Omega_1 \dot{\eta} d_5 \left(d_5 - d_1 \cos\eta\right) .
\end{aligned}
$$

Appendix B

The Principal Moments of Inertia of a Clamshell

The effort required to analyze and study the angular motion of any given body can be greatly reduced by a knowledge of the principal axes centered at its c.m. In the case of clamshells, the search for this orthogonal axis set is considerably simplified by the fact that each of these bodies can be considered to have a readily identifiable plane of mass symmetry. Referring back to Figure 1, it can be seen that this plane is defined by the y_1 and y_3 axes. Hence the y_2 axis is a principal axis through the clamshell c.m., and the moment of inertia about it is a principal moment of inertia:

$$J_{z_2} = J_{cy2} .$$

The orientation of the other two principal axes may be determined by noting the moment of inertia about an arbitrary axis which passes through the clamshell c.m. and lies in its plane of mass symmetry. In this case, we have

$$J = J_{cy1} \cos^2 \lambda + J_{cy2} \sin^2 \lambda - 2J_{cy5} \cos \lambda \sin \lambda ,$$

where λ is the angle between the y_1 axis and the arbitrary axis. When this moment of inertia is an extremum, we have a principal moment of inertia. The extremums may be easily obtained in the traditional manner by differentiating the preceding function and setting the derivative equal to zero when λ equals β:

$$\left.\frac{dJ}{d\lambda}\right]_{\lambda=\beta} = 0$$

$$= 2\left(J_{cy3} - J_{cy1}\right) \cos \beta \sin \beta - 2J_{cy5} \left(\cos^2 \beta - \sin^2 \beta\right) .$$

Noting that

$$\sin 2\beta = 2 \cos \beta \sin \beta ,$$

and

$$\cos 2\beta = \cos^2 \beta - \sin^2 \beta ,$$

we get

$$\beta = 0.5 \tan^{-1}\left(\frac{2J_{cy5}}{J_{cy3} - J_{cy1}}\right).$$

Then

$$J_{z_1} = J\Big]_{\lambda=\beta}$$

$$= J_{cy1}\cos^2\beta + J_{cy3}\sin^2\beta - 2J_{cy5}\cos\beta\sin\beta$$

and

$$J_{z_3} = J\Big]_{\lambda=\beta+\pi/2}$$

$$= J_{cy1}\sin^2\beta + J_{cy3}\cos^2\beta + 2J_{cy5}\cos\beta\sin\beta\ .$$

Appendix C

Equations for the Leading Edge Pivot Type of Roll-Out Clamshell System

Some of the equations for the leading edge pivot type of roll-out clamshell systems are presented in this appendix for comparison. Based on Figure C1, it can be shown that

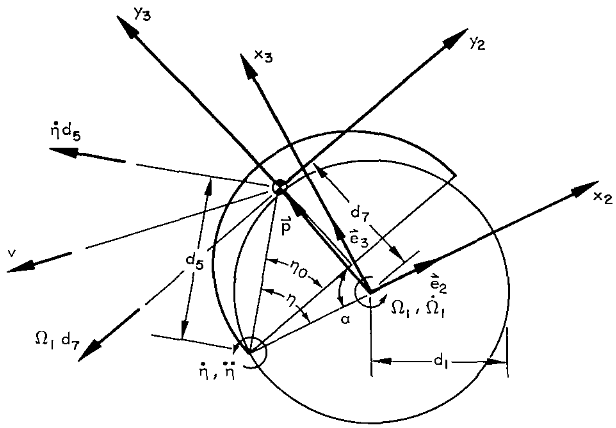

Figure C1—Alternative roll-out clamshell system.

$$v^2 = \dot{R}_1^2 + \dot{\eta}^2 d_5^2 + \Omega_1^2 d_7^2 + 2\Omega_1 \dot{\eta} d_5 (d_5 - d_1 \cos \eta)$$

and

$$T = 0.5\left(J_{vx_1} \Omega_1^2 + M\dot{R}_1^2\right) + J_{cy1} (\Omega_1 + \dot{\eta})^2 + mv^2 .$$

Hence

$$Q_{\Omega_1} = \left[J_{vx_1} + 2\left(J_{cy1} + md_7^2\right)\right] \dot{\Omega}_1 + 2\left(J_{cy1} + md_5^2\right) \ddot{\eta} + \left(2m\Omega_1 \dot{\eta} d_5 + m\dot{\eta}^2 d_5\right) d_1 \sin \eta - 2\left(m\ddot{\eta} d_5\right) d_1 \cos \eta$$

and

$$Q_\eta = 2\left(J_{cy1} + md_5^2\right) \ddot{\eta} + 2\left(J_{cy1} + md_5^2\right) \dot{\Omega}_1 - 2\left(m\dot{\Omega}_1 d_5\right) d_1 \cos \eta - 2\left(m\Omega_1^2 d_5\right) d_1 \sin \eta .$$

Likewise

$$F_{x_1} = m\ddot{R}_1 ,$$

$$F_{x_2} = -\left(m\ddot{\eta} d_5\right) \sin \eta - \left(2m\Omega_1 \dot{\eta} d_5 + m\dot{\eta}^2 d_5\right) \cos \eta - \left(m\dot{\Omega}_1 d_7\right) \sin \alpha + \left(m\Omega_1^2 d_7\right) \cos \alpha ,$$

and

$$F_{x_3} = \left(m\ddot{\eta} d_5\right) \cos \eta - \left(2m\Omega_1 \dot{\eta} d_5 + m\dot{\eta}^2 d_5\right) \sin \eta - \left(m\dot{\Omega}_1 d_7\right) \cos \alpha - \left(m\Omega_1^2 d_7\right) \sin \alpha .$$

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