Simulation Capability for Dynamics of Two-Body Flexible Satellites

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Theme

OFTEN, when a new satellite configuration requires investigation, the equations of motion must be derived, programed, and checked in order to predict the dynamic behavior of the vehicle. In this paper, a new computer program is described which eliminates these tasks for a class of two-body flexible satellites. One application is the rotating counterweight space station.

The end bodies referred to herein as the "Laboratory" and the "Counterweight" are separated by the "Connecting Structure." The entire satellite is referred to as the "Space Station" (Fig. 1). Both end bodies are flexible structures with arbitrary shape and mass distribution. The Connecting Structure is also flexible, but its mass is neglected.

Problems which may be studied using the program include deployment and retraction of the Connecting Structure with simultaneous or sequential spin-up and spin-down, the effects of moving rigid masses such as a cargo elevator or crew members on board the Laboratory, and the effect of fluid pumped through a piping system on the Laboratory. Various features, including control systems and Connecting Structure characteristics, have been included in subroutine form so that these items may be easily replaced with minimum disruption to the main program. Special constraint options permit the user to rigidize the entire Space Station or certain portions of the vehicle; thus the easier understood rigid-body results can be compared with the more complex flexible-body solutions.

It is also possible to use the program to study the dynamics of the Laboratory alone when no Counterweight is present. Thus, many rotating and nonrotating satellite configurations can be studied, since the Laboratory characteristics may be varied as input data.

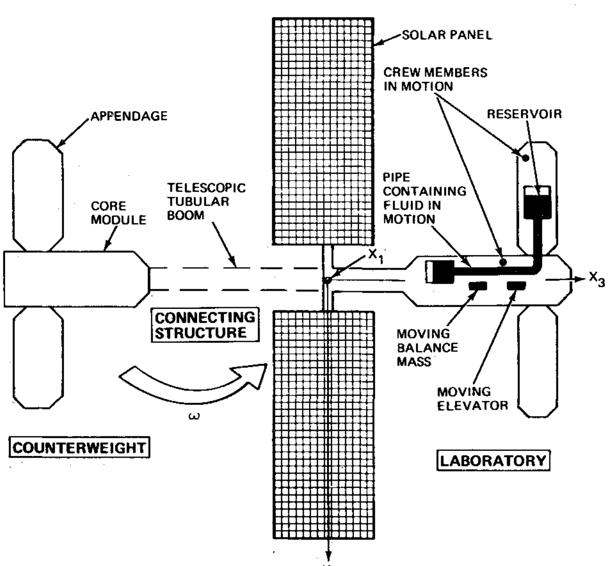

Fig. 1 Typical configuration that can be analyzed using the computer program.

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Index categories: Spacecraft Attitude Dynamics and Control; Structural Dynamic Analysis.

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The mathematical model is valid for an arbitrary number‡ of lumped masses (including rotatory inertia) on the Laboratory and the Counterweight, and the position and orientation of these masses is also arbitrary. A fluid confined within a pipe segment on a typical Laboratory mass point is included. Each of the two fluid-system reservoirs may be located on any Laboratory mass point; one reservoir is nominally filling and the other is nominally emptying. Fluid flow is assumed to be uniform. A maximum of eight moving rigid masses (a cargo elevator, crew motion, etc.) may be present on the Laboratory.

The flexible coordinates of each end body are expressed in terms of the elastic free-free modes of vibration. Viscous damping is assumed in the Connecting Structure, and modal damping is assumed elsewhere.

A separate preprogram was prepared to synthesize the modes of the Laboratory or Counterweight from a knowledge of the modes of their various component substructures (such as modules or solar panels). The synthesized modes may be passed directly from the preprogram to the main program, or if desired, the user may enter modes obtained elsewhere.

Control systems: The control-system subroutines include 16 jets which are mounted on the Laboratory for both attitude and spin-rate control. The position of the Counterweight relative to the Laboratory can also be controlled in order to simulate deployment and retraction. The idealized actuator, which is assumed, precisely controls the undeformed length of the Connecting Structure. Undesirable gyroscopic wobble (a transverse angular-velocity component) of the rotating vehicle is damped out by driving a control-moment gyroscope in accordance with the highly efficient 90° h-lag law.[3] During cargo elevator operation, undesirable motions of the spinning vehicle are corrected by using an accelerometer to detect the resulting accelerations and a balance mass is moved accordingly.

Sample Numerical Results

Configuration: The configuration shown in Fig. 1 was used to demonstrate the program. The two solar panels located on the

‡ In the computer program the maximum number of lumped masses is 100 for each body.

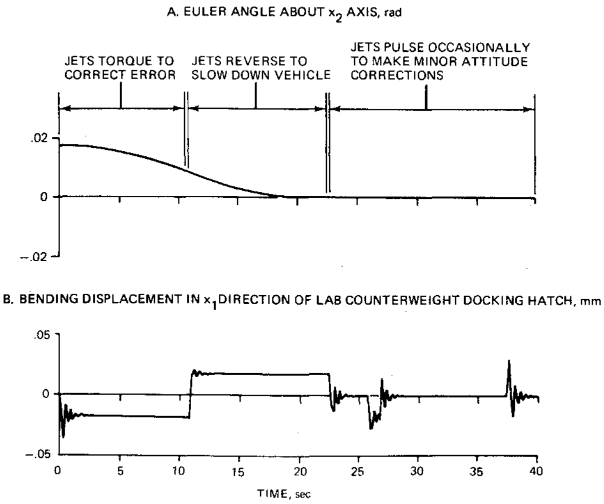

Fig. 2 Selected responses during attitude control maneuver.

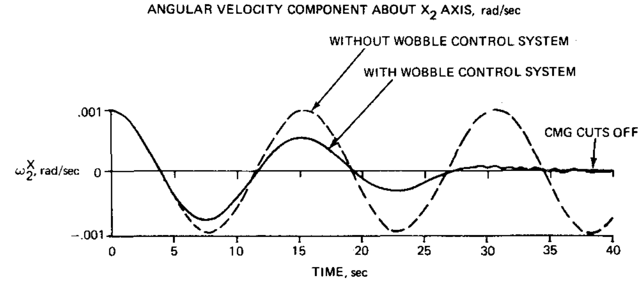

Fig. 4 Performance of wobble-control system.

Laboratory are extremely flexible. The Counterweight is relatively rigid; its lowest flexible-mode frequency was 6.851 Hz, whereas the sixth Laboratory frequency was 0.382 Hz. It was therefore decided to idealize the Counterweight as a rigid body in the time-history computer program. A total of 18 coördinates are used, the six lowest-frequency flexible laboratory modes, six rigid-body coordinates locating the Laboratory, and six rigid-body coordinates for the Counterweight. The Connecting Structure was assumed to be an elastic tubular beam with uniform characteristics per unit length. All control-system equipment was mounted on the Laboratory core module.

Attitude control: During the attitude-control maneuver, the system was not rotating and the Connecting Structure was fully retracted. The Space Station was initially tilted about each of its three axes so that each Euler angle was 0.01745 rad (1.0 deg). The control system then attempts to simultaneously reduce each angle to the commanded value of zero. Figure 2a shows the reduction of the Euler angle about the X_2 axis. Similar behavior occurs about each of the other two axes.

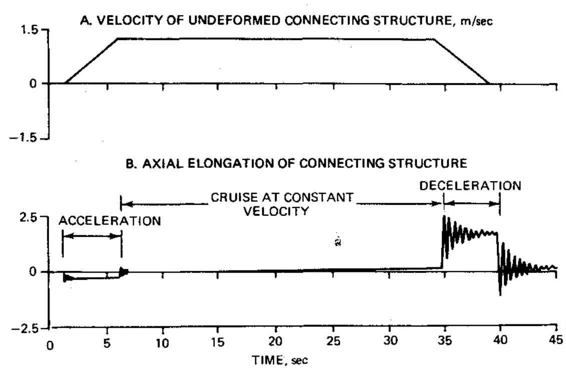

Fig. 3 Deployment maneuver at 0.2 rpm.

While controlling the angular position, the jets bend the docking hatch as shown in Fig. 2B.

Deployment with spin-rate hold: Figure 3a shows the prespecified motion of the undeformed Connecting Structure as it deploys from 0 to 42.822 m. Figure 3b shows the axial deformation in the beam during deployment. As deployment begins, the end bodies are pushed apart causing compression in the beam. When the maximum velocity is reached and deployment proceeds at constant velocity, the beam is expanded slightly by the centrifugal force. At approximately 35 sec, the deceleration begins and the expansion in the beam is increased significantly. The final expansion is much larger than the initial compression, mainly because the beam is more flexible when more of it is deployed. For the same reason, the transient vibration occurs at a lower frequency when deployment is terminating.

Wobble control: Figure 4 illustrates the performance of the wobble control system. Up to approximately 27 sec, the curve is essentially identical to a run made for a rigid Space Station. After 27 sec, some small higher-frequency oscillations predominate due to elastic vibration.

Additional runs and capability: Additional runs described in the complete paper illustrate a spin-up maneuver, mass balance control during motion of a freight elevator, and vibration excited by pumping fluid through the vehicle. Also, the vibration at points in the vehicle is illustrated during some of the runs. Although the illustrated runs show single maneuvers, the program may also be used to simulate combination maneuvers where several control systems are simultaneously active. Additional program capability includes computation of the Space Station center of mass in inertial coordinates, the total angular momentum vector projected onto inertial coordinates, the total system kinetic energy, and the internal resultant force and torque vectors anywhere within the vehicle.

References

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[2] Lowe, E. and Austin, F., "A Study of the Dynamics of Rotating Space Stations with Elastically Connected Counterweight and Attached Flexible Appendages, Volume II, Computer Program User's Manual," CR-112244, Feb. 1973, NASA.

[3] Austin, F. and Berman, H., "Simple Approximations for Optimum Wobble Damping of Rotating Satellites Using a CMG," *AIAA Journal*, Vol. 10, No. 9, Sept. 1972, pp. 1160–1164.