Space Station Dynamic Analysis With Active Control Systems Using MSC/NASTRAN

by :

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Extended Abstract

Since the early stages of the space station program one of the concerns has always been the interaction between structural flexibility and the various on board control systems. Each configuration change initiated a structure/control interaction study to determine whether control requirements can be satisfied.

In general the dynamicist develops a dynamics model and generates modal data or provides a dynamic response environment for the controls engineer to perform structure/control interaction analysis. Using a dynamic response environment,however, for structure/control interaction analysis can produce misleading results since the analysis is open loop. For highly flexible structures such as the space station the effect of the control forces may not be negligible.

Performing coupled structure/control interaction analysis in one program allows the dynamicist to understand the effect of the control systems on the dynamic behaviour of the structure. The effect of the configuration changes on structure/control interaction can be studied rapidly and efficiently. The focus of this paper is on using MSC/NASTRAN for performing space station dynamic analysis with active control systems.

The space station basic structure is made up of 5 meter cubical truss bays, and its first structural mode is at 0.2 HZ. One of the configurations analyzed is shown in figure 1. CROD elements are used in modeling the truss structure and stick models represent the hab/lab modules. The active control systems are modeled using the TF and NOLIN elements.

Micro-g environment and payload pointing accuracy were two requirements that had to be met for each configuration. The micro-g requirement limits the peak acceleration for certain experiments that are to be performed in the lab module to 10^{-5} g.

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[1]- Members of technical staff.

The payload pointing accuracy requirement limits the error on pointing of certain payloads to a maximum of a few arc-seconds.

The complete dynamics/control model of the space station configuration shown in figure 1 is composed of:

1- Finite element model of the space station.

2- Three 5 th order transfer functions representing a three axes magnetic isolation system for filtering out high frequency acceleration levels from a 1500 lb experiment in the lab module.

3- Transfer functions representing a 3 gimbal payload pointing control system for a 9000 lb telescope.

4- Alpha joint position-rate feedback control system for power pointing.

5- CMG position-rate feedback control system for attitude control.

Figure 2 shows the finite element model of the space station and the location of the control systems. The system equations including those of the control systems can be solved by using the direct integration method in physical coordinates, a modal superposition method, or a hybrid modal/physical approach. The latter approach is used in this model. The three gimbals on the telescope mount which are represented as hinges in the model add three zero frequency modes to the system six rigid body modes. For the experiment in the lab module only the translational axes(Tx, Ty, Tz) are considered and the degrees of freedom are represented by 'e' points and are retained in physical coordinates. The alpha joint control system is represented as a spring and a damper although one can hinge the model at the alpha joint(resulting in one zero frequency mode for each alpha joint) and apply control torques by means NOLIN elements. The CMG control system is also modeled as an equivalent spring/damper system.

The effect of crew disturbances on the micro-g environment and payload pointing performance was one of the conditions studied and the results are presented here. Crew disturbance was simulated as two equal and opposite half cycle sine waves with a delay in between representing a crew member kicking off of one side of the lab module and landing on the other side.

Figure 3 shows the Z direction acceleration environment at the base of the experiment in the lab module. Peak acceleration is at 259×10^{-6}g which does not meet the micro-g requirement. Figure 4 shows the maximum Z acceleration on the experiment to be 0.36×10^{-5}g. It is clear that the magnetic isolation system reduces the acceleration levels to acceptable values. Figure 5 shows the gap vs. time in the Z direction between the experiment and the base. Figure 6 shows the Ry rotation at the base of the telescope. The maximum rotation is 21 arc-seconds which does not meet the pointing accuracy requirement. Figure 7 shows the Ry pointing error of the telescope. Maximum rotation is 0.045 arc-seconds meeting the pointing accuracy requirement.

By using MSC/NASTRAN during the early stages of the space station program for performing dynamic analysis with active control systems, it was possible to study the effect of configuration changes on structure/control interaction. Although highly nonlinear control systems cannot be modeled in MSC/NASTRAN, the existing capability can be efficiently used for linearized control laws and some simple nonlinearities [2]. This can be very useful for quick assessment of changes in the control system or modifications to the structure. The transient analysis presented in this paper was also perofrmed using a Transient Response Analysis Program(TRAP) which was generated at Rockwell. Both MSC/NASTRAN and TRAP showed the same results. Although TRAP does not limit the user with respect to the type of control system being simulated, the advantage of using MSC/NASTRAN for quick assessment of structure/control interaction is that the complete analysis can be done in one program and loads can be recovered.

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[2]- The authors of this paper have not worked with nonlinear control systems in MSC/NASTRAN. The capabilities of the program, however, indicate that some nonlinearities can be simulated.

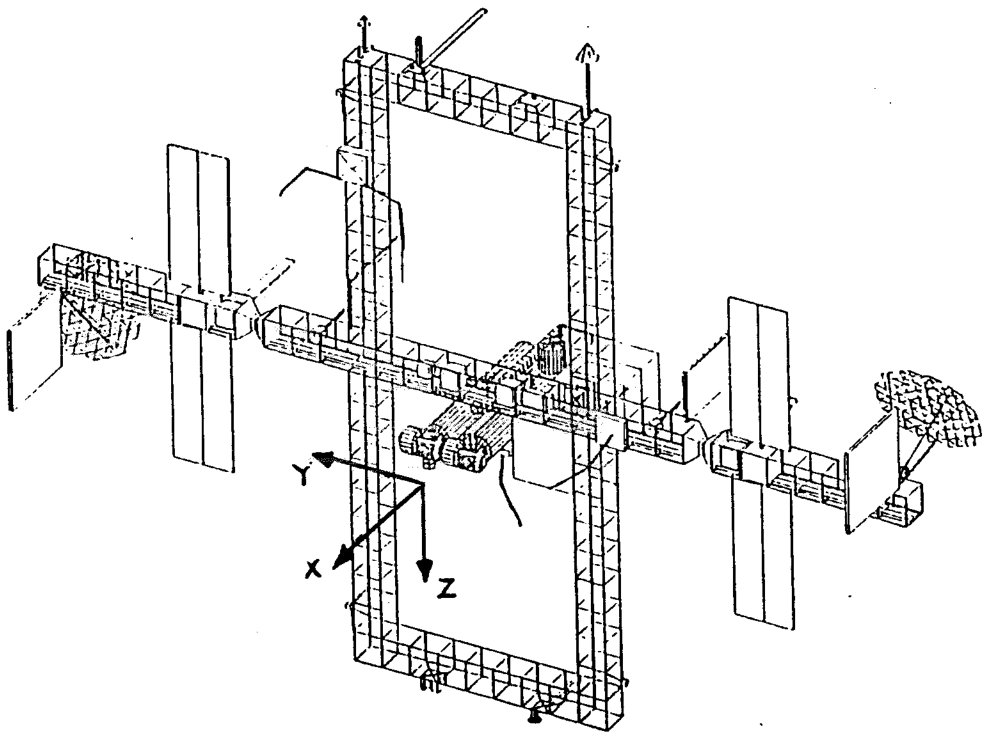

Fig. 1. Space Station Dual Keel Configuration.

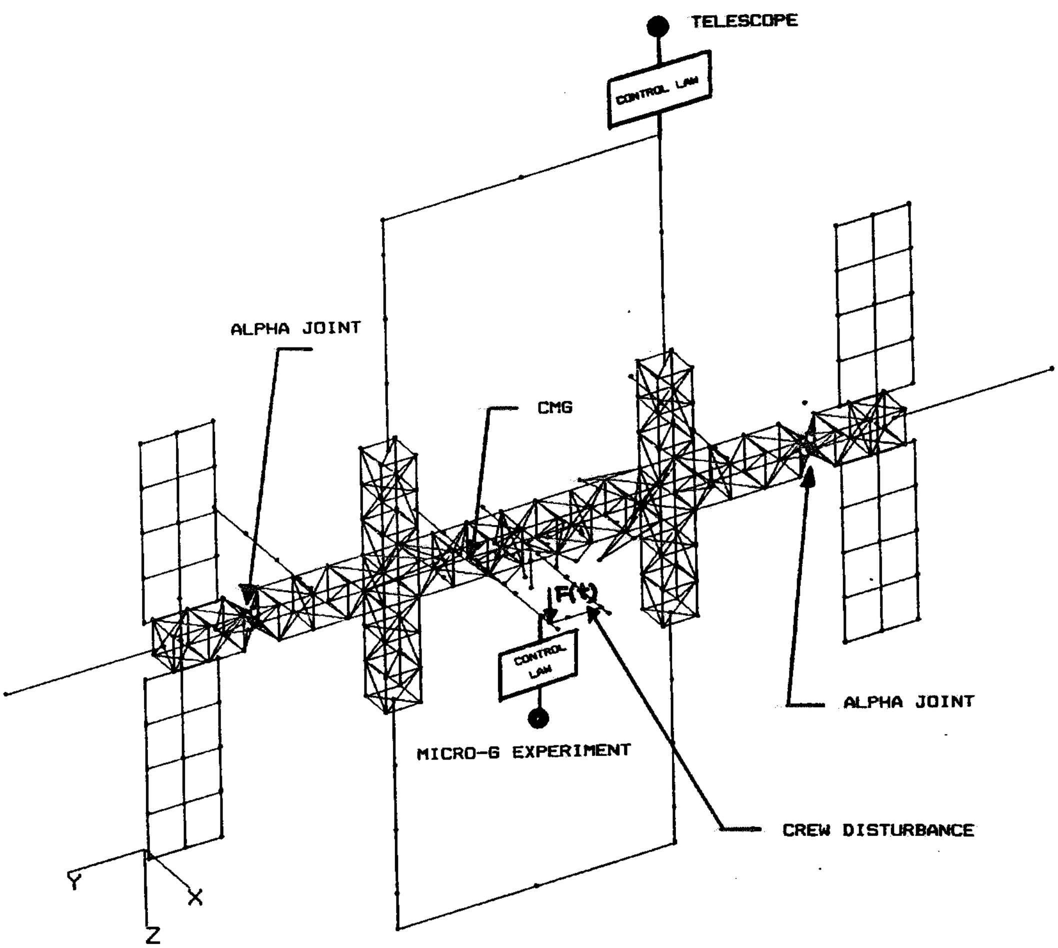

Fig. 2. Finite element model of the dual keel space station indicating the location of the control systems and the application point of crew disturbance.

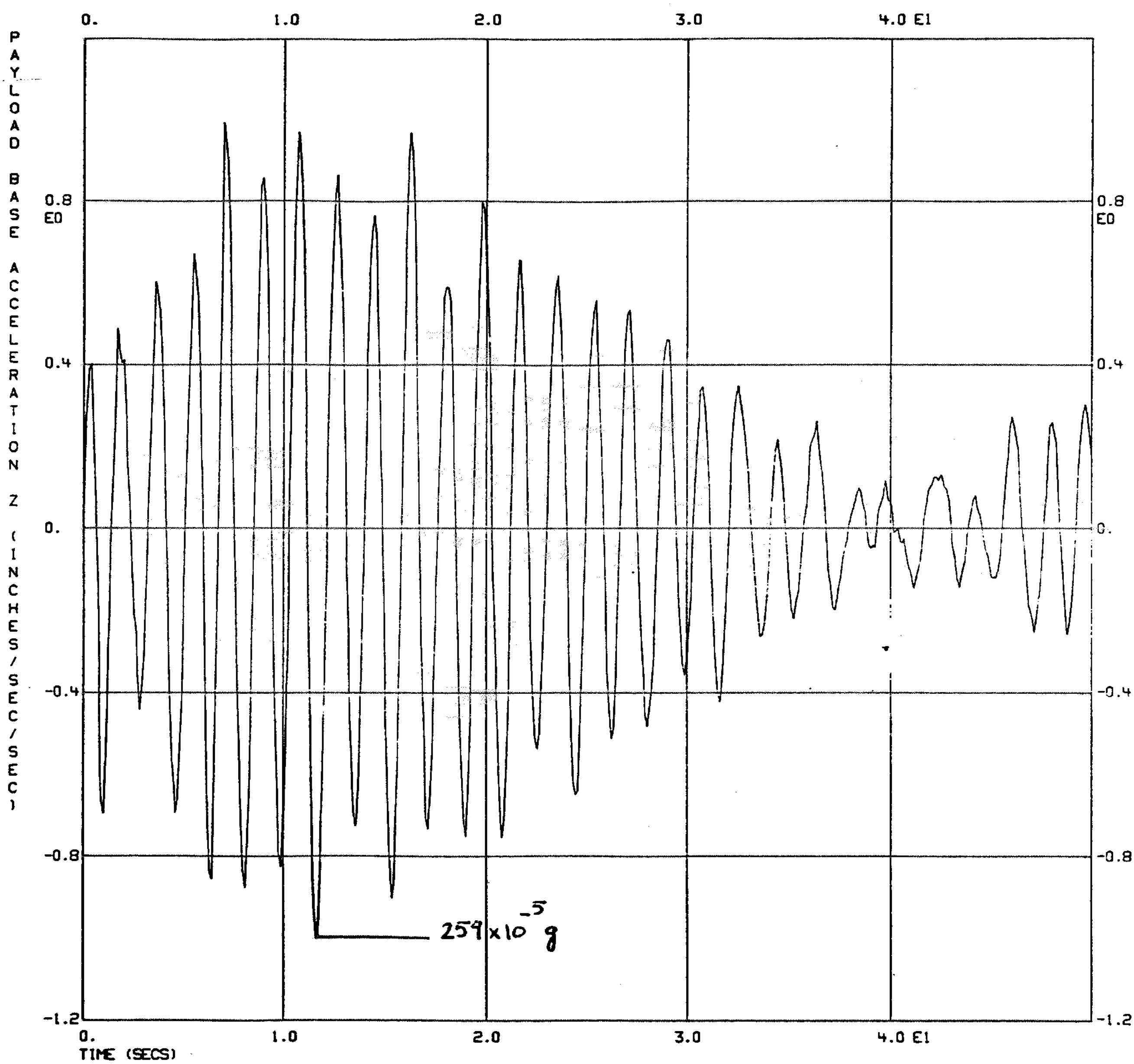

Fig. 3. Time history of the Z direction acceleration at the base of the experiment in inches/sec².

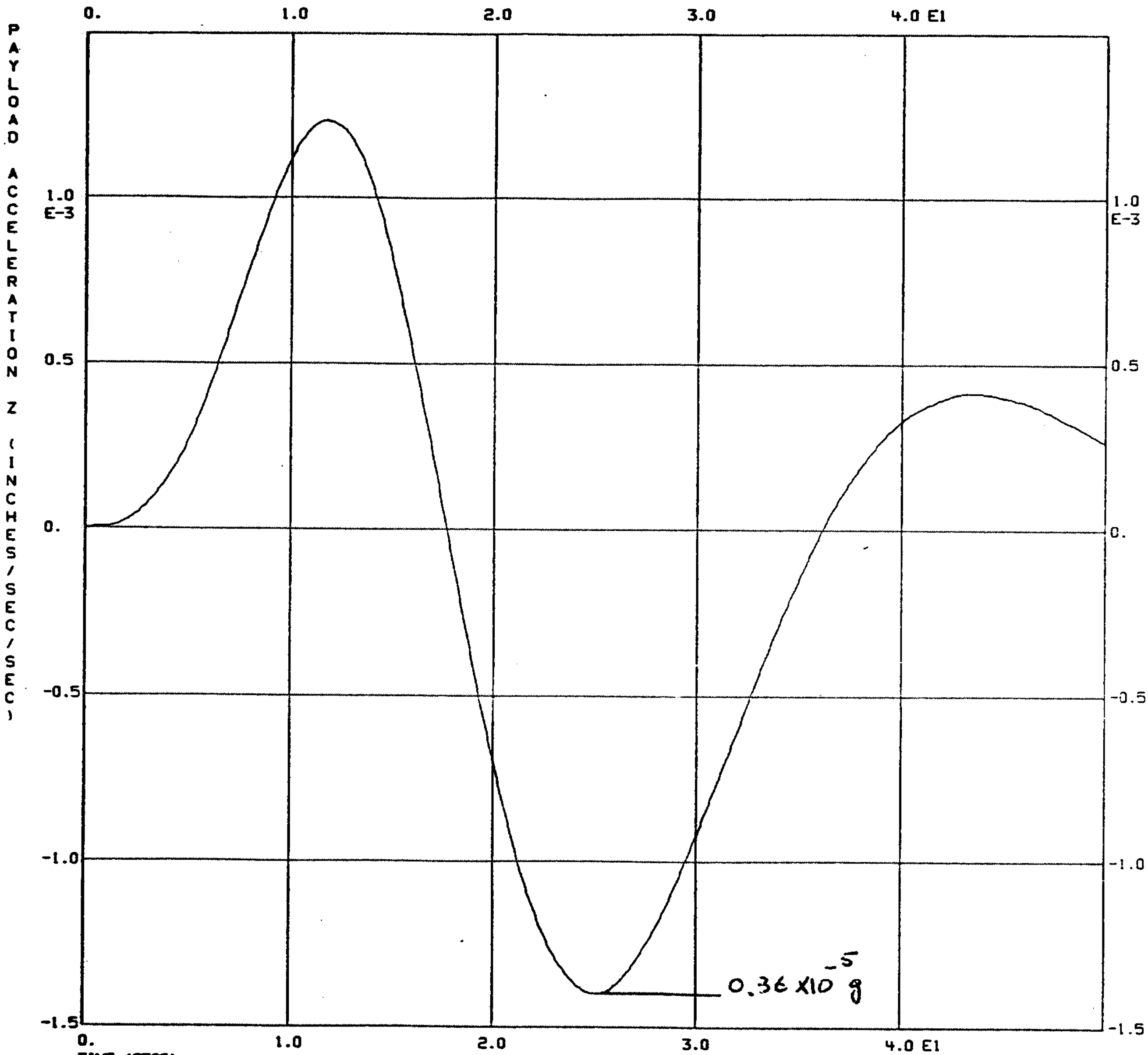

Fig. 4. Time history of the Z direction acceleration at the experiment in inches/sec².

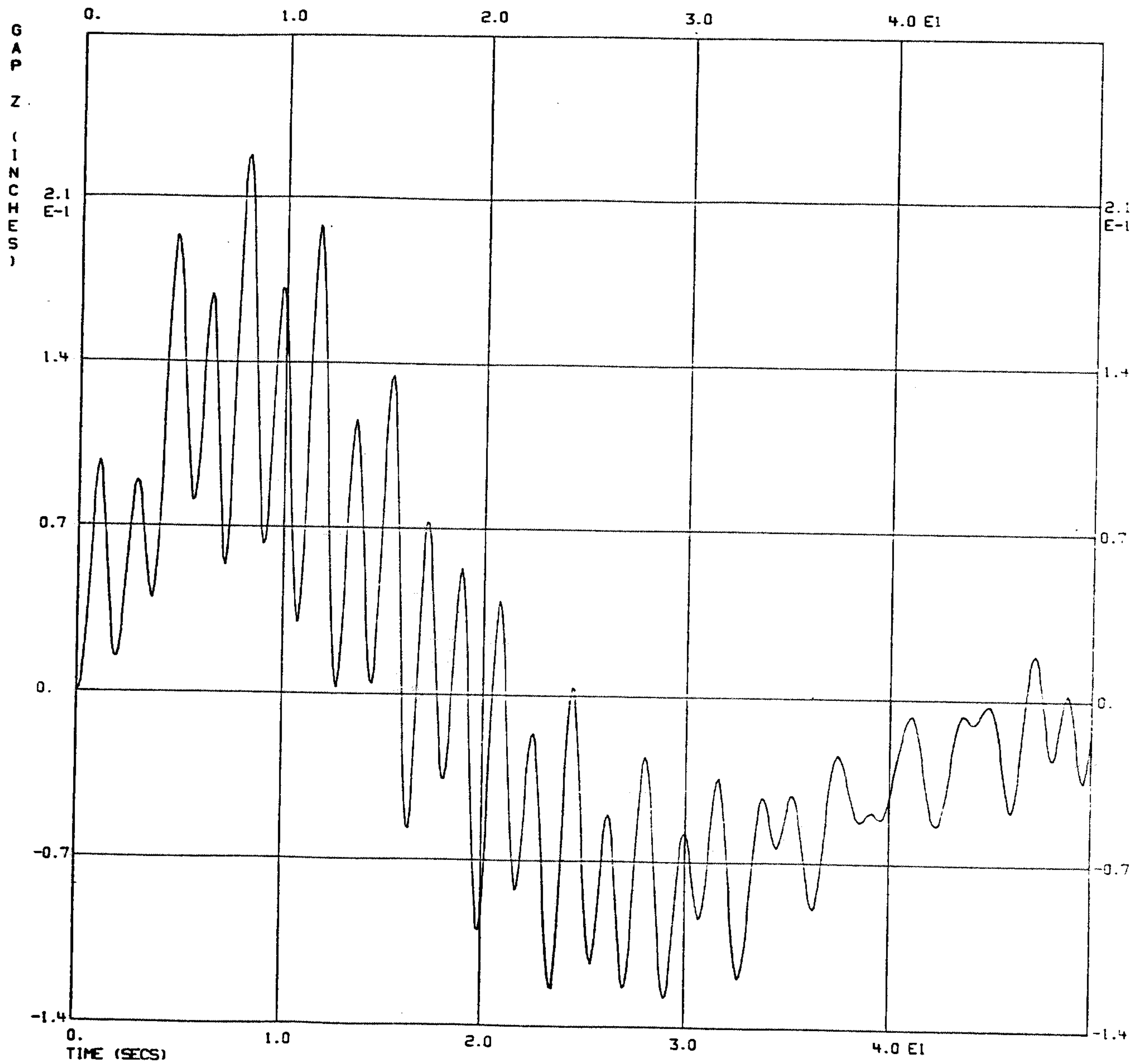

Fig. 5. Time history of the gap between the base and the experiment in inches.

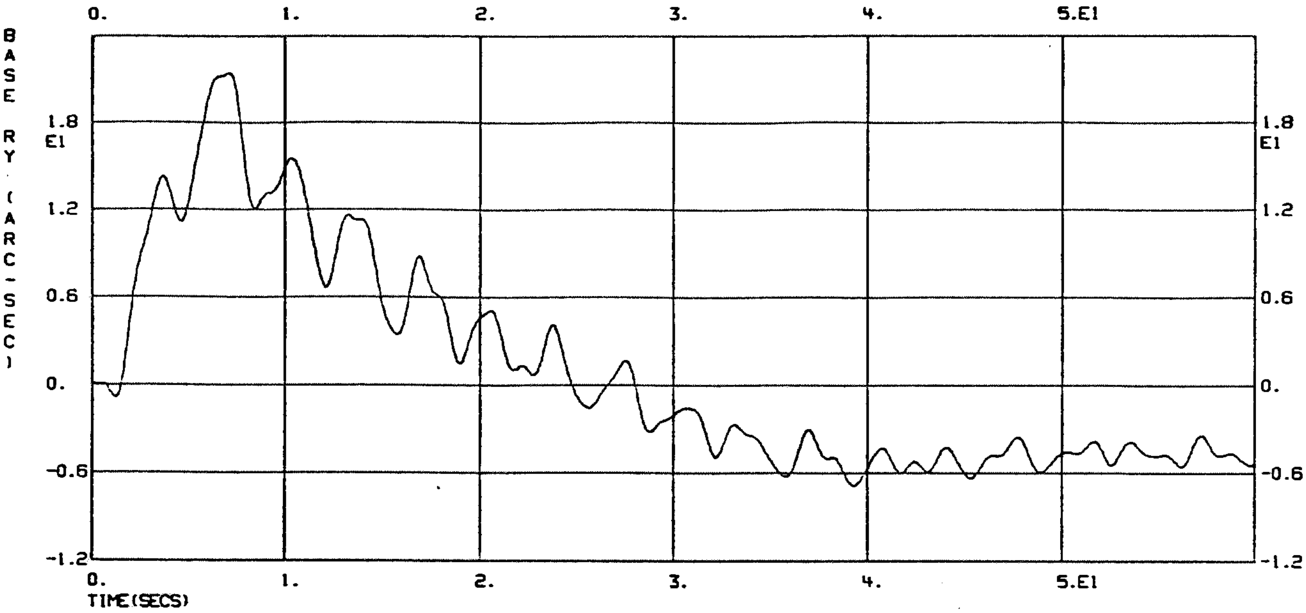

Fig. 6. Time history of the telescope base rotation about the Y axis in arc-seconds.

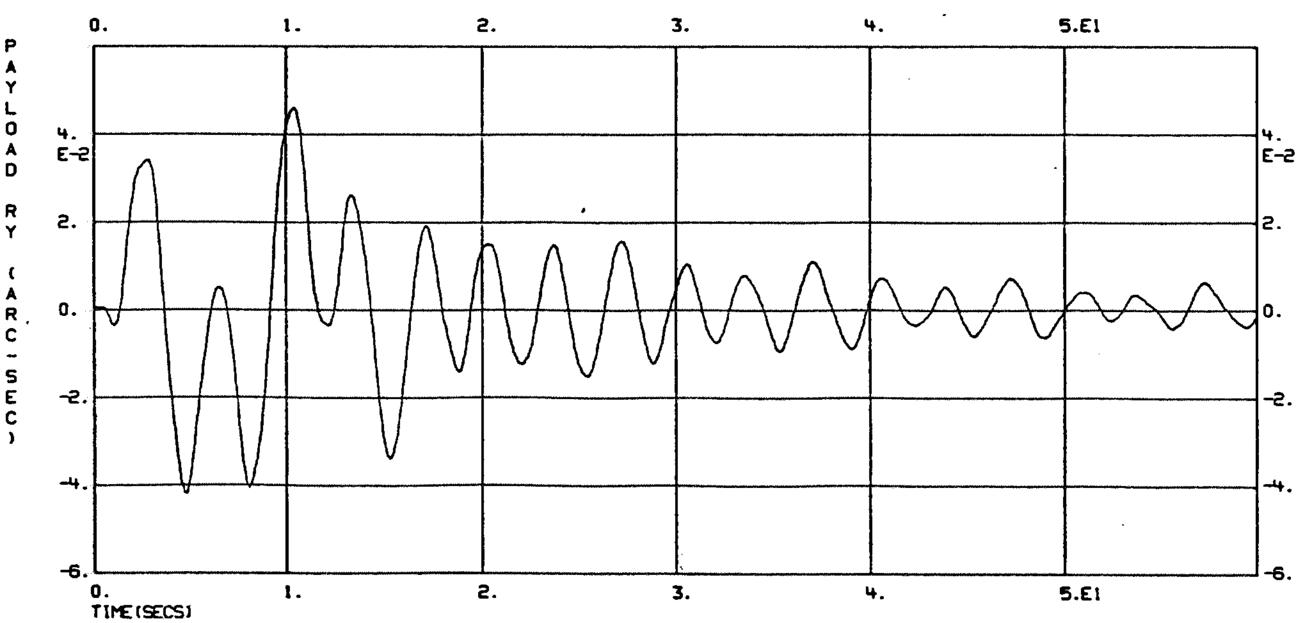

Fig. 7. Time history of the telescope rotation about the Y axis in arc-seconds.