Reports

Optical Environment in Gemini Space Flights

Abstract. *The optical environment of spacecraft is discussed in terms of sky luminance, spacecraft corona, spacecraft scattered light, and glare sources. Rocket data show that sky luminance is not normally a significant factor; that spacecraft corona may be important at times; and that scattering from spacecraft protrusions and glare sources may be very significant. The range of effects for the scattered light sources is very broad and will depend on spacecraft geometry. An alternative approach in terms of primary sources is used to emphasize the overriding importance of sunlight scattered directly or indirectly.*

Ney and Huch (*1*) have published a discussion of the problem of daylight star sightings from manned satellites. E. Argyle (*2*) and I. Schmidt (*3*) have added some comments on the effects of the physiology of the eye on this problem. The problem presumably becomes important in connection with navigational systems, not only for Gemini flights, but for subsequent deep-space flights where the space ship will be under continuous solar illumination. Ney and Huch consider three classes of illumination: (i) sky luminance, that is, the background field in which the stellar point sources are imbedded; (ii) spacecraft corona, that is, sunlight scattered from particles originating from the spacecraft; and (iii) scattering of light from the spacecraft itself, for example, from windows. We present here some data obtained during rocket flights which have a bearing on the analysis of Ney and Huch, and we add one additional factor which appears to be of the same order of importance as the preceding factors and may, in fact, be the predominant one under certain plausible conditions. The rocket flights involved were made for the purpose of measuring the day airglow rather than the scattering properties of the atmosphere. The by-products of the investigation, however, do have a direct bearing on the problem at hand.

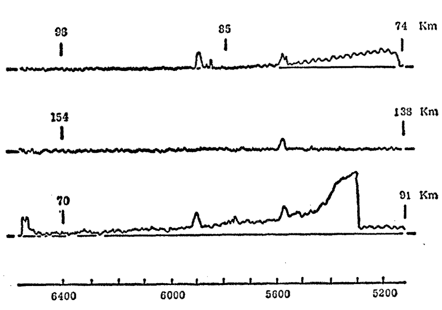

Fig. 1. Unreduced spectral scans from a rocket flight on 13 November 1963, White Sands, New Mexico. Heights at selected points on the scan are indicated above each scan. The top two scans are from the ascent portion, the bottom scan from the descent portion of the flight.

The background field consists of scattered light (primarily of solar origin), airglow, and extraterrestrial light. Some unreduced spectral scans from a rocket flight on 13 November 1963 at White Sands, New Mexico, are shown in Fig. 1. The airglow emissions at 5577 Å [OI] and, on the lowest altitude scans, 5893 Å [NaI], are evident. On the first part of the first scan the continuum background due to scattered sunlight still makes an appreciable contribution but when the altitude of the rocket is 85 to 90 km the scattered light is below the instrumental background. In the third scan, from the descent portion of the record, the increased signal due to the effect of particles introduced by an explosive charge during engine separation is evident. Our rocket measurement of day skylight intensity (*4*) between 20 and 90 km has shown that at heights greater than 90 km the day skylight intensity is equivalent to that of the night sky from the ground. Of the major airglow emissions in the visible spectrum, only the sodium line appears when the altitude of the rocket is below 100 km and, in our data, it shows only on the lowest altitude scans. A second line, 5577 Å [OI], present up to high altitudes but predominantly produced at an altitude of about 95 km, appears to have a high altitude component at about 170 km (*5*). The third major emission, 6300 Å [OI], is primarily a high altitude emission. Although there are differences in the intensities measured by us (*6*) and those of other investigators (*5, 7*), these differences are not sufficient to affect the present situation. In these spectral regions the line contribution would be at most of the order of kilorayleighs or tens of kilorayleighs, and this, integrated over the visual range, will result in a background luminance field no larger than the night sky continuum. Thus it would appear, as Ney and Huch also conclude, that at satellite altitudes the natural background illumination is insufficient by far to interfere with daylight star sightings.

The second factor, spacecraft corona, is more difficult to estimate without a knowledge of the size distribution of particles in the spacecraft vicinity. Ney and Huch, using certain specific simplifying assumptions regarding particle size, light scattering by particles, and

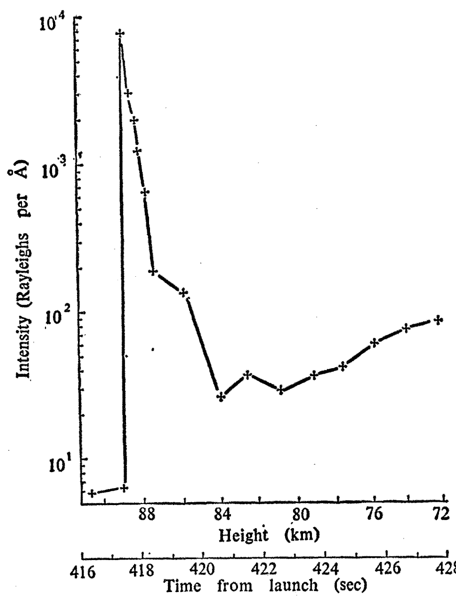

Fig. 2. Scattered light intensity as a function of time following detonation of an explosive charge to produce engine-payload separation.

rate of mass ejection, have calculated the approximate residence time and expected luminance of the spacecraft corona. From our experimental data it is possible to obtain a crude estimate of the extent of particle scattering and of the length of time this is effective. Despite the fact that the ambient conditions for our data were considerably different from those of the spacecraft, the data should provide estimates, when suitably modified, which are useful for spacecraft operations. In our rocket flights the engine and payload are separated on the downleg by an explosive charge. This normally produces tumbling of the payload, including the spectrometer, thereby rendering subsequent data too difficult to usefully analyze. On one flight, however, after engine separation the spectrometer continued to point upward. The increase in light intensity resulting from scattering by particles from the explosive engine separation is shown in the third scan of Fig. 1. This portion of the data is shown in more detail in Fig. 2. The data have been converted to rayleighs per angstrom and are shown as a function of both height and time. The increase of the baseline with decreasing height is, of course, the increase of primary scattering with increasing density. The decay of the perturbation introduced by the particles of explosive origin can be approximately represented exponentially with a time constant of about 0.5 to 2.0 seconds. The decay may be due to vehicle motion, cloud expansion, or diffusion. If we equate the decay time to the residence time of the particles then this is consistent with the estimate of Ney and Huch for 1-μ particles under spacecraft conditions. A comparison of the intensities, however, leads to a serious discrepancy with the estimates of Ney and Huch. The use of their equation (*1*) leads to a calculated intensity some 10^6 times higher than that which we observe. Some of this difference may be due to geometrical factors, that is, the explosive charge, being on the circumference of the rocket, may produce an annular cloud rather than the spherical surface we assume, and the spectrometer may be looking into the hole of this doughnut. We do not feel that this is sufficient since in the normal course of the pitch and yaw of the rocket we would be scanning different parts of the annulus and would therefore expect to see a greater brightness variation than is observed. We feel that a more careful calculation of the scattered light would be in order since the effect may be significantly less than indicated by Ney and Huch.

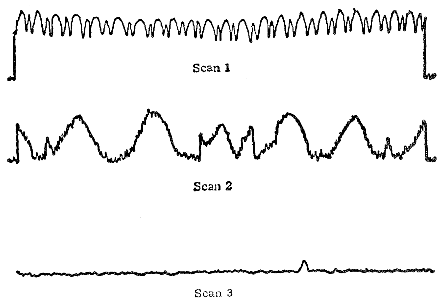

Fig. 3. Spectral scans illustrating the effect of optical baffling. Scan 1 is from a flight from Eglin Air Force Base, Florida, 29 January 1962; scan 2, from Fort Churchill, Canada, 18 July 1964; and scan 3, from White Sands, New Mexico, 13 November 1963. All scans are at heights greater than 100 km to eliminate the effects of rayleigh scattering.

The third factor considered by Ney and Huch is scattering within the spacecraft windows. This is the most difficult factor to estimate in advance, since the sun is such a bright source that even if only a very small amount of this light is scattered into the instrument it will be sufficient to mask the faint source being looked for. Bright spots on protrusions from the spacecraft could introduce appreciable scattered light. The effect of instrumental scatter can perhaps be best illustrated from experimental data. Figure 3 shows three scans from different flights which illustrate the effects of optical baffling, or more accurately, the lack of it. All three flights were made for the purpose of measuring day airglow emissions. In the first flight the optical baffling was such that no airglow emissions were evident; the entire output consisted of scattered sunlight modulated by the spin of the rocket. In the second scan some scattered sunlight is present, as is clear from the modulated output, and the airglow emissions are superimposed upon this. In the third scan the baffling is sufficient, so that only atmospheric emissions are present. It is clear that for stars to be visible in the daylight every precaution must be taken to eliminate all stray light from bright spots. Masking due to reflections from within the spacecraft because of internal pilot lights and the like can presumably operate with similar effect.

Finally, we may consider the fourth factor, the effect of light sources which are out of the line of sight but within the field of view of the observer's eye, that is, glare or dazzle sources. Holladay (*8*) has investigated the action of a light source in the field of view in increasing the minimum perceptible luminance difference. The paper is pertinent since the search for a star against a background field is the problem of the least luminance difference that can be detected. Holladay finds that the equivalent total background luminance equals

$$F + (2.9E/D^2) \qquad (1)$$

where F was the actual background luminance in millilamberts, E the meter-candles of illumination at the observer's eyes from the dazzle source, and D the elevation in degrees of the dazzle source above his line of vision.

An accurate calculation of glare effect cannot be made without a detailed knowledge of spacecraft geometry but we can illustrate here the possible effect. If we assume solar illumination on a diffuse surface 1 cm² and 1 m from the observer's eye at an angle of about 10°, then, using the table of Tousey and Koomen (*9*), the limiting magnitude of stellar visibility is reduced from the sky brightness value of about 6th magnitude to about 4th magnitude. For a diffuse surface of 100 cm² area 1 m away at an angle of 10°, the limiting magnitude is further reduced to about 1st magnitude. For both cases the veiling luminance is effectively determined by the glare source, the background sky luminance being negligible by comparison. The effect of a portion of the earth's disk within the field of view of the observer can be treated in the same way by adding a factor for albedo. The veiling luminance will then depend on the solid angle subtended. For plausible values of solid angle the limiting stellar magnitude can be reduced to as low as -1. It is clear that glare alone can have a far-reaching effect on the observation of stars in the daytime.

Thus far we have considered a number of specific sources which introduce a background field in which the point source, the star, is embedded. It is instructive to approach the problem in a slightly different way, that is, from the point of view of the primary sources. These are: (i) ambient luminescence, that is, airglow and aurora; (ii) internal sources, that is, control lights, pilot lights, and the like within the spacecraft itself; and (iii) sunlight, either direct or reflected from a surface or surfaces. We shall consider each of these separately.

The simplest way of estimating the effect of airglow and aurora is to estimate the change in limiting stellar magnitude from the night sky value, that is, about 6th magnitude. We have previously pointed out that the day airglow is not significantly different from night airglow as far as background illumination is concerned. Some effect might be found if one is *in* the airglow layer because of the difference in the path lengths. For any reasonable layer thickness the ratio of path lengths between horizon and zenith will be 60 or less. This luminance increase leads to a reduction to about 4.8 for the limiting stellar magnitude. Furthermore, with one exception, the major airglow emissions are all below satellite altitudes. The airglow effect on stellar visibility may therefore be neglected. The aurora can at times be a sufficiently strong source to reduce stellar visibility. If we take as an extreme an aurora producing three orders of magnitude more luminosity than the airglow the limiting stellar magnitude will be reduced to about 4. Normally the bulk of auroral luminosity will be below satellite altitudes and should be effective only at low angles. The aurora is aligned along magnetic field lines and if one is in an aurora the visibility will be less along the vertical than along the horizontal, in contradistinction to the airglow situation. However because of the luminosity profile [see (*6*) for a published profile of a daytime aurora at satellite altitudes] this should not seriously change our estimate of limiting stellar magnitude.

Internal sources of light consist of pilot lights, control lights, and all other luminescent objects. These will act by multiple reflection on all internal surfaces resulting in a veiling luminance by scattering in either the window or the eye. In any event the internal optical environment cannot be calculated without very specific information on light sources and their geometry. It would probably be best to carry out ground tests in a spacecraft to determine this factor. Internal sources need not be a hindrance, however, if provision is made for turning off all light sources at will.

The third and by far the most important source is the sun, whose effect appears in many guises: scattering from dust particles surrounding the spacecraft, reflections from spacecraft surfaces, scattering in the windows, earthlight, and moonlight. Scattering from dust particles can be most generally represented as producing a luminance of the form

$$B = \left[F \sum_i (\delta + A_i\Omega_i) \right] f(n,a) \quad (2)$$

where F is the solar constant; the δ is 0 when the sun is screened and 1 otherwise; and A_i, the diffuse albedoes of the earth, moon, spacecraft, or other objects in the vicinity; the Ω_i, the solid angles subtended; and the $f(n,a)$ is the scattering function which is dependent on the type of scattering, the number density, and the area of the particles.

Scattering within the window could be represented by a similar function as far as the sources of illumination are concerned, but we must add in a cos θ factor to take account of the anisotropic nature of the window surface. The effect of glare can be obtained in a manner very similar to that of particle scattering, since the veiling luminance will be proportional to

$$F \sum_i \frac{(\delta + A_i\Omega_i)}{D^2} \quad (3)$$

In Table 1 a number of illustrative calculations are given for particular situations. These have been chosen as plausible cases in order to decide which factors have the most effect for earth satellite situations. For moon flights, of course, the relative importance of these factors will be altered. Enough sources of veiling luminance are present in the environment of a spacecraft that the limiting magnitude of stellar visibility can easily be radically reduced. It is clear that more care must be exercised in setting up baffling arrangements which can eliminate most of these sources. The effect of a small specularly reflecting surface, even when it is eliminated as a dazzle source, can become important by scattering in the window.

Further discussion can best be carried out in the context of specific geometrical arrangements. Here we have indicated several of the factors which can significantly contribute to the question of stellar visibility in the daytime, although we have not conidered some, such as dark adaptation, which are not limiting when time is available.

Table 1. The left-hand column lists sources of flux at the spacecraft window. The center column lists the equivalent veiling luminance for these sources when dazzling an observer looking out of the window. Values for different angles between the dazzle source and the line of sight of the observer are given. The last column gives the veiling luminance produced by scatter in the window where it is assumed that 0.1 percent of the incident flux is diffusely transmitted by the window.

Sources of flux	Veiling luminance of dazzle source (mlam) at D of				Veiling luminance due to window scattering (mlam)
	2.5°	5°	10°	20°	
		Earthlight			
Subtending 0.1 steradian	1.3×10^3	2.3×10^2	5.8×10^1	1.4×10^1	2.0
Subtending .01 steradian	1.3×10^2	2.3×10^1	5.8	1.4	0.2
Subtending .001 steradian	1.3×10^1	2.3	0.6	0.14	0.02
		Sunlight			
1 cm² diffuse reflector 1 m from window	2.8	0.5	0.105	0.031	2.8×10^{-3}
1 cm² specular reflector 1 m from window	8.8×10^4	1.57×10^4	4×10^3	9×10^2	137.0
Full moon	0.195				3×10^{-4}
Spacecraft corona of 10 rayleigh/angstrom					3×10^{-6}

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