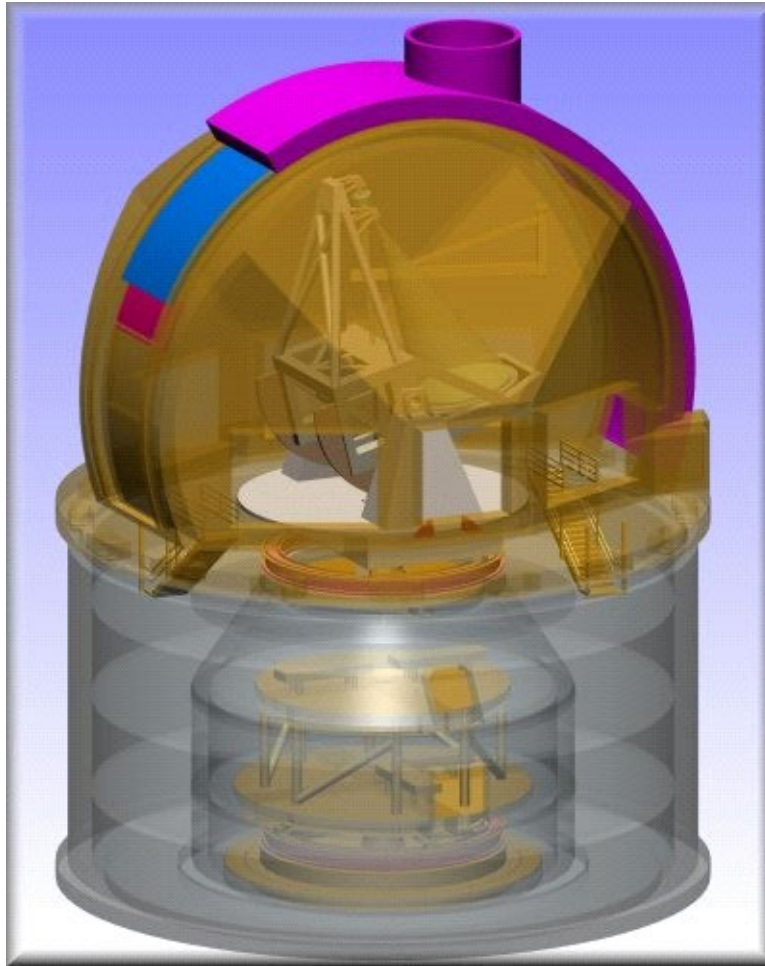


Primary Mirror Cooling Concepts



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1 Introduction

This document briefly describes several cooling concepts for the primary mirror (M1) of the Advanced Technology Solar Telescope (ATST). Some back-of-the-envelope heat transfer calculations are presented here, but more detailed analyses are deferred to a separate Technical Report.

Since the ATST optics reside in open air, the temperature of each optical surface must be individually controlled to track that of the ambient air. Estimates indicate that a surface–air temperature difference $\Delta T \leq 1$ K or so will adequately control mirror seeing. The 4-m diameter M1 sees up to 1100 W/m^2 Solar irradiation. About 10% is absorbed in the mirror surface, giving a surface heat flux $\dot{q}'' = 110 \text{ W/m}^2$. Integrated over the entire surface, the absorbed power \dot{Q} is approximately 1.4 kW.

The following sections list several cooling concepts for M1. Several of these concepts may be adopted in combination in the final design. Thermal performance of the most promising concepts will be presented in a separate Technical Report.

2 Liquid-Cooled Contact Plates

In this concept, several liquid-cooled plates are placed in contact with the cell side of M1 (Figure 1). The plates are attached in the area not occupied by the active optics actuator

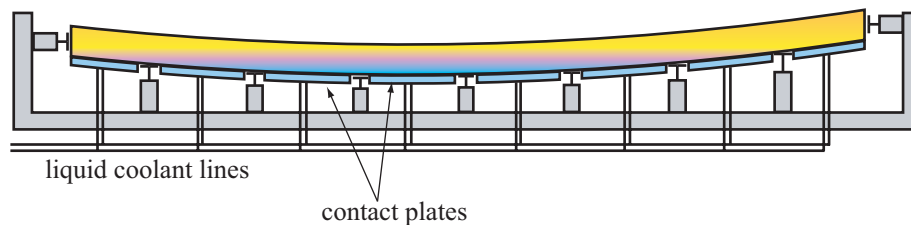


Figure 1: Liquid-cooled plates contact the cell side of M1.

attachment points. Thermal coupling between the plates and mirror substrate is supplied by a thermally conductive foam sheet approximately 2 mm thick. 3M makes a suitable product called a Thermally Conductive Interface Pad, having thickness 2.5 mm and thermal conductivity 2–5 W/m-K. Coolant lines may be arranged in series to link several plates together, or in parallel, giving control over a number of zones. Moderate flowrates produce heat transfer coefficients (h) of over $1000 \text{ W/m}^2\text{-K}$ from the backside substrate edge to the coolant.

3 Sun Side Air Flushing

In this concept, air moving over the mirrored face cools M1 at the very point that energy enters the substrate (Figure 2). Flushing can be provided by a number of air knives spaced about the perimeter (as in the SOAR telescope), or by a jet array. Ambient air moving at

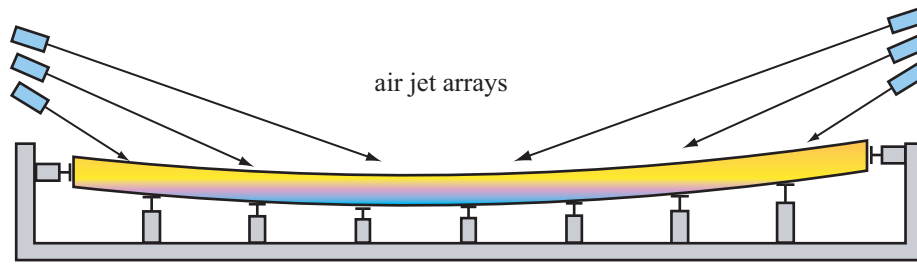


Figure 2: Sunside cooling with forced air.

moderate velocity ($U = 10\text{--}20\text{ m/s}$) over a 4-m flat plate gives $h \simeq 5\text{--}10\text{ W/m}^2\text{-K}$. Cooled by this method alone, M1 will rise some $10\text{--}20\text{ }^\circ\text{C}$ over ambient temperature. It is clear that face cooling alone will be insufficient to satisfy the seeing requirement on ΔT . However, face cooling may be implemented as a way to control seeing with a separate primary cooling system.

4 Radiation Plate

A liquid-cooled cold plate is placed inside the cell in this concept (Figure 3). Energy is transferred from the bottom side of the mirror substrate to the cold plate by radiation ($h_r \simeq 5\text{ W/m}^2\text{-K}$). This is similar to the system built into the Gemini telescopes.

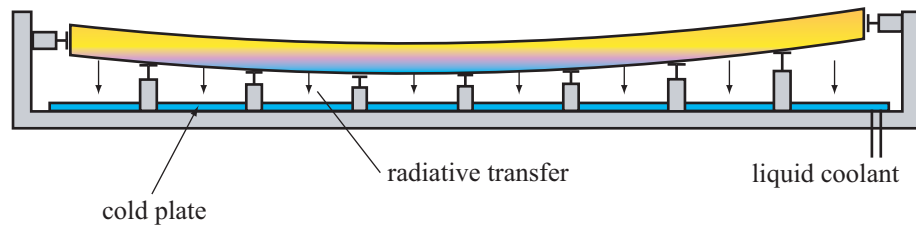


Figure 3: Backside cooling by radiation to a cold plate.

5 Radiation Plate Plus Stirring

Adding fans to the concept of Section 4 more than doubles the cooling efficiency (Figure 4). Convection adds an additional $5\text{--}10\text{ W/m}^2\text{-K}$ to h_r , giving a total heat transfer coefficient of $10\text{--}15\text{ W/m}^2\text{-K}$.

6 Cell Side Air Flushing

In this concept, chilled air is blown across the cell side of M1 (Figure 5). Edge seals prevent chilled air from leaking to the beam side of the mirror and introducing seeing.

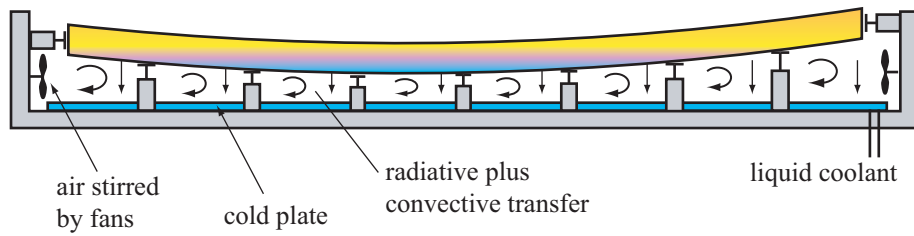


Figure 4: Backside cooling by radiation and convection. Fans stir the air between a cold plate and the mirror substrate.

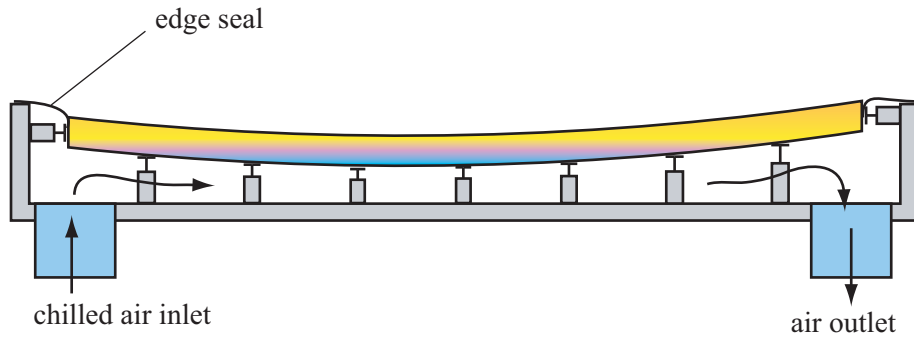


Figure 5: The cell side of the substrate is cooled by flushing with chilled air.

7 Air Jet Array

In this concept, chilled air is blown through an array of jets impinging normal to the cell side of M1 (Figure 6). The cell air is chilled as it is recirculated across liquid-air heat exchangers located either in the mirror cell or nearby. Heat is carried off the telescope by liquid coolant. A jet manifold plate separates the spent jet air from the incoming freshly-chilled air. Edge seals prevent chilled air from leaking to the beam side of the mirror and introducing seeing. The main advantage of this arrangement is that impinging jets give much larger heat transfer coefficients, h , than circulating duct air. For example, in a duct flow $h \simeq 5\text{--}10 \text{ W/m}^2\text{-K}$ while air jets can give up to $150 \text{ W/m}^2\text{-K}$ (see Martin, 1977).

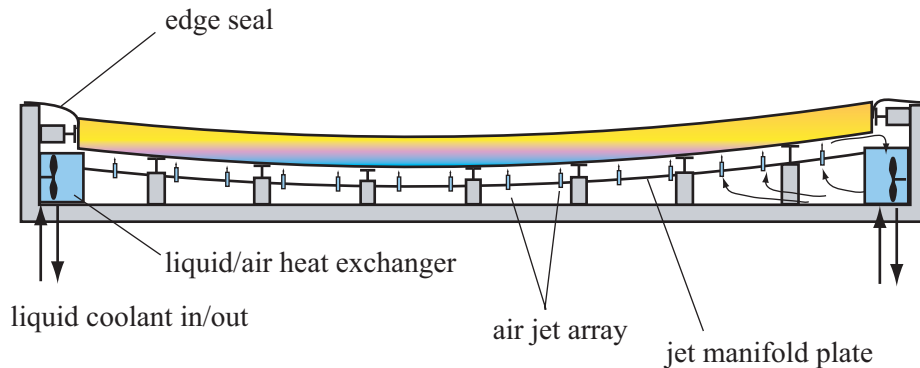


Figure 6: The cell side of the substrate is cooled by an array of air jets.

8 Combinations

Realistically, several of the above concepts may be combined to cool M1. One likely cooling scheme is to use an air knife on the Sun side (meant primarily to control seeing) and liquid-cooled contact sheets on the cell side of the substrate.

9 Notes

1. Air cooling requires much larger volume flowrates than liquid cooling. Large hoses must be integrated with the telescope structure, and fan power increases operating costs.
2. Contact methods (Section 2) have large h ($\simeq 1500$ W/m²-K) and hence, less demanding requirements on coolant temperature. The heat flux \dot{q}'' is fixed by the cooling requirements, and so the required coolant temperature is

$$T_{coolant} = T_{surface} - \frac{\dot{q}''}{h}. \quad (1)$$

When h is very large, the required coolant temperature is simply the desired backside substrate temperature. When h is small ($\simeq 5$ W/m²-K), as in the radiation plate scheme (Section 4), the required cold plate coolant temperature is much lower than the desired backside substrate temperature. A possible compromise is the air jet array scheme, which easily gives $h \simeq 50$ W/m²-K.

10 References

- 1) Martin, H, "Heat and Mass Transfer Between Impinging Gas Jets and Solid Surfaces," *Advances in Heat Transfer*, vol. 13, p. 1, 1977.