Control of Contamination in Cryogenically Cooled Satellite Telescopes

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Abstract

IF a cooled high-sensitivity infrared telescope is to be used in manned space flight, the undesirable effects of contamination on such an instrument must be understood. First, absorption and scattering can be caused by deposition of condensible gas molecules on cooled surfaces; second, radiation emission and absorption can come from solid particles and molecules surrounding the satellite. This paper is concerned with the former effect on a large infrared (IR) telescope (about 1 m in diameter) cooled to about 20 K. The primary purpose of this investigation[1] is to estimate the effectiveness of the purge gas method of contamination control. This method attempts to drive condensible molecules from the telescope tube by venting coolant gas (helium) out the telescope tube. Numerical results are presented for the Shuttle Infrared Telescope Facility (SIRTF)[2] orbiting at an altitude of 350-400 km for 7-28 days, which offers sensitivities over the 1μm to 1mm spectrum at least 1000 times greater than can be achieved from the ground.

Contents

Condensible molecules can be either atmospheric molecules or molecules that emanate from the satellite. The latter includes molecules exhausted from thrusters and vent systems, as well as those outgassed from the satellite body. Some of these molecules may return to the telescope because of intermolecular collisions with atmospheric molecules or reflections from the satellite's surface. Direct incidence of atmospheric molecules on key surfaces must be avoided because their flux rate is very large and, because of their high velocities, they may damage the surfaces upon impingement. The contaminant flux rate is estimated to be on the order of 10^{13} molecules/cm^2-s for the background case and 10^{14} molecules/cm^2-s for the worst case when the thrusters and venting system are operating.[1] The incident flux has a strong angular-dependent spatial distribution because of its large mean velocity with respect to the satellite. The constituents of condensible contaminants are H_2O, O_2, CO_2, H_2, N_2, and a number of hydrocarbons that emanate from the satellite.

The telescope is attached to the Space Shuttle as shown in Fig. 1. A typical space IR telescope has mirrors, conical baffles, cylindrical baffle, and sunshade, as illustrated in Fig. 2. Almost all of the condensible molecules that enter the telescope tube will condense on the cooled surfaces on the first, or at most the second, impact, because the sticking coefficients (except helium) are very close to unity. Assuming that the spatial distribution of the incident flux is uniform at the aperture, the deposition rate can be estimated easily using the concept of the view factor because of the nearly free

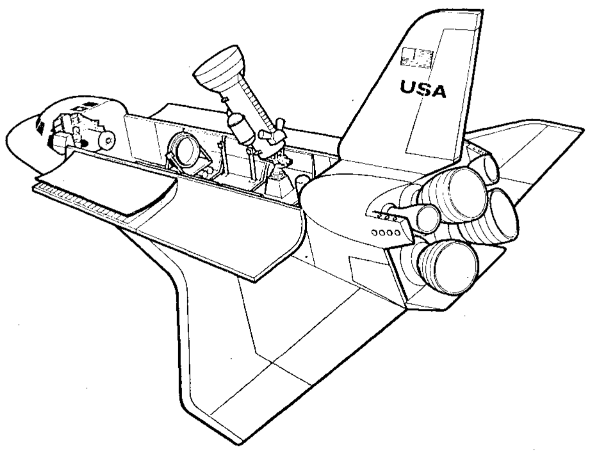

Fig. 1 Spacelab infrared astronomy facility (reprinted from Ref. 2).

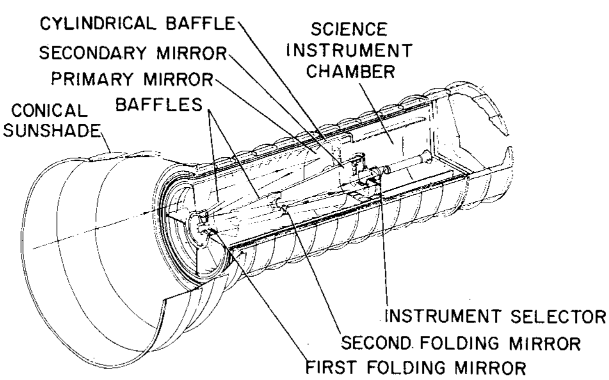

Fig. 2 Shuttle infrared telescope facility (reprinted from Ref. 2).

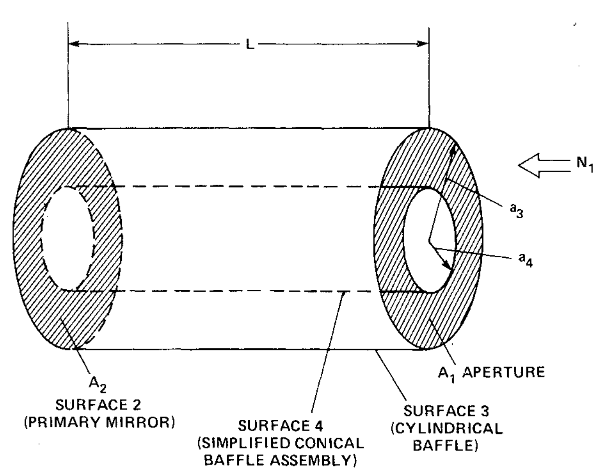

Fig. 3 Analytical model of SIRTF: $a_3 = 59.3$ cm, $a_4 = 29.3$ cm, $L = 508$ cm.

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Index categories: Thermal Surface Properties; Rarefied Flows.

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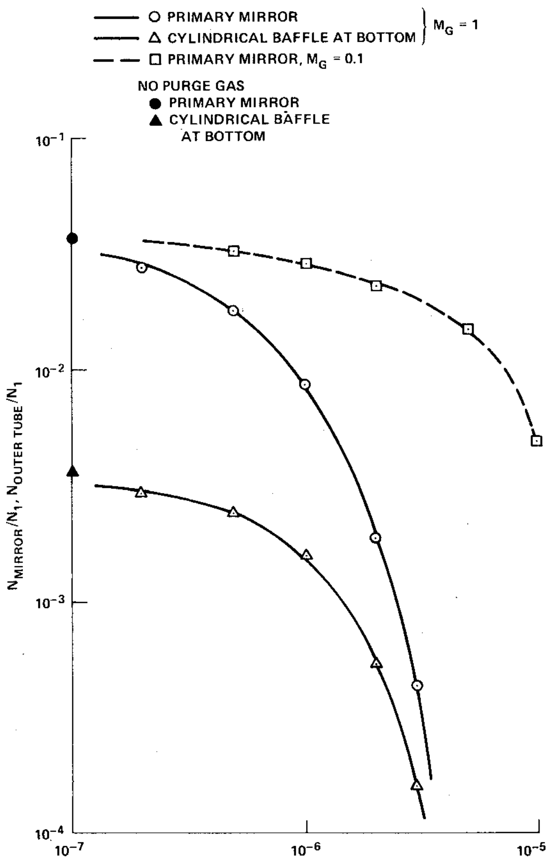

Fig. 4 Attenuation of oncoming contaminant flux by purge gas.

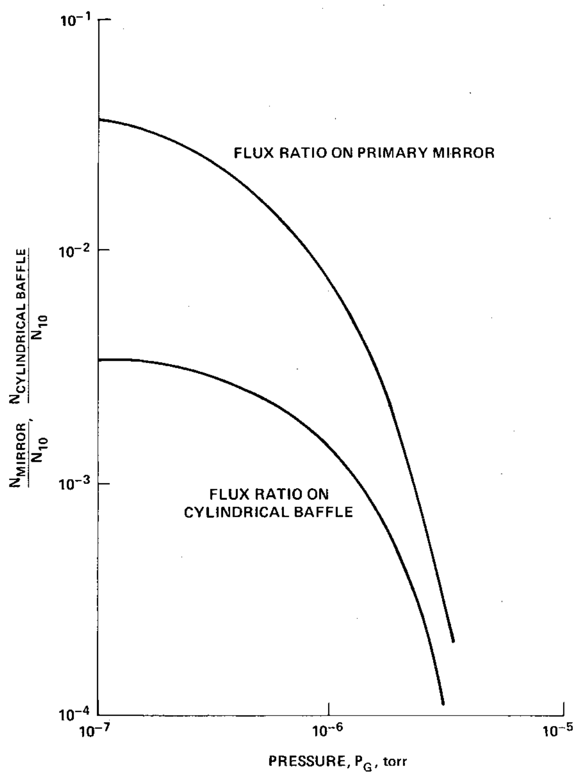

Fig. 5 Total effect of purge gas on contamination attenuation.

molecular flow condition. This analysis predicts that the flux rate on the primary mirror at the bottom of the telescope tube will be 3.7% of the original flux rate at the aperture (N_l) for an analytical model of the SIRTF (Fig. 3). Condensed molecules will pile up, forming a thin solid layer. Deposition layers will degrade the reflectance of the mirror. One of the requirements on astronomical telescopes is that the radiation loss due to absorption by condensibles on optical surfaces in any band $\Delta\lambda = 0.1\lambda$ in the optical and IR should be less than 1% for the entire mission. Experimental results[3-7] show that the deposition layer should be less than a few microns thick. According to the analysis,[1] this thickness would be reached in a few weeks during the mission from background contamination if contamination control were not used.

One method of contamination control is to decrease the oncoming contaminant flux rate by the use of a purge gas. The analysis presented here is made on the basis of the kinetic theory using a zeroth-order approximation. Details of the analyis can be found in Ref. 1.

In Fig. 4, the flux ratios at the primary mirror (located at the bottom of the telescope tube), N_{mirror}/N_l, and on the cylindrical baffle (bottom), $N_{cyl.\ baffle}/N_l$, are given as a function of purge gas pressure. The result is shown for two cases of the purge gas flow velocity: first, the speed of sound ($M_G = 1.0$) and, second, 1/10th the speed of sound ($M = 0.1$). The purge gas is assumed to be helium at 20 K, and the gaseous contaminant is assumed to be water at 300 K. The purge gas is eventually exhausted from the telescope barrel. Collisions with contaminant molecules during expansion into vacuum only slightly attenuate the oncoming flux. In Fig. 5 the total attenuation effects, N_{mirror}/N_{l0} and $N_{outer\ tube}/N_{l0}$, are given, including the effect during expansion into vacuum, where N_{l0} is the oncoming flux without purge gas.

These results show that the pressure of the purge gas must be higher than 2×10^{-6} Torr for $M_G = 1.0$ and much higher yet for an equivalent result if $M_G = 0.1$. Even if $M_G = 0.1$, the quantity of the purge gas for control may be less than that required for cooling. The purge gas may also interact with particulate contaminants near the telescope aperture to increase their residence times in the field of view (FOV). Systematic computations were made evaluating the effect of flow on the motion of particulate contaminants. The only effect found was a slight increase (less than 12%) in the residence times within the telescope FOV for a very small class of particles with very limited particle ejection velocities and ejection angles from the satellite. The heat transferred from the purge gas is small enough to neglect because the temperature of the gas is not higher than that of the telescope.

References

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