# THE ORBITER STABILITY EXPERIMENT ON STS-40[1]

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## ABSTRACT

The Orbiter Stability Experiment (OSE) was developed and flown to evaluate the steadiness of the STS Orbiter as a potential platform for instrumentation that would image the Sun in its extreme ultraviolet and soft X-ray radiations. We were particularly interested in any high frequency motions of the Orbiter's orientation due to normal operations and manned activities. In this paper we present preliminary results of our observations. Other than the expected slow motion of the Orbiter within the specified angular deadband of 0.1 ° during our observations, we found that high frequency (above 1 Hz) angular motions ("jitter") were not detectable at the 0.25 arc sec detection limit of our most sensitive detector, for most of the period of observation. No high frequency motions were recorded during intervals that we identify with vernier thruster firings. However, one short interval with detectable spectral power to a frequency of 10 Hz has been found to date. It has not yet been correlated with a particular activity going on at the time. The results of our observations may also be of value in assessing perturbations to the Orbiter's micro-gravity environment produced by normal operations.

## OBJECTIVE OF THE EXPERIMENT

The primary objective of the OSE was to obtain a characterization of the Orbiter's spectrum of high frequency angular motions (which we term "jitter"), produced by the operation of mechanical systems, thruster firings, and man motions during normal crew activity. The presence of such rapidly varying motions, although small and not detectable by visual observations, could contribute to a residual microgravity environment at locations on the Orbiter that are not at the center of rotation. The OSE measured angular displacements, and hence, angular accelerations, directly by observing changes in the orientation of the Orbiter in pitch and roll relative to the Sun, using sensors typically flown on solar sounding rockets. We recorded the position of the Sun relative to the Orbiter for upwards of 40 minutes, as the Orbiter was

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maintained in a $-Z_o$ solar inertial attitude by vernier thruster firings.

## DESCRIPTION OF THE INSTRUMENTATION

### OPTICAL SUN SENSORS

The OSE detected the angular Orbiter's motion of the Orbiter's $-Z_o$ axis by measuring the direction of incoming sunlight relative to two optical sun sensors mounted externally on a GAS experiment plate. The sensors used were Lockheed Intermediate Sun Sensors (LISS) provided by the Lockheed Missiles and Space Co. SPARCS Office, White Sands Missile Range, NM, under contract to the Wallops Flight Facility of NASA's Goddard Space Flight Center. Each sensor provided independent pitch and roll measurements. These devices can detect angular changes as small as 0.1 arc sec at frequencies up to 1000 Hz. They are typically flown on fine-pointed solar sounding rockets and have been qualified at vibration levels far higher than are encountered with the Shuttle. Characteristics of the sensors and other significant operating parameters of the OSE are provided in Table 1.

The sensors were carefully aligned to the GAS bridge, which was located at the aft end of the Orbiter bay. Consequently, any change in the position of the Sun within the fields of view (FOV) of the sensors accurately represented a change in the angular offset of the direction of incoming sunlight relative to the Orbiter's inertial guidance system.

### ALIGNMENT OF THE OSE SUN SENSORS TO THE ORBITER'S $-Z_o$ AXIS

Accurate alignment of the sun sensors to the Orbiter was necessary as the estimated tolerance buildup between the experiment and the orbiter navigational base, located in the nose of the Orbiter, was estimated to be as high as $1.5^{\circ}$, and therefore comparable to the FOV of the sensors. For this reason, also, the FOV of one of the sensors was intentionally expanded (resulting in a loss of angular sensitivity) from its nominal $+/- 2^{\circ}$ to $+/- 3^{\circ}$ to assure that some observations would be acquired, even if the worst case misalignment actually occurred. The sensors were first mounted to and aligned with a specially designed mounting plate that was in turn mounted to the top of the GAS can. This mounting plate was accurately aligned to the GAS bridge during integration, following an alignment procedure using an inclinometer and sensitive bubble level. Final alignment of the sensors to the GAS bridge was within 1 arc min in pitch and 7 arc min in roll. A unique flexible thermal blanket for the top of the GAS can was designed and built to accommodate the sun sensors while providing maximum solar isolation for the GAS can.

The Orbiter was maintained in a $-Z_o$ solar inertial mode within a $+/- 0.05^{\circ}$ deadband during our observations. At the time of Sun acquisition by the OSE, the alignments of the two LISS sensors to the Orbiter's navigational base were -3.2 and -2.2 arc min in pitch and -2.3 and -5.3 arc min in roll, far better than the estimated error envelope of $+/- 1.5^{\circ}$. One LISS was positioned with a $180^{\circ}$ rotation about its line of sight so as to provide signals of opposite polarity for orbiter pointing deviations. This was a means of discriminating against undetected electronic noise and drifts in the shared electronic system. Thermal stabilization of the electronics, using heaters, was incorporated to assure that observations would take place with the electronics at their nominal operation temperature range of 25-30°C. These heaters were eventually not required as the Orbiter's attitude provided a benign thermal environment, and the OSE's internal electrical dissipation quickly raised the instrument's electronic system to nominal operating temperatures. The instrument was operated both with and without a solar input to determine the level of internal electronic noise. Such noise produced a white noise spectrum against which the spectrum of vibrations recorded during Sun-pointed operation could be compared.

## OBSERVATIONS

The OSE was powered up for two intervals of time totally nearly three hours (that included both dark and sunlit portions of the orbit). The periods of operation during the STS-40 mission were Mission Elapsed Time (MET) 01:23:56 (day/hr/min) to 02:02:01 and 02:07:26 to 02:08:21. Intervals of anomalous tape recorder operation (loss of synch, but not necessarily loss of data) are apparent in our data playback after the first 40 minutes of operations and make data analysis more difficult. We have therefore limited our preliminary analysis to the first 40 min of data. During that interval, the offset of the Orbiter's $-Z_0$ axis from the solar direction as the vehicle moved in its deadband about its pitch axis (Y axis) produced a signal reminiscent of a rectified sine wave (figure 1), with the Earth's residual atmosphere at orbital altitude

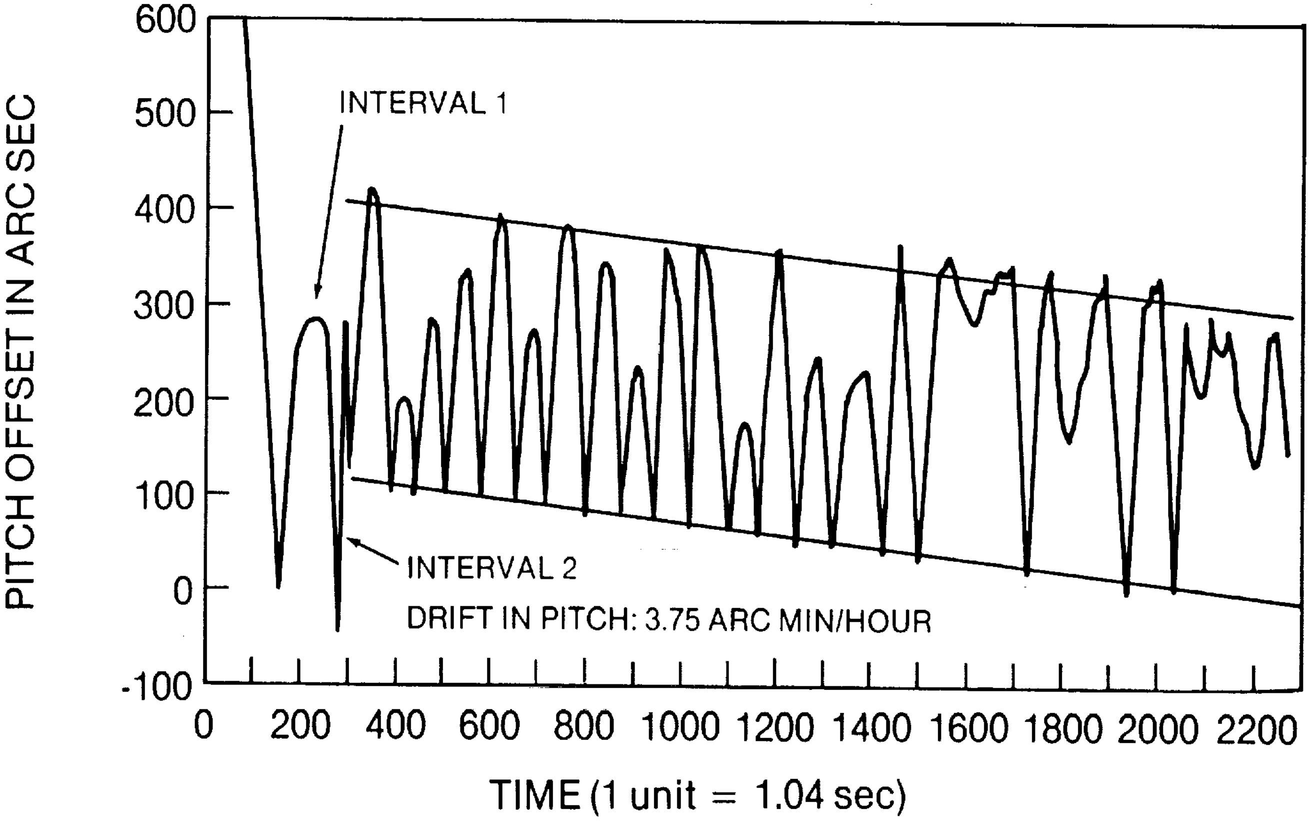

Figure 1. Deviations in Orbiter pitch as a function of time for the initial period of OSE observations on STS-40. Measurements with Sensor 1 are shown.

providing a drag force that typically rotated the Orbiter against one side of the deadband. The motions of Orbiter about its roll axis (X axis), shown in figure 2, were less regular in frequency.

The drift in the envelope of pitch deviations, shown by the sloping straight lines in figure 1, was almost exactly the same for both LISS, and therefore not due optical degradation. For this time interval, the drift was 3.75 arc min/hour, which is about 2.5 times the drift in pitch recorded by an optical sun sensor on STS-3 (data supplied informally by the SUSIM investigator on STS-3) for a much longer (10 hr) period of solar inertial pointing. In that instance, realignment of sun sensors to the center of the Sun was re-established when the Orbiter's navigational base was updated using star trackers. We propose that, in both instances, the drift in the envelope of pitch deviations was due to a drift in the Orbiter's navigational coordinate system relative to the Orbiter's structure (i.e., a drift in the navigational gyros) rather than a drift in the sun sensors relative to the Orbiter's structure. The drift in the envelope of roll deviations was approximately 3 arc min per hour, as can be seen from an inspection of figure 2.

The objective of the OSE observation was to record high frequency motions of the Orbiter bay that might be superimposed on the expected larger scale motion of the Orbiter within its deadband. Such higher frequency components, commonly called "jitter", might be attributable to the normal operation of mechanical systems or to the usual motions of the astronauts during their normal working

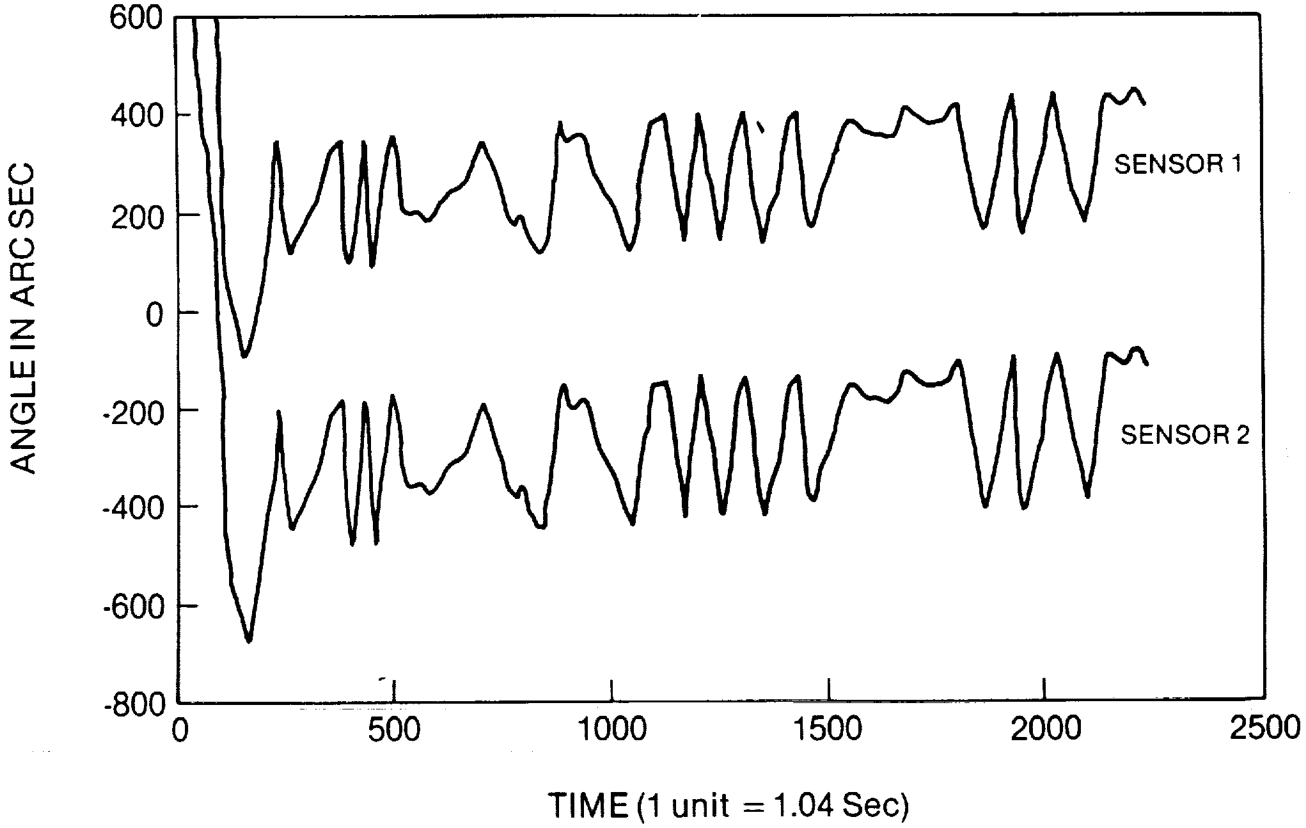

Figure 2. Deviations on Orbiter roll (about its X axis) during the initial period of OSE operation on STS-40. Outputs of both LISS sun sensors are shown.

activities. Our initial scan of the bulk of the usable observations, which occurred during the sunlight portions of one orbit, indicates that any such jitter must have been at or below the limit of detectability (0.25 arc sec) for almost the entire observing interval. An example of the signal output for the pitch channel of Sensor 1, the high sensitivity sensor, during an interval of time that included thruster firings is shown in figure 3. The Orbiter's motion appears smooth throughout, and in comparing plots of the outputs of the two pitch channels visually, we find no detectable correlation of high frequency signal variations.

Figure 3 also shows that the reversal of orbiter motion due to a thruster firing at the extremes of its deadband is smooth. No detailed correlation of our data has yet been made however, and it is not clear to what extent the smooth reversal of attitude is the result of a sequence of vernier thruster firings or whether it reflects a low frequency response by the Orbiter to a single firing. In any case, no angular vibration at frequencies above about 1 Hz attributable to a vernier thruster firing is detectable with the present instrument.

To date, we have found only one interval when pointing deviations (other than oscillations within the dead-band) were clearly present. That interval, shown in Figure 4, lasted for about 25 sec. It occurred, perhaps coincidentally, during a reversal of Orbiter motion in its deadband. The reproducibility of line of sight deviations in the two pitch channels gives confidence that the varying signals are in fact real fluctuations in Orbiter pointing at the 0.5 to 2 arc sec level.

## ANALYSIS

We have begun to characterize the Orbiter's angular motions in terms of power spectral density (PSD) for intervals of time when interesting perturbations were been recorded. As a baseline, we derived the PSD for an interval of instrument operation without solar input (recorded in the laboratory during final integration activities). The PSD for such operation is flat, i.e., independent of frequency, to a limiting frequency of about 20 Hz. We have similarly calculated PSD for sample intervals of OSE on-orbit operation. For a portion of the interval shown in figure 3 that was free of thruster firings, we find no power above 1 Hz in the PSD of deviations of our high-sensitivity observations from a polynomial fit to the data. For the 25 sec-long interval of erratic pitch motions (jitter) shown in figure 4, we find no spectral power above the instrument's ambient electronic noise level for frequencies above 10 Hz. The PSD fits a power law with an exponential of -2.6 for frequencies between 0.5 and 10 Hz. Angular motions of 0.5 arc sec or greater (peak-to-peak) in pitch or roll were limited to frequencies of 1 Hz or less. The erratic pointing deviations shown in figure 4 have not yet been identified with any specific event or activity aboard the spacecraft.

## SUMMARY

The Orbiter Stability Experiment performed well during the STS-40 mission

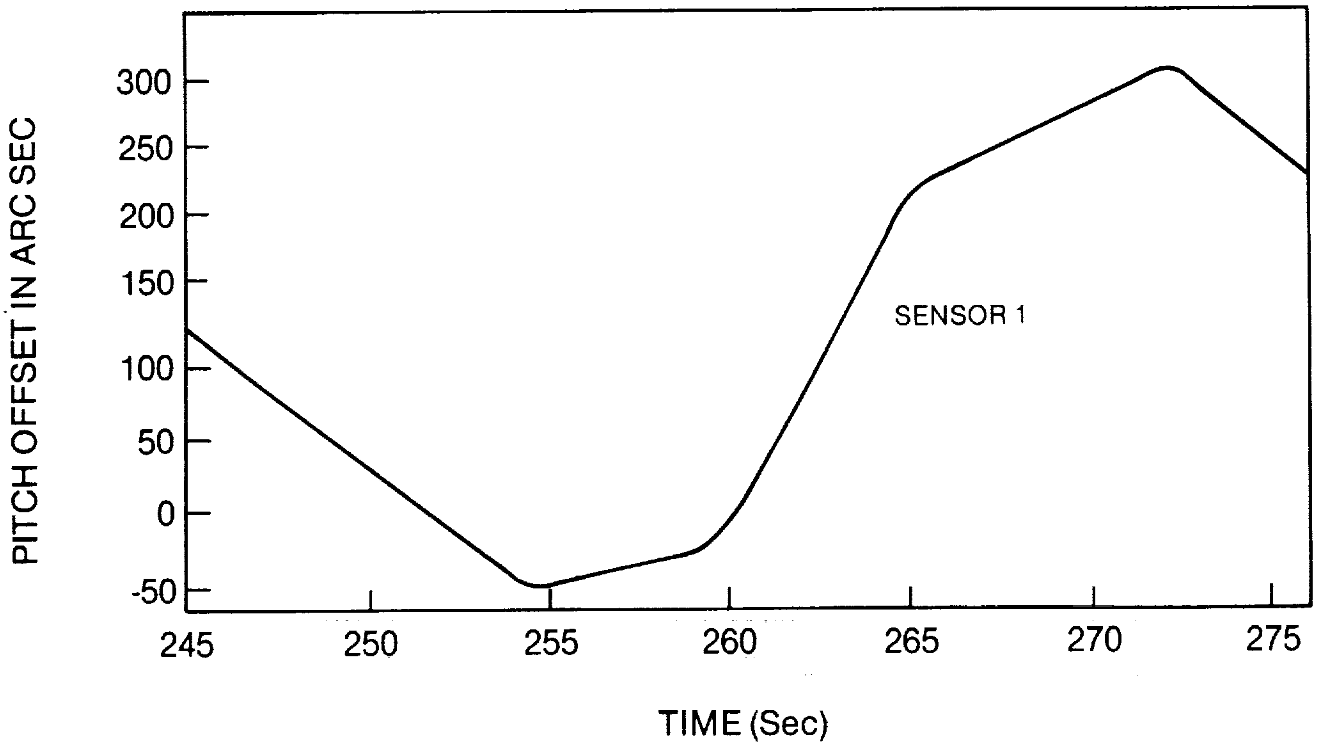

Figure 3. Output of the high sensitivity pitch channel (Sensor 1) during an interval when vernier thrusters were used to maintain the Orbiter's attitude. This interval is indicated as Interval 2 in figure 1.

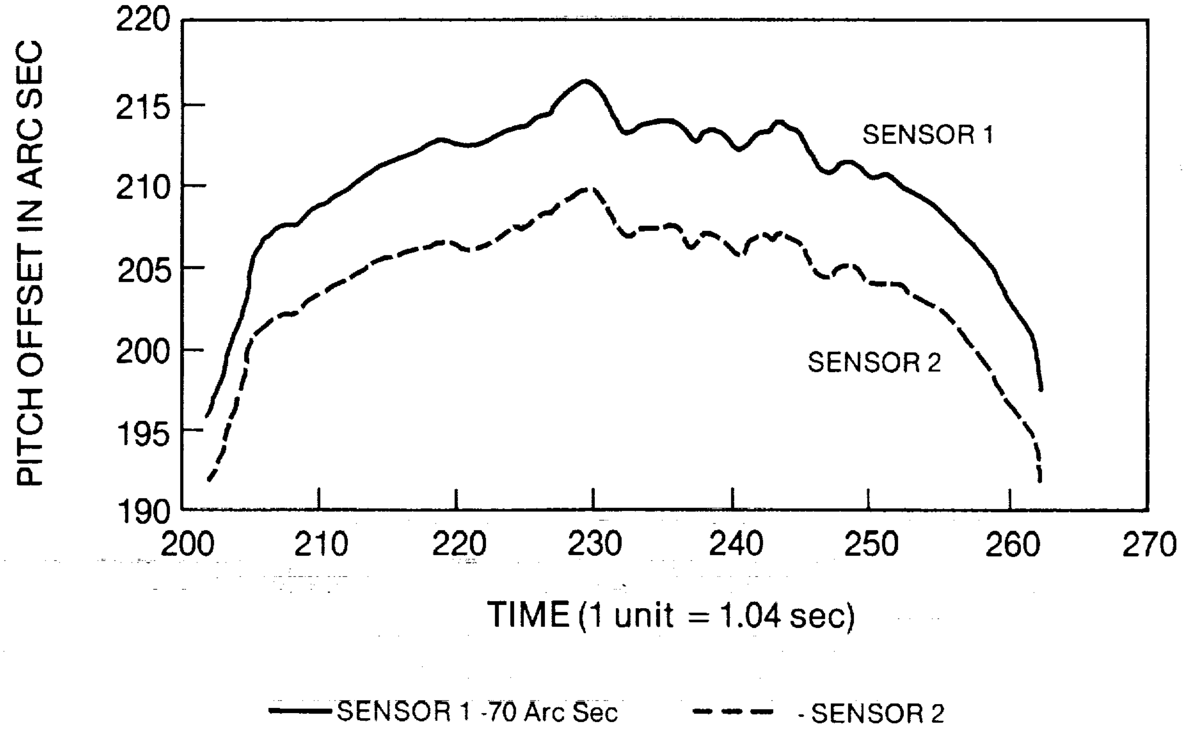

Figure 4. Comparison of pitch channel outputs from an interval near the beginning of sun-pointed operation. The small (0.5 to 2.5 arc sec) pointing deviations are exceptions to the smooth motions of the Orbiter typically encountered. This interval is indicated as Interval 1 in figure 1.

and demonstrated the relative absence of high frequency jitter about the Orbiter's pitch and roll axes. The original intent of the experiment was to characterize such motions for purposes of designing an image motion compensation system for a proposed solar optical imaging instrument (which was never built). It succeeded in making the desired measurements. We plan to perform an extended and more rigorous analysis of the observations in the future, and in particular, plan to correlate our observations with Orbiter thruster firings. The eventual data base may provide correlative data for linear acceleration measurements made on-board STS-40, and we have participated in meetings of NASA's Microgravity Measurements Working Group in an effort to disseminate OSE results to other organizations that may be able to use them in characterizing the Orbiter's motions.

## TABLE I. - CHARACTERISTICS OF THE OSE INSTRUMENT

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| Sensors | Two Lockheed Intermediate Sun Sensors |
| Sun Sensor Intrinsic Noise | Typically 0.08 arc sec RMS |
| Angular Range | +/- 2° (+/- 3°)[1] |
| Angular Sensitivity | 0.23 arc sec (corresponding to the least significant bit (LSB) in data digitization) for the high-sensitivity sensor |
| OSE Equivalent Electronics Noise | 0.17 arc sec RMS (0.75 OF LSB) |
| Frequency Cutoff | 11 Hz with a nominal 12 DB/Octave rolloff |
| Data Sampling Rate (Each of Four Data Channels | 58 Hz |
| Data Storage | Data multiplexed and recorded on a Lockheed Model 4200B tape recorder |
| Duration of Operation | Three hours maximum (Limited by tape recorder capacity) |
| Power Supply | Gates X-cells in a hermetically sealed container |

[1] One sensor's field of view (that of Sensor 2) was electronically expanded to +/- 3°, with reduced angular sensitivity (0.39 arc sec) to assure that some observations would be acquired, even under worst-case misalignment to the Orbiter.