Mitigation of Scattered Solar Radiation from Condensed Attitude Control Jet Plumes

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Introduction

IN a previous paper[1] we reported on the observation and analysis of strong visible and ultraviolet signatures due to solar scattering by condensed argon attitude control system (ACS) jet plumes. In that paper, based on extrapolations of available laboratory jet condensation data[2] and solid particle optical properties,[3] we predicted that nitrogen ACS plumes would produce scattered solar signatures similar to those of argon. However, a review of the available laboratory jet condensation data[2] and solid particulate optical properties of neon[1,4] led us to conclude that ACS jets utilizing neon as a propellant should exhibit solar scattering signatures more than two orders of magnitude smaller than those due to similar jets employing argon.[1]

Neon was substituted for argon in the target module attitude control and settling jets for a flight of the U.S. Air Force's Multispectral Measurements Program (MSMP) subsequent to the flight report in our previous paper.[1] This note reports that no observable solar scattered signals from the neon ACS jet exhaust plume were observed above the experimental background level. This lack of observed jet plume signatures is consistent with the predictions presented in Ref. 1.

Experimental Description

The MSMP TEM-3 experiment reported here was similar to the TEM-2 experiment described in Ref. 1. The target module ACS and settling jet characteristics are presented in Table 1. Ultraviolet signature observations were performed from an off-board sensor module containing two digicon photometers, also described in Ref. 1. Wavelength band isolation for the 10×10 pixel digicon instruments was obtained by using interference filters. Visible observations utilizing a television recording system with an RCA type V vidicon were also performed. Further details on the instrument characteristics and their calibration can be found in Refs. 1, 5, and 6.

Experimental Prediction

The major difference between the target module control jet systems on the TEM-2 and TEM-3 flights (besides the substitution of neon for argon as the propellant) was a slightly higher source pressure on the later flight.

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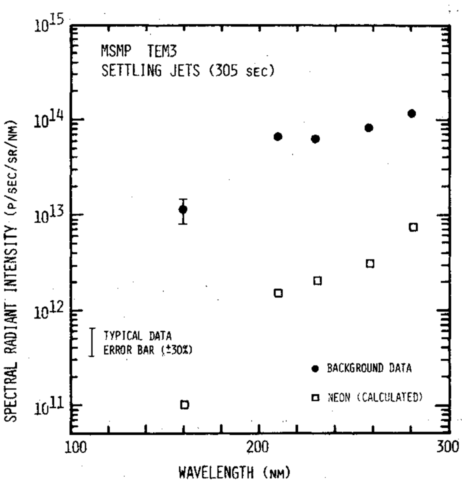

Fig. 1 Comparison of observed background intensity to neon cluster solar scattering model predictions for the settling jet plume.

Table 2 contains predictions based on the laboratory observations of Ref. 2, the equivalent nozzle theory of Ref. 7, and the methodology of Ref. 1 for the control jet plume condensed cluster size (atoms per cluster) and cluster diameter for the TEM-2 and TEM-3 flights. As Table 2 indicates, the mean cluster diameters predicted for the TEM-3 neon jet plumes are about one-quarter of those predicted for the TEM-2 argon jet plumes.

The most intense solar scattering is expected to be associated with the settling jets because they produce the largest clusters and have the largest mass flow. Therefore, the remainder of the quantitative discussion will consist of solar scattering predictions for the settling jets.

Solar scattering by a single neon cluster of diameter D is calculated in the Rayleigh limit using

$$S(\theta) = \frac{3}{64}(1+\cos^2\theta)D^2 Q_{\text{scat}} I_o(\lambda) \tag{1}$$

where θ is the solar scattering angle, $I_o(\lambda)$ is the incident solar flux, and

$$Q_{\text{scat}} = \frac{8}{3}\left(\frac{\pi D}{\lambda}\right)^4 \left|\frac{m^2-1}{m^2+2}\right|^2 \tag{2}$$

where m is the refractive index of solid neon and λ is the photon wavelength. The solar flux used in this analysis for the spectral interval between 100 and 200 nm was obtained from a correlation related to solar cycle suggested by Hinteregger[8] based on the 10.7μm flux. Between 200 and 300 nm, the fluxes recommended by COSPAR are used[9] since the solar in this wavelength region is virtually independent of solar cycle. The refractive index of neon is 1.07 ± 0.02.[1,4] The solar scattering angle for the flight experiment presented here was approximately 56 deg. Values of S(56 deg) are given in Table 3.

The final portion of the intensity calculation is an estimation of the total number of neon clusters within the fields of view of the photometers. As with the argon analysis, all of the neon is assumed to condense and the cluster spatial distribution is characterized by the Brook Vacuum Expansion Model.[10] The result is that for both the MSP and HSP photometers there are 1.2×10^{19} neon clusters within the field of view of each instrument. The neon source spectral radiances are then obtained by multiplying this number by the single particle source intensities listed in Table 3. The results are depicted in Fig. 1. The calculated neon settling jet signal levels per unit length of plume are over 100 times smaller than those due to argon settling jet scattering observed in TEM-2,[1] which has 6×10^{17} clusters within the field of view. The TEM-

Table 1 Target module ACS and settling jet source characteristics

	Cone half-angle, deg	Area ratio	Throat diameter, mm	Nominal source pressure, bar	Nominal source temperature, K
Pitch, yaw ACS	15	47:1	4.8	15.6	300
Roll ACS	15	23:1	1.6	15.0	300
Settling jet	15	15.5:1	4.8	17.8	300

Table 2 Neon and argon cluster size information

	Jet source pressure, bar		Atoms per cluster		Cluster diameter, μ	
			N_{Ar}	N_{Ne}	D_{Ar}	D_{Ne}
Target Module	TEM-2	TEM-3	TEM-2	TEM-3	TEM-2	TEM-3
Pitch, yaw ACS	14.6	15.6	7.0×10^5	2.2×10^4	0.038	0.0105
Roll ACS	14.0	15.0	1.2×10^5	3.7×10^3	0.021	0.006
Settling jet	16.7	17.8	9.0×10^5	2.8×10^4	0.042	0.0114

Table 3 Predicted single particle scattering intensitites for the TEM-3 flight

Filter	Wavelength region, nm	S(56 deg) (photons/s/sr/nm/particle)
HSP-1	160 ± 15	4.1×10^{-8}
MSP-1	210 ± 15	6.1×10^{-7}
MSP-2	230 ± 13	9.7×10^{-7}
MSP-3	258 ± 10	1.0×10^{-6}
MSP-4	280 ± 5	3.0×10^{-6}

3 field of view is larger than that in TEM-2, resulting in a larger background signal.

Figure 1 also contains the effective background source intensity, that is, the measured background intensity treated as if it arose from the immediate vicinity of the target module. Clearly, solar scattering by neon clusters is much too weak a source to account for the observed background signal, unlike argon cluster solar scattering observed during TEM-2.[1] This result is fully consistent with the fact that observed UV photometer and visible vidicon background signals are not correlated with either target module settling or ACS jet activity for TEM-3.

Conclusions and Discussion

As predicted in Ref. 1, the observation reported here clearly proves that scattered solar radiation from control jet planes can be substantially mitigated by substituting neon for either argon or nitrogen as the cold gas propellant. This mitigation is extremely important for satellite systems wishing to maintain low background levels of scattered light contamination in the visible and ultraviolet spectral regions.

As discussed in Ref. 1, other methods of reducing condensed particle sizes, and therefore scattered light signatures for a given propellant, include heating the propellant, increasing the nozzle half-angle, decreasing the nozzle diameter, or decreasing the jet source pressure. There is a clear need for a coupled laboratory and theoretical analysis program to fully characterize nozzle condensation mechanisms and rates for common control jet and small rocket motor plume species. Such a program could provide satellite designers with the data and algorithms necessary to design an efficient control system while minimizing optical contamination effects.

Acknowledgment

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