SYNOPTIC: Fuel Optimal Reorientation of Axisymmetric Spacecraft, M. Dixon, The Aerospace Corporation, El Segundo, Calif.; T. N. Edelbaum, Charles Stark Draper Laboratory; J. E. Potter and W. E. Vandervelde, Massachusetts Institute of Technology, Cambridge, Mass.; *Journal of Spacecraft and Rockets*, Vol. 7, No. 11, pp. 1345–1351.

Spacecraft Attitude Dynamics and Control

Theme

The problem of reorienting axisymmetric spacecraft using reaction control jets while minimizing a cost functional which is proportional to the fuel expenditure for a fixed maneuver duration is considered in this research. The (local) optimality of two-impulse maneuvers, involving only initial and final control torques, is discussed. Fuel expenditures for this type of maneuver are compared with those for current reorientation techniques.

Content

The reorientations are not limited to small-angle rotations, and axial cross-coupling is not neglected. However, the following assumptions are made. 1) The maneuvers start and terminate with zero angular velocities. 2) The only external torques are the control torques applied by the thrusters. 3) The vehicle has two equal principal axis inertias ($J_x = J_y$). 4) The thrusters are capable of providing sufficiently large torques so that the thrust durations are negligible compared to the coasting periods. The last assumption is generally realized because large thrusters, which are required for re-entry and emergency conditions, are fired only in short burst for vehicle reorientations to conserve fuel. An additional assumption is used to derive an average reorientation cost. 5) From any initial vehicle orientation, all final orientations are equally likely. Two vehicle thruster configurations are considered. Figure 1 shows a typical fixed-thruster configuration; the thrusters are immobile relative to the vehicle and can provide torques only along the principal axes. Figure 1 becomes a gimballed-thruster configuration if the shaded band on which the thrusters are mounted can rotate about axis $\bar{k}_b$; i.e., the torques may be directed either along the vehicle axis of symmetry, or in any direction perpendicular to this axis. Now, if the shaded band could rotate about $\bar{k}_b$ and the jet quads could rotate about axes $\bar{\imath}_b$ and $\bar{\jmath}_b$, a spherical thruster configuration would result, capable of providing torques along an axis in any direction.

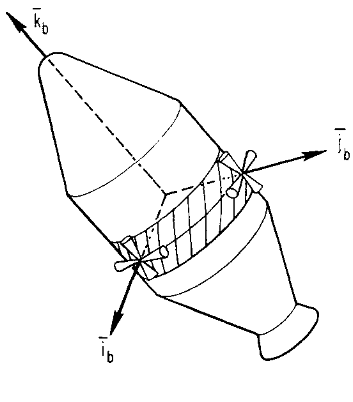

Fig. 1 Typical thruster configuration.

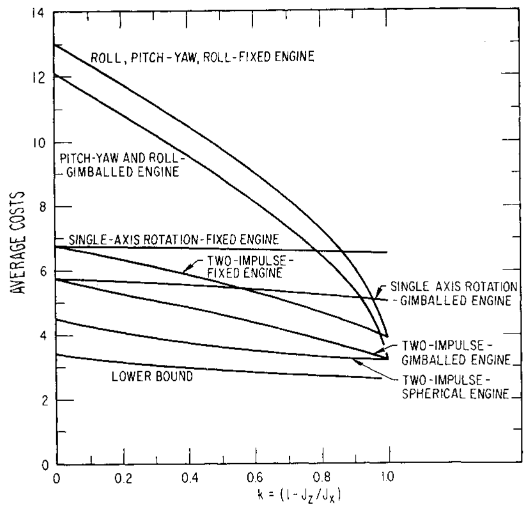

Fig. 2 Average reorientation costs ($b = J_z/J_x$).

The cost minimization problem is formulated in terms of six coupled state variables: three vehicle angular velocities and three Euler angles. Using an extended form of the Pontryagin Maximum Principle, which allows the controls to become impulsive, to perform the minimization introduces six new variables termed costates. Special state and costate transformations are used to reduce the complexity of the costate differential equations so they may be solved analytically. The analytical costate solutions then are used to determine when an assumed two-impulse control sequence, involving only initial and final control torques, is an extremal control. When the thrusters are assumed to have equal exhaust velocities and lever arms, two-impulse transfers have been found to be locally optimal in every reorientation attempted for the gimballed thruster configuration and are locally optimal for approximately half of the fixed thruster vehicle reorientations. These two-impulse transfer techniques were compared with two currently employed reorientation methods: rotations of the vehicle about a single inertially fixed axis; and roll, pitch-yaw and roll maneuvers, where the initial and final roll angles are optimized. The results of this comparison (Fig. 2) indicate that two-impulse transfers in general provide substantial fuel savings over these existing techniques. A lower bound for the reorientation cost, which all reorientation methods must exceed, is presented also. This lower bound indicates that the possible fuel savings of general multiple-impulse transfers over two-impulse transfers may not warrant their additional computational complexity.