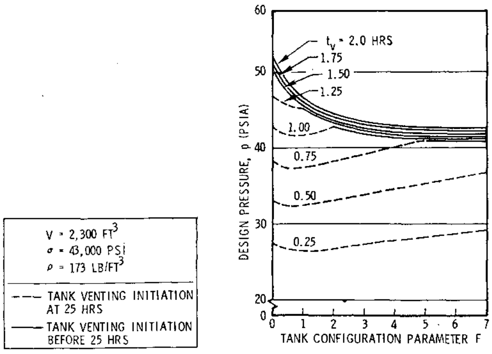

Fig. 4 Configuration effect on the optimum hydrogen tank design pressure.

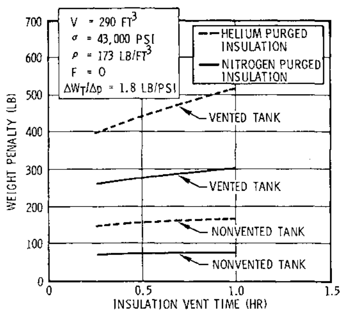

Fig. 5 Total oxygen tank weight penalty.

storage were also calculated and the results are shown in Fig. 3. The thicknesses for the two cases practically coincide since the optimum tank design pressure is very close to the assumed initial tank saturation pressure (approximately 14.7 psia). Therefore, a tank which is vented at 14.7 psia is very close to an optimum design for the chosen tank geometry and allowable design stress.

The mass history of the oxygen tank is shown in Fig. 2. Two insulation systems were considered for the oxygen tank, 1) a nitrogen purged, nitrogen backfilled system and 2) a helium purged, helium backfilled system. Results of analysis indicate that the oxygen tank should not be vented during the entire mission and all of the heat input into the tank should be stored in the bulk of the liquid. The weight penalties associated with the systems considered are shown in Fig. 5, indicating a substantial weight advantage of the nonvented tank over the vented one.

The analysis indicates that both structural and thermal parameters must be considered in designing a minimum weight cryogenic storage system. In an optimum system both heat storage in the bulk of the propellant and propellant boiloff must be utilized to accommodate the heat input into the propellant. The ratio of the heat stored in the bulk of the propellant to the heat allowed to boil off propellant depends on the mission thermal environment, insulation thermal conductivity, propellant mass, type of propellant, and the propellant tank structural weight penalty imposed by designing a system to a pressure above some minimum pressure necessitated by heat storage in the bulk of the propellant. The frequently used process of minimizing a storage system weight considering only an insulation thickness and boiled off propellant as pertinent parameters is often inadequate.

120-In. Large Space Telescope (LST)

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Introduction

THE need for continuation and expansion of present programs in space astronomy, has been recognized by the scientific community.[1-3] For example, atmospheric distortion limits the resolving capability of the Hale 200-in. telescope at Palomar to that of a 12-in. telescope in orbit.

The Large Space Telescope (LST) program called for by the scientific community is now formally included as a line item in the NASA/OSSA budget. The discoveries possible with this instrument's 10-ft-diam aperture of diffraction limited performance will dwarf the discoveries of all previous instruments.

Mission

A viable LST observation program must last at least 10 yr with no more than two flight vehicles. Each vehicle must have the capability to function as an international observatory, in much the same manner as the Palomar terrestrial observatory. In addition, a variety of experimental packages must be available for use with the same collecting optics. The experiments should be conceived and guided by a cross section of the astronomical community as principal investigators. The utility of these experiments can be further extended by the participation of guest investigators as now successfully practiced on OAO-2.

A Baseline LST Configuration

The LST configuration presented in Fig. 1, while not optimized, is a reasonable approach toward meeting mission objectives. This configuration has primarily been used as a baseline to analyze systems and subsystems, identify major trade areas, and form a springboard toward realization of an optimized design. Major subsystems including stabilization and control (S&C), communications and data handling (CDH), electrical power, and the pneumatics are packaged as separate modules capable of replacement in orbit via the space shuttle. They are located at the spacecraft (or rear) end of the configuration.

Forward of the spacecraft structure is the "reference base," a specially stabilized structure to relate all geometrically critical components on the vehicle. The fine-error sensor of the S&C system is located on the axis of the reference base. This sensor is the innermost loop of the concentric or nested S&C modes but not contained in the S&C module. The experiments are radially disposed in the reference base. They are independent and modularly packaged and removable externally. The reference base also supports the telescope, precisely relating it to the experiments and fine-error sensor, via the primary and secondary mirror support structures.

The aft end of the spacecraft structure is fitted with a docking adapter. The docking ring has a central opening through which the fine-error sensor package can be replaced. All modules can be replaced by manipulator arms which are part of the shuttle deployment mechanism.

This independent experiment module configuration permits great flexibility in payload (experiment) complement: experiments may be replaced in orbit permitting updating through

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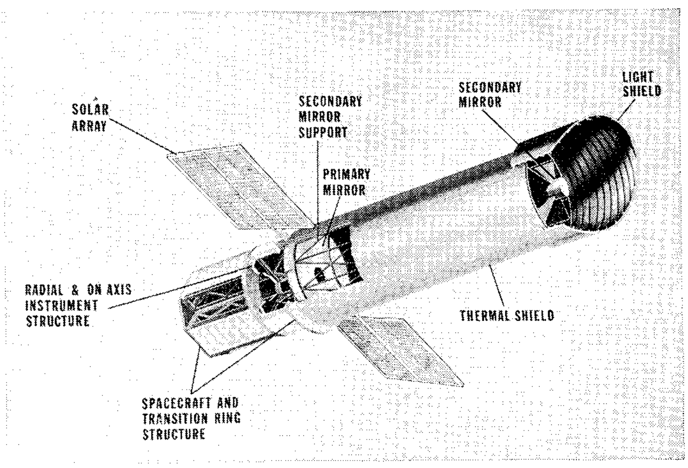

Fig. 1 Large space telescope structural composite.

the observatory life; the unavailability of an experiment need not delay launch; a wide range of astronomical observations can be accomplished with the single telescope optics; and each experiment may match its own optics and detector to the telescope without affecting the others. The configuration also makes possible significant simplification of the experiment packages since they are not required to generate their own fine-error signals.

It is now clear that manned attendance of the LST spacecraft can be realized via the Earth orbiting shuttle. Such attendance will permit maintenance, repair, resupply and update, producing significant economies and extending vehicle life.[4] Manned operation of the vehicle, on the other hand, would do more harm than good, because of disturbances, the added system complexity for pressurization, and the possibility of optical contamination from life support effluents.

A long-life LST is envisioned independently of manned attendance—through intensive application of highly successful techniques developed with OAO-2. Mission Control of Goddard Space Flight Center has displayed great ingenuity and resourcefulness with the precise controllability of the OAO-2, extending its life through use of redundant modes and increasing its scientific capability beyond that originally anticipated. These techniques place "man in the loop" and constitute a genuine advance in space technology.

Shuttle support should include both retrieval and launch capability to permit ground overhaul and redeployment. Basically, support throughout mission life would consist of exchanging experiment and subsystem packages in orbit. Therefore, these packages must be of modular design. All subsystems must support the optics in such a way as not to significantly degrade the diffraction-limited potential.

Optical System

Spectral region of interest

Most of the absorption and emission lines of interest to be observed by the LST are below wavelengths of 3000 Å. The design of the optical elements and their coatings should, therefore, maximize energy-collecting efficiency at wavelengths down to 900 Å.

Since future astronomical experiments cannot be defined now, it is highly desirable to design as versatile a collecting instrument as possible. In addition to the aforementioned ultraviolet regions, modern instruments will be expected to extend into the infrared region. The prime region of spectral interest is from 1000 Å to 10,000 Å; the secondary region of concern extends from 1 to 20 μ.

Field of view

An optimum field of view for any proposed experiment would be wide and flat, with diffraction-limited performance throughout. However, for astronomical experiments with a 120-in. aperture, a practical field of view is several arc min with resolution of less than 0.1 arcsec throughout. The baseline design provides essentially diffraction-limited performance over a 6 arcmin field of view. It employs an annular field surrounding this central field for offset fine guidance for which some image degradation is tolerable. The very small amount of field curvature innate in the design is well within the "depth of focus," so that the useful field remains essentially flat.

Telescope optical design summary

An f/9 optical system design was chosen to present the typical problems to be investigated for a 120-in. telescope and to provide diffraction limited performance in the experiment field. The optical configuration is shown in Fig. 2. The f/9 example uses a 3-m f/3 primary and 0.915-m-diam secondary with a 3X magnification. The Ritchey-Chretien design provides a coma-free experiment field of 6 arcmin. The fine guidance subsystem uses an annulus of 10–40 arcmin diam for guiding on at least two stars to stabilize the experiment image.

The secondary mirror is shown spider-mounted with positioning mechanisms to control focus, tilt, and decentration. The telescope structure also supports one of the boresighted star trackers for the spacecraft. The focal plane is 75 in. behind the vertex of the primary. This permits the various experiments and the fine guidance subsystem to be contained in a single reference base and will permit experiment replacement or updating in orbit.

Primary mirror

A diffraction-limited optical system is required, which by the Rayleigh limit means that the wavefront cannot deviate from a spherical form by more than a quarter wave. Since errors existing on the primary and secondary are twice magnified by reflection, the figure requirements of the primary and secondary must be of the order of $\lambda/20$, in order to realize the $\lambda/4$ or less aberrated wavefront. A further complication arises from the fact that the mirror must be fabricated and tested under the influence of gravity, while it will operate in a zero gravity condition in outer space.

The passive monolithic approach to the design of the primary mirror has been used as a baseline configuration because it represents the simplest approach to a primary mirror for the LST. The passive mirror approach now has credibility due to materials technology advances. Further, it would make earlier deployment possible due to its simplicity relative to active systems which can change shape in orbit. A more

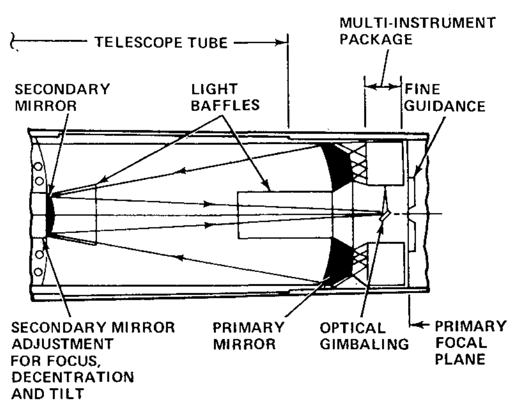

Fig. 2 3-m telescope f/9 system optical schematic.

extensive discussion of primary mirror alternatives is given in Ref. 5.

A monolithic light-weighted silicic mirror structure concept was chosen for the baseline configuration. At the present juncture it appears that either CER-VIT[R] or ULE[R], or possibly a similar material, Zerodur[R], could be successful. The near-zero expansion will ease the previously almost impossible task of controlling thermal deformation of the mirror surface. Dimensional stability and thermal anisotropy have been demonstrated as adequate.[6] A recent study[7] revealed that silicic materials have effectively zero permanent deformation with stress and time (microcreep) at least within limits of 1000-psi stress and 100-hr application. But these limits should provide good design flexibility. Thus, if deformations during figuring are controlled, the mirror should have a good chance of retaining its shape to the required optical tolerance in zero g. No problem should be experienced with either material in achieving the necessary degree of surface finish.[8]

Stabilization and Control (S & C) System

The stabilization and control system of the observatory incorporates advances in the state of the art, since to maintain diffraction-limited image quality over a 120-in. aperture the image must be stabilized to 0.004 arcsec. In the baseline configuration this is accomplished by "beam steering" or optical gimbaling, as the innermost loop of a series of concentric attitude control modes.

A split field arrangement of the fine stabilization loop is employed (see Fig. 3), in which the central 6 arcmin is reflected to any one of several experiment packages located circumferentially. The annular guide field of 40 arcmin is covered by a mechanically translating sensor package, with a 2 arcsec acceptance aperture, and guided by linear feedback devices with 1 μ resolution. Jitter of the guide star image in the sensor is compensated by equal and opposite rotations of the experiment mirror, which combines both switching or experiment selection and image stabilizing functions. The spacecraft attitude control system must place and hold the guide star within the 2 arcsec sensor field, requiring a boresighted star tracker (BST) with an order of magnitude capability increase over that on OAO-2. Such a BST has been judged technically feasible, by extending the present design.

Thermal Considerations

External thermal environment

The external thermal environment for the observatory consists of solar, Earth albedo and Earth emission thermal radiation. These orbital heat fluxes vary as a function of orbital altitude and inclination, and time of year. For an anticipated altitude of 300 naut mile (345 sta mile) and an inclination of 35°, the variation in orbital suntime will be 63%–77%. Orbital heat fluxes are computed for use as boundary conditions in both steady-state and transient thermal analyses.

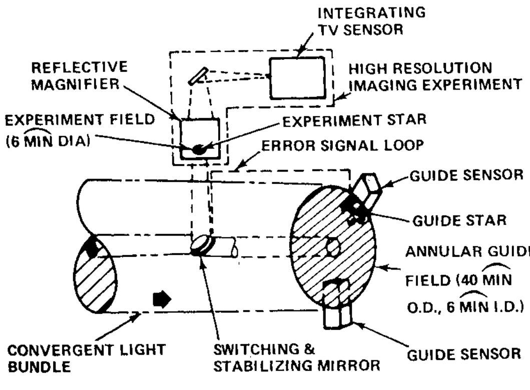

Fig. 3 Fine-stabilization concept.

Over-all configuration

The thermal design approach of the entire observatory is to separate the vehicle into three major sections: the telescope tube; the reference base; and the subsystem supporting structure. Thermal and mechanical isolation of each of these sections from the other has two significant advantages: first, the transfer of thermal distortions between sections is eliminated; second, the independence of each section allows nearly independent design and provides for multipurpose sections.

The thermal design approach of the telescope tube is to isolate the secondary mirror support structure from the external environment. The structure is isothermalized to provide a uniform environment for the primary mirror and to minimize distortions in the structure. The primary mirror temperature is controlled by controlling the temperature of the telescope tube. The circumferential heat pipes in the telescope tube will tend to isothermalize the primary mirror environment, therefore reducing mirror thermal gradients.

Conclusions

Detailed definition of the baseline configuration was performed in all subsystem areas, drawing heavily on OAO experience. Areas included and not discussed in this paper are structural design, communications and data handling, electrical power, and maintainability and reliability.

The concept of maintainability in orbit is revolutionary, and has great impact on the total program. Preliminary implications have been reported in Ref. 4; other papers reporting in more detail are in preparation. Through exploitation of the concept, the LST program is expected to be highly cost-effective.

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