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CONTROLS, ASTROPHYSICS, AND STRUCTURES EXPERIMENT IN SPACE (CASES)

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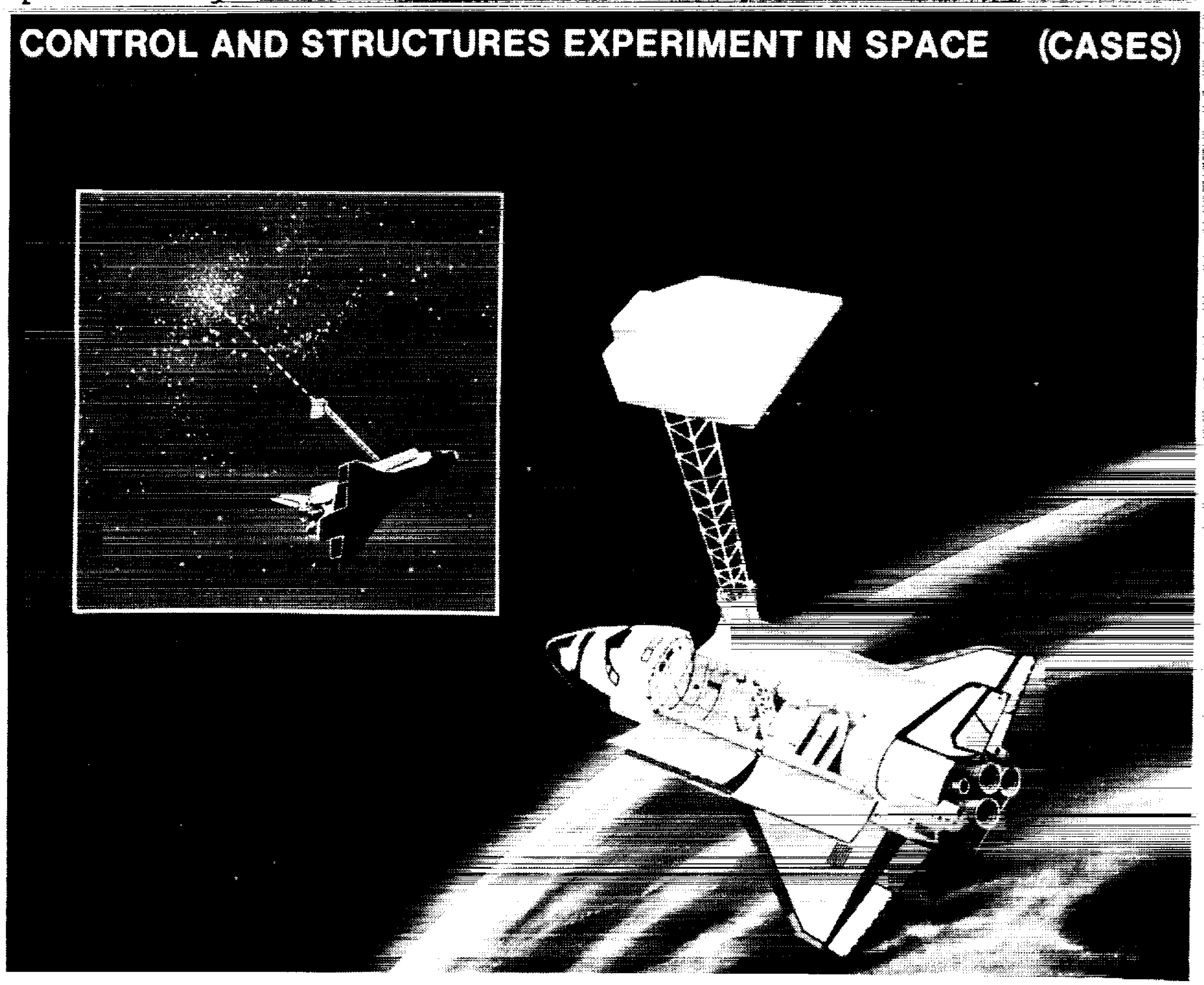
ABSTRACT

As the size and performance requirements of future NASA and DoD spacecrafts and payloads tend to increase, the associated control systems that must effect these requirements tend to interact with the vehicle's structural dynamics. Some of the Control Structure Interaction (CSI) issues are being addressed in a flight experiment which is entitled CASES (Controls, Astrophysics and Structures Experiment in Space). As one of the first CSI flight experiments, the main emphasis for CASES is to provide a test bed for validating CSI developments and, simultaneously, to pave the way for subsequent CSI experiments and science missions by establishing precedents for flight qualifying Large Space Structures (LSS)-class spacecraft. In addition, CASES provides an opportunity to obtain data bases for in-space controls and structures experiments and, at the same time, to gather hard X-ray data from pertinent galactic sources.



INTRODUCTION

The CASES will investigate critical control technology applicable to stabilizing and pointing large flexible structures in space. To fully understand and control LSS, the ability to identify and characterize system parameters in space must be demonstrated. To perform system identification the experiment on-orbit modal tests must be conducted to determine natural frequencies and mode shapes. System parameters will then be used to modify control gains used in closed-loop tests. These tests will verify both CSI controller design methodologies and parameters predictive techniques. Such verification is impossible on the ground because of gravity, seismic, and atmospheric effects.

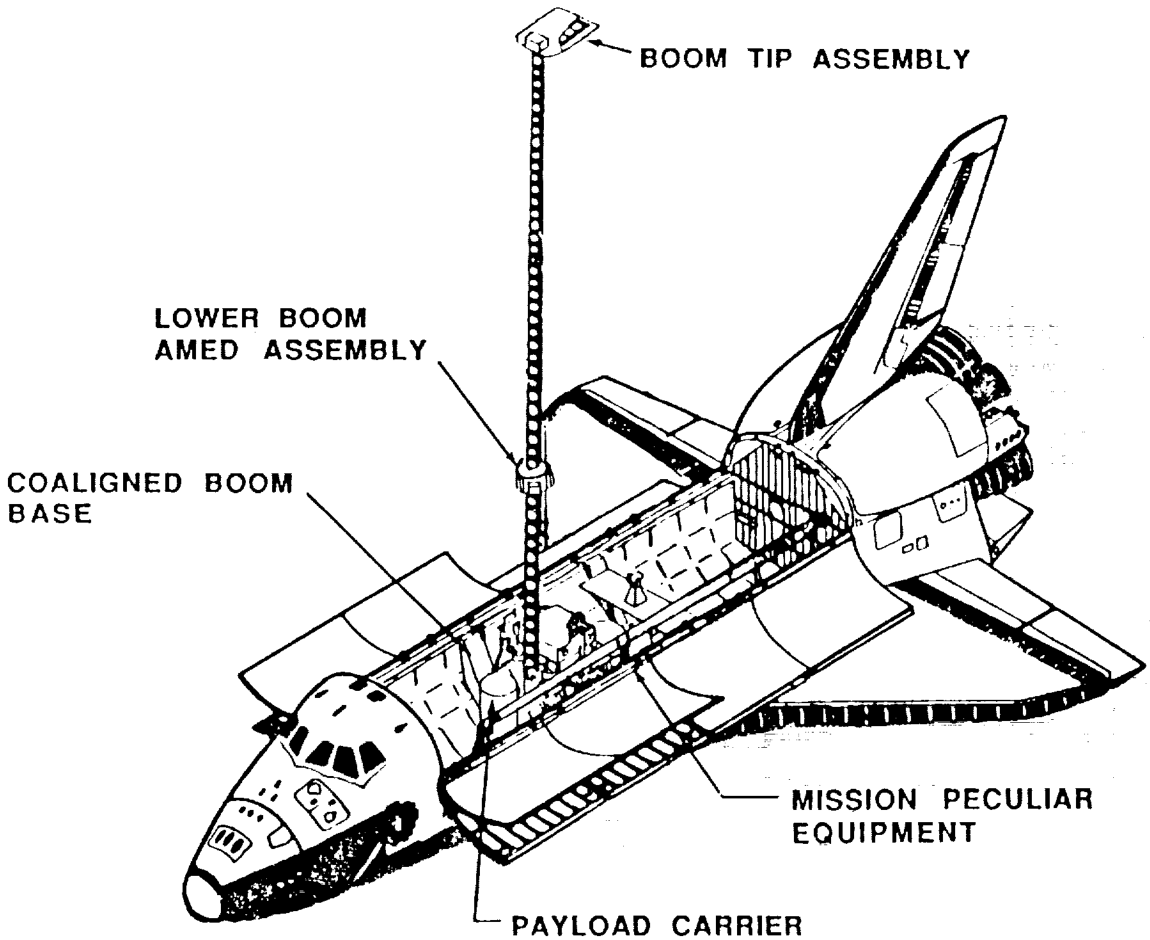
The control of a 32-m extendable boom, as used in the Solar Array Flight Experiment (SAFE) program, will be performed using small cold gas thrusters for pointing and Angular Momentum Exchange Devices (AMEDs) for active damping to suppress vibrations. Since the boom is rigidly attached to the orbiter, the orbiter/boom system can be pointed to a predetermined target for periods of at least 30 minutes. In addition,tracking and slewing of the orbiter at small angular rates by the tip-mounted thrusters will be demonstrated.

The CASES will provide accommodations for an Astrophysics/Solar Physics Hard X-ray Imaging experiment. This experiment will address important issues in high-energy astronomy (in particular, the identification of the energy source seem at the galactic center and determination of the energy release mechanics in solar flares). The high-energy imaging is made possible by aperture plates mounted on the tip of the boom. They provide both coded aperture and Fourier-transform imaging on position sensitive, proportional counter arrays placed in the cargo bay (at the base of the boom). High spatial resolution is made possible by the large separation between masks and detectors afforded by the boom.

At this time it is envisioned that funding for the CASES definition phase study will be available in FY 1989 with actual work starting in the beginning of CY 1989. Development (phase C/D) program start is planned in FY 1990 with the CASES flight occurring in late CY 1993.

The CASES program is sponsored jointly by the office of Space Science and Applications and the Office of Aeronautics and Space Technology. Marshall Space Flight Center (MSFC) will manage the overall program. Langley Research Center will support MSFC in experiment definition and conduct the Guest Investigators Program. Johnson Space Center will assess the operational aspects of the program relative to the orbiter systems.

CONTROL, ASTROPHYSICS, AND STRUCTURES EXPERIMENTS IN SPACE



CSI Experiment Objectives

The CASES will provide an on-orbit test bed for demonstrating the flight readiness of several key aspects of CSI technology. Since the proposed CSI control concepts represent a significant departure from conventional control methods, the emphasis will be on the ability to accurately predict, based upon analytical models and ground test methods, the on-orbit open- and closed-loop performance of a beam-like LSS, and then to successfully verify the implementation of these CSI methods in orbit. The success of this mission will enable future missions, which may require CSI technology but which are too large for full-scale ground tests, to be safely operated in-orbit with control systems derived from analytic models alone.

- Determination of the degree to which theory and ground tests can predict open- and closed-loop performance of large, flexible deployable structures in space.
- Evaluation of system identification and state estimation algorithms in the space environment.
- Analysis of deployment dynamics and structural damping in space.
- Ground and flight demonstration of Multiple Input/Multiple Output (MIMO) control laws, and robustness of such control laws to model uncertainties and perturbations.
- Demonstration of pointing and tracking control of a LSS using linear Bidirectional Thrusters (BLT's) acting over a long flexible moment arm.
- Evaluation of the operational use of unobtrusive sensor technology for measuring low-frequency, low-amplitude motions of LSS.
- Demonstration of real-time MIMO control law reconfiguration and fine tuning in orbit.
- Achievement of well-defined (sub-arcminute) pointing and stability requirements in support of the X-ray imaging experiments that necessitate the use of CSI technology.

CASES
CSI EXPERIMENT OBJECTIVES

SYSTEM IDENTIFICATION TECHNIQUES

- o ON-ORBIT APPLICATIONS
  - OPEN LOOP
  - CLOSED LOOP
- o SENSITIVITY AND PERTURBATION METHODS
- o UNOBTRUSIVE MEASUREMENT TECHNIQUES

STRUCTURES

- o MECHANISM DEMONSTRATIONS
- o CHARACTERIZATION
- o VALIDATION OF ANALYTICAL AND GROUND TEST METHODS
- o DEPLOYMENT DYNAMICS
- o INVESTIGATION OF STATIC DEFORMATIONS

CONTROLS

- o POINTING OF FLEXIBLE BODIES
- o VIBRATION SUPPRESSION
- o TRACKING AND SLEWING OF FLEXIBLE BODIES
- o SENSOR/EFFECTOR APPLICATIONS
- o REAL-TIME CONTROL CHANGES AND UPDATES
- o SENSITIVITY AND ROBUSTNESS CHECKS
- o DEVELOPMENT OF MISSION OPERATIONS FOR INTERACTIVE CONTROL EXPERIMENTS
- o PERFORMANCE GOALS COMPATIBLE WITH SCIENCE OBJECTIVES (SUB-ARCMINUTE)

SCIENTIFIC OBJECTIVES

Hard X-ray emission is the signature of energetic processes which, through the release of large amounts of energy, accelerate charged particles to high energies. Although these processes appear to be quite common throughout the universe, an exact physical description of the acceleration mechanism still eludes us. On the local scale the Sun is the source of such events. Here we believe that magnetic fields emerging from the solar surface are forced into unstable configurations by the motion of the solar atmosphere. Reconnection of the magnetic lines of force to form a new configuration, with a lower potential energy, results in a rapid release of energy, much of which goes into the acceleration of charged particles. This energy release is observed as a solar flare. Magnetic activity in stars is quite commonplace and in many instances gives rise to considerably more energetic events than we observe on our Sun.

Within our galaxy we believe that hard X-rays are emitted by material which is accelerated to high velocities as it falls into the gravitational potential of extremely dense, compact objects such as neutron stars, or through nuclear processes that occur explosively within these objects. On an even larger scale are the unknown processes that drive the energy release mechanisms in quasars and the nuclei of galaxies. It is speculated that this energy may be released by the infall of material into supermassive black holes or from frequent collisions within a dense cluster of neutron stars or stellar black holes at the galactic center.

Our understanding of the processes involved in the acceleration and propagation of the high-energy particles can be advanced, in both the solar and extra-solar environments, by tying down the location of the emission so that the hard X-ray signature can be related to the conditions existing before and during the release of energy and by allowing the phenomena to be observed with different instruments capable of specialized diagnostic observations over a wider spectral range. At the present time one of the roadblocks to improved understanding has been the wide disparity between the angular resolution of the hard X-ray observations and those in other wavebands. The CASES will be a major step in eliminating these disparities. The large separation between the ends of the boom makes possible angular resolutions of one to two arcsec, an improvement of between one and two orders of magnitude over past observations. This is achieved without having to exceed the current performance of detectors or aspect systems.

Two specific studies have been selected as the strawman objectives for the CASES. The selection was based both on their inherent scientific interest and for their compatibility with the proposed instrument performance.

SCIENCE OBJECTIVES FOR CONTROL ASTROPHYSICS STRUCTURES EXPERIMENT IN SPACE (CASES)

SOLAR OBSERVATIONS

DETERMINE THE HIGH TEMPORAL AND SPATIAL CHARACTERISTICS OF HARD X-RAY EMISSIONS FROM SOLAR FLARES AND MICRO FLARES.

USING THESE DATA INVESTIGATE THE NATURE OF ENERGY RELEASE, TRANSFORMATION, AND SOURCES IN THE SUN'S ATMOSPHERE.

GALACTIC OBSERVATIONS

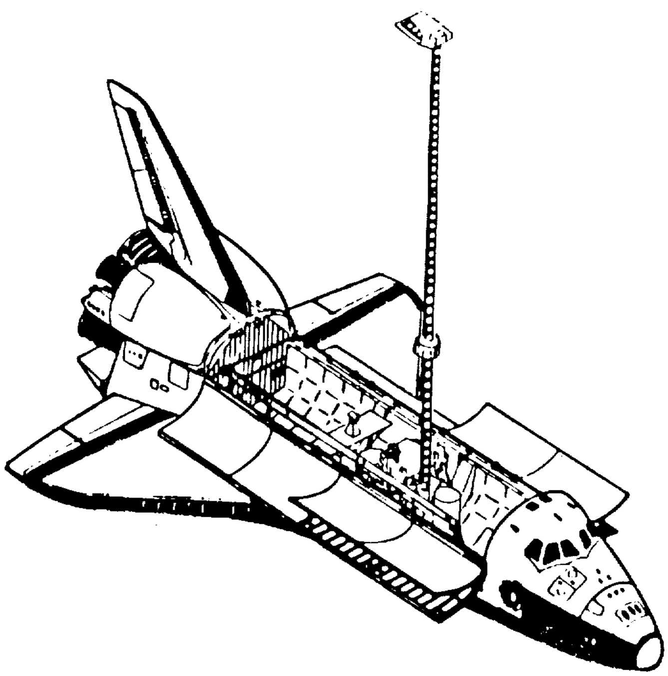
DETERMINE THE EMISSION CHARACTERISTICS AND CELESTIAL POSITION OF HARD X-RAY EMISSIONS AT THE GALACTIC CENTER.

USING THESE DATA CORRELATE THE X-RAY EMISSION WITH INFRARED AND RADIO SOURCES AND DIFFERENTIATE BETWEEN EMISSION MODELS OF BLACK HOLES AND RECENT STAR BURST FORMATION AT THE GALACTIC CENTER.

CASES MISSION AND EXPERIMENT REQUIREMENTS

The mission and experiment requirements for this experiment are summarized below. The mission requirements are an altitude of 200-300 nmi, inclination of 28.5°, and mission duration of 6 days.

The experiment requirements for the Astrophysics and Guest Investigators include minimum operation time from 8 hours to 3 days.



MISSION REQUIREMENTS

- O 200-300 Nautical Miles
- O 28.5° Inclination
- O 6 Days of Orbit Operation
  - 1 Day for Experiment Alignment
  - 2 Days of Operation for the Hard X-Ray Imaging Experiment
  - 3 Days for Guest Investigators to run their experiments

EXPERIMENT REQUIREMENTS

HARD X-RAY IMAGING EXPERIMENT

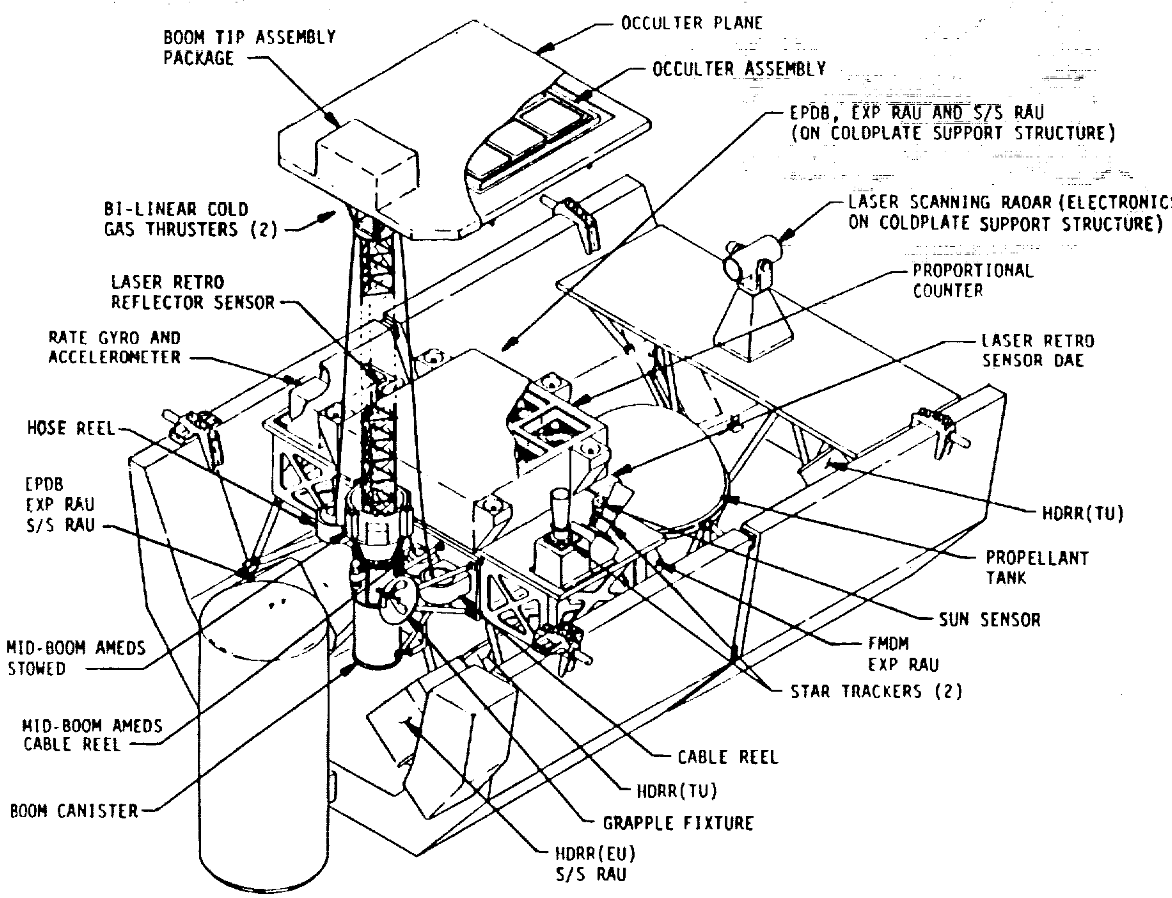
- O Needs a translation table that can move the mask ±6 inches in the X-Y orbiter plane. Also ± 1° in pitch and yaw.
- O The mask cannot tilt more than >.25°
- O Need 8 hours minimum but 48 hours of operation preferred.

CASES EXPERIMENT CONFIGURATION

The configuration for the CASES experiment is shown below. All the major components of the experiment are labeled. The proposed CASES configuration uses as much of the Spacelab equipment as possible to reduce costs. As can be seen, CASES uses two Spacelab Pallets and an Igloo in which reside three AP101SL flight computers. The undefined acronyms in the figure are as follows:

FMDM - Flexible Multiplexer DeMultiplexer
HDRR - High Data Rate Recorder
EPDB - Electrical Power Distribution Box
RAU - Remote Acquisition Unit
S/S - Subsystem
EU - Electronic Unit
TU - Telemetry Unit

CASES EXPERIMENT ON SPACELAB PALLETS



CASES

MODAL ANALYSIS

The model analysis follows.

* The first mode (lowest cyclic frequency) has a cyclic frequency of 0.0345 Hz (28.98 sec/cycle). This is the lowest natural frequency of the system and results in the largest tip displacements.

* The third mode is the first torsional mode of the structure and has a cyclic frequency of 0.1306 Hz. This is the lowest torsional mode and results in large angular displacements (twist) of the tip mass.

* Modes 1 and 2 are bending modes in the xz and yz plane, respectively, and result in large tip displacements. Mode 1 also develops rotation about the z axis because of the tip C.G. offset.

* Mode 3 is the first torsional mode (about the z axis). Bending is also present during this mode because of the C.G. offset.

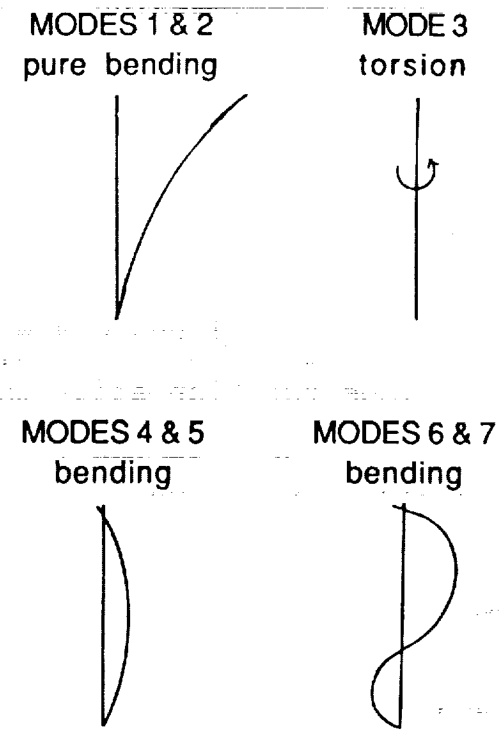
* Modes 4 and 5 represent the second set of bending modes in the xz and yz planes, respectively. At these modes the tip mass displacement is relatively small and acts as a node.

* Modes 6 and 7 are more complex bending modes, also in the xz and yz planes. The displacement of a point just ahead of the mid-boom assembly is very small, as is the displacement of the tip. Both the tip and the point ahead of the mid-boom assembly act as nodes.

CASES

MODAL ANALYSIS

MODE #	EIGENVALUE	CYCLIC FREQUENCY (Hz)
1	0.04707	0.03453
2	0.04768	0.03475
3	0.67314	0.13058
4	10.1710	0.50758
5	10.3799	0.51277
6	89.0345	1.50176
7	96.3628	1.56234



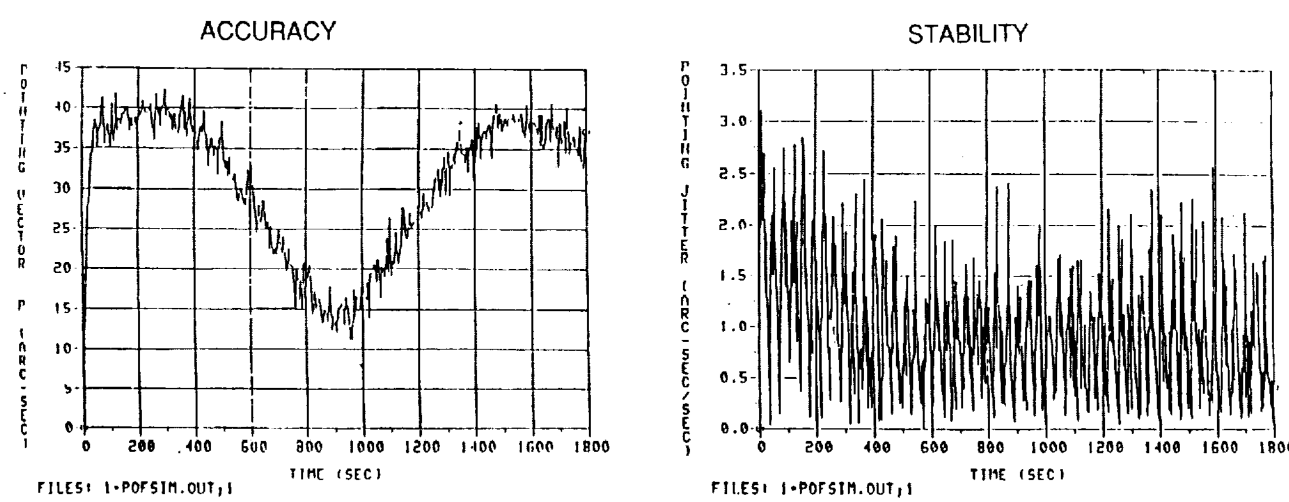
POINTING REQUIREMENTS

The hard X-ray images are built up by photon counting rather than by integration. Consequently, provided it is possible to develop, post facto, an accurate aspect solution, the requirements on the pointing system are not particularly severe. They are expressed in terms of the pointing error that is defined as a vector equal to the difference between unit vectors along the internal and pointing axes. The internal axis is a line joining corresponding points on the upper and lower grids and the pointing axis is the line from a reference point on the lower grid directed toward the target. The requirements that we have established are:

- Accuracy: The pointing error shall not exceed 2.0 arc min. This is set by field-of-view considerations.
- Stability: The jitter in the pointing error shall be less than 4 arc sec per sec. This requirement is derived from the frequency with which the star tracker can be sampled.
- Roll: Drift in roll shall be maintained within 2° in any one-hour period, and the system shall be capable of acquiring new roll positions with a frequency of once per orbit and an accuracy in the initial position of 1°.

The performance of the control system has been modelled using several different control algorithms. Results for accuracy and stability, typical of worst-case conditions, are reproduced in the chart. The models include the effect of crew motion and gravity gradient and aerodynamic torques. The results are based on ground test and inflight data and provide a high level of confidence in our ability to control the boom with a precision that is adequate for the scientific observations.

POINTING SIMULATIONS



ATTITUDE CONTROL EQUIPMENT LIST

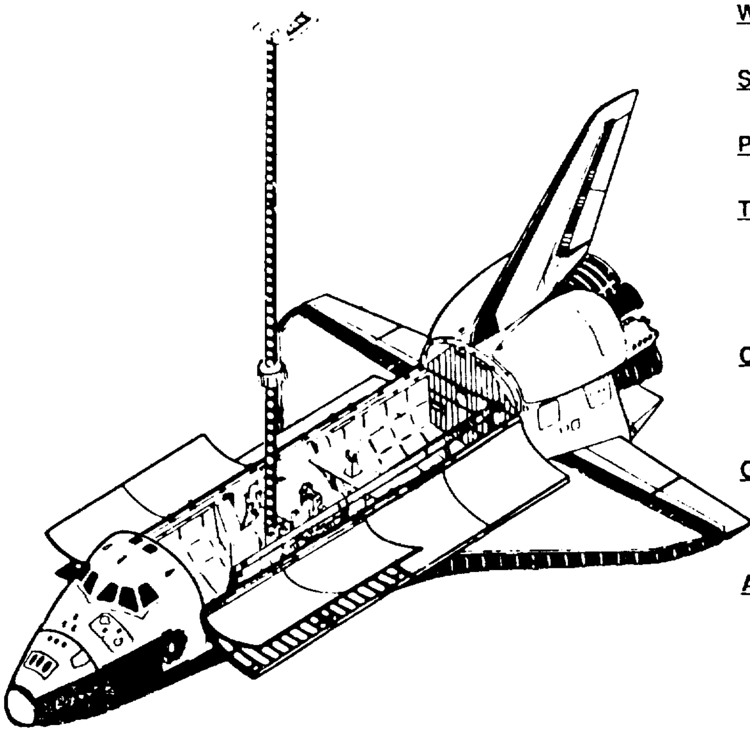
This figure consists of an equipment list for the GN&C subsystem that will meet the experiment requirements. The power and weight for each component are shown. The orbiter GN&C system is also used during this experiment. The components are broken down into the components on the base, components on the boom and components on the tip of the boom. The Bidirectional Linear Thrusters (BLTs) are used for fine pointing and also slewing and vibration suppression. The Angular Momentum Exchange Devices (AMEDs) are used for vibration suppression and distributed control of the boom. The star trackers and fine Sun sensor are used for pointing direction knowledge, and the rate gyros give deviations from this desired pointing over time. The laser scanning radar is used for system identification.

EQUIPMENT	NUMBER	POWER (W)	WEIGHT (LBS)
BASE			
STAR TRACKERS	2	20	88
FINE SUN SENSOR	1	25	22
RATE GYROS	2	20	42
ACCELEROMETERS	3		
RFT	1	55	50
LASER SCANNING RADAR	1	150	200
BOOM			
AMEDS	3		
PLUS ELECTRONICS		15	25
RATE GYROS	2		
TIP			
AMEDS	3		
PLUS ELECTRONICS		15	25
RATE GYROS	2		
BLT	2	5	6
ROLL TORQUE MOTOR	1	5	10.5
PARAMETER MODIFICATION SYSTEM	1	10	40

CONCLUSIONS

There are no technical or safety issues resulting from preliminary studies that are without resolution. The preferred configuration for this experiment is a two Spacelab Pallet train with Igloo. The Spacelab AP101SL computers will be used and housed in the Igloo. There are ample volume, power, weight, and crew time for payload sharing to help utilize extra pallet space. This figure is a summary of the configuration and the subsystems represented in this experiment.

The general control of the Space Shuttle using the CASES experiment will need to be validated through vigorous ground simulations. These simulations will be performed in the CSI ground facility that will be located at MSFC and will be called the CASES Advanced Development Facility.



WEIGHT:	13600 LBS
STRUCTURE:	Boom Length 105 ft.
POWER:	Total Power 3236 W
THERMAL:	Standard Spacelab Thermal Protection System (inc. cold-plates)
C & DH:	Overall rate of 2 MBS On-board Storage Periodic Downlink
GNC:	Stability should be within 3 sec/sec Pointing within 1 min
ACS:	500 lbs High Pressure Gaseous Nitrogen (GN_2) 1.5 lb Bi-linear Thrusters