Gravity-Gradient Momentum Management

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Theme

ORBITING space vehicles which use momentum exchange control elements such as control moment gyros (CMGs) and reaction wheels are faced with the problem of possible saturation of such devices. The use of gravity-gradient torques for desaturation control would allow the dissipation of accumulated momentum without expending vehicle propellants.

This study is concerned with the momentum management problem as related to a cylindrical vehicle with the minimum momentum-of-inertia axis solar or stellar oriented. This particular configuration represents the most difficult class of vehicles for gravity-gradient desaturation. The regions of momentum control are compared for a reflexive maneuvering and a gravity tracking desaturation philosophy.

Contents

Required desaturation maneuvers take place during a specified portion of occultation and are executed about the vehicle axes at discrete angles in the orbital plane. These maneuvers are functions of the orbital parameters, physical properties of the vehicle, and the accumulated momentum characteristics.[1]

The first technique[2] investigated consisted of performing a large angle maneuver about the vehicle axis in the orbital plane and subsequent trim maneuvers about two vehicle axes. The second technique[3] consisted of performing large and small angular maneuvers about all vehicle axes in such a manner as to track the gravity vector during occultation.

The orbiting vehicle is illustrated in Fig. 1 in a nominal inertial pointing flight mode. For a perfectly circular orbit, the gravity-gradient torques acting on the vehicle are given by[1]

$$T = \begin{bmatrix} T_{gx} \\ T_{gy} \end{bmatrix} = -\frac{3}{4}\,\omega_0{}^2 \Delta I \begin{bmatrix} \sin 2\lambda(1-\cos 2\alpha) \\ 2\cos\lambda \sin 2\alpha \end{bmatrix}$$

where the inertia difference is $\Delta I = I_{xx} - I_{zz}$, and $T_{gz} = 0$ for $I_{xx} = I_{yy}$. The quantity ω_0 is the orbital rate, α is the orbital position, and λ is the angle between the longitudinal axis and the orbital plane. Integration of these torques yields the momentum whose rate of accumulation depends upon the inclination parameter λ. Momentum behavior is shown in Fig. 2 for 45°. The use of a convergent control law causes the rate of average momentum accumulation to decrease to zero as shown in this figure.

For the case of instantaneous maneuvers in an environment without aerodynamics, only a large X axis maneuver to a symmetric or reflexive position for 50% of the orbit would be required. In an actual vehicle, there may be a resultant accumulation due to gravity about the other vehicle axes in the course of performing a large vehicle maneuver. Also, it is often desirable to employ less than 50% of the orbital plane for desaturation. These restrictions would render the desaturation problem insoluble unless maneuvers are performed about orthogonal vehicle axes.

The results that occur for an actual flight simulation depend primarily upon the permissible maneuver rate and the amount of momentum accumulated about orthogonal vehicle axes. A given set of results for any particular vehicle would be representative of all cylindrically shaped vehicles since the same inertias are used during accumulation and desaturation.

The momentum control region for variations in desaturation percentage at several inclinations is shown in Fig. 3 for the first desaturation technique. Increasing the allowable maneuver rate ω_c yields increased system performance, especially at large inclinations. The curves must approach theoretical desaturation percentage limits[1] when all maneuvers are instantaneous.

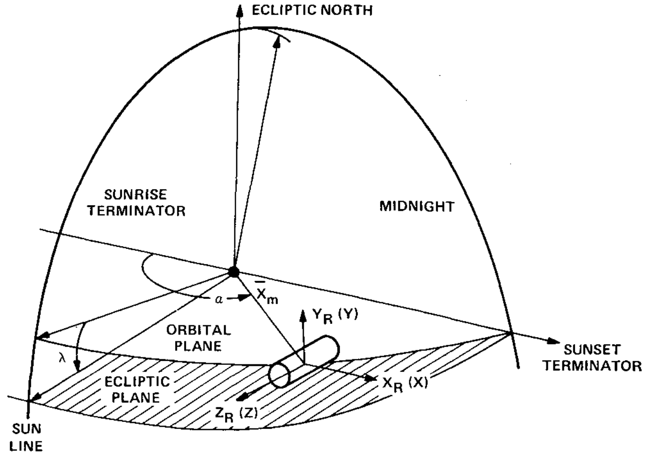

Fig. 1 Nominal flight mode geometry.

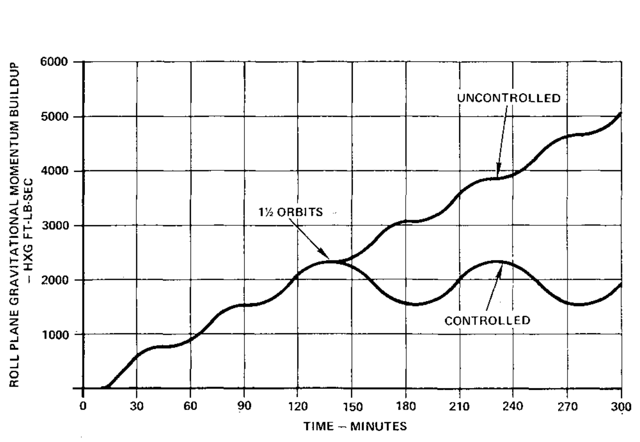

Fig. 2 Momentum buildup due to external bias torques.

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Index categories: Manned Space Station Systems; Unmanned Earth Satellite Systems.

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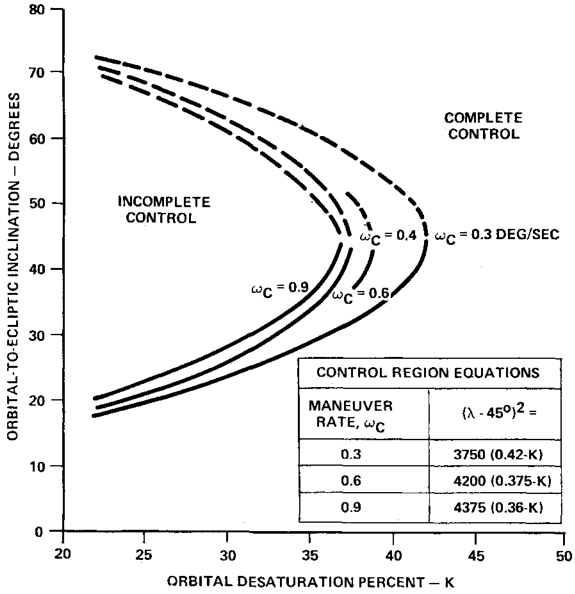

Fig. 3 Control regions for reflexive maneuvering.

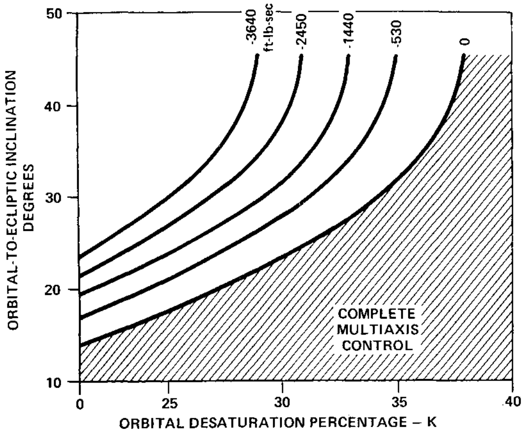

Fig. 4 Control regions for gravity tracking.

The general properties for the second technique are exhibited in Fig. 4, where primary divergence is about the X axis. The general nature of the divergence is represented by the gradient lines showing bias momentum at the end of 15 orbits. For the case where aerodynamics are added, the curves will move an appropriate amount to the right at each inclination. Even though the per orbit accumulation values appear large, the larger inclinations are maintained for only a few orbits since Earth oblateness will cause an orbital precession resulting in changing declination λ.

The two momentum desaturation techniques effectively control momentum within specified regions. These techniques are applicable to other vehicle configurations and flight conditions. For the case where the pointing axis inertia is closer to the other axes, only small angle maneuvers are necessary to accomplish desaturation.[1]

References

[1] Powell, B. K., "Gravity Gradient Desaturation of a Momentum Exchange Attitude Control System," AIAA Paper 71-940, New York, 1971.

[2] Kennel, H. F., "Angular Momentum Desaturation for ATM/LM/CSM Configuration Using Gravity Gradient Torques," TM X-53764, Aug. 1968, NASA.

[3] Kennel, H. F., "Large Angle Method for Space Vehicle Angular Momentum Desaturation Using Gravity Torques," TM X-53958, Oct. 1969, NASA.