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PHOTOHELIOGRAPH THERMAL CONCEPTS STUDY

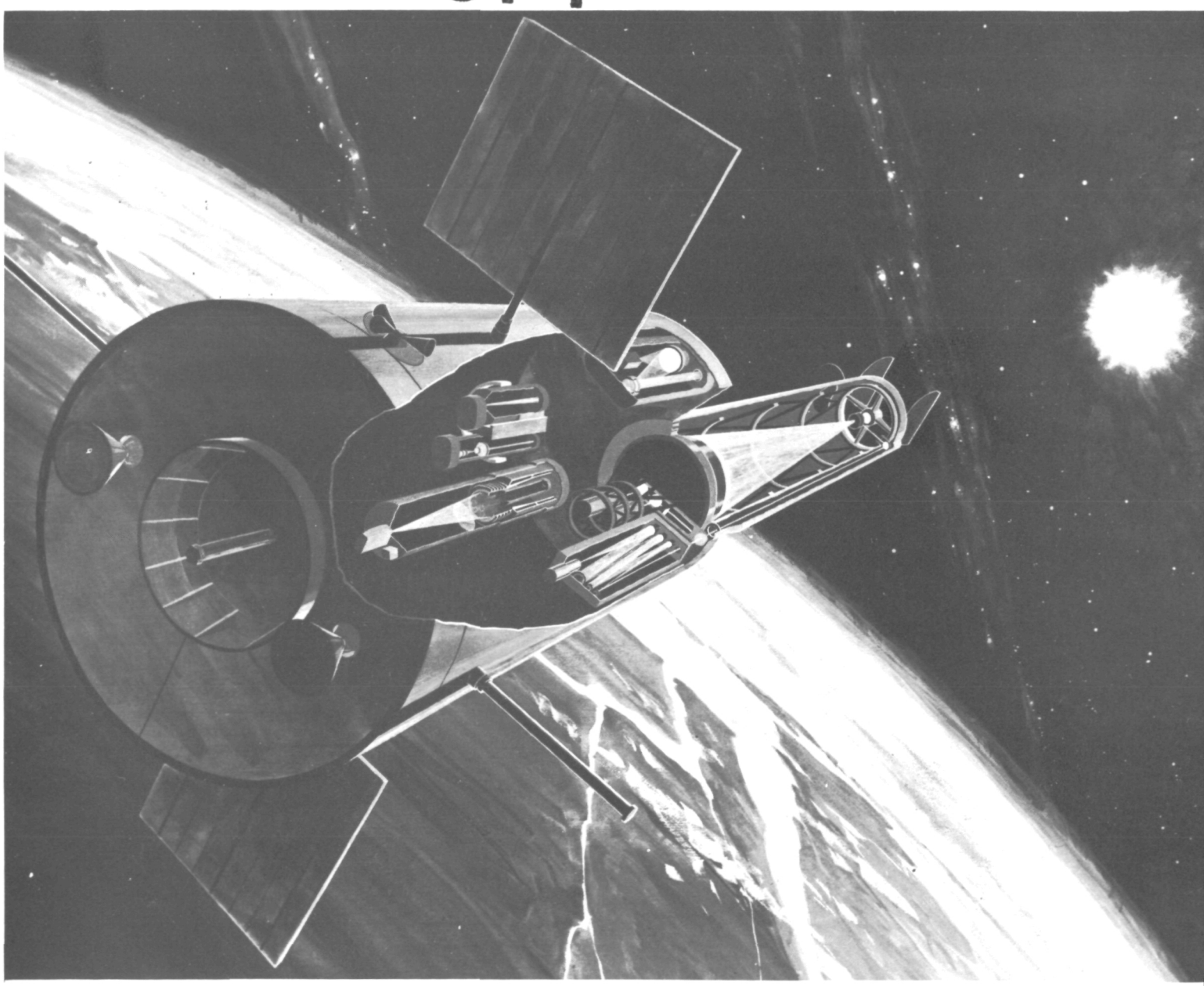
VOLUME I

SUMMARY

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MARSHALL SPACE FLIGHT CENTER
ALABAMA 35812

Under contract NAS8-28520

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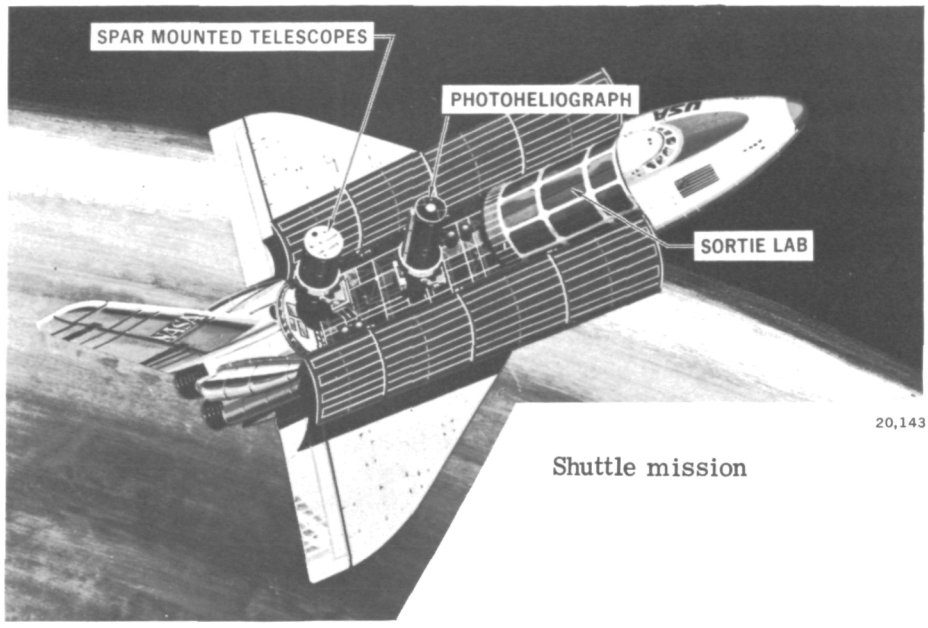
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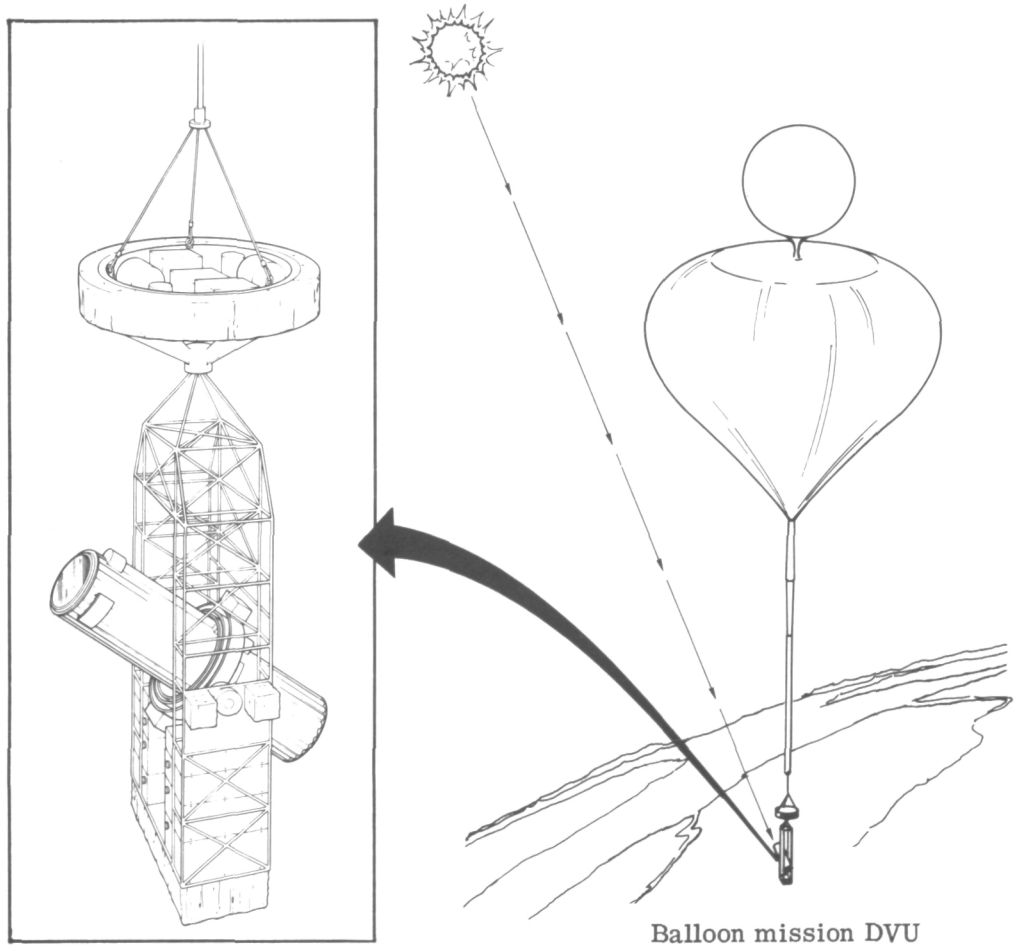
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Shuttle mission



Balloon mission DVU

100-centimeter photoheliographs

1. INTRODUCTION

The purpose of this volume is to summarize the results of the Photoheliograph Thermal Concepts Study performed by Itek Corporation for Marshall Space Flight Center under Contract NAS8-28520. Volume II presents the design details of the findings reported here.

To begin this report without confusion, we define what we mean by "photoheliograph." A photoheliograph is an instrument system whose purpose is to observe the sun at high resolution in the spectral range from approximately 1100 to 11,000 Å. Basically, it comprises near-diffraction-limited, normal incidence, reflective optics and has a variety of high resolution instruments at the focal plane, including imagery sensors, spectrographs, spectroheliographs, and magnetographs. In addition, it contains subsystems for thermal control, line of sight stabilization, alignment, and electronics, as required for each mission.

The main objective of the Photoheliograph Thermal Concepts Study was to define and compare the performance of thermal subsystem concepts for each of three photoheliograph designs oriented toward unique solar observation missions. These designs and missions may be categorized as:

1. A 150-centimeter photoheliograph for Large Solar Observatory (LSO) missions. This design is intended for multi-year orbital operations as a part of a complement of solar telescopes in a free-flying LSO configuration (see cover).

2. A 100-centimeter photoheliograph for Shuttle sorties. This design is intended for observation periods of up to 2 weeks while mounted in the cargo bay of the Shuttle Orbiter vehicle (see frontispiece).

3. A 100-centimeter photoheliograph for balloon missions. This design is intended to be a design verification unit (DVU) and precursor to the orbital flight designs. Mission duration is on the order of a single day at an altitude of approximately 24.4 kilometers (see frontispiece).

For each of these photoheliograph designs we defined the basic thermal environments, boundary conditions, and applicable thermal control concepts, determined the interactions between concepts and environments, and selected a baseline thermal control concept for the three classes of photoheliographs described here.

A second objective of the Photoheliograph Thermal Concepts Study was the definition of a set of experimental work plans describing the major efforts required to further the detailed design and to confirm analytical performance predictions.

This study is closely related to the recently completed Photoheliograph Definition Study performed by Itek for Marshall Space Flight Center under Contract NAS8-28147. In particular, the definition study furnished the basic configurations of the photoheliograph designs analyzed in this thermal concepts study and most of the data required for the establishment of performance requirements and system operating limitations. The definition study also served to establish the LSO thermal concept baseline, including the lightweight, specular core primary mirror.

2. MOST SIGNIFICANT FINDINGS

The most significant findings of this study and of the Photoheliograph Definition Study (NAS8-28147) are summarized in this section. Of course, the most significant finding of the two studies is that we have feasible concepts for each subsystem for each mission.

2.1 MOST SIGNIFICANT FINDINGS FOR 150-CENTIMETER PHOTOHELIOGRAPH FOR LSO

The system performance goals are shown in Table 1. The system may be best understood by referring to Fig. 1, which indicates the appropriate thermal control elements.

The most significant findings of the Photoheliograph Definition study were:

1. The lightweight, monolithic, specular core mirror is feasible for the photoheliograph (see Fig. 2).
2. In an occulted orbit, periodic refocusing of the system will be required due to primary mirror bending.
3. The secondary, first fold, and second fold mirrors tend to run cold and must be heated to 21.1 °C.
4. Heat pipes appear attractive for removing heat from both the primary mirror and the heat shield mirror.

The most significant findings of the Photoheliograph Thermal Control Concepts Study were

1. The solid mirror concept is acceptable as an alternative to the specular core, lightweight, monolithic design. There is some sacrifice in system performance, but the design as analyzed does meet the thermal error allocations.

2. The insulation of the internal surface of the meteoroid shell raises the structural temperature levels significantly (~15.5 to 32.2 °C) as well as reducing the normal orbital transient response. Overheating of the primary mirror may present a thermal problem if this concept is pursued.

3. Only the primary mirror and heat shield mirror require supplementary cooling techniques. The relay flats and the secondary are currently cold biased and require supplementary heating during operation.

4. Degradation of the primary and heat shield mirror reflective coatings by increase in solar absorbtivity results in overheating of the respective mirrors. This phenomenon requires further study both to assess the magnitude of the change in absorbtivity and to determine the final approach toward thermal control to compensate for the increased solar loadings resulting from the degradation.

5. The maintenance operation results in rapid cooldown of the primary and heat shield mirrors when the solar loading is off. Since large temperature changes are clearly undesirable, a method of thermal control that prevents the transfer of heat during maintenance periods is required.

2.2 MOST SIGNIFICANT FINDINGS FOR 100-CENTIMETER PHOTOHELIOGRAPH FOR SHUTTLE

Our thermal studies for the 100-centimeter photoheliograph have resulted in the development of a thermal control baseline for Shuttle sorties (Table 2). The major elements of this concept are noted in Fig. 3.

The most significant findings of the Shuttle sortie studies were:

1. Thermal interactions between the telescope and Shuttle have thus far not shown themselves to be a major driving force on telescope thermal design.

2. The solid primary mirror has been selected for this design primarily because at this size (1 meter), it has reasonable weight and it is a low cost element that will meet our established optical performance requirements. The lightweight, specular core concept is an acceptable alternative offering a lower weight, higher cost backup.

3. The cold plate/heat pipe/space radiator has been selected as the primary mirror heat rejection system because of its simplicity and low weight. A fluid loop cooling system that effectively replaces the heat pipe is an acceptable alternative concept, although it results in an increase in system weight and requires a more complex heat transfer system.

4. Passive thermal control of the secondary metering structure is provided by an uninsulated, low ϵ coated external shell that has been selected because of the reduced structural temperature response, as well as the lower gradients developed. By constraining the structure material to an athermalized graphite-epoxy composite, a high ϵ thermal coating may be used as an alternative thermal control finish.

5. The heat shield mirror is actively cooled by means of a heat pipe/space radiator system selected for low weight and simplicity. As in the case of the primary mirror heat rejection system, and with identical reasoning, a fluid loop cooling concept may be employed.

6. The secondary mirror, relay flats, and main support ring are actively held at 21.1 °C by thermostatically controlled electric heaters, which is a simple approach to maintaining a constant temperature.

7. The instrument support structure and external shell are passively controlled by a low α, high ϵ thermal finish and internally insulated structural members. This combination has been selected because of its lower thermal response to orbital perturbations that induce sensor motions.

8. Thermal control of both 21.1 °C and −17.8 °C instruments was selected after an examination of alternative concepts. The concepts chosen (direct radiation for 21.1 °C and conductive strap for −17.8 °C) were selected because of their simplicity and low costs. Acceptable alternatives are available for both set-point values.

2.3 MOST SIGNIFICANT FINDINGS FOR 100-CENTIMETER PHOTOHELIOGRAPH FOR BALLOON

We have developed a baseline thermal control concept for the balloon mission that meets the majority of the system requirements (see Table 3). The elements of this baseline concept are noted in Fig. 4 and are discussed below.

The most significant findings were

1. A study of thermal instability mechanisms has shown the need to maintain temperature levels and telescope geometry so as to avoid what we call "thermal pluming" or "turbulence."

2. A study of the available techniques for avoiding pluming leads us to believe that a telescope enclosed by a cold vacuum container is the preferred approach.

3. Further studies on our part indicate the need to eliminate gondola structure beneath the telescope aperture, and hence we are led to a gondola structure as shown in the frontispiece.

4. The solid primary mirror is considered to be a key element in the thermal control baseline for the 100-centimeter balloon system. As a result of the short mission duration, we have established that a solid mirror has sufficient heat capacity to maintain optical performance without external cooling. The adiabatic concept results in a much simpler system for the primary mirror.

5. Likewise, the heat shield mirror thermal control baseline is based on a variation of the adiabatic concept. We propose the use of phase change material for the storage of absorbed solar energy. An alternative concept based on the radiative fin cooling scheme is possible for the short duration mission requirements.

6. The secondary metering structure is passively controlled by means of a high emittance surface finish and no insulation. Consideration of the mission indicates that this simple approach will provide satisfactory performance.

7. The baseline thermal concept for the outer shell is established by the need to provide passive cooling to the ambient air temperature level during launch and to maintain this level during the observation period. A thermal finish pattern that provides for a high emittance is used on the upper half of the cylindrical shell while a low emittance surface is used on the lower half. The high ϵ surface maximizes heat loss to space while the low ϵ surface minimizes heat gain from the "hot" earth. Heat transfer within and across the outer shell is maximized by a high ϵ internal finish.

8. A similar rationale applies to the earth shade with respect to thermal control coatings selected for the baseline.

9. The thermal baseline for the aperture window is established by radiation exchange with the earth shade and with space. The earth shade also acts as a shield to prevent albedo and/or earth infrared radiation from reaching the window directly. Although this technique produces a window of the right temperature, the gradients predicted for the concept analyzed are not consistent with quality optical performance. Further work is required to reduce these gradients to the 0.55 to 1.65 °C range.

3. SUGGESTED FUTURE WORK

The Photoheliograph Thermal Concepts Study has resulted in the synthesis of baseline thermal control concepts for three discrete missions. At this time it is apparent that a logical program progression requires that our initial effort be directed toward the definition of the 100-centimeter photoheliograph for balloon missions. Toward this goal, we have identified specific tasks that are required to complete the baseline concept analysis for the balloon-borne photoheliograph and to confirm the baseline by experiment.

3.1 ANALYTICAL EFFORTS

Thermal analysis of the aperture window indicates unacceptable thermal gradients during observation. Further analysis of the transient behavior of the aperture window is recommended to completely define the problem and develop an acceptable design concept.

The heat shield thermal control concept using phase change materials for heat storage requires additional detailed analysis of heat exchange within the system components to confirm the workability of the concept. These analyses will evolve into a final conceptual design.

3.2 DEVELOPMENT TESTING

Natural convection phenomena and thermal pluming of the atmosphere may be predicted analytically using certain heat transfer criteria for simple geometries. Experimental verification of the conditions that determine thermal pluming, especially at the aperture window, is a key element in the design of the 100-centimeter photoheliograph for balloon missions.

Likewise, the translation of analysis of the phase change material concept for thermal control of the heat shield mirror into experimental verification of the concept is a worthy experimental study and another key design element.

While not directed toward confirmation of balloon mission thermal requirements, an experimental program to confirm primary mirror thermal design and optical performance is recommended. This test, which is the basic experimental verification of the proposed primary mirror thermal control concepts, must be performed before the Shuttle and LSO photoheliograph designs are finalized.

Table 1 — 150-Centimeter LSO Recommended Thermal Control Baseline

Primary mirror	Monolith with high reflectance, specular core, partially open back, cooled from back by cold plate
	Cold plate connected to radiator by heat pipe
Primary mirror mount	Main ring heated 21.1 ± 1 °C
Secondary mirror	Solid mirror, thermostatically controlled at 21.1 ± 1 °C
Secondary metering structure	Low α/ϵ meteoroid shield, uninsulated
Heat shield mirror	Solid metal mirror conductively cooled by heat pipe connected to external radiator
Relay flats	Solid mirror thermostatically controlled at 21.1 ± 1 °C
Instrument structure	Not addressed

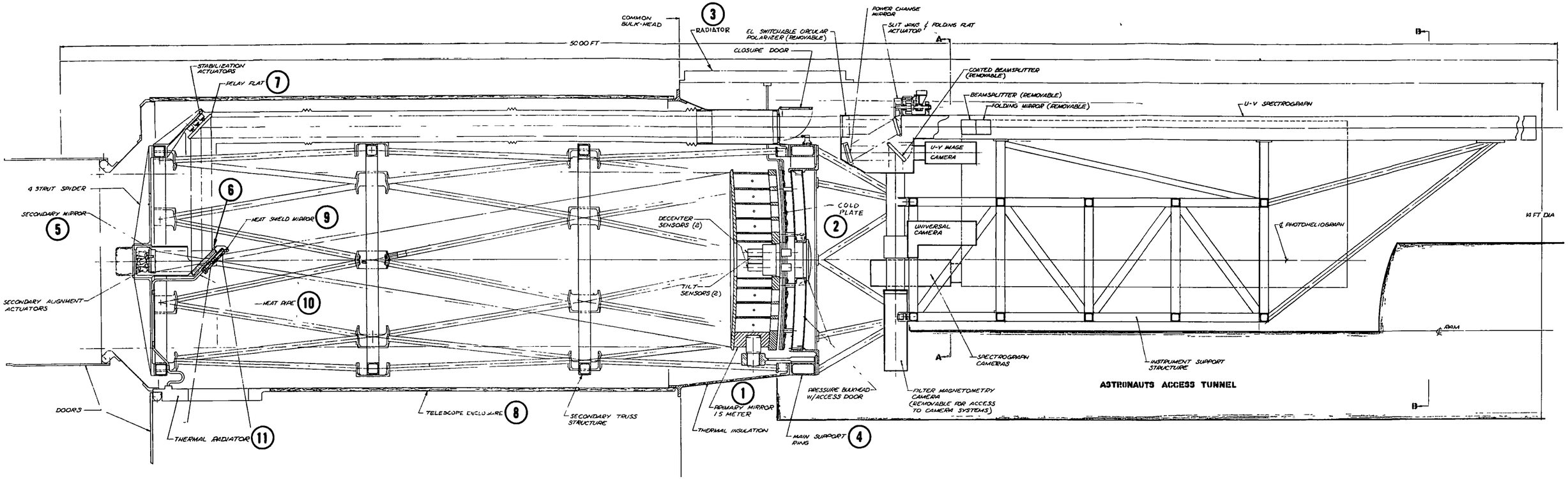


Fig. 1 — 150-Centimeter LSO Thermal Control Concept

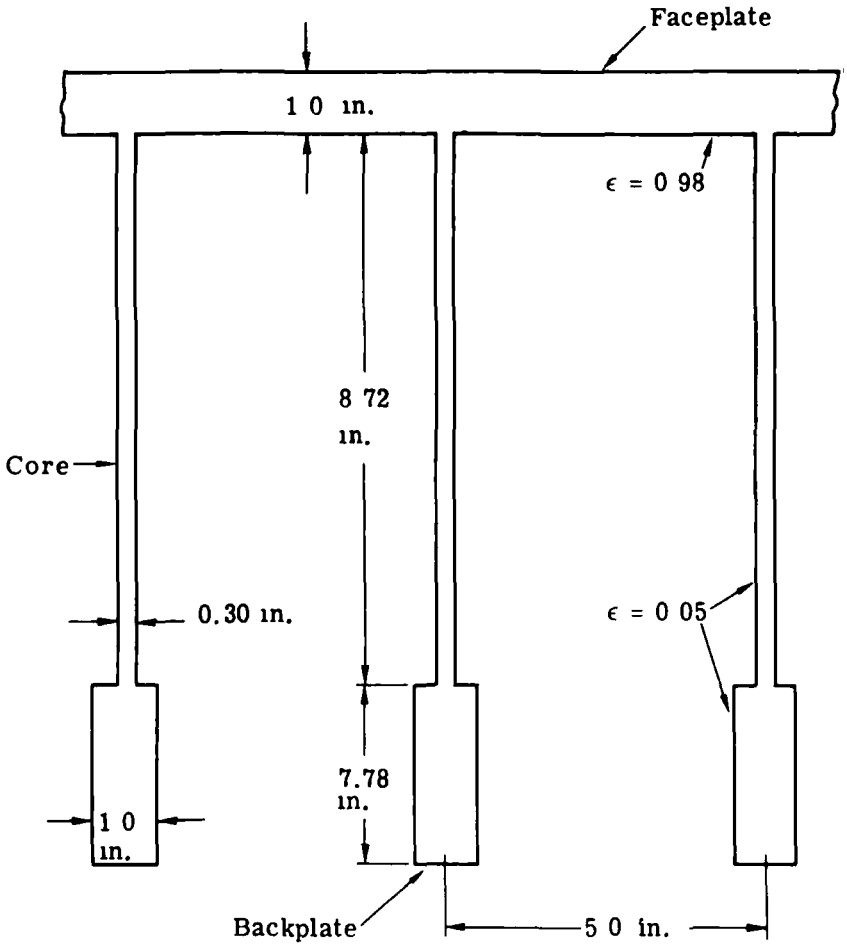


Fig. 2 — Specular core, lightweight primary mirror

Table 2 — 100-Centimeter Shuttle Recommended Thermal Control Baseline

Primary mirror	Solid
Primary mirror cooling	Cooling plate, heat pipe, thermal switch, radiator
Meteoroid shield/metering truss	α/ϵ = 0.12/0.04, no insulation or meteoroid shield; ϵ = 0.9, metering truss
Heat shield mirror	Heat pipe, thermal switch, radiator
Secondary and relay mirrors	21.1 °C thermostatic control
Meteoroid shield/instrument structure	α/ϵ = 0.22/0.88, meteoroid shield; ϵ = 0.04, instrument structure
21.1 °C instrument control	Radiation cooling with makeup heaters
−17.8 °C instrument control	Solid conductor cooling strap

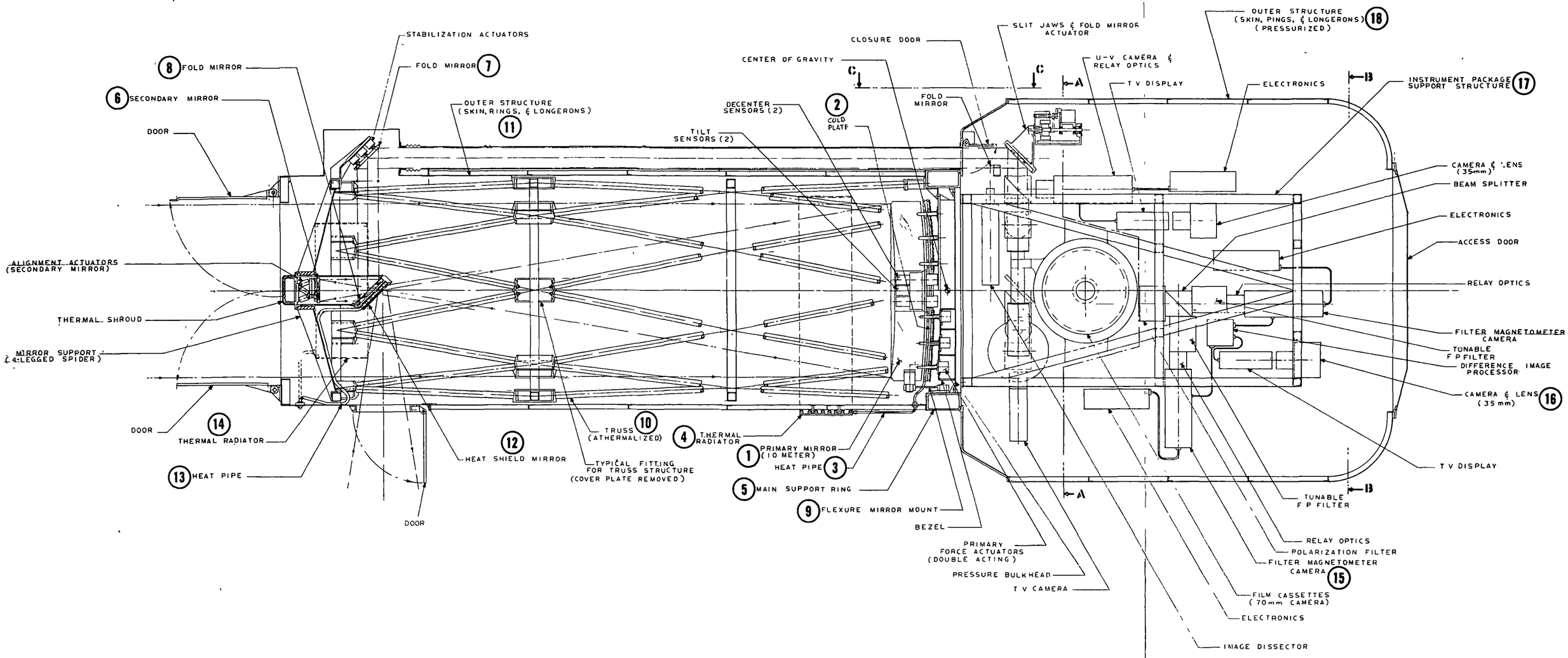


Fig. 3 — 100-Centimeter Shuttle Thermal Control Concept

Table 3 — 100-Centimeter Balloon Recommended Thermal Control Baseline

Primary mirror	Solid
Primary mirror cooling	Adiabatic
Outer shell	Top ϵ = 0.9, bottom α/ϵ = 0.05/0.02, no insulation
Metering structure	High ϵ, no insulation
Heat shield mirror	Phase change material
Earth shade	Inside ϵ = 0.9, outside α/ϵ = 0.05/0.02
Window	Active bezel control at −57 °C
Secondary, relays, and main support ring	21.1 °C active control
Instrument structure and instruments	Same as Shuttle

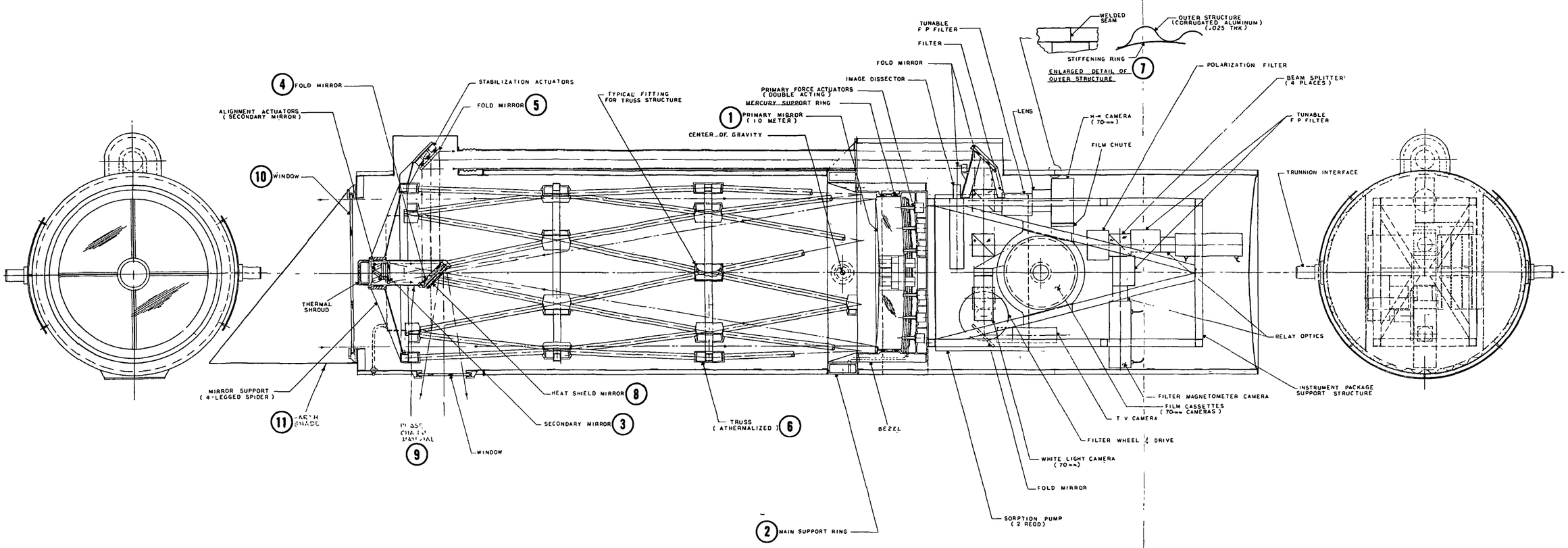


Fig. 4 — 100-Centimeter Balloon Thermal Control Concept