IN-ORBIT FLEXIBLE SPACECRAFT DYNAMICS PROGRAM

Joseph V. Fedor

A continuous flexible body nonlinear dynamics computer program has been developed in support of flight programs such as IMP I, IMP H, and IMP J and RAE 1 and RAE B. A version of this program successfully predicted the performance of the RAE 1 spacecraft, the world's largest satellite in orbit, in every major respect. The most recent version (for IMP I) can simulate up to ten arbitrarily oriented flexible antennas attached to a spinning or nonspinning satellite (gravity gradient or three-axis control) and compute the spacecraft and antenna motion as a function of time for predeployment, deployment, and in the orbital environment. This computer program promises long-term utility in the analysis of flexible spacecraft dynamics and attitude control.

Prior to the RAE flight program, satellites were considered essentially rigid in the analysis of satellite attitude dynamics. However, the RAE spacecraft (Figure 1 shows an artist's conception of it in orbit), with its 0.05-mm thick, 1.27-cm diameter, 225-m-long antennas, making it 450 m from tip to tip, no longer satisfies the rigid body assumption. Forces previously ignored in regard to the distorting of spacecraft, such as gravity gradient forces, orbit centrifugal force, thermal bending, and solar pressure, had a profound effect on the shape and stability of the satellite. As is known, the RAE spacecraft was a rousing scientific and technological success. Further, the computer program developed specifically for the RAE spacecraft predicted its performance in every major respect.

Recently, the IMP I, IMP H, and IMP J program emerged, and GSFC was confronted with the analysis of another type of flexible spacecraft. This time, the spacecraft was a spinning one with the added complexity of applied control torques. Figure 2 shows the IMP I spacecraft. It has six orthogonal booms for the electric field measurement experiment: two booms along the spin axis and four radial booms. The radial booms are 60 m long and 120 m from tip to tip; the spin axis booms are each 6 m long. From the experience of the RAE program development, a concept for a second-generation generalized flexible body dynamics program evolved. The intention was to come up with a program that could handle not only spinning flexible spacecraft but also gravity gradient and three-axis control. The computer program was developed by a contractor and has been operational here at GSFC for the past year in the support of in-house flight programs.

The computer simulation of the spinning mode should be capable of handling the following aspects of the problem:

Effects of deployment of up to 10 antennas in any arbitrary direction,

Behavior of flexible antennas (open and closed cross section),

Nonlinear motion of spacecraft in all three dimensions,

Structural damping,

Thermal bending,

Solar pressure,

Magnetic torques,

Gravity gradient torques,

Aerodynamic forces,

Attitude control torques,

Viscous nutation damper,

Four-body calculated orbit or simple Keplerian orbit,

Precession of orbit,

Occultation by earth,

Convenient input-output routines (for parameter study).

A few key terms should be noted here. They are *continuous flexible body* and *practical computer running time.* The computer program takes into account the continuous flexible nature of the antennas or booms by representing deflections in terms of shape functions. By integration of the spatial dependence in the formulation of the equations of motion, a large amount of algebraic simplification is obtained. This results in a significant reduction in computer running time when compared to the time required for the segmented approach to flexible body analysis. Further, boom deployment presents no problem in the continuous simulation, while it does present a problem in the segmented approach.

Figure 3 shows a comparison of RAE flight data of roll, pitch, and yaw with the predictions of the computer program in the gravity gradient mode. The time span of the data is 12 hr, which corresponds to approximately three orbits; the solid curve represents the flight data, and the dashed curve represents computer predictions. It will be observed that there is fair to good agreement in roll and pitch and excellent agreement in the yaw angle.

The computer program is currently being used in the IMP I flight program, the Lunar RAE program, the IMP J program, and several GSFC in-house studies.

In conclusion, it is of value to point out that, based on current usage and adaptability, the computer program promises long-term utility in the analysis of flexible spacecraft dynamics and attitude control.

Figure 1—Artist's conception of the RAE spacecraft.

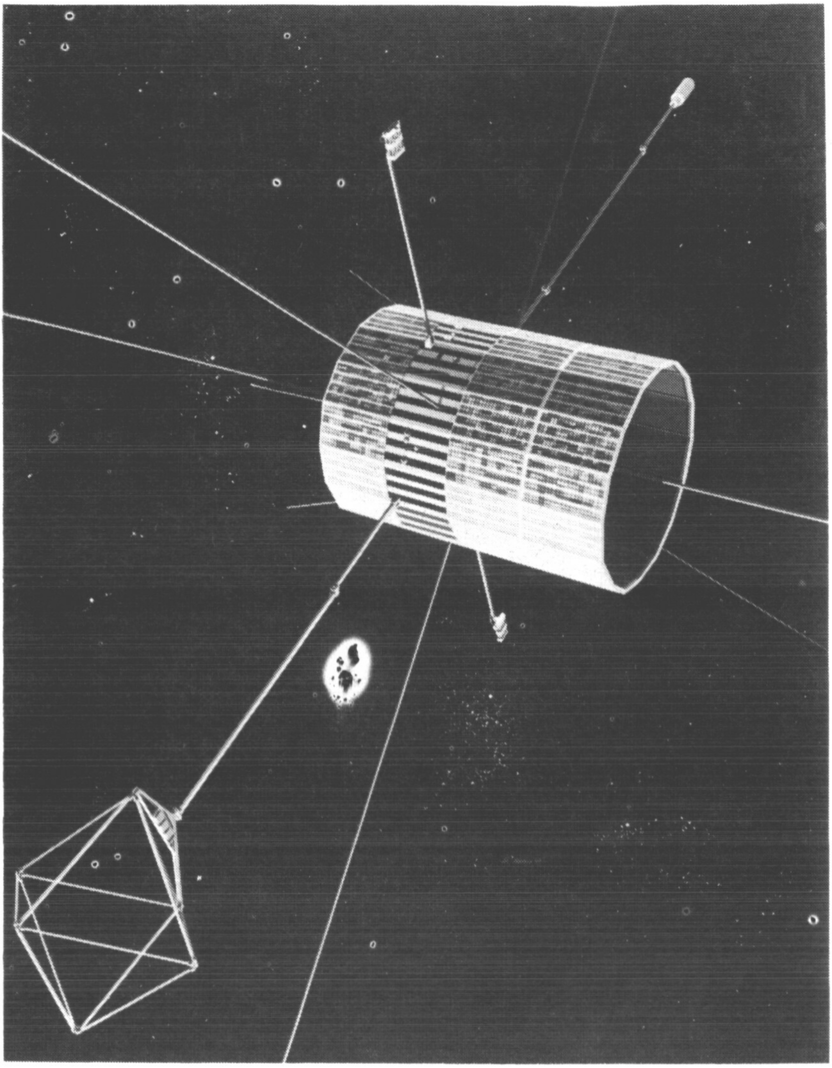

Figure 2–The IMP spacecraft.

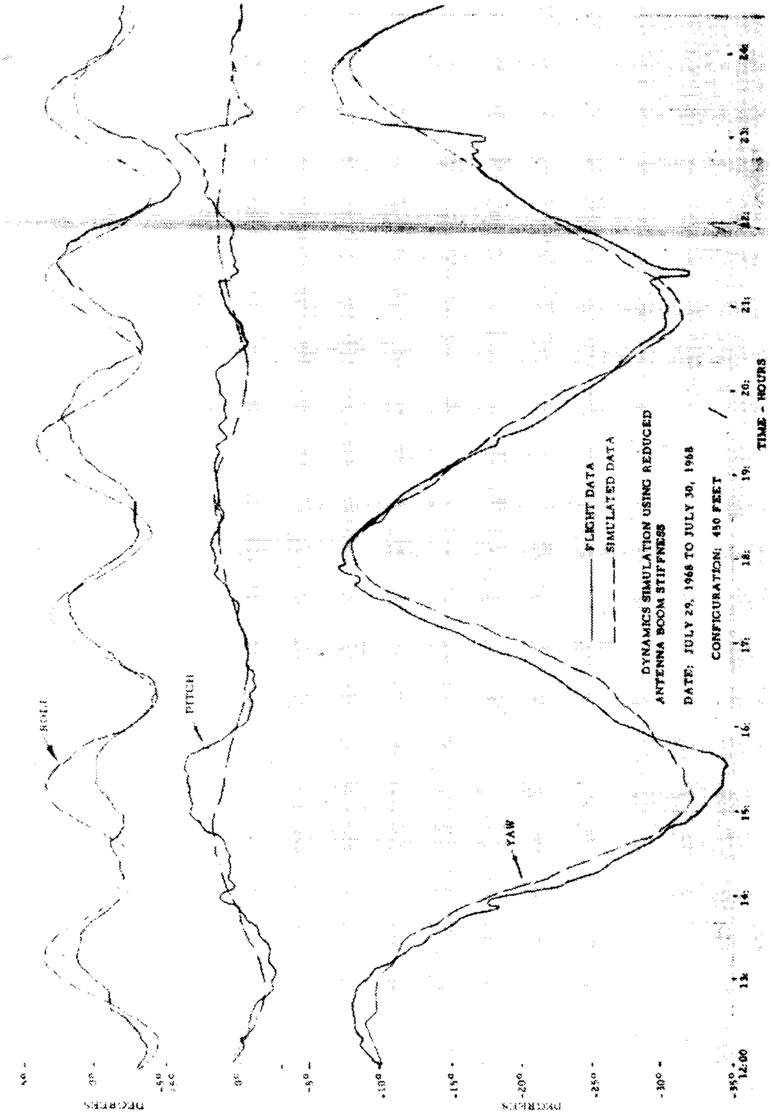

Figure 3–Comparison of RAE flight data with computer-predicted data.