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SPACE SYSTEMS DIVISION

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IMPACT OF SPACE STATION APPENDAGE VIBRATIONS ON THE POINTING PERFORMANCE OF GIMBALLED PAYLOADS

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OVERVIEW

A permanently manned Space Station is planned to be launched in the mid 1990's and will orbit at about 460 Km and 28 1/2 degrees inclination. The current baseline configuration is the "dual keel" concept and is about 400 ft. long. The spacecraft will orbit in a nadir pointing, gravity gradient orientation with the X axis in the direction of flight. An initial electrical power capacity of approximately 75 Kw will be generated by a combination of photovoltaic solar arrays and point focusing collectors with heat engines. A central thermal heat rejection system for Attached Payloads is planned and will use fluid loops and large articulating radiators.

OVERVIEW

- o SPACE STATION CONFIGURATION
- o GIMBALLED PAYLOAD CONCEPTS
- o SPACE STATION DISTURBANCE ENVIRONMENT
- o VIBRATION RESPONSES AND FAST FOURIER TRANSFORMS
- o DYNAMICS/CONTROL SYSTEM MODEL
- o PERFORMANCE RESULTS

SPACE STATION CONFIGURATION

The Space Station shown represents a Large Space Structure (LSS). As there are no plans to control the flexible modes (in an active distributed sense) and as there are no plans to estimate (observe) flexible vibrations for feed-forward reasons, non-trivial disturbances will exist at locations where gimballed payloads will be mounted. This base plate disturbance represents the major source of error for the gimbal control system.

The Space Station attitude will be controlled by at least six large Control Moment Gyros (CMGs). Momentum build-up will be managed by off-nadir angles or Torque Equivalent Angles (TEA) that generate desirable, momentum-dumping gravity gradient torques. Current estimates of the maximum nominal TEA angles are ±5° in all axes with rates of .02°/sec per axis.

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SPACE STATION CONFIGURATION

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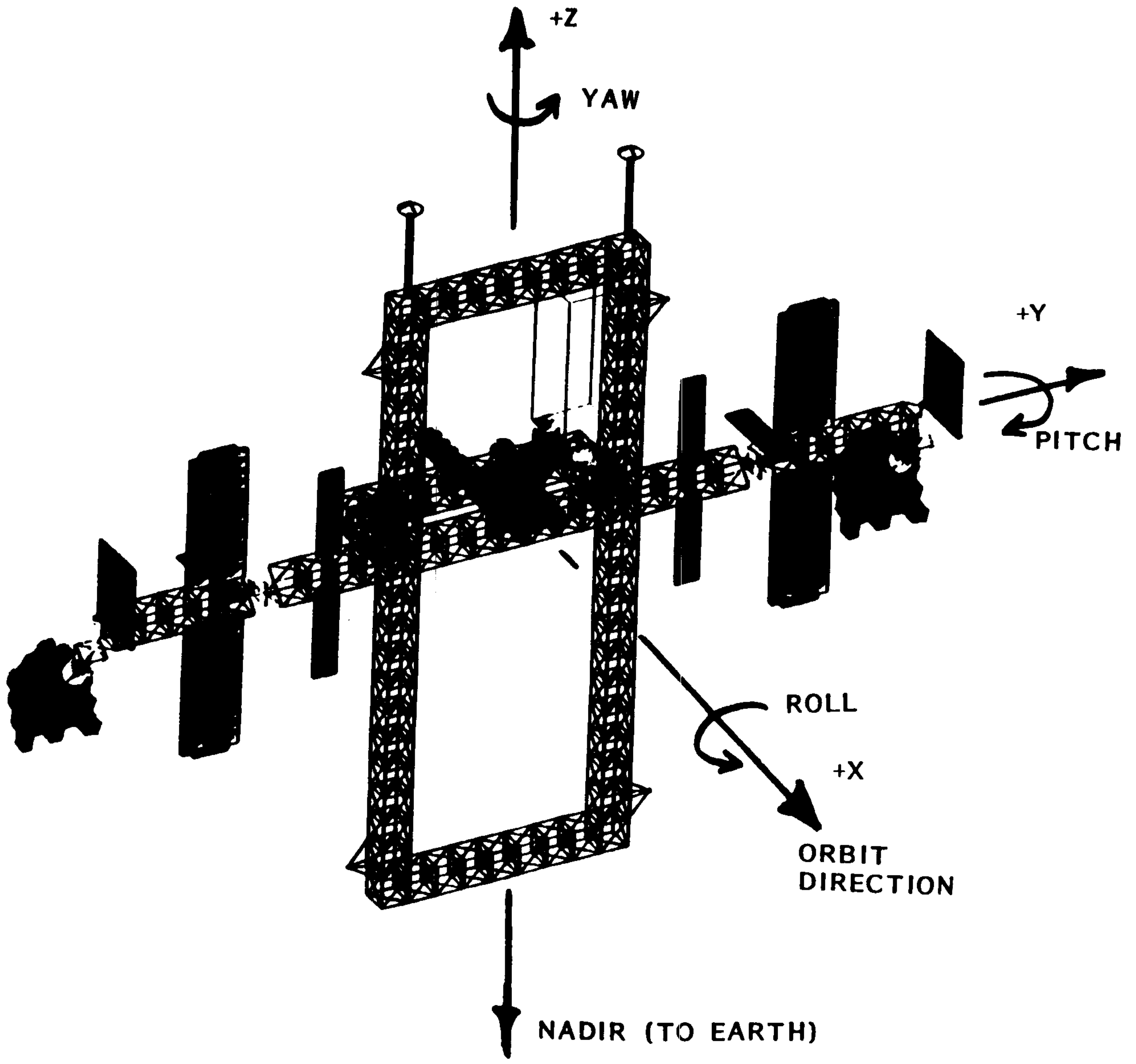

ORIGINAL PAGE IS
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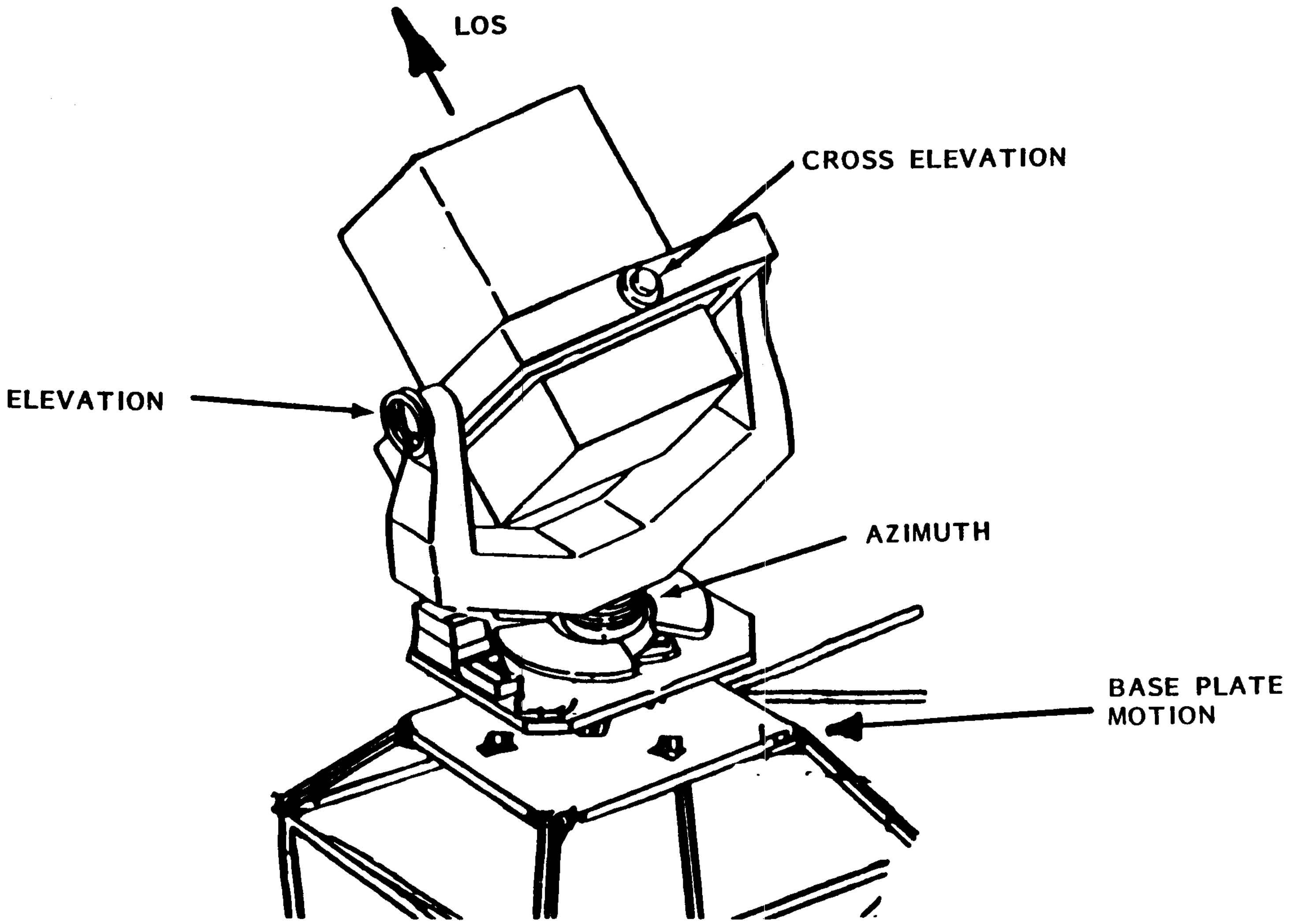
PAYLOAD GIMBAL CONCEPT

Because the Space Station will not be stationary in its reference frame, generic and reusable pointing mounts are envisioned as the most cost-effective method achieving most payload pointing requirements.

Two types of gimbal concepts exist: one for an end-mount and one for a CG mount. The end-mount design is more versatile in payload accommodation than is the CG mount (shown) but suffers from a CG offset problem. The CG mount arrangement shown has a third axis of rotation which alleviates gimbal lock situations.

PAYLOAD GIMBAL CONCEPT



SPACE STATION DISTURBANCE ENVIRONMENT

Small "ever-present" types of Space Station disturbances include: venting, slosh, machinery and pump vibrations, solar array and radiator motions, CMG torques, payload articulations, and console operations. Larger disturbances which occur in a less random manner include: crew member kickoffs, nominal MRMS (Manipulator) operations, tether operations, laboratory centrifuge operations, and astronaut treadmill activities. Very large disturbances which occur at very predictable and discrete points in time are Shuttle docking, RCS reboost (Station keeping via thrusters), and large excursions of the MRMS with massive payloads. It has been determined that the maintenance of precision pointing during periods of large disturbances would not be cost-effective as the induced vibrations are much larger than the other disturbance types. It is expected that these discrete occurrences will be coordinated with payload objective timelines to minimize data loss. However, payload pointing capabilities must be maintained for the two smaller disturbance levels. These levels represent quiescence or background disturbance levels.

SPACE STATION DISTURBANCE ENVIRONMENT

- SMALL DISTURBANCE SOURCES
  - VENTING, SLOSHING, MACHINERY, CMG's
  - SOLAR ARRAY AND RADIATOR MOTION
  - PAYLOAD MOTIONS, CONSOLE OPS, RODENTS
  - THERMALLY - INDUCED VIBRATIONS
- MODERATE DISTURBANCE SOURCES
  - CREW KICKOFF, TREADMILL OPS, CENTRIFUGE
  - TETHERS, NORMAL MRMS OPS

- DEFINED AS QUIESCENT OR BACKGROUND DISTURBANCES
- REQUIRED TO MEET POINTING SPECIFICATIONS

- LARGE DISTURBANCE SOURCES
  - RCS REBOOST, SHUTTLE DOCKING, LARGE MRMS OPS
  - WILL OCCUR AT PREDICTABLE AND DISCRETE POINTS IN TIME
  - MORE THAN 30X LARGER THAN QUIESCENT LEVELS
  - CURRENT PLAN: RELAX POINTING REQUIREMENTS DURING THESE PERIODS

METHOD OF ANALYSIS

To investigate the effects of background sources of excitation, a NASTRAN model of the Space Station was developed. Forcing functions which modeled a "standard" crew kick-off in the pressurized module, treadmill operations, and a centrifuge with a 20 pound mass imbalance were used as inputs to the NASTRAN Model. Vibration levels were assessed at various locations on the Space Station where pointed payloads were likely to be attached, and the largest rotational/translational case was selected. This location turned out to be at the corner of the upper boom.

METHOD OF ANALYSIS

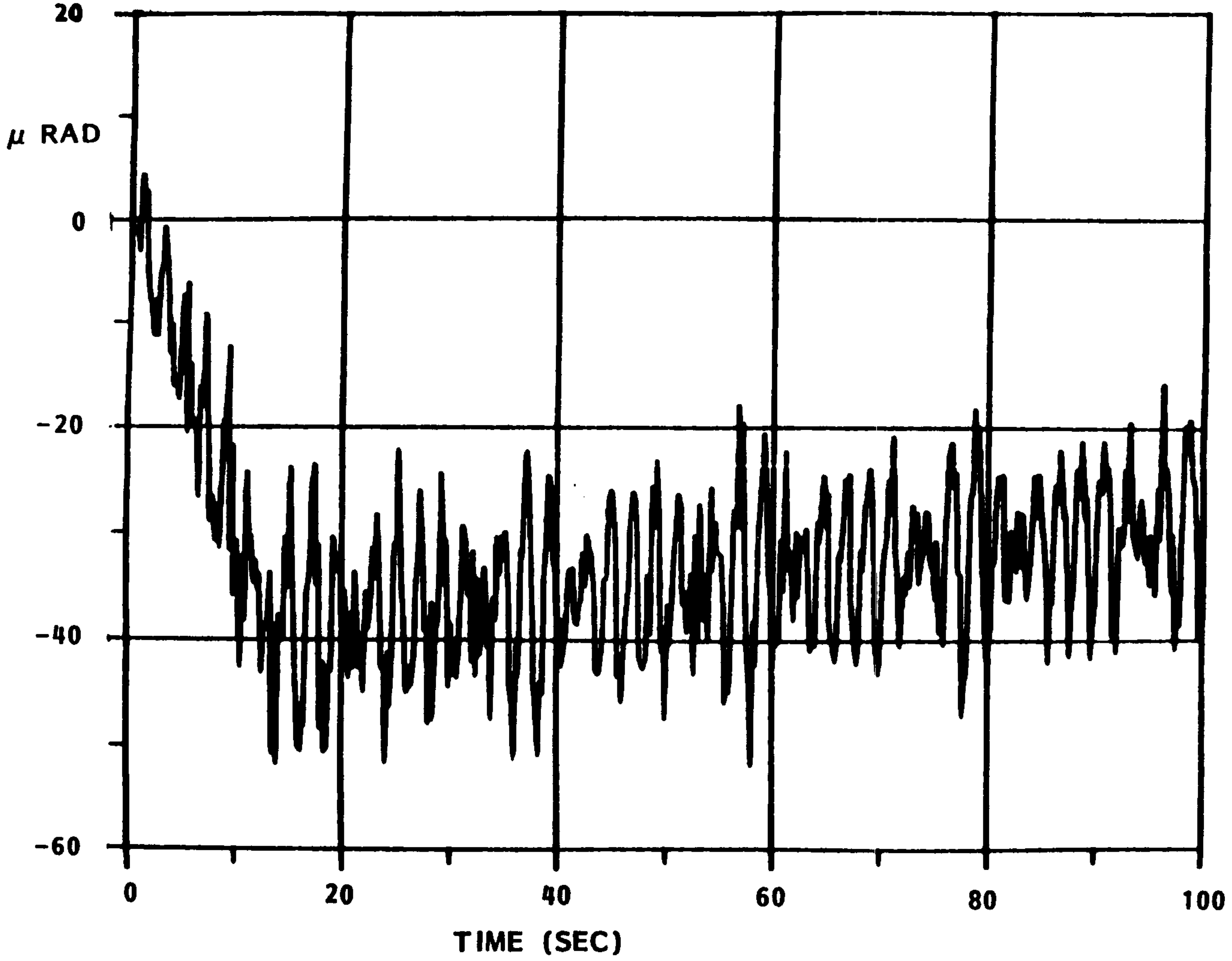
- SELECT DISTURBANCE SOURCES
  - CREW KICKOFF, CENTRIFUGE, AND TREADMILL OPS
- OBTAIN NASTRAN MODEL OUTPUT RESPONSES
- ASSESS VIBRATION LEVELS AT VARIOUS LOCATIONS OF SPACE STATION WHERE PAYLOADS MAY BE ATTACHED
- SELECT WORST CASE ROTATION AND TRANSLATION
- PERFORM FAST FOURIER TRANSFORM (FFT) ANALYSIS
- USE THE FFTs IN THE CONTROL SYSTEM DYNAMIC MODEL TO ASSESS IMPACT ON POINTING PERFORMANCE

DISTURBANCE RESPONSE

This time history plot is generated from NASTRAN modal data and the selected disturbance inputs. The response is for the rotational motion about the pitch axis. Effects of the crew kick-off can be seen with an initial displacement of approximately 40 microradians (8.3 arc-sec). High frequency vibrations are evident with a maximum peak-to-peak variation of about 7.7 arc-sec.

DISTURBANCE RESPONSE

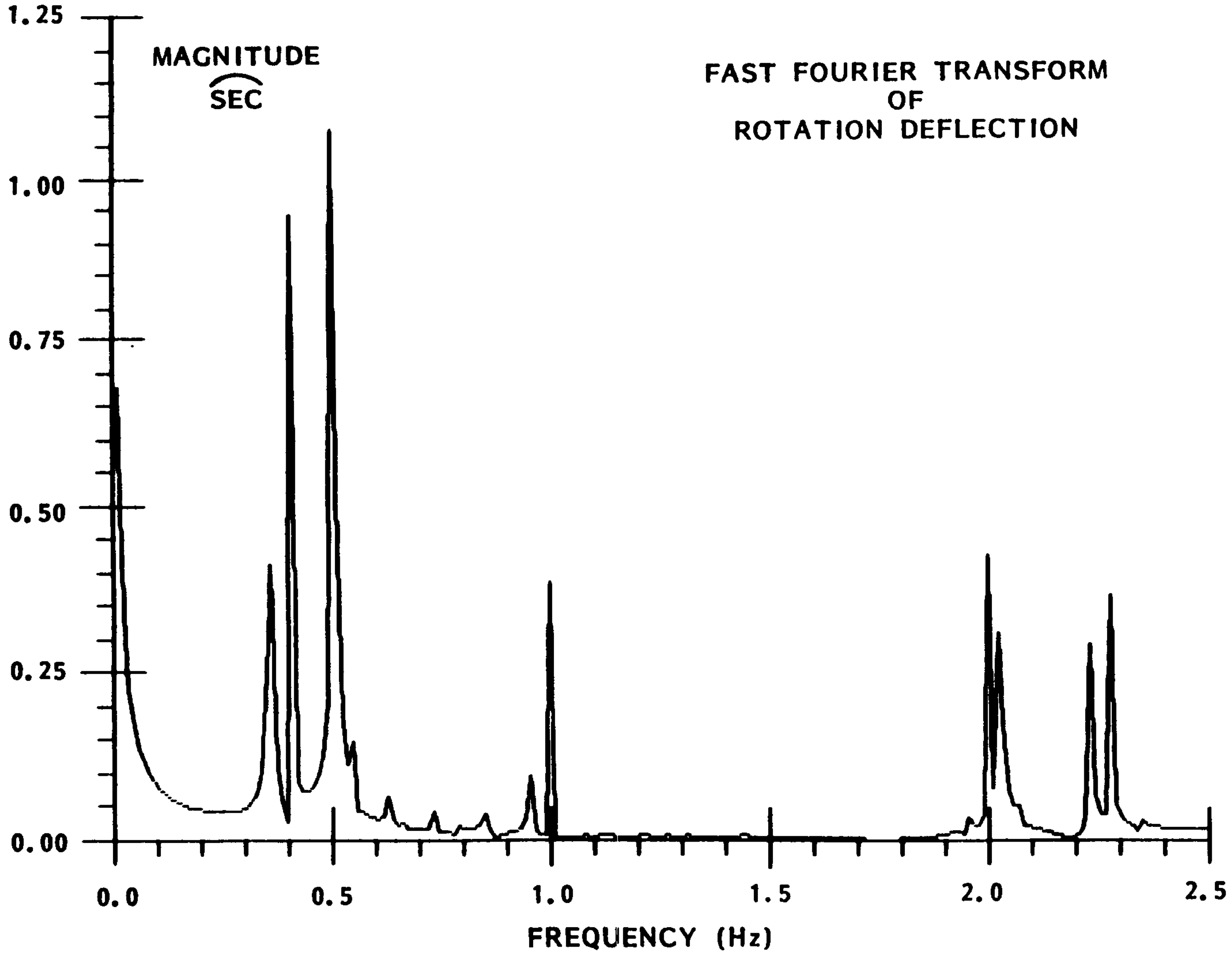
UPPER BOOM ANGULAR DEFLECTION



ROTATION DEFLECTION FFT

The previous time history was analyzed using Fast Fourier Transform (FFT) techniques and the results are shown in this figure. The peaks represent the rotational amplitudes of the major sinusoids present in the signal. In general, base plate motions with frequencies outside the control system bandwidth (nominally 1 HZ) will pass without attentuation. That is, base plate motions cause corresponding pointing errors.

ROTATION DEFLECTION FFT



FAST FOURIER TRANSFORM
OF
ROTATION DEFLECTION

LINEAR ACCELERATION FFT

Another time history of worst case linear acceleration (ft/sec^2) was analyzed using the FFT process and the result is shown in this figure. Linear accelerations act through center-of-gravity offsets on the payload mass and cause disturbance torques about the gimbal axes. These torques cause additional pointing errors. The large peaks at 1 HZ and 2 HZ are caused by treadmill operations. Isolation of the treadmill will lower these peaks.

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LINEAR ACCELERATION FFT

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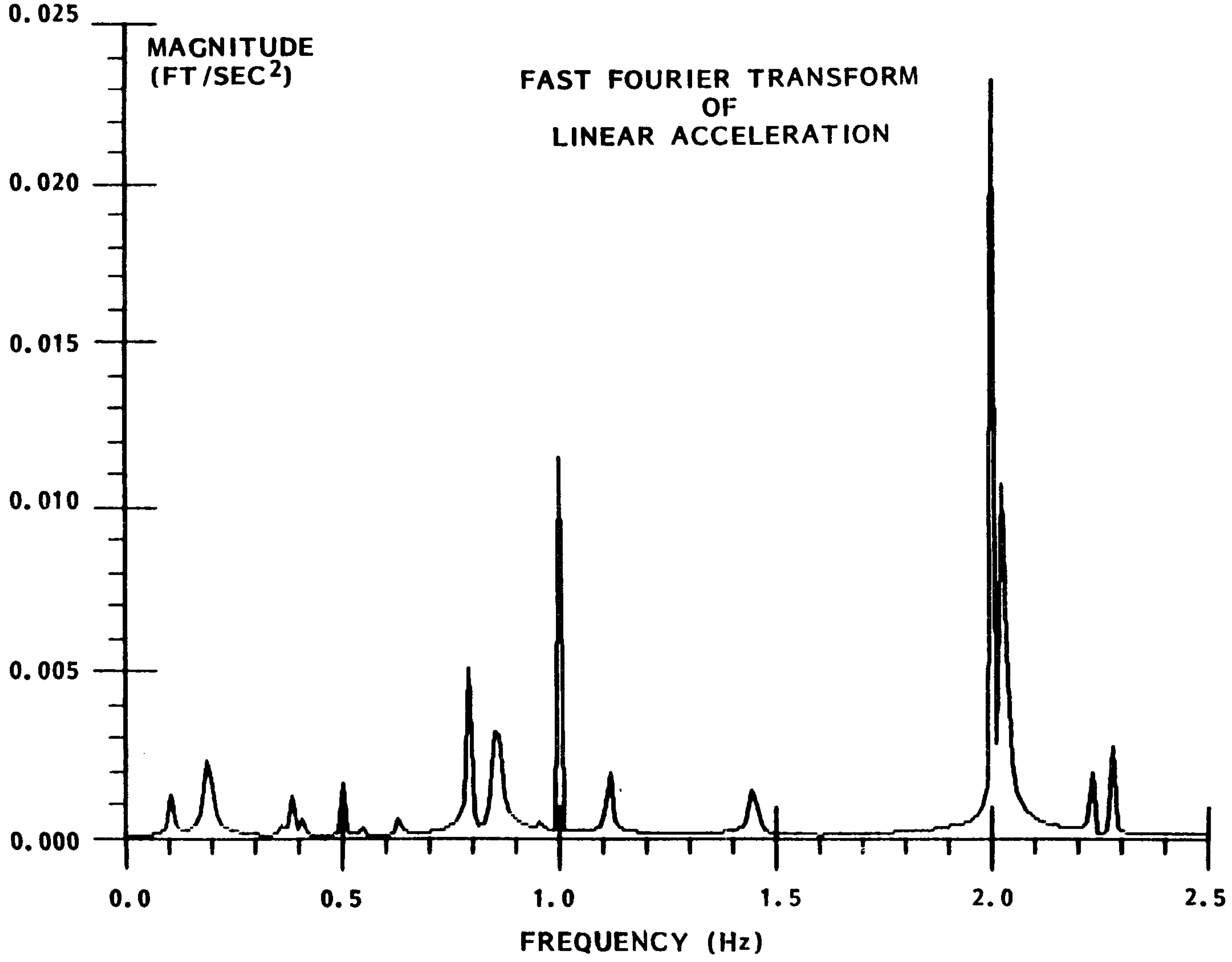
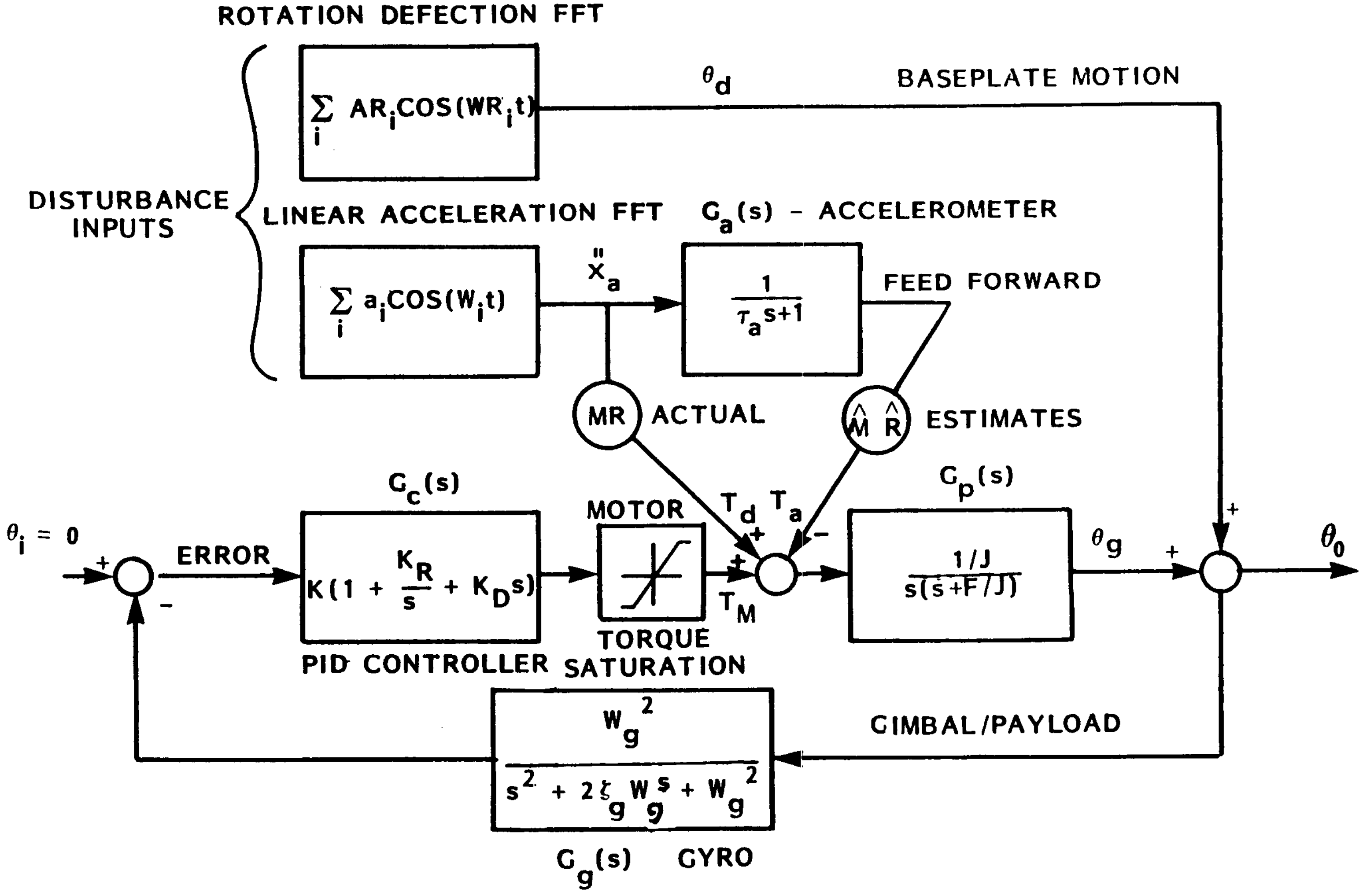


DYNAMIC MODEL

The type of controller chosen for the conceptual design of the PPS is the classic Proportional - Integral - Derivative (PID). This control design is not optimal and other techniques probably could provide higher performance; however, the PID design is well understood and provided needed versatility in the early stages of analysis. Major assumptions for the model included no non-linearities, no noise, no sampling effects, no flexibility problems, perfect torque motor, no cable wrap-up torques, and perfectly known orbital velocity. The accelerometer provided the capability for introducing a feed-forward signal into the loop.

DYNAMIC MODEL



TYPICAL SIMULATION RESULTS

A time domain simulation model of the PPS dynamic system was developed and a typical simulation result is shown in the figure. It can be seen that the pointing error is about ±15 $\widehat{sec}$ while the base plate motion is about ±5 $\widehat{sec}$. This additional error is due to the CG offset. Nominal parameters are:

M = 2000 Kg
R = .1 m
J = 1100 slug - ft^2
F = 100 ft-lb/rad/sec
Bandwidth = 1 HZ

No Accelerometer Feedforward

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TYPICAL SIMULATION RESULTS

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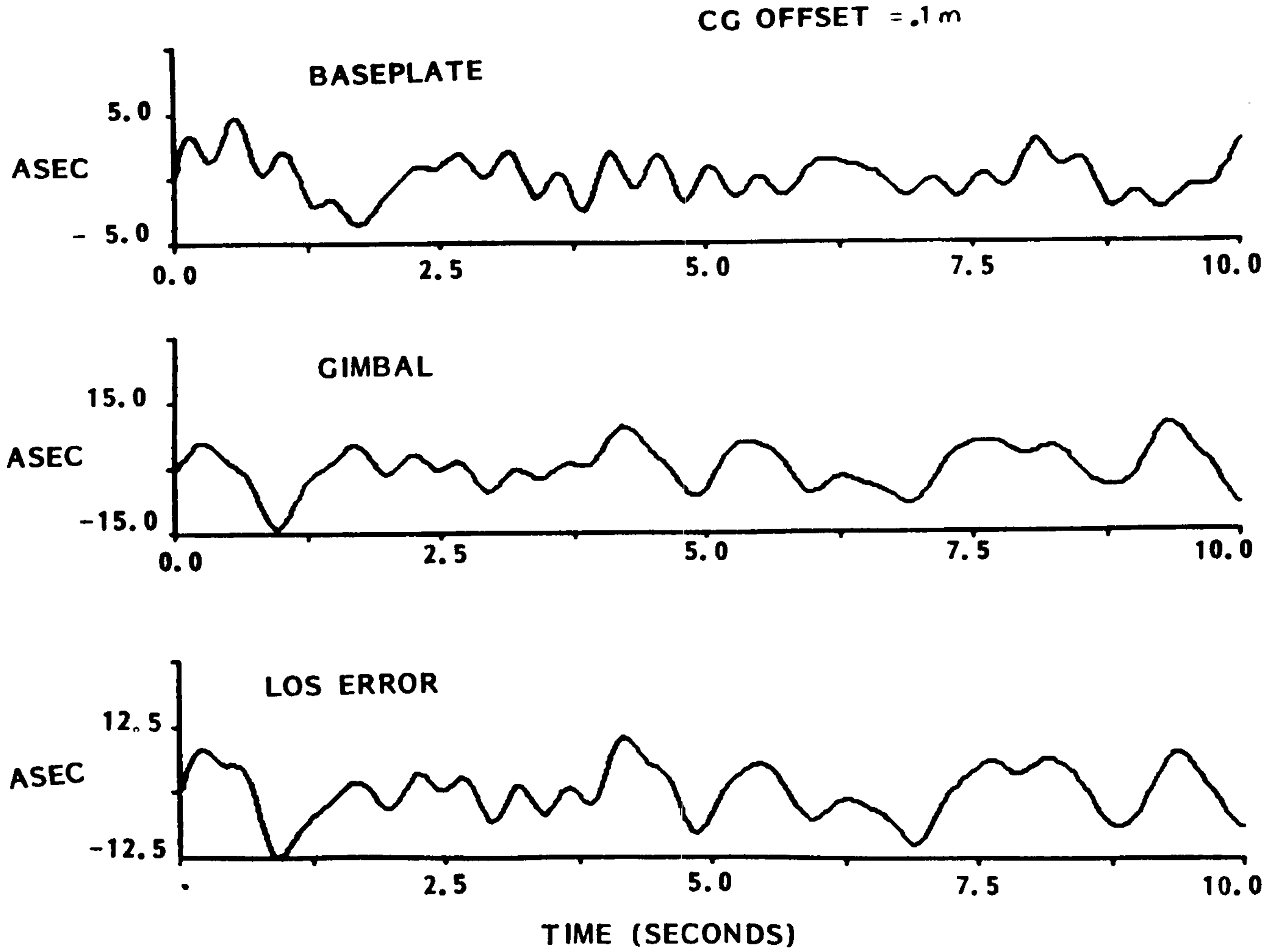
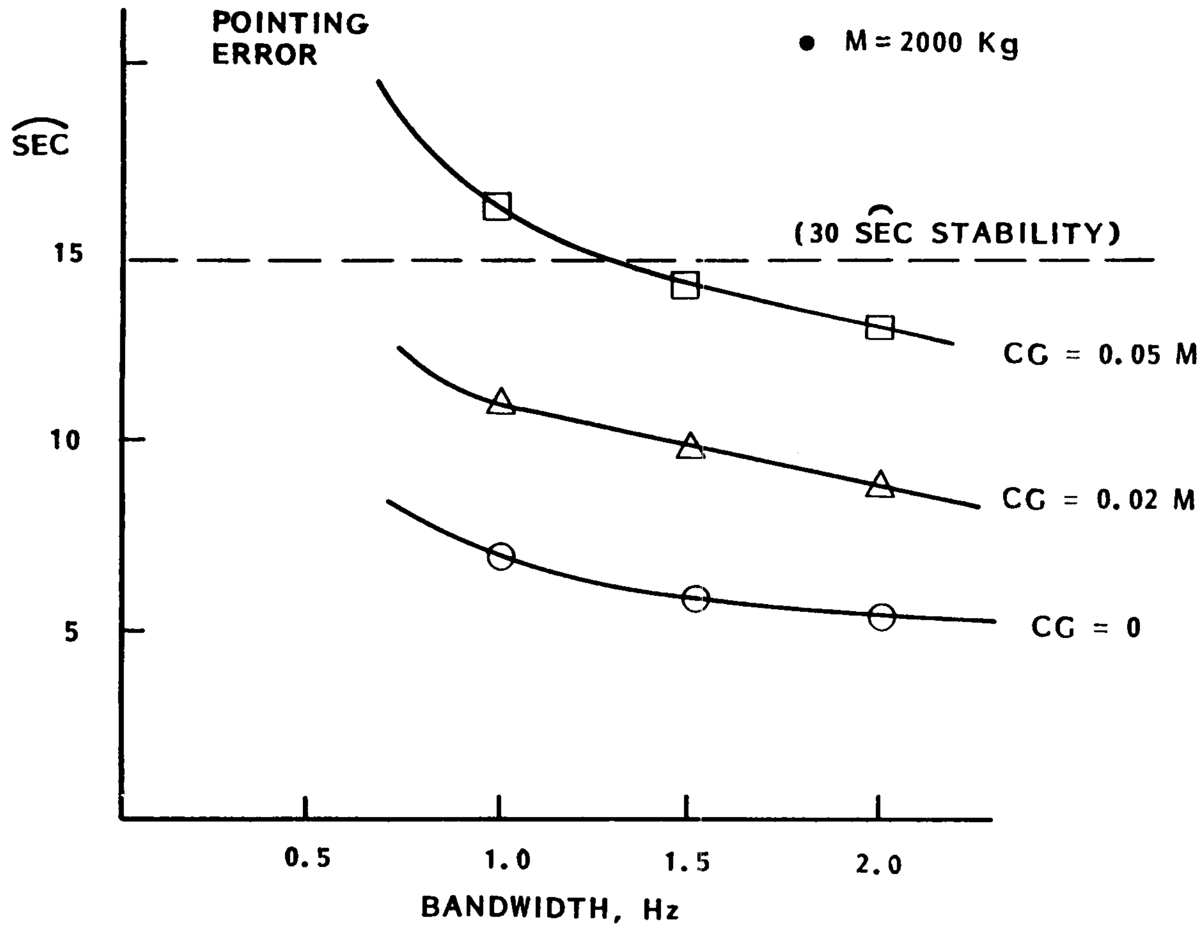


POINTING ERROR SENSITIVITY

One of the most important and descriptive parameters of a control system is its bandwidth. In general, bandwidth, or passband, is the range of frequencies that can pass through a control system. Bandwidth is defined herein as "the -3db point of the closed-loop transfer function". Many factors impact the bandwidth of a system and include: controller design, structural flexibilities, nonlinearities, component bandwidths, component noise characteristics, and gain/phase stability margin specifications.

Variations in pointing error or stability error are shown in the figure for different bandwidths and various CG offsets. It is estimated that there will be a ±.05m CG uncertainty on orbit even with the use of an on-line mass balancing system. Without such a balancing system, an error of about ±.2m is estimated.

POINTING ERROR SENSITIVITY



CONCLUSIONS

A study of the interface problems between the Space Station Structure (vibrations) and the Payload Pointing Control System was undertaken. A major goal of the study was to identify any bounding factors that might limit the achievement of required pointing accuracies. A major result is that the Space Station will have a disturbance-rich environment and background levels will be large enough to impact the pointing of some of the payloads. The need for an interface vibration specification between the structure and payloads was identified.

CONCLUSIONS

- o PRELIMINARY INTERFACE STUDY BETWEEN SS STRUCTURE AND PAYLOAD POINTING SYSTEMS COMPLETED
    - o BASIC RESULT - SS BACKGROUND OR QUIESCENT DISTURBANCE LEVEL IS LARGE ENOUGH TO IMPACT PAYLOAD POINTING.
    - o IDENTIFIED NEED FOR SPECIFICATION OF VIBRATION LEVELS AT PAYLOAD INTERFACE.
- o STUDY SOUGHT TO IDENTIFY BOUNDING PARAMETERS AND LIMITS
    - o INCREASES IN CONTROL SYSTEM BANDWIDTHS CAN DECREASE POINTING ERRORS. HOWEVER, STATE-OF-ART COMPONENTS LIMIT BANDWIDTHS TO ABOUT 1-2 HZ.
    - o MASS BALANCING SYSTEM REQUIRED - TO KEEP CG OFFSETS TO WITHIN ±.05 M.
    - o DISTURBANCE FREQUENCIES OUTSIDE THE CONTROL BANDWIDTH INDUCE LARGEST ERRORS. ISOLATION OF OFFENDING SOURCES MAY BE REQUIRED.