it is held in position with a snap ring. PR-1221-B2 sealant is applied between the chamber threads and the aft face of propellant grain. Loctite is applied to the threads of the chamber and the spin motor/aft closure assembly is threaded over the main motor SCID lines and installed into the exit cone using PR-1221-B2 sealant. The aft end of the closure is sealed with PR-1221-B2 sealant and cured for 2 hr at 120°F.

Spin-motor nozzle plugs are positioned and bonded on the spin motor ignition harness using PR-1221-B2 and cured for 2 hr at 120°F. Two of these assemblies are then bonded into the spin-motor nozzle with one solid plug using PR-1221-B2 and cured for 2 hr at 120°F. The loaded thrust chambers are sealed and stored until needed.

The ends of the SCID lines are bonded into the squib holder using EPON 934 and cured for 2 hr at 140°F. The yoke assembly is positioned on the motor, and the squib holder is positioned into the yoke assembly. The squib holder is held in place with three set screws. The spin motor SCID is positioned over the yoke release pin and held in place with a steel clip and a set screw; PR-1221-B2 then is placed around the SCID on the outside of the clip. The assembly is placed in cure for 2 hr at 120°F. An O-ring is lubricated and installed in the squib holder, and the squib holder closure is installed and secured by the collar. Any scratches on the anodized motor components are repaired by an alodine brush-on solution.

Decal and identification (Human Engineering) tags are applied to the motors. Motors are placed in special polyethylene shipping containers, and inspected, and the containers are sealed.

Concluding Remarks

This design concept provides considerable flexibility. By increasing or decreasing the spin motor propellant loading, or the burning surface of the propellant web and/or nozzle diameter, and/or the effective flow angle of the nozzle, this multipurpose motor can be quickly and easily tailored to many variable axial and tangential thrust combinations.

Lunar Mascon Effects on Orbits of Apollo-Type Spacecraft

IRVING MICHELSON*

Illinois Institute of Technology, Chicago, Ill.

Introduction

SINCE the discovery of large concentrations of mass under certain areas of the moon's surface in August 1968, their influence in modifying the trajectories of lunar orbiters has been verified by Apollo 8 and by Apollo 10 spacecraft. The mascons, as they have become known, present real hazards to navigation as long as they remain less than fully identified. Detailed measurements and calculations may not be completed for a year or more, but preliminary calculations like the one described herein can provide a useful practical guide for minimizing mascon-induced orbital instabilities. Specifically, it is shown that the judicious selection of orbital apse direction is particularly effective for this purpose.

Characteristics of Mass Concentrations in the Moon

Careful analysis of Lunar Orbiter satellite tracking data[1] led to the conclusion that unpredicted orbital changes were caused by enormous mass concentrations apparently situated beneath the surface of five near-side maria. The mascon under Mare Imbrium is estimated to be upwards of 100 miles in diameter and to represent about 1/200,000 of the total mass of the moon; the group of mascons may total 1/50,000 of the moon's mass. Subsequently their presence was confirmed when Apollo 8 orbit exhibited pronounced and unpredicted variations. Specifically, the apolune distance (maximum orbital distance from the lunar centroid) increased measurably from one circuit to the next in a manner the exact opposite of the familiar orbital decay of Earth satellites. In the latter case atmospheric resistance to spacecraft motion leads to decreasing apogee distance. Since the moon lacks an atmosphere but possesses mascons instead, the supposition was made that the mascons are responsible for the anomalies of the Apollo 8 orbit and those of the more recent Apollo 10. Precise knowledge of mascon locations and magnitudes, required for calculating trajectory corrections for Apollo 11 and other close lunar orbiters is not presently available but awaits further progress in lunar studies.

Simplified Estimation of Mascon Orbital Influence

In the absence of accurate data on the mascon sizes and positions that determine the appropriate perturbation Hamiltonian functions for precise computation, a useful first estimate of the orbital modifications they produce is accomplished by elementary methods. By regarding the orbit as a Keplerian ellipse, the perilune distance r_1 is expressed in terms of the standard parameters semi-major axis a and eccentricity e by the formula

$$r_1 = a(1 - e)$$

When it is recalled that in a reference frame moving with the moon, the rotation of which is ignored, the mascons are stationary and therefore do not modify the energy of motion of spacecraft during a near-passage encounter, it follows that a remains constant but not necessarily the eccentricity e. Perilune modification in one orbital cycle is denoted δr_1 and consequently related to the modified eccentricity δe by the formula

$$\delta r_1 = -a\delta e \tag{1}$$

It is clear that perilune change δr_1 depends on how the eccentricity of the orbit is altered by the encounter with the mascons, and the same is true of the apolune distance r_2 given by $a(1 + e)$. D'Alembert's classic technique for studying the motion of Lexell's comet of 1770 may be adapted to treat the flyby of Apollo 11 in the vicinity of the mascons in a manner reminiscent of the comet's flyby encounter with the planet Jupiter. Specifically, the fact that the duration of the appreciable attraction by the mascons is small compared to the orbital period suggests idealizing the encounter as instantaneous (the same idea is employed in approximate analysis of rocket vehicle performance, the thrust being treated as impulsive). Then the orbit of the spacecraft is made up of elliptic segments connected by a certain discontinuity that represents the total effect of the flyby encounter.

The (discontinuous) change δe is then expressed in terms of the corresponding change of the areal constant h (given by the square root of $\mu a(1 - e^2)$ where μ is the moon's gravitational constant proportional to its mass M);

$$\delta h/h = -e\delta e/(1 - e^2) \tag{2}$$

The areal constant h is also expressible in terms of the orbital distance r, orbital speed q, and the path angle γ defined as the complement of the angle formed by extending the radial line from the moon to the spacecraft, and the direction of the velocity vector corresponding to q. The relationship is simply

$$h = rq \cos\gamma$$

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* Professor of Aerospace Engineering. Member AIAA.

and since both the distance r and the speed q are unaffected by the encounter, it follows that the areal constant is changed in proportion to the change of path angle $\delta\gamma$, i.e.,

$$\delta h/h = -(\tan\gamma)\delta\gamma \tag{3}$$

Finally the change of path angle $\delta\gamma$ is seen to be identical with the (negative of the) deflection angle Δ associated with the hyperbolic relative encounter between the mascons and the close-passing spacecraft. That the encounter orbit is relatively hyperbolic is assured by the fact that the total mass of the mascons is vastly smaller than the principal lunar mass, notwithstanding that they may be much closer to the spacecraft than the moon's center is. The deflection Δ produced by a single mascon of mass m and gravitational constant μ_m is easily found to be given by the "miss distance" l from the velocity vector of q to the mascon center, by the formula

$$\Delta = 2\frac{m}{M}\cdot\frac{a}{l}\,\frac{1 - e^2}{1 + 2e\cos\theta + e^2} \tag{4}$$

when, as in the present case, the right side is numerically small compared with unity. Successive substitutions of (4), (3), and (2) into (1) then leads to the formulas for the cumulative displacements of perilune and apolune, in dimensionless form as

$$\frac{\delta r_1}{a} = -\frac{\delta r_2}{a} = 2(1 - e^2)^2\,\frac{\sin\theta}{(1 + e\cos\theta)(1 + 2e\cos\theta + e^2)} \times \frac{m}{M}\cdot\frac{a}{l} \tag{5}$$

where θ is the true anomaly and the path angle formula

$$\tan\gamma = e\sin\theta/[1 + e\cos\theta]$$

is employed, obtainable by differentiation of the orbit equation

$$r = a(1 - e^2)/[1 + e\cos\theta]$$

Conclusions and Interpretations

According to Eq. (5), a single mascon of mass m and such depth as to give miss distance l when added to the distance of the spacecraft above the lunar surface, leads to observed *increase* of apolune distance, $\delta r_2 > 0$ when the mascon location is ahead of perilune (i.e., $\sin\theta < 0$). Further, both r_1 and r_2 remain constant if the apse line passes through the mascon, here treated as coplanar with the spacecraft orbit. It follows that the effects of two mascons on the opposite sides of the moon 180° apart cancel each other and that the orbit disturbances of numerous arbitrarily located mascons are minimized by maintaining near-parabolic orbits. An added measure of protection against navigational disturbances created by mascons is afforded by locating the orbital axis (line of $\theta = 0$) so as to pass through an appropriately defined center of the field of mascons. The effects of numerous mascons is in any case represented by a sum of terms like those appearing on the right side of (5).

It should be noted that J. L. Lagrange, in the third chapter of the second part of Vol. 2 of *Mécanique Analytique,* posed the identical problem to the one considered here, prefacing his analysis with the observation that the problem could have absolutely no application in the solar system. Lagrange thought of disturbing masses as necessarily having independent motions, and not solidly held within larger masses, as in the case with mascons and the moon. His analysis, characteristically ingenious and clever, does not lend itself to easy interpretation in the manner of the approximation (5), however.

Reference

[1] Muller, P. M. and Sjogren, W. L., "Mascons: Lunar Mass Concentrations," *Science,* Vol. 161, No. 3842, 1968, pp. 680–683.

Heat-Sterilizable Capsule Spin Motors

D. J. NORTON*
Jet Propulsion Laboratory,
California Institute of Technology, Pasadena, Calif.

Nomenclature

F = force on the spacecraft
h = distance from nozzle to point in plume
I = moment of inertia
L = external torque
M = Mach number
P_0 = stagnation pressure
q_∞ = dynamic pressure
$\dot{q}$ = heating rate
R = radius, gas constant
r_e = nozzle exit radius
S = separation distance between capsule and spacecraft
T_B = propellant bulk temperature
T_0 = stagnation temperature
t = time
Z = distance between plane of spin motor and c.g.
α = pointing angle due to spin-up
β = nutation angle
γ = specific heat ratio
δ = total pointing angle error
η = spin motor canting angle
ϵ = nozzle expansion ratio
$\dot{\theta}_0$ = initial tip-off rate
ρ = density of gas in plume
σ = standard deviation
ϕ = relative angle between spacecraft and capsule
ω = angular velocity

Subscripts

e = nozzl exiet properties
0 = stagnation conditions

Introduction

THIS Note discusses an investigation of the use of heat-sterilized solid-propellant motors for the spin stabilization of planetary landing capsules. Figure 1 presents a

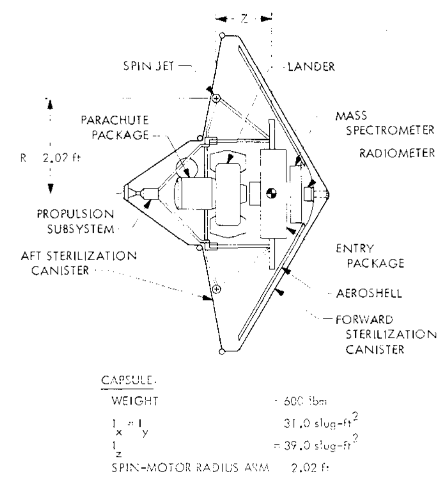

Fig. 1 Capsule configuration.

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* Senior Engineer/Captain, U.S. Army Ordnance Corps, Solid Propellant Engineering Section. Member AIAA.