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Performance Considerations for the Astrometric Telescope Facility on the Phase I Space Station

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Summary

The Astrometric Telescope Facility (ATF) is an optical telescope facility of extreme astrometric precision whose principal scientific purpose is the detection and study of planetary systems orbiting nearby stars. The ATF was planned as an initial operational capability (IOC) payload for the Space Station. A change in the Space Station program this year has resulted in a two-phase program. Phase I consists of the original Station's transverse boom with 75 kW of power initially, growing to 125 kW with addition of solar dynamic power, and Phase II adds the upper and lower booms. Only Phase I is currently approved and funded for development. If early operations are important for payloads such as ATF which were originally planned for the upper or lower booms, their suitability for the Phase I Space Station must be evaluated. This paper presents the results of such an evaluation for the ATF.

The primary suitability considerations for an ATF Space Station mounting site are mechanical vibration, optical surface contamination (exhaust gases from station-keeping, gaseous and liquid dumping, pressurized module leakage, and particulates), and observable field of view. Specific quantitative environmental data for vibration, exhaust gases, and particulate contamination for the Station are incomplete. Therefore, the results reported here are preliminary and based upon limited data and some modeled estimates. Only the field of view evaluation was straightforward and based on dimensions from the Space Station Phase B engineering study.

Findings from this study show that the Phase I Space Station is marginally acceptable as an ATF platform. The Phase I Station provides an adequate field of view for observations, the vibrational environment is acceptable, and the contamination level during Station quiescent times (without venting) is acceptable. However, the contamination evaluation here is based on partial data and when the contamination levels are fully specified they are expected to exceed ATF's contamination requirements. Therefore, the acceptability of siting the ATF on the Phase I Station will depend upon engineering solutions being found to control the contamination environment. Thus, comparing the Phase I Station to the Phase II Station upper boom for siting ATF, the Phase I Station with higher levels of contamination and vibration levels, is a less desirable platform for ATF. The basic robust design for ATF with minimal design enhancements and with favorable control in the design of the Station, could make the Phase I Station acceptable for ATF operations.

Introduction

The concept of using astrometry for detection of other planetary systems is an outgrowth of efforts to detect dark stellar companions to stars by observing wobbles of those stars. Peter Van de Kamp was one of the first to advance this concept. In reducing 25 yr of observational data to identify a dark companion for Barnard's star, he noted that the measured perturbations were much too small to be a dark companion star. He, therefore, postulated that the wobble was the result of a "small" body, a planet, that was orbiting Barnard's star. Subsequently George D. Gatewood, at the suggestion of Nicholas D. Wagman (the then Director of the Allegheny Observatory), showed that the apparent wobbles resulted from cleaning the optics part way through the 25 years of observation. Nevertheless, the concept of measuring the perturbations of stars to infer the presence of planets orbiting stars was established. NASA's ATF is an astrometric telescope specifically designed for detecting other planetary systems by measuring perturbations of stars. At 10 parsecs, the measurement precision required to detect planetary systems is 10 μarcsec, approximately equivalent to looking at an hydrogen atom at arm's length. This apparently impossible task is greatly simplified through the use of a high-precision rigid ruling. The moving ruling modulates the light from the target star and some 30 reference stars, to obtain millions of precise relative angular measurements between the target and reference stars.[1] The measured parameter is the time phases of the light intensities received from each of the stars as modulated by the moving ruling. By averaging these measurements, random errors will be reduced to the required measurement precision of star motions for detection of planetary systems. Systematic errors are sufficiently controlled by engineering design, and the consistency of measurements through the same optics of the phase angles from the target stars to much more distant background stars. Analysis of the long-term accumulation of data will discover and remove effects of parallax and proper motions.

Reference 1 provides the engineering and systems detail for the strawman ATF design including its attachment to the Phase II Space Station. The highlights of that study were summarized in a paper[2] presented at the SPIE's conference in The Hague, Netherlands March 30 to April 3, 1987.

This paper specifically examines the possibility of attaching and operating the ATF on the Phase I Space Station. The results presented here are preliminary. Detailed information about the Space Station required for a rigorous evaluation is not available, so this evaluation was only an initial determination of feasibility. Simplifying assumptions were necessary. Space Station contractors will be selected soon to build the Space Station and detailed systems descriptions and additional environmental specifications should become available shortly thereafter. Some changes from the system configuration used in this analysis are expected and these results will be updated.

Phase I Space Station description

The current best estimates and projections used for this study concerning the Station are summarized as follows:

Space Station Physical Details

Figure 1 shows a sketch of the Phase I Station with overall dimensions and several key station elements identified. Mass of the fully operational Phase I Station after flight 17 in August 1996, is estimated at nearly 450,000 lb. Electrical power available will be 75 kW with Space Station requirements using about 50 kW leaving only 25 kW for users. With flight 21 in February 1997, electrical power availability will increase to 125 kW with the addition of solar dynamic generators and about 75 kW will be available to users. Data handling support is designed for as much as 10 Mbps/payload, but in the initial period maximum data rate supported could be less than 10 Mbps/payload. Availability of thermal control fluids for pointed payloads is currently unresolved.

Space Station Environment

Space Station environmental concerns of critical interest to the ATF mission are twofold: 1) the mechanical vibration expected at its attach point to the Space Station during payload operations affecting pointing and control; and 2) the particulate and gaseous contamination (pressurized module leakage, material outgassing, and proximity and station operations) affecting operational lifetimes for the optics. Other problems such as EMI, thermal interactions between payloads, and physical interference between payloads are not considered here because they are of secondary importance compared to those just cited.

Evaluation of the expected vibration generators on the Space Station (e.g., astronaut wall push-off, centrifuges, etc.) indicates that the treadmill is probably the largest contributor to mechanical vibration. A typical, force-time plot for this activity is shown in Figure 2 and an example of the vibration expected at the ATF attachment location for highest loaded of the three orthogonal axes is shown in Figure 3. The curve shown in Figure 3 is for a unit pound of force, and for the average astronaut weight (Figure 2), the ordinate should be multiplied by 180 lb. Both lumped-mass and finite-element models were used in the analysis but the results were comparable and the result for the simple lumped-mass model is shown.

The molecular column density specification[3] for the Space Station is that all gaseous species will not total more than 5 x 10^{13} molecules/cm^2. The expected gaseous contamination levels from outgassing, leakage, and venting for several species are summarized in Table 1. These values are seen to be dominated by total venting at the rate of 0.1 gm/sec and leakage from the pressurized modules based on a total leakage rate of 5 lb/day. These rates have been estimated and details will be published soon in a study report by Science and Engineering Associates, Inc. for NASA's Office of Space Science and Applications. Study results show that for the preceding leakage value, deposition rates are approximately one to two orders of magnitude higher then expected on the upper or lower booms of the Phase II Space Station and exceed the basic deposition criteria stated in JSC 30000 for the Space Station. Other sources of contamination such as STS operations, Station reboost, and payload venting are yet to be defined, and will further worsen the environment.

Particulate level for the Space Station is specified as less than 1 particle, ≤ 5 μ/orbit/10^{-5} steradian as seen by a 1-m-diam-aperture telescope. Particulate environment for the Space Station is currently inadequately known. Only micrometeoroid impact and ejected particulate levels are defined and expected to be on the order of 0.2 particles/10^{-5} steradian. This is well below the Space Station specification. However, orbital debris currently estimated at approximately 10 times this level and contributions from other potential particulate sources (e.g., rotating solar panels, rotating parts of the boom, payload gimbels, moveable airlocks, mobile manipulator, etc.) must be better characterized so that payloads will know what total particulate level can be expected.

ATF performance requirements and analysis

Observation

The ATF requires observation access to nearly the whole sky for periods totaling about 20 hr/yr for each of the 127 star fields for 20 yr to fulfill the mission requirement to observe a statistically significant number of various types of stars. A strawman list[1] of 127 stars was assembled to test this requirement. A computer program[4] simulating the observation scenario was written with the appropriate constraints (for Space Station operations, telescope slewing, avoidance of the velocity vector, and avoidance of the Earth limb, Sun, Moon and Space Station appendages) to evaluate the feasibility of meeting the ATF mission requirements.

Previous evaluation[1] showed that the upper boom location allowed viewing of all 127 of the strawman list of stars without difficulty. For this analysis, the center of the transverse boom and a location one-fourth (10 m) the distance from the center of the transverse boom to the solar arrays (plus and minus y directions) were evaluated. Figure 4 defines the coordinates used, and identifies the placement of ATF on the transverse boom. The center position is not practical because of higher contamination levels and expected interference with the manned modules. The minus y location was chosen because it provides the best coverage of the northern hemisphere of the sky with minimal sacrifice to viewing of the southern hemisphere. Exercising the simulation program for the ATF attached on the Phase I Space Station showed that 124 stars out of the 127 strawman list of stars could be viewed. Three stars could not be viewed because their high southern declinations caused the solar arrays to obscure them. The strawman list could be revised to exclude these three stars without affecting the validity of the planetary search results. Therefore, the transverse boom or Phase I Space Station is acceptable for the ATF observation requirement.

Contamination

The ATF is an optical telescope, giving rise to three primary contamination concerns: 1) molecular and particulate deposition on the optical surfaces that will cause scattering and adsorption; 2) free particles that float into the field of view and provide a source of scattering and false signals; and 3) molecular number column density that create a source of scattering and absorption of the signal (star light) thus affecting seeing.

The ATF requirements for molecular deposition is derived from the requirement that the optics perform adequately for the 20-yr mission without cleaning or changeout, which translates into a deposition rate not to exceed 100 Å/yr. (3.2×10^{-14} gm/cm^2/sec). The Phase I Space Station has an estimated deposition rate for optical instruments with 0.1 steradian field of view of 2×10^{-13} gm/cm^2/sec. Linear extrapolation to the ATF field of view of 0.005 steradian, results in a deposition rate on the order of 10^{-14} gm/cm^2/sec. There is a positive margin for molecular deposition that is sufficient. But other contributors to molecular contamination not accounted for in this calculation, could lead to exceeding this margin. The ATF primary mirror is designed for operation at 20°C above ambient to reduce molecular deposition. The problem of particulate deposition resulting from space operations is expected to be less of a problem than that resulting from ground assembly, handling, and storage and from launch operations. The particulate deposition from Space Station operations is unknown as yet, but the aperture cover on the ATF will be closed during major contamination events (such as STS docking and Space Station reboost) to prevent particulate and excessive molecular species entry to the optics.

Free-floating particulates of 1 to 5 μ will be a problem for ATF because they will act like stars by reflecting sunlight into the focal plane. The particulate environment around the Space Station has not been fully identified. The JSC 30000 specifies the Space Station environment as having only one particle ≤ 5 μ/orbit visible in a 10^{-5} steradian field of view as viewed by a 1-m-diam-aperture telescope. Performance to this specification will be acceptable to ATF.

Seeing for the ATF will be affected by the molecular column density of the Station atmosphere. Currently the ATF requirement is not to exceed 10^{14} molecules/cm^2 with an uncertainty of two orders of magnitude. The current Phase I Space Station specification for molecular column density limits the total to 5×10^{13} molecules/cm^2, providing a small, but acceptable margin. But the values shown in Table I for leakage and venting appears to result in a drastically worse atmosphere, so better understanding is needed for these events.

Based on these factors, it appears that the contamination environment for the Phase I Space Station, with the exception of molecular atmospheric density would be acceptable for the ATF mission.

Mechanical Vibrations

The vibrational environment for ATF due to manned activities on the Phase I Space Station is more severe then for ATF on the upper boom of the Phase II Space Station. This is due to the closer proximity of ATF to the disturbances. But, because the Phase I Station will have a smaller number of large pointing science payloads (possibly only one), interactions with other payloads will be reduced. The ATF requires that mechanical vibrations within the frequency range from 5 Hz to 200 Hz be controlled to stability levels of 0.01 arcsecs within several of the ruling frequency. If the vibration frequencies can be characterized, the ruling frequency can be variably controlled between 10 and 100 Hz and the 0.01 arcsec stability requirement can be relaxed to 0.1 arcsec.

The ATF project contracted a study with Honeywell-Sperry to explore possible techniques for vibration isolation of the ATF to the required levels of pointing stability (with vernier pointing capability to 1 arcsec as part of the vibration isolation system). The vibration isolation study[5] used an input disturbance level of 10^{-2} g on the upper science boom. The study results showed that isolation levels of 60 to 80 db were readily achievable with magnetic suspension techniques, and that isolation at those levels will meet the ATF requirements on either the Phase I or II Space Station. Vibration levels for the Phase I Station, were evaluated by the "Space Station Pointing and Control Working Group" formed by NASA's

Office of Space Science and Application. Both a distributed and a lumped-mass model of the Phase I Space Station were used for the vibration analysis. Review of expected vibration sources indicated that the treadmill was the worst. Impact on the ATF, without the benefit of vibration isolation for pointing accuracy and pointing stability are shown, respectively, in Figures 5 and 6. As seen, pointing accuracy is adequate, but the stability requirement is exceeded and some mechanism for vibration isolation is required. It should be pointed out that the analysis was for a single coherent frequency and there is some danger in generalizing this result; but for an initial evaluation this level of confidence is satisfactory. As more reliable design details become available, this problem will be revisited.

Based on these preliminary vibration analyses for the ATF on the Phase I Space Station, it appears that the ATF pointing accuracy and stability requirements can be met if vibration isolation is provided.

Conclusion

Results from this feasibility evaluation of attaching the ATF to the Phase I Space Station shows that while there are definite concerns, there is a good possibility that ATF can operate on this Space Station, but that molecular contamination is an especially serious area of concern. Primary areas of concern are molecular contamination and molecular column density. The use of vibration isolation is expected to satisfactorily overcome the increased vibration levels for ATF that are expected on the Phase I Space Station. Additional analysis of the contamination environment, and the available methods for dealing with it, will be necessary to arrive at the final determination of the acceptability of the Phase I Space Station as the ATF operations base.

References

1. "Astrometric Telescope Facility: Preliminary Systems Definition Study," Vols. I and II, NASA TM 89429, March 1987.

2. Nishioka, Kenji, Scargle, J. D., and Givens, J. J., "An Astrometric Facility for Planetary Detection on the Space Station," Fourth International Symposium on Optical and Optoelectronic Applied Science and Engineering, Hague, Netherlands, March 1987.

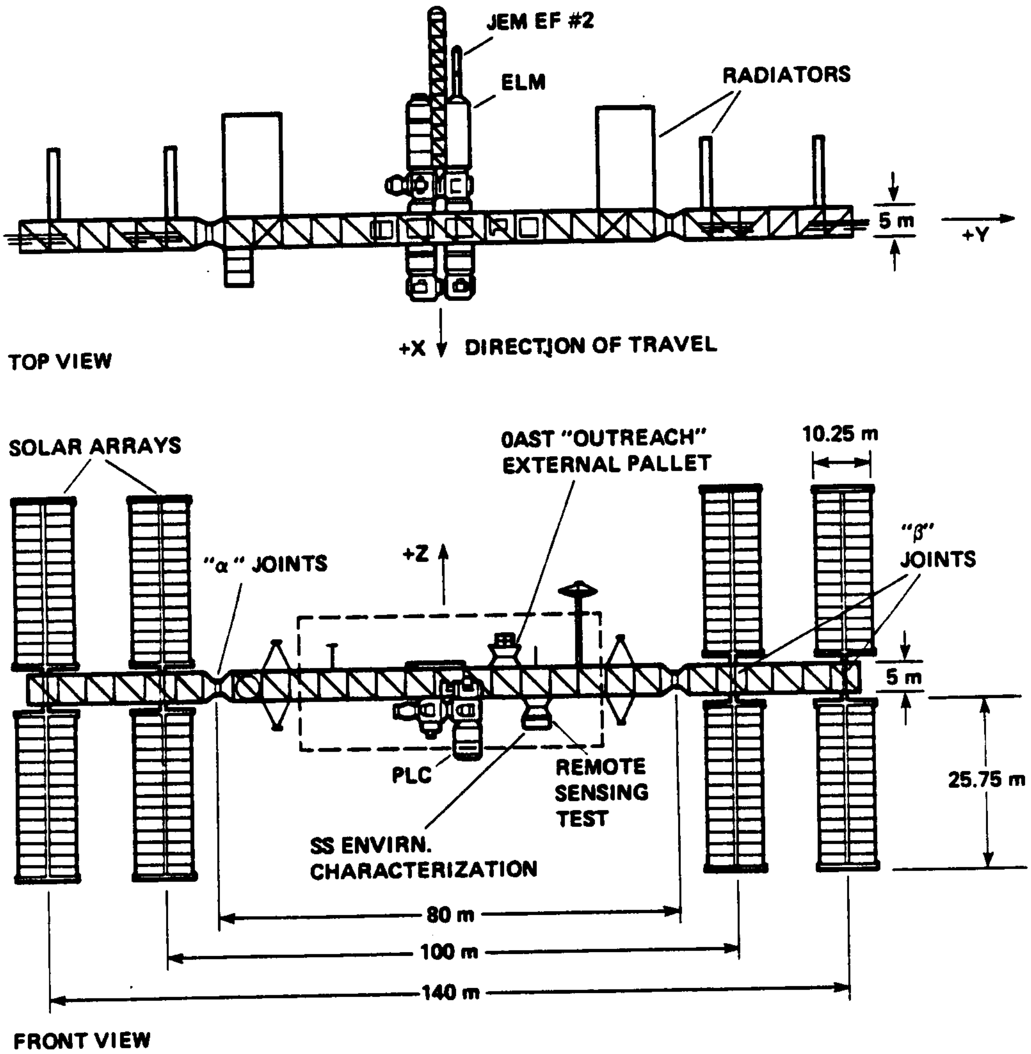
3. "Space Station Program Definition Requirements Document," NASA Lyndon B. Johnson Spaceflight Center, JSC30000, 1987.

4. Alfred C. Mascy et al., "Detection of Planetary Systems from Space Station - A Star Observation Strategy," AIAA Paper 87-0317, Jan. 1987.

5. "Astrometric Telescope Facility Isolation and Pointing Study," NASA CR NAS2-32815, 1987.

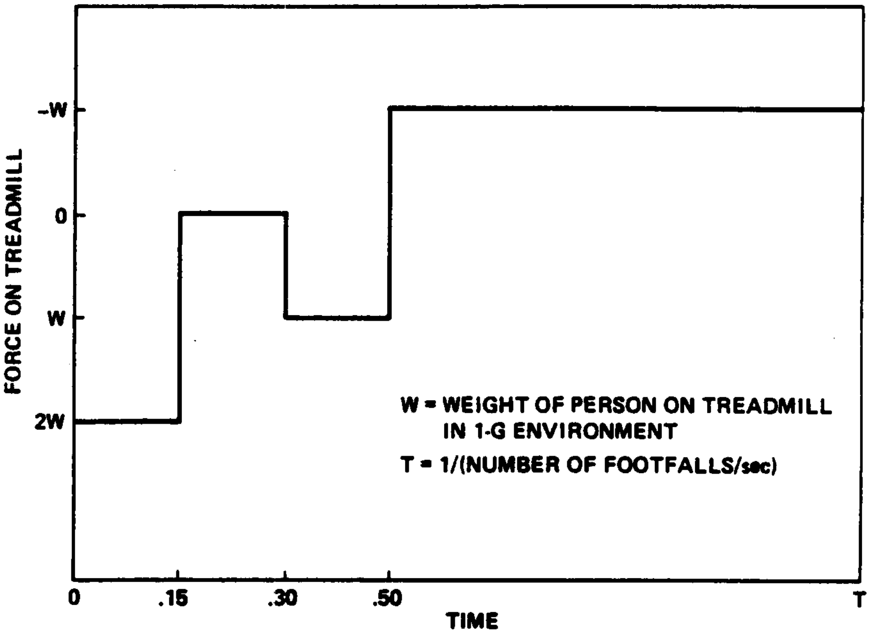
Table 1. Space Station Quiescent Period-Molecular Sources

TYPE	SOURCE	RATE, molecules/cm^2-sec
OUTGASSING	STATION STRUCTURES AND COMPONENT SURFACES	9.4×10^{12}
LEAKAGE	ACTIVE AND INACTIVE SEALS, AIR LOCK, AND DOCKING RING	1.4×10^{16}
VENT	VENT	5.3×10^{16}



NOTE: JEM EF #2 – JAPANESE EXPERIMENTS MODULE EXPOSURE FACILITY NO. 2
ELM – EXPERIMENT LOGISTICS MODULE
PLC – PRESSURIZED LOGISTICS CARRIER

Figure 1. Phase I Space Station physical description.



- SOURCE IN 1983 CSDL MEMO, RE: OAST STUDY FOR JSC
- TYPICAL PARAMETER VALUES ARE: W = 180 lb AND T = 1.0, 0.5 AND 0.3 sec
- FORCE APPLIED AT AFT END OF HAB MODULE WILL BE IN EACH OF THE X, Y, AND Z AXES

Figure 2. Treadmill disturbance.

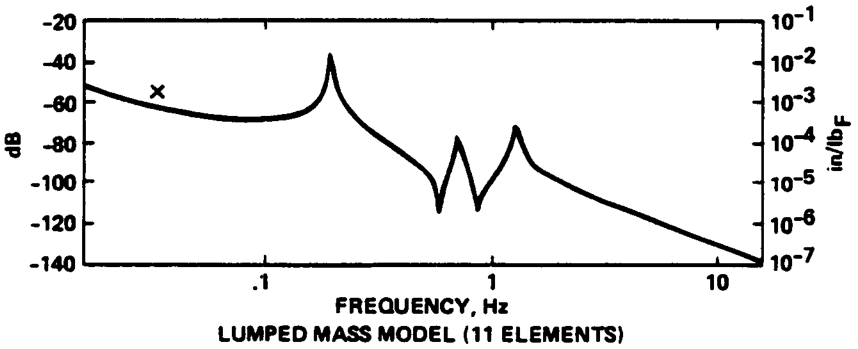


Figure 3. Motion at Space Station payload interface adapter caused by x-axis force in laboratory module.

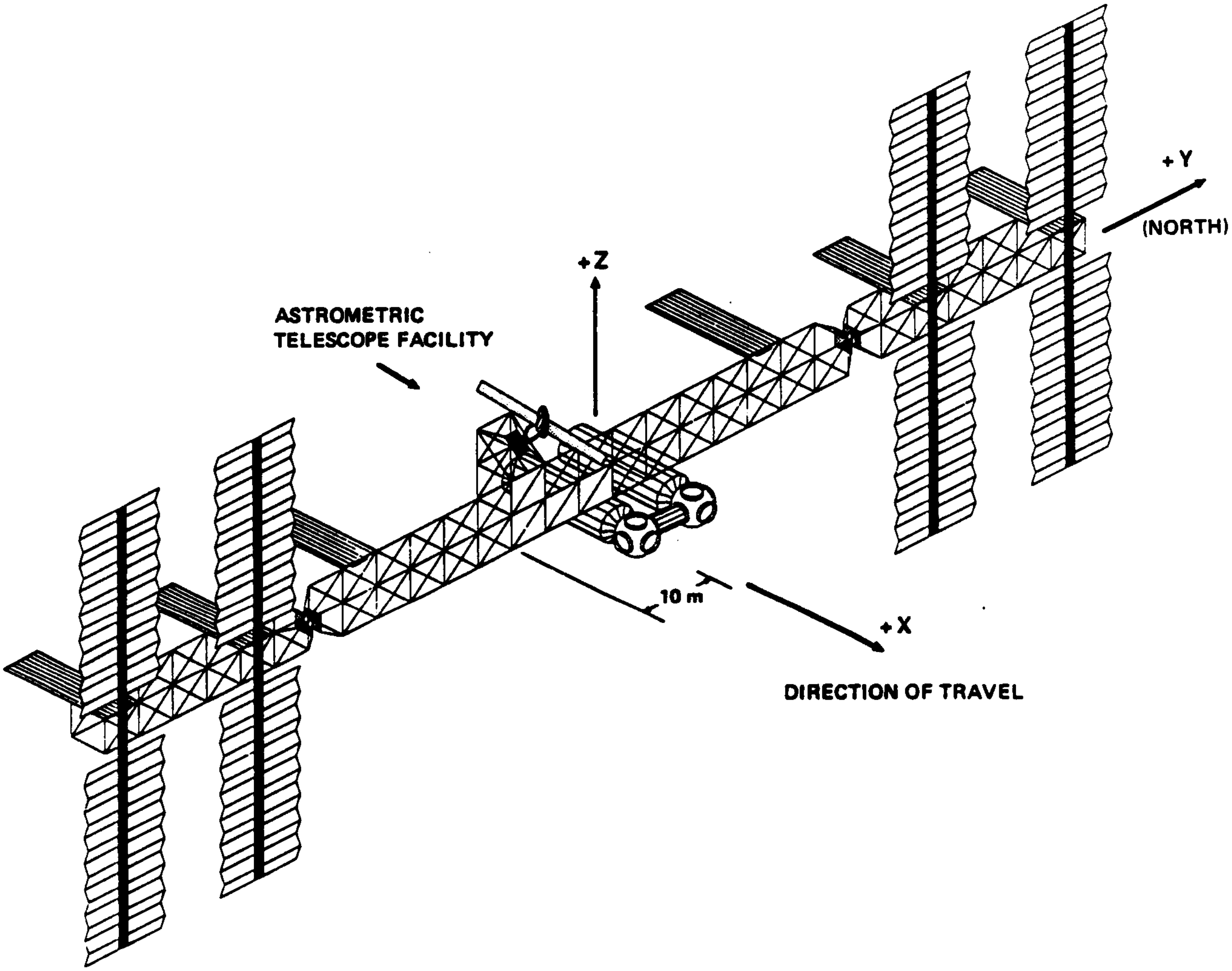


Figure 4. The ATF attachment to the block-1 Space Station.

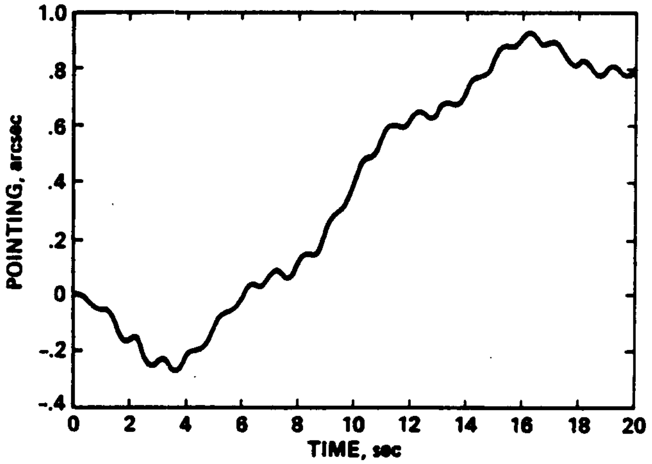


Figure 5. Inertial pointing accuracy vs. time for (ATF, 1-cm c.g. offset, no isolator) 1-Hz treadmill disturbance.

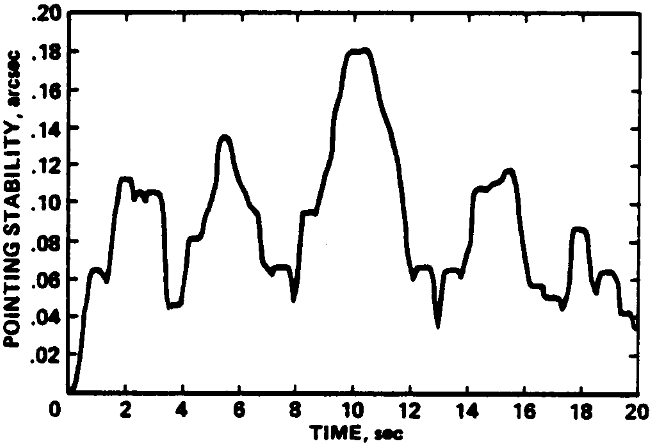


Figure 6. Inertial pointing stability vs. time for (ATF, 1-cm c.g. offset, no isolator) 1-Hz treadmill disturbance.

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16. Abstract

The Astrometric Telescope Facility (ATF) is an optical telescope facility of extreme astrometric precision whose principal scientific purpose is the detection and study of planetary systems about nearby stars. With the recent change in the Space Station program to a two phase program, the suitability of initial operations from the Phase I Station need to be evaluated for early operations. This paper presents the results of such an evaluation for the Astrometric Telescope Facility.

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