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Particulate contamination control in the Optical Telescope Assembly for the Hubble Space Telescope

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Abstract

This paper will review the particulate control program applied to the design, construction and testing of the Optical Telescope Assembly. Allowable levels of contamination were derived from system performance requirements using performance predictive models. These levels were used as guidelines in establishing control and monitoring procedures for the assembly process. Measurements taken at critical junctures indicated that cleaning of the optics was required. Cleaning operations were performed at the latest stage of assembly possible. Subsequent measurements verified the effectiveness of the procedures. Optical surface tests, conducted after Space Telescope environmental testing, revealed that the optical surfaces were well within acceptable limits.

Introduction

The Hubble Space Telescope represents the largest single advance in astronomical instrumentation since the Hale 5-meter Telescope at Mt Palomar. Designed to operate throughout the ultraviolet, visible and near infrared spectrum, it will also provide a factor of 50 improvement in sensitivity and a factor of 10 better resolution. Its extreme sensitivity and resolution, however, are susceptible to degradation from a number of environmental effects. This is especially true for observations at ultraviolet wavelengths. The most difficult environmental factor to protect against is the all-pervasive dust in the Earth's atmosphere. Even the best "clean rooms" are not perfectly clean and special precautions are required to assure that the best possible observatory is delivered to the astronomy community.

Requirements

Dust particles, settling out from the atmosphere and accumulating on the surface of the mirrors, will degrade performance in a number of ways. Obscuration of the primary mirror results in a direct reduction of optical throughput. Small apertures have a diffraction pattern many times the full aperture diffraction limit, resulting in greater light scattering from bright sources into neighboring faint images. Dust particles scatter light over wide angles to illuminate the telescope baffles, thereby adding more photons to the focal plane background.

Each of these effects was modeled in terms of image contrast in the focal plane and level of particulate contamination, as measured by the area obscured on the primary mirror. A total system budget was established allowing up to five percent obscuration of the primary mirror in orbit at the start of the mission. This total budget was further allocated, allowing no more than one percent mirror obscuration in the completed Optical Telescope Assembly prior to integration with the spacecraft.

Process controls

During the construction of a telescope, a lengthy period of time elapses between the coating of its mirrors and the completion of the telescope assembly. All operations subsequent to the coating are performed in a well controlled clean room. However, since no clean room is perfectly clean it is inevitable that some dust particles settle on the optical surfaces. In the case of Space Telescope, the primary mirror (Fig. 1) was coated in December 1981. The Optical Telescope Assembly (OTA) was completed in October 1984. During the intervening three years the mirror surface could not possibly improve - it could only deteriorate by the accumulation of contaminants.

Besides performing all final assembly work in a Class 10,000 clean room and much subassembly work in Class 1000 or 100 clean areas, all items of flight hardware were surface cleaned prior to their integration into the OTA. The large light baffles, in particular, were cleaned by repeated acoustic exposure and vacuum cleaning. Their large size and close proximity to the optics make them the dominant contamination source in subsequent environmental testing, unless special care is taken in their cleaning.

Mirror cleaning

Use of clean rooms, rigorous procedural control of operations and careful cleaning of hardware were all necessary, but they were not sufficient. The long, labor-intensive assembly operations in the immediate vicinity of the primary mirror and the need to have the mirror resting face up for long periods of time made some accumulation of dust on its surface inevitable, even though it was covered most of the time.

Measurements made a year or so after the coating showed the beginning of a particulate layer that may adversely affect the ultraviolet sensitivity of the observatory. A cleaning plan was developed that would allow us to "vacuum clean" the mirror surface at the latest possible time in the assembly cycle. Thereafter, the mirror would be kept covered until integration with the space shuttle at Kennedy Space Center.

The special cleaning tool involved the combination of nitrogen gas jets to dislodge the particles and a vacuum hose to suck away the debris, as illustrated in Fig. 2. During the cleaning operation the mirror was suspended face down. The cleaning head was mounted to a special carriage that permitted the entire mirror surface to be cleaned from underneath (Fig. 3). The cleaning was performed during June of 1984, prior to completion and delivery of the OTA the following October.

For verification, the cleaning head was replaced by a camera system permitting close up macro-photography of the mirror surface. Photographs taken before and after the cleaning showed the operation to have been highly successful. The photographs were automatically scanned and the particle images cataloged according to size. The particle size distribution and total area obscured were calculated and the results plotted (Fig. 4). Before cleaning, approximately three percent of the mirror aperture was obscured by particles. The cleaning operation reduced this to about 0.67 percent, well below the one percent allocation established for the finished OTA.

Monitoring of the particle fallout rates in the clean room revealed that no significant particle buildup occurred during those few weeks of final assembly after the mirror cleaning. The transportation environment was also carefully monitored to assure contamination-free delivery to the Lockheed Missile and Space Company (LMSC) assembly facilities in California. Particulate measurements by LMSC in May 1986, later in the Space Telescope assembly sequence, showed very little contamination of the primary mirror.

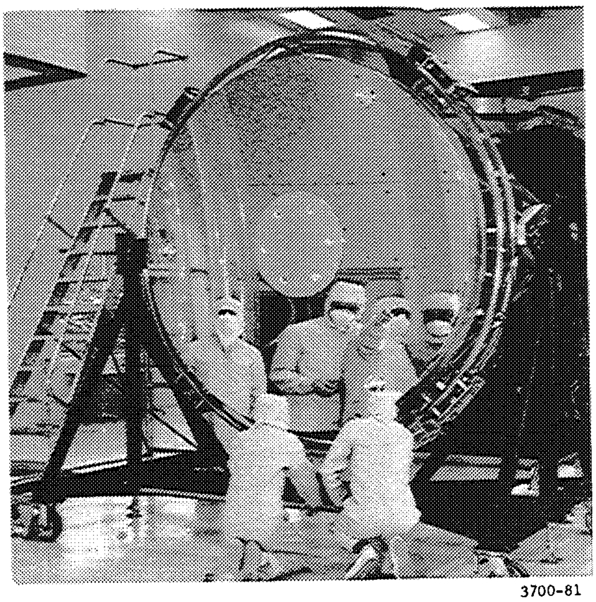

Figure 1. Hubble Space Telescope Primary Mirror.

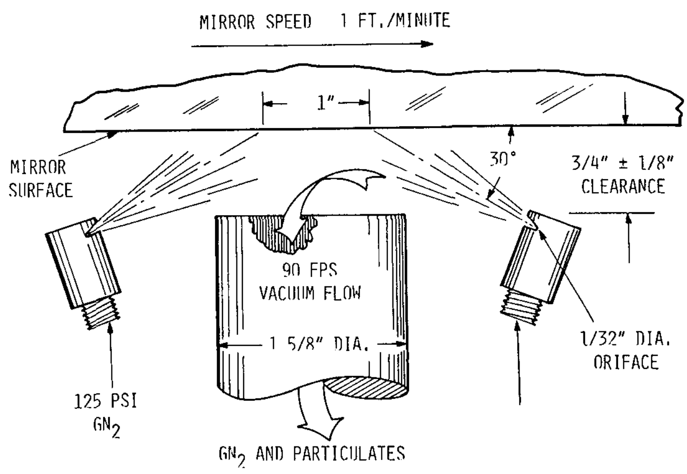

Figure 2. Telescope mirror cleaning head configuration.

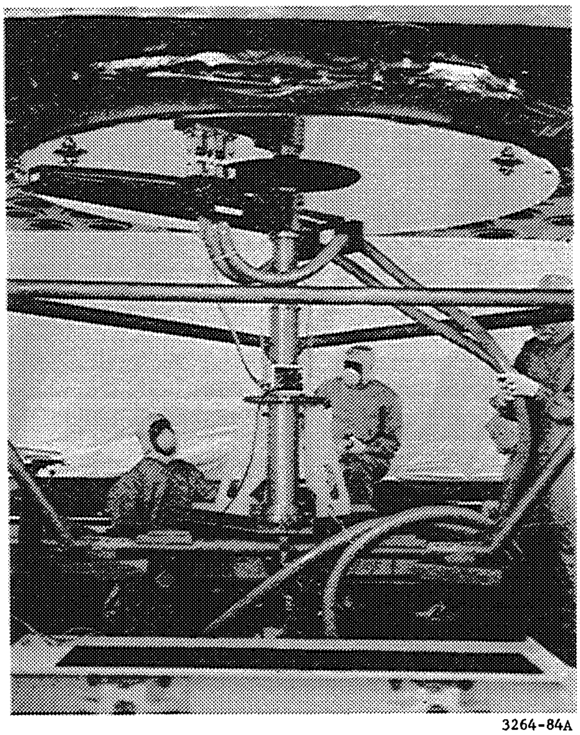

Figure 3. Primary Mirror cleaning operation.

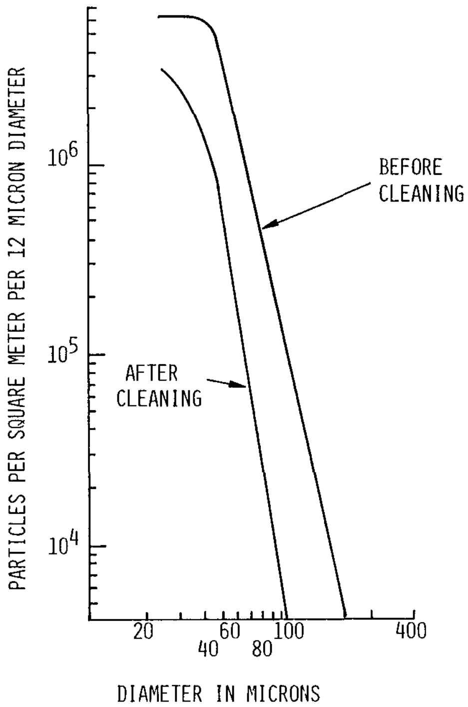

Figure 4. Measured particle size distribution functions.