SSF LOADS AND CONTROLLABILITY DURING ASSEMBLY

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The Orbiter Primary Reaction Control System (PRCS) pulse width and firing frequency is restricted to prevent excessive loads in the Space Station Freedom (SSF). The feasibility of using the SSF Control Moment Gyros (CMG) as a secondary controller for load relief is evaluated. The studies revealed the CMG not only reduced loads but were useful for other SSF functions: vibration suppression and modal excitation. Vibration suppression lowers the g level for the SSF micro-g experiments and damps the low frequency oscillations that cause crew sickness. Modal excitation could be used for the modal identification experiment and health monitoring. The CMG's reduced the peak loads and damped the vibrations. They were found to be an effective multi-purpose ancillary device for SSF operation.

INTRODUCTION

The Shuttle Digital Auto Pilot (DAP) software determines jet-firing commands for attitude hold or attitude maneuvers. The desired Orbiter attitude and/or rates are determined by the DAP for automatic control or requested by the crew (via hand controller) for manual control (see reference 1). The DAP then attempts to achieve and maintain these attitude and rate commands within the crew-specified: attitude error deadbands, and rate limits. The errors are the difference between the DAP commands and the estimates of the states, derived from the Inertial Measurement Unit (IMU) data. Jet firings are commanded whenever the errors exceed the margins.

For Space Station Freedom (SSF) assembly, the standard Orbiter DAP induces large loads on the SSF; thus an alternate mode of operation (ALT mode) in which the jet firing pulse width, time between firings, and number of jets fired are restricted. The PRCS ALT mode reduces induced loads on the SSF with a pulse width restriction of 80 ms, a maximum of two simultaneous jet firings, and long delay times. Controllability becomes a problem when the delay time exceeds 10 seconds. The potential loads/controllability problems led to consideration of two alternate concepts: active CMG's and a damping platform. In this paper, the CMG studies performed at Rockwell International with IR&D funds are presented.

RESULTS

CMG 's WITH PARALLEL PROCESSING :

The study results showed that the four SSF CMG's can:

1. provide vibration suppression which should reduce ALT DAP restrictions during mated PRCS maneuvers,
2. improve the environment for micro-gravity experiments,
3. reduce the trampoline vibrations which cause crew sickness,
4. provide load relief and vibration suppression during docking/berthing,
5. excite the SSF structural modes for modal identification and health monitoring.

The CMG's can perform these tasks in parallel with SSF attitude control or during mated Orbiter PRCS attitude control. The effectiveness of the CMG's for vibration suppression or modal excitation depends on their locations relative to the anti-nodes of the system structural modes. For micro-gravity vibration suppression, effectiveness also depends on the capability to measure the low levels of vibration. The measured rates are needed for the controller feedback.

In Figure 1, the CMG controller is shown in parallel with the SSF attitude control system. The CMG controller removes the rigid body component of the angular rate with a s/(s+a) high pass filter and produces a torque proportional to the angular rate. The CMG's have a capability to produce a torque of 200 ft-lb for short periods of time and 100 ft-lb for longer periods. The CMG's can respond to 50 Hz inputs. This capability is not used for the low bandwidth (0.04Hz), low sample rate (10 samples/second) SSF attitude control system. The CMG parallel processor needs a sample rate of 60 samples/second to damp modes with frequencies below 15 Hz. The constant (a) in the CMG parallel processor was chosen as 0.1 rad/second (0.02 Hz). With a 60 Hz sampler the CMG's would respond to signals with frequencies between 0.02 and 15 Hz.

The generic SSF model (see figure 2) used in the IR&D study was a nine node beam model with SSF MB5 pre-PIT (Pre-Integrated Truss) mass properties and an equivalent truss structural stiffness. The beam model was coupled to a rigid Orbiter. The CMG's were attached to the seventh node 3000 inches from the Orbiter. The torque from the CMG's was filtered (with a limiter) to prevent torques above 400 ft-lb (4800 lb-in). The CMG's can produce 800 ft-lb of torque for short periods of time but a conservative evaluation was sought. An 80 ms pulse with an amplitude of 900 lb (simulates a PRCS single jet firing with a minimum pulse width) was applied to the Orbiter where the tail jets are located. The present SSF MB configurations extend forward of the Shuttle when mated. The nose jets are not fired because of plume impingement. The interface loads, CMG applied torque, Orbiter angular rate, and the angular rate at the location of the CMG's were recovered. The simulation was performed with the Dynamic Analysis and Design System (DADS) program. The Craig Bampton NASTRAN beam model component modes were generated and converted to DADS format. Two sets of modes were used in the study: a 21-mode set with four x-directional bending modes and a 38-mode set with eight x-directional bending modes. No structural damping was included, so the CMG's were the only source of damping.

The interface load for a single pulse with and without an active CMG controller is shown in figure 3. The peak moment of 60,000 lb-in is reduced to 50,000 lb-in with the active CMG's. The CMG's damp the low frequency amplitudes from 50,000 to 25,000 in one cycle (11% damping), but the higher frequency (1 Hz) amplitudes are lightly damped. The CMG's may be located near the 1 Hz anti-node of that mode. The CMG's produce a torque proportional to the angular rate (at the CMG location). The angular rate (see figure 4) is dominated by the low frequency component. The angular rate and CMG torque in figure 4 show some small amplitude 1 Hz motion. The CMG torque peaks are clipped by the 4800 lb-in torque limiter. If this CMG parallel processor was invoked for each SSF mated configuration, the amount of peak load reduction and damping would be a function of that configuration. Without CMG's, SSF has one percent structural damping. A 50,000 lb-in quarter Hz oscillatory interface moment would take 11 cycles or 44 seconds to decrease to 25,000 lb in. The interface moments for the SSF mated MB2 configuration have significant quarter Hz frequency content.

In a loads problem, one always considers the possibility that more input modes are needed for convergence. Four cases were run with 2,4,6, and 8 modes. The response for the 2 mode case was different but the other three were similar. In figure 5, the responses for 2 and 8-mode inputs are displayed. Four modes were sufficient for convergence.

Using the CMG's for vibration suppression would require an SSF DAP redesign or adding an additional micro-processor. Both alternatives are expensive and would impact the SSF schedule. Justification for that change would only happen if the load margins proved to be insufficient. If that change was made, the CMG could be designed for other modes of operation with no impact. For example, the CMG's could have an operational mode for mode excitation (it would be used for modal testing).

A Modal Identification Experiment (MIE) is planned for SSF. A similar experiment was performed on the Shuttle. The Program Test Inputs (PTI) shown on the top in figure 6 were input to the elevons and the rudder at three different times of flight. The inputs contained 2 cycles of oscillation at four frequencies. The data was used to determine damping and frequency information for assessment of flutter margins. Similar inputs could be used to generate torques for SSF,eg., 2 cy of 1.07 Hz and 5 cy of 3.3 Hz (shown on the bottom in figure 7). The CMG torques are generated with open loop inputs. The two cycle 1.07 Hz torque excited both the 1.07 Hz mode and the 0.2 Hz modes as seen in figure 7. The interface moment magnitude in figure 7 is dominated by the 1.07 Hz frequency but the low frequency component is seen in Orbiter angular rate. The five cycle 3.3 Hz torque excites two modes (see figure 8) but the 3.3 Hz response dominates. A better way of exciting the vehicle and controlling the amplitude would be to input an oscillatory signal that increased slowly in amplitude and was terminated when the response reached some predetermined value. The vehicle would have less energy in secondary modes with this approach. This could be used for health monitoring.

SSF structure may be damaged by space debris or meteorites. The damage could impair the operation of the SSF. The SSF structural health could be monitored by inputting PTI's and periodically checking the signature of accelerometers and/or rate gyros. The signatures must be updated when the configuration changes. Health monitoring is important from a safety standpoint.

The CMG's vibration suppression capability could be used to damp low frequency modes (these low frequency vibrations can cause astronaut sickness) and may be able to damp modes exceeding required micro-g experiment levels. In both cases, measurement of the vibration levels for the feedback controller would be difficult. For example, in the phase B SSF studies, a 25 lb crew member push off caused vibration levels 300 times the acceptable g level of 1E-05 g's. The push off also caused an attitude angle at the base of a payload pointing experiment of 24 arc-sec with an oscillatory component of about 2 arc-sec /sec. Laser type rate gyros can sense changes of 1-2 arc-sec. In this case, it would be difficult to damp the vibrations below 1 arc-sec/sec. In reference 2, the authors claim that they can reduce the quantization by several orders of magnitude. Their zero-lock laser gyro has a resolution of 1.5 arcseconds without enhancement and 0.001 arcseconds with resolution enhancement. The problem of measuring the vibration levels with resolution enhancement or relocating the sensor may solve this problem.

The oscillatory acceleration levels for micro-g experiments could be removed with electro-magnetic isolation systems, but there are problems associated with them. The isolators are designed for light objects and would need increased power to accommodate the heavy material processing experiments, and there also is a problem at the interface between SSF and the experiment. The isolator levitates the payload but the experiment needs power and cooling fluids to flow across the interface. These secondary paths can eliminate the isolation provided by the electro-magnetic system. It may be easier to suppress the vibration on the entire SSF. More studies are needed to determine if the CMG's could improve the environment for micro-g experiments.

CONCLUSIONS

The interface loads caused by a single pulse PRCS firing for a pre-PIT MB5 SSF mated configuration were reduced with an active CMG parallel processing controller by 20% and the controller added 11% damping to the system. The amount of load reduction and damping for actual mated SSF configurations will be configuration dependent. Without CMG's, the existing one percent structural damping will take 11 cycles (44 seconds for a 0.25Hz oscillation) to reach half amplitude. The changes necessary to implement CMG vibration suppression are expensive and would impact the SSF schedule. If the ALT DAP does not provide enough margin for loads while maintaining control during assembly, alternate concepts would be considered. The CMG's provide an ancillary control system which serves multi-purpose functions. The CMG's can provide damping and load relief for every phase of SSF operations. It can also be used for mode identification and health monitoring. With sensitive sensors, the CMG's can remove low frequency vibrations which cause astronaut sickness and remove the crew-induced oscillatory g-levels for a better environment for the micro-g experiments.

REFERENCES

1. *"Space Shuttle Orbiter, Operational, Level C, Functional Subsystem Software Requirements, Guidance/Navigation/Control, Part C flight Control, Orbiter DAP"*, STS83- 009C-01-20 November 29,1990.
2. M. Fernandez, B. Ebner, & N. Dahlen, *"Zero-Lock Laser Gyro"*, 12th Annual AAS Guidance and Control Conference Feb 4-8, 1989, Keystone, Colorado.

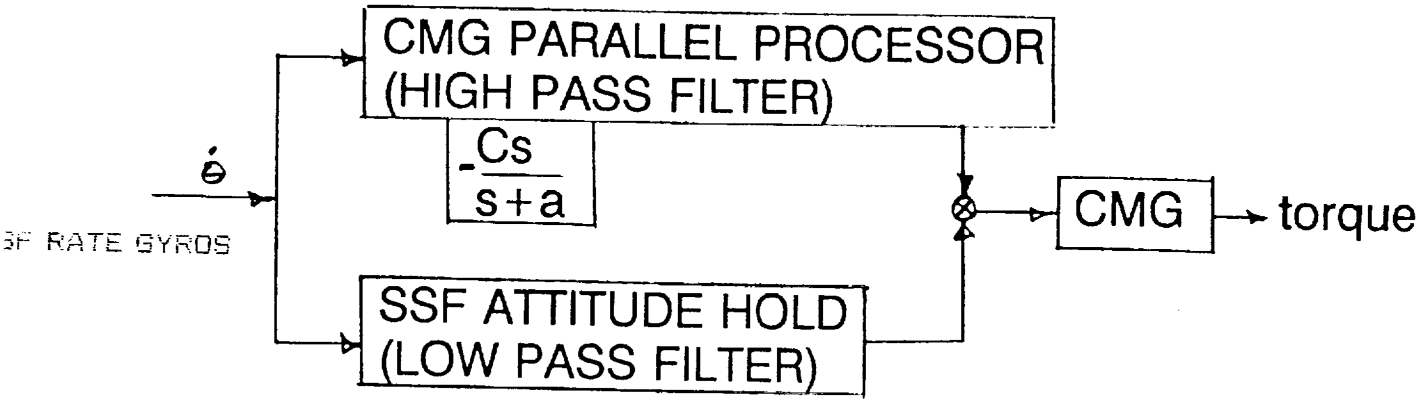


FIGURE 1. CMG PARALLEL PROCESSOR

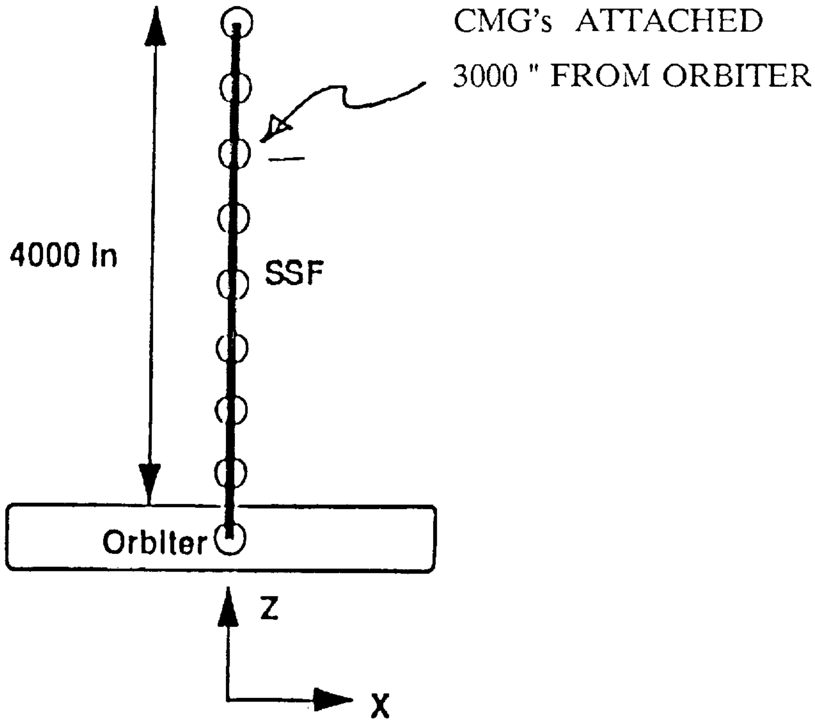


FIGURE 2. GENERIC SSF / ORBITER SIMULATION MODEL

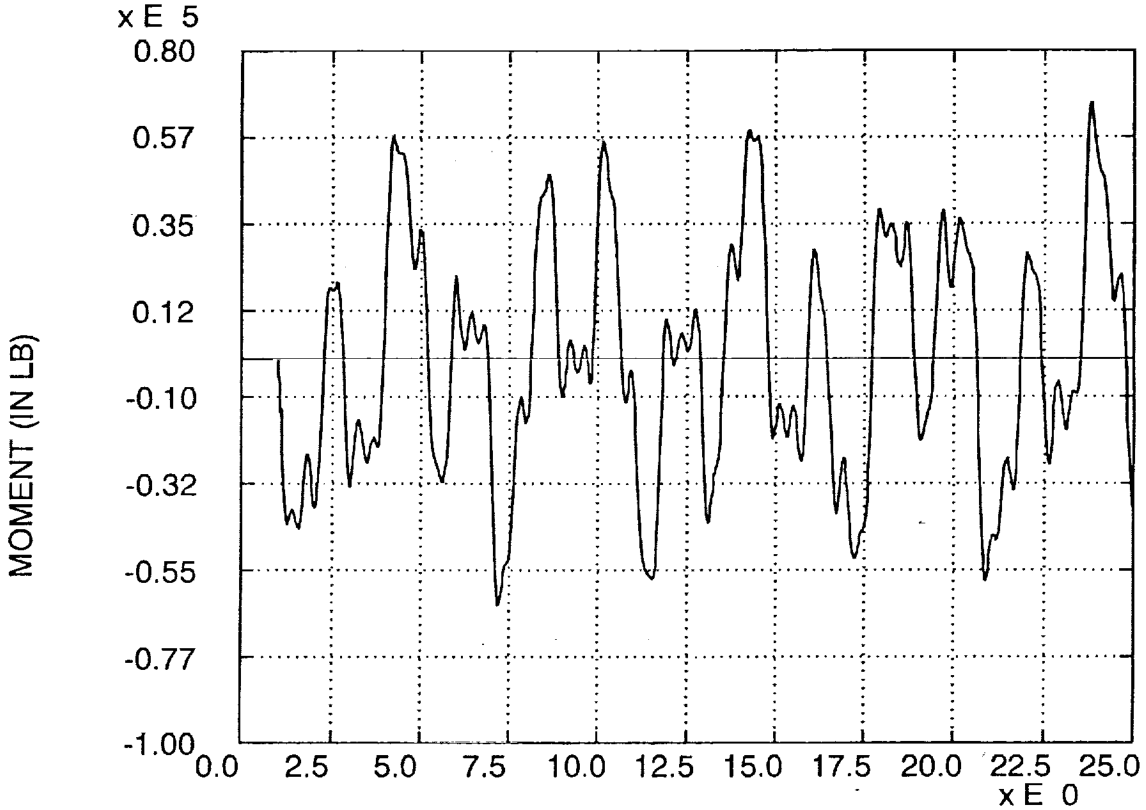


FIGURE 3A. INTERFACE MOMENT W/O CONTROL T(SEC)

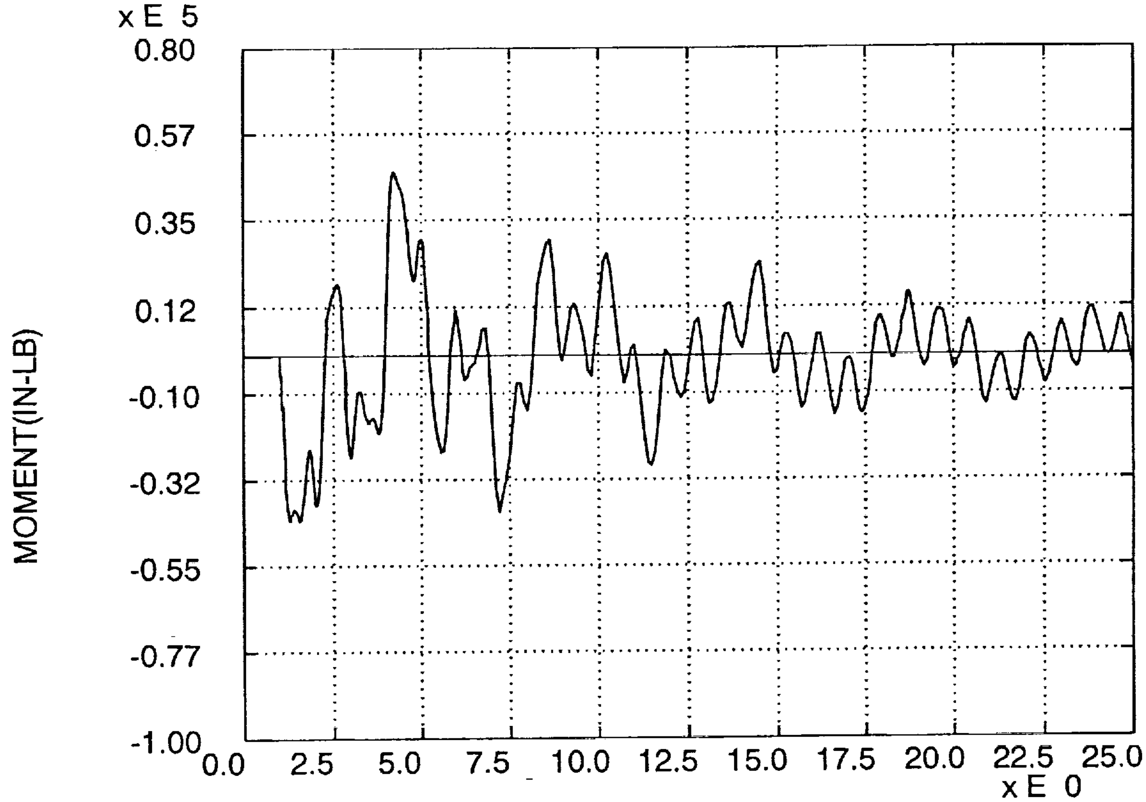


FIGURE 3B. INTERFACE MOMENT W CMG CONTROL T(SEC)

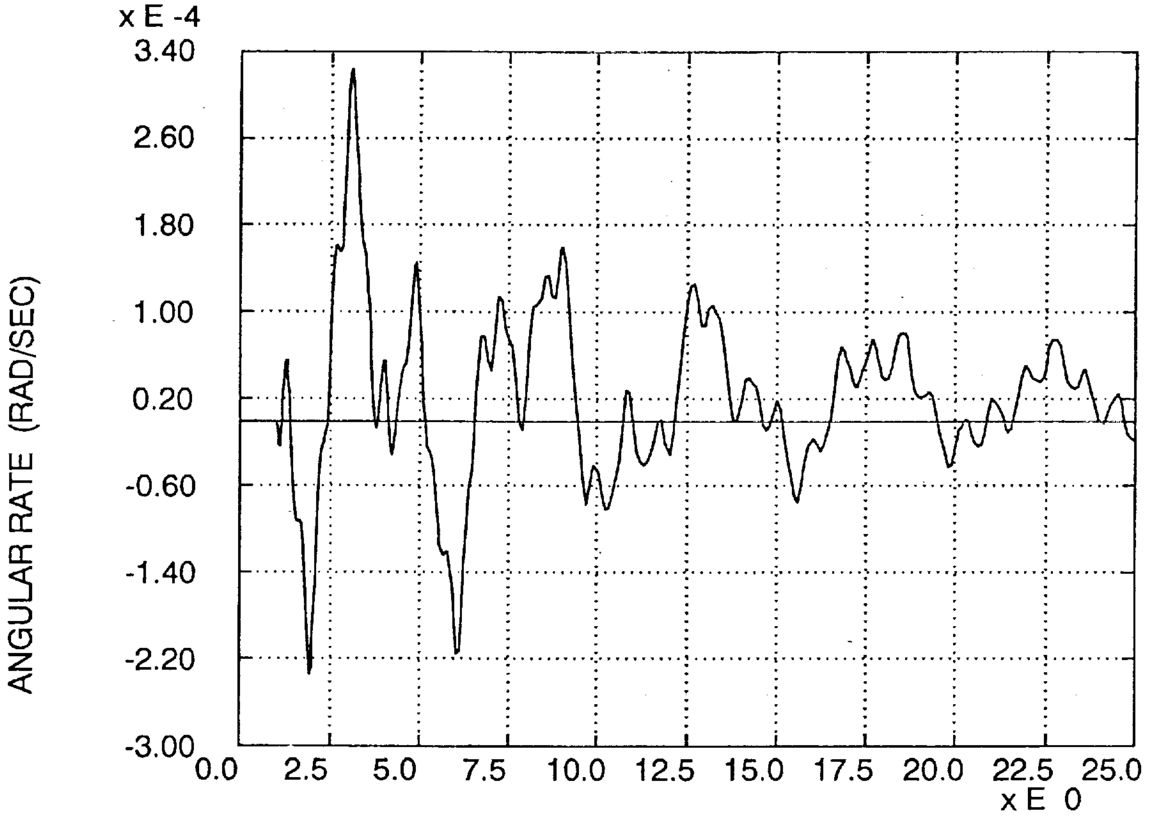


FIGURE 4A. CMG ANGULAR RATE T(SEC)

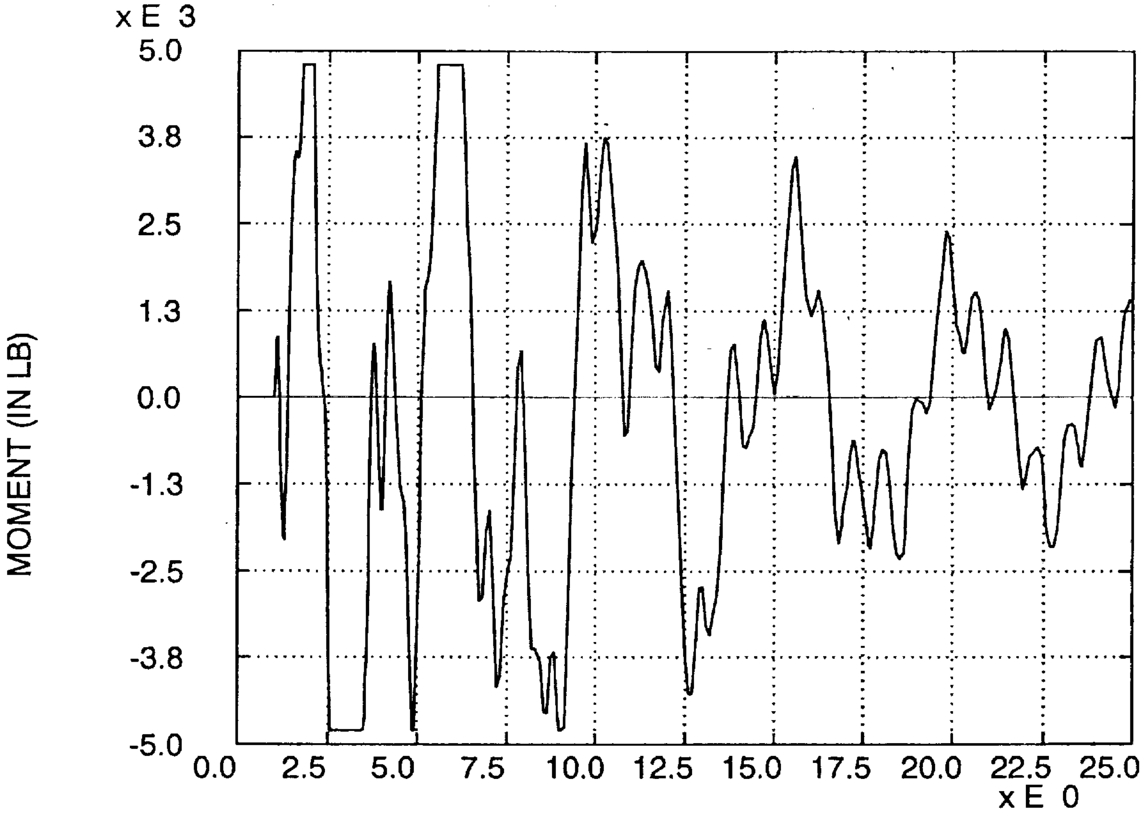


FIGURE 4B. CMG TORQUE T(SEC)

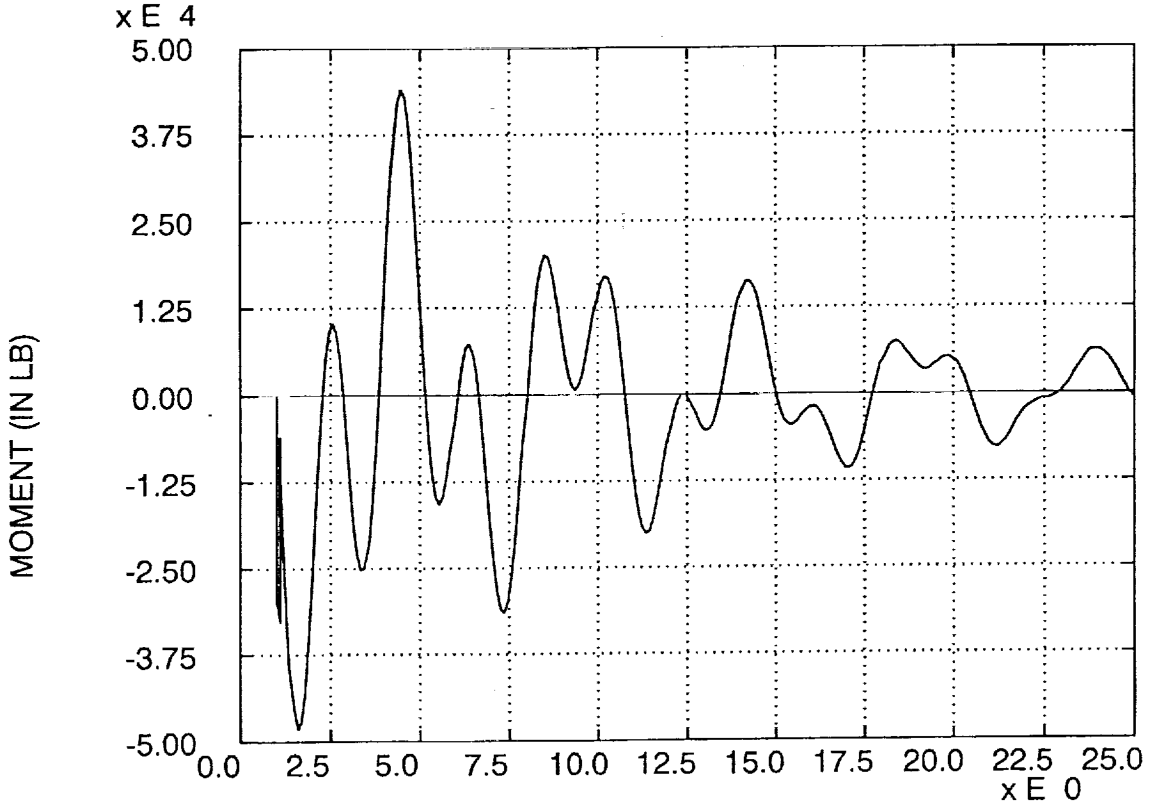


FIGURE 5A. INTERFACE MOMENT - 2 MODE INPUT

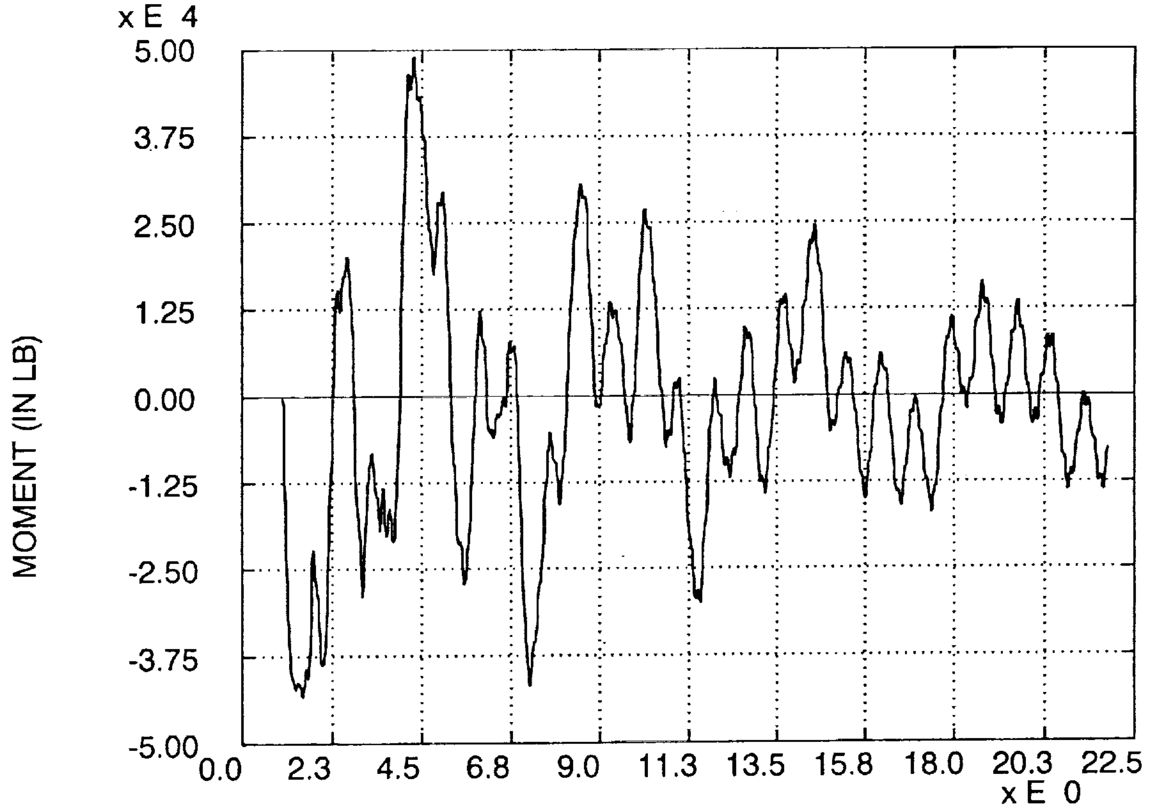
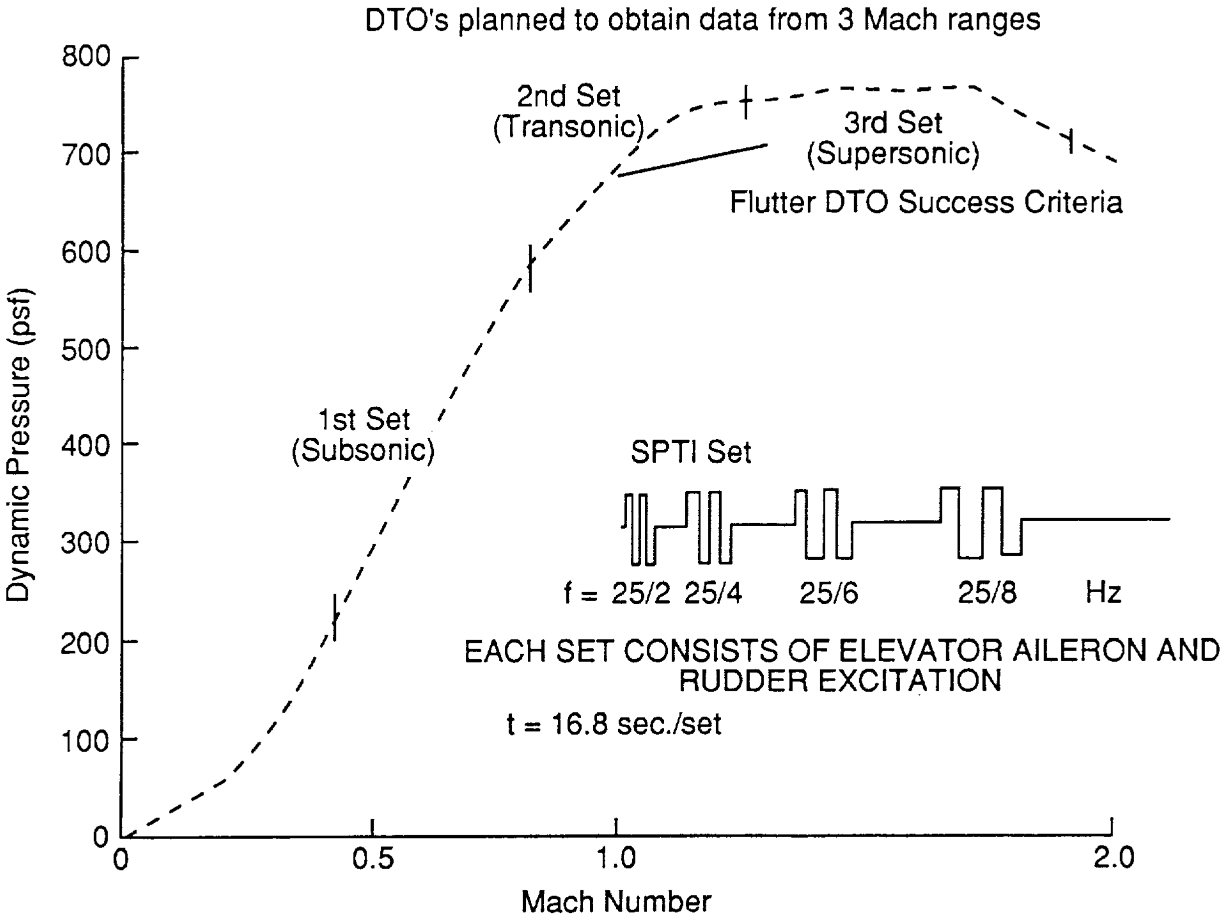


FIGURE 5B. INTERFACE MOMENT-8 MODE INPUT



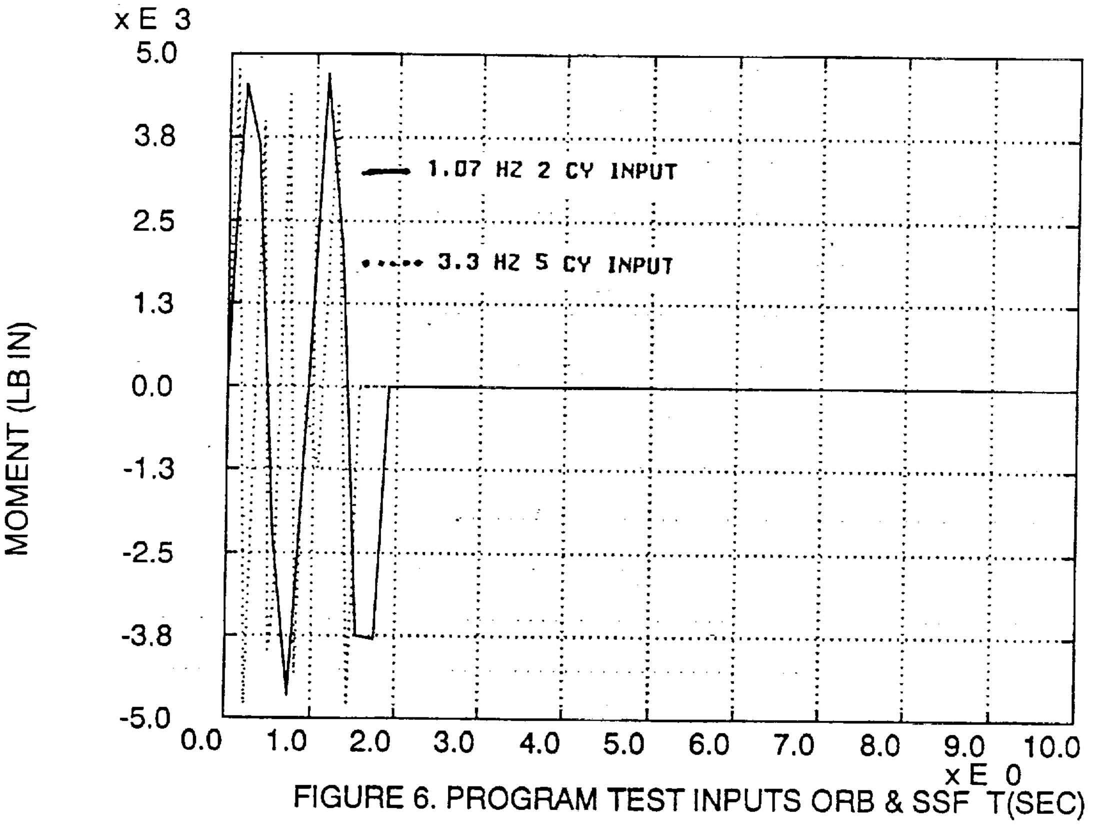


FIGURE 6. PROGRAM TEST INPUTS ORB & SSF

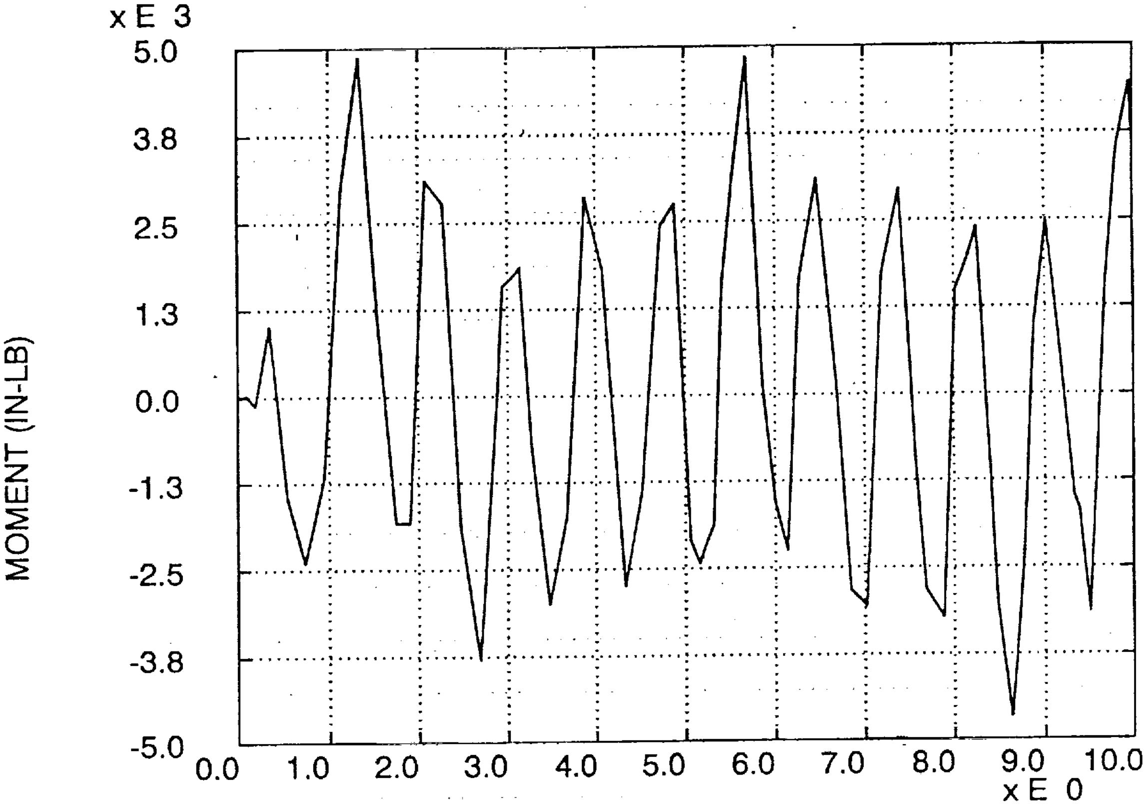


FIGURE 7A. RESPONSE TO 1.07/2 CY INPUT

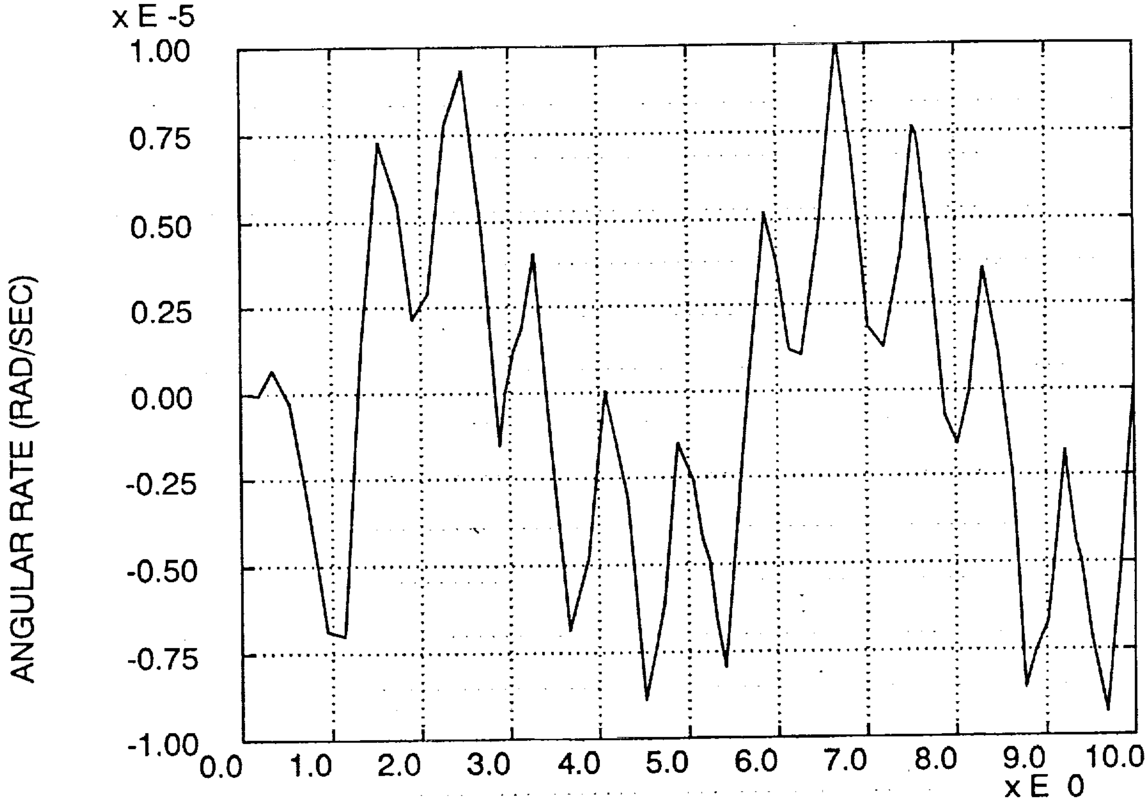


FIGURE 7B. RESPONSE TO 1.07/2 CY INPUT

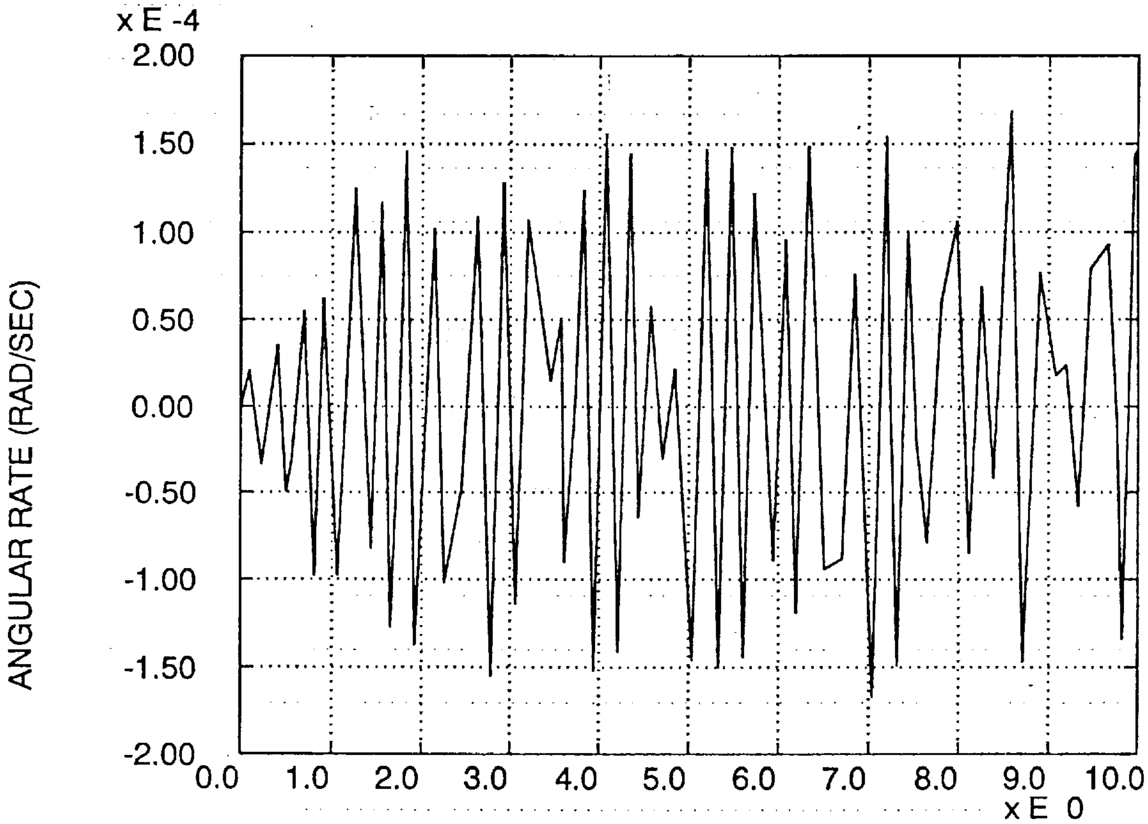


FIGURE 8. RESPONSE TO 3.3 HZ /5 CY INPUT