Technical Comments

Comment on "Effects of Simulated Mars Dust Erosion Environment on Thermal Control Coatings"

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In a recent Note,[1] Adlon et al., presented erosion data for several coatings in a hypothetical Martian dust environment. Two of the coatings tested were reported as NiAl (Metco 404) and as 40% NiAl + 60% ZrO_2 (Metco 413). The published manufacturer's specifications for these two powders differ from the compositions listed by Adlon et al. Table 1 shows the reported description for these two powders.[2–5]

Table 1 Manufacturer's description for Ni/Al powders[2–5]

Material	Name	Composition	Coating description
Metco 404	"nickel aluminide"	20% Al (core), 80% Ni (cladding)	Approximately equal proportions of NiAl and Ni_3Al with some miscellaneous oxides
Metco 413	zirconia-"nickel aluminide" cermet	...	35%-zirconia plus 65%-"nickel aluminide"

There seems to be some confusion resulting from the name Metco uses to describe its 404 powder—"nickel aluminide." (Metco uses quotes around the term "nickel aluminide.") We are submitting this comment in the hope of cautioning other workers about assuming a chemical formula from a trade name. In addition, since the raw powder is unreacted, there should be further compositional changes during thermal spraying. The coating will probably be more nickel rich than the starting powders because of the increased vapor pressure of aluminum. This comment should not be taken as a criticism of the work of Adlon et al., since their work was concerned with the types of coatings available for thermal control, and not with the chemical formulas.

References

[1] Adlon, G. L., Rusert, E. L., and Slemp, W. S., "Effects of Simulated Mars Dust Erosion Environment on Thermal Control Coatings," *Journal of Spacecraft and Rockets*, Vol. 7, No. 4, April 1970, pp. 507–510.

[2] *Product Data Bulletin, Metco 404 "Nickel Aluminide" Power*, Metco, Inc., Westbury, N. Y., 1968, pp. 1–6.

[3] "Flame Sprayed Metco 404 'Nickel Aluminide,'" Bulletin 148 5M 18–63, 1963, Metco, Inc., Westbury, N. Y.

[4] "Metco Spraying Data: Metco 404 404NS, 'Nickel Aluminide,'" Instructions Q-6786, Issue C, Metco, Inc., Westbury, N. Y.

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Received July 13, 1970.
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Comment on "Angle of Attack and Lateral Rate for Nearly Circular Re-Entry Motion"

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Lotkin, in Ref. 1, attempts to solve for the angle-of-attack convergence and lateral rate behavior of a re-entry vehicle using relations he derived in an earlier paper[2] starting from the equations of translational motion. The solution he devises bears little semblance to previously obtained solutions to this same problem, as would be expected, since the problem he addresses is correctly described by the moment equations of rotational motion. The angle-of-attack convergence behavior of a rolling re-entry vehicle has been treated extensively[3–10] and results published in the literature reduce to the simple case considered by Lotkin when one ignores aerodynamic and normal force damping, roll-rate variations, and Magnus effects, and makes the further simplifying assumptions of small angles of attack and nearly circular motion. The case treated by Lotkin is rederived here for completeness.

Euler's moment equation for rotation of a rigid body about its mass center is[11]

$$\mathbf{M} = \dot{\mathbf{h}} + \boldsymbol{\omega} \times \mathbf{h} \tag{1}$$

where **M**, **h** and **ω** are the resultant moment, angular momentum and angular velocity vectors, respectively. Components of **ω** and **h** in Euler angle coordinates, as described in Ref. 3 and Fig. 1, are

$$\begin{aligned} \omega_\xi &= \dot{\psi}\cos\delta & h_\xi &= I_x p \\ \omega_\eta &= \dot{\delta} & h_\eta &= I_y \dot{\delta} \\ \omega_\eta &= \dot{\psi}\sin\delta & h_\zeta &= I_y \dot{\psi}\sin\delta \end{aligned} \tag{2}$$

which yield from Eq. (1) the roll, pitch, and yaw moment

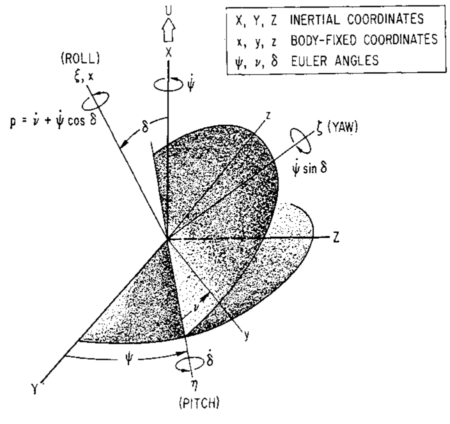

Fig. 1 Euler angles for three-degree-of-freedom rotational motion.

Received July 20, 1970.
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Table 1 Average values $\bar{\delta}$ and $\bar{s}$

H	$\bar{\delta}$ (Ref. 1)	$\bar{\delta}$ [Eq. (11)]	$\bar{s}$ (Ref. 1)	$\bar{s}_+$ [Eq. (12)]	$\bar{s}_-$ [Eq. (12)]
0 (kft.)	8.00 (deg)	8.00 (deg)	2.00 (deg/sec)	8.01 (deg/sec)	− 2.99 (deg/sec)
100	6.80	3.67	24.08	13.14	−10.83
200	0.40	1.65	10.10	27.24	−26.21
220	0.11	1.45	3.08	30.72	−29.80
240	0.03	1.37	0.38	32.64	−31.78
247	(0.02)	1.37	...	32.47	−31.61

equations, respectively,

$$\begin{aligned} M_\xi &= I_x\dot{p} \\ M_\eta &= I_y\ddot{\delta} + I_xp\dot{\psi}\sin\delta - I_y\dot{\psi}^2\sin\delta\cos\delta \\ M_\zeta &= I_y(d/dt)(\dot{\psi}\sin\delta) + I_y\dot{\psi}\dot{\delta}\cos\delta - I_xp\dot{\delta} \end{aligned} \tag{3}$$

If we assume that the only aerodynamic moment acting on the vehicle is the pitch moment due to angle of attack, then

$$M_\xi = M_\zeta = 0,\ M_\eta = C_{m_\alpha}\delta q_\infty Ad \tag{4}$$

and Eqs. (3) can be written

$$\begin{aligned} \dot{p} &= 0 \\ \ddot{\delta} + \Omega^2\delta + \mu p\dot{\psi}\sin\delta - \dot{\psi}^2\sin\delta\cos\delta &= 0 \\ (d/dt)(\dot{\psi}\sin\delta) + \dot{\psi}\dot{\delta}\cos\delta - \mu p\dot{\delta} &= 0 \end{aligned} \tag{5}$$

where $\Omega^2 \equiv -C_{m_\alpha}q_\infty AD/I_y$ and $\mu \equiv I_x/I_y$. The third of Eqs. (5) can be written in the form

$$(d/dt)(\dot{\psi}\sin^2\delta) + \mu p(d/dt)(\cos\delta) = 0 \tag{6}$$

which, with the result p = constant from the first of Eqs. (5), can be integrated to give

$$\dot{\psi}\sin^2\delta + \mu p\cos\delta = \text{const}$$

or, for small δ such that $\sin\delta \approx \delta$ and $\cos\delta \approx 1 - \delta^2/2$,

$$(\dot{\psi} - \mu p/2)\delta^2 = \text{const} \tag{7}$$

Eq. (7) describes the relation between the total angle of attack and the yaw rate $\dot{\psi}\sin\delta$. For nearly circular motion the pitch rate $\dot{\delta}$ is essentially zero and the total lateral rate $s = [\dot{\delta}^2 + (\dot{\psi}\sin\delta)^2]^{1/2}$ is the yaw rate $\dot{\psi}\sin\delta$ or $\dot{\psi}\delta$ for small δ. The average values of s and δ as a function of time are obtained from Eq. (7) by observing that the average value of the precession rate $\bar{\dot{\psi}}$ is related to the pitch natural frequency Ω through the second of Eqs. (5). For small δ this equation can be written in the form

$$\ddot{\delta} = (\dot{\psi}^2 - \mu p\dot{\psi} - \Omega^2)\delta \tag{8}$$

For nearly circular motion $\ddot{\delta} \approx 0$ and the average values of $\dot{\psi}$ are found from Eq. (8) to be

$$\dot{\psi}_\pm = (\mu p/2) \pm [(\mu p/2)^2 + \Omega^2]^{1/2} \tag{9}$$

which is a function only of Ω for the case of constant roll rate. The $\pm$ designates the positive and negative precession rates, respectively. Equation (9) also defines the body-fixed frequencies (the average values of the rate of rotation of the windward meridian about the vehicle) since, by definition, $p \approx \dot{\nu} + \dot{\psi}$, where $\dot{\nu}$ is the windward-meridian rotation rate, so that

$$\bar{\dot{\nu}}_\pm = p - \bar{\dot{\psi}}_\pm = p(1 - \mu/2) \mp [(\mu p/2)^2 + \Omega^2]^{1/2} \tag{10}$$

At some initial altitude where $\bar{\delta} = \delta_0$ at $\Omega = \Omega_0$, the precession rate $\dot{\psi}$ in Eq. (7) is described by Eq. (9) and the subsequent angle-of-attack behavior is given by

$$\bar{\delta}/\delta_0 = \{[(\mu p/2)^2 + \Omega_0^2]/[(\mu p/2)^2 + \Omega^2]\}^{1/4} \tag{11}$$

The corresponding average values of the total lateral rate $\bar{s}$ are given by

$$\bar{s}_\pm = \bar{\dot{\psi}}_\pm\bar{\delta} \tag{12}$$

where $\bar{\dot{\psi}}_\pm$ is defined by Eq. (9). The average values $\bar{\delta}$ and $\bar{s}$, calculated from Eqs. (11) and (12), using the aerodynamic and trajectory parameters in Lotkin's Table 1,[1] are compared with Lotkin's results in Table 1† of this Comment. Either the positive or negative precession mode would prevail depending on the exoatmospheric conditions. The criterion for determining this is discussed in Ref. 3. Also discussed in Refs. 3–9 are more extensive treatments of re-entry vehicle angle-of-attack convergence behavior including aerodynamic damping, roll-rate variations, large angle-of-attack motion and Magnus effects.

References

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† The rapidly decaying exponential form of C_{m_α} assumed by Lotkin does not represent, physically, the usual behavior observed for this parameter.