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VISION AND ASTRONAUTICS

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Since the earliest times the astronomers obtained their information about celestial bodies through direct visual observation. In the last decades photography started to play a role as an objective method and at the present time, in some instances, radio astronomy is applied. But it is still recognized that vision cannot be fully replaced by objective methods. For instance it is nearly impossible to register details of the surface of the planet Mars during a "Clearing" of its cloudy atmosphere on a photographic film, when it lasts for a fraction of a second only, whereas the human eye is able to catch some impressions. Astronomy takes advantage of the scientific results of visual physiology and the latter gains from astronomy, e. g. our visual acuity standard is based on the statement about the resolvability of two stars which have a separation of one minute.

With the development of astronautics the visual problems are to some extent the same as those of astronomy yet in certain respects the *conditions of seeing* are differents: the astronomer observes the celestial bodies through our atmosphere. In the daytaime the sky appears bright due to light scattering particles in the air. This diffused light is of a blue color because the short wavelengths are scattered more than the long wavelengths. The stars are not visible because of lack contrast. At night, even in a moonless night, the sky is never entirely black. That is due mainly to airglow in the upper atmosphere. This phenomenon is light emitted by atomic oxygen, nitrogen and sodium brought into an excited state by ultraviolet radiation during the day. Also zodiacal light, which is light reflected from micrometeorites, starlight and galactic light, both direct and scattered, contribute to the luminance of the night sky. The average luminance of a moonless sky is of the order of 10^{-4} cd/m^2 (nit). Due to attenuation by the atmosphere through absorption and scattering all celestial bodies appear by about 20% darker than outside the atmosphere.

In space, which for practical purpose begins at an altitude of about 150 km, the atmosphere is too rarefied to scatter light appreciably. The sky, therefore, appears permanently dark except of a faint brightness provided by direct starlight, galactic light and zodiacal light. The luminance of the sky in space is of the order of 10^{-5} nit. Stars, sun, and moon are permanently visible and appear brighter than on Earth and also whiter because short wavelengths are not scattered out. More stars are visible than through the atmosphere. The illuminance by the sun at the outer limit of our atmosphere is equal to about 140000 lux, whereas at the earth surface it is only slightly above 100000 lux even under the through the cone of the Earth shadow, there is always extreme brightness on that most favorable conditions.

On Earth we have a day-night cycle. In space, except when the astronaut passes side is deep shadow except when, depending on the position and distance, it is partly brightened uy by moonlight and by earthlight. This photo-scotic condition (Strughold), extremely dark shadows outside and inside the cabin poses special visual problems for the astronaut.

The *visual tasks* to be performed are mainly detection and observation of oncoming space crafts, satellites, meteorites and of planets as prospective landing targets, including the planet Earth, since to the orbiting astronaut the Earth itself attains the properties of a luminous celestial body. It causes the strange situation that the surround is bright below and dark above, the reverse of the situation at the Earth surface, where in the primary position of the eyes, the lower part of the retina is usually adapted to a greater luminance than the upper part.

The visibility of an object, the clearness with which an object stands out from its surroundings, is a function of *luminance contrast*, which is defined by the relationship $C = \frac{Lo - Lb}{Lb}$ where Lo is the luminance of the object, Lb the luminance of the background. The liminal contrast value, the threshold contrast, depends on a number of variables, e. g. the background luminance, the size of the object, and phychological factors. Data for contrast thresholds are available in the literature (Blackwell). Small light sources, subtending about 1 minute of arc or less for the light adapted eye, or up to 10 minutes of arc for the dark adapted eye, are a special case of contrast thresholds insofar as the visibility is then affected proportionally to the illuminance E. at the plane of the eye. The relationship $E = I/d^2$ is known as the law of inverse squares, I representing the intensity of the observed point light source, d its distance. When the eyes of the astronaut are adapted to the sky luminance of 10^{-5} nit, the threshold illuminance Et equals 2×10^{-9} lux. This value corresponds to a star of 8th magnitude. Knowing also the intensity I, for instance in the case of an artificial satellite, its visual range can be computed, that is, the farthest distance at which it should be just visible. The intensity of a spherical satellite with specular reflection can be computed from a formula $I = \frac{Es\ R\ r^2}{4}$ where Es is the illuminance by the sun, R the average reflectance of the satellite, r its radius. For a white diffusing spherical satellite and also for planets the intensity is given by the formula $I = E_S R_{r^2} \frac{2}{3} \cdot \frac{\sin\alpha + (\pi - \alpha)\cos.\alpha}{\pi}$ where alpha is the phase angle, subtended at the center of the satellite or planet by the direction to the sun and to the observer. When seen through the atmosphere the intensity values must be multiplied by its total transmittance.

The next problem is the recognition of details in order to identify the luminous object. Here another function of the eye will be utilized, namely *visual acuity* which comprises different functions, e. g., the detection of single spots, of single lines, the separation of two or more lines or spots, seeing of contours, and breaks in contours and distinction of more or less familiar forms. All these functions depend on a multitude of variables. One of the most importante factors affecting visual acuity is illumination. Visual acuity does not only depend upon the luminance of a small central area containing some details, but also upon the luminance of the surround, which is the chief determinant of the adaptation level of the eye. For low and medium luminances of the central area, maximal visual acuity is obtainable when the luminance of the surrounding area is the same as that of the central. In case of high luminances, e. g., when the astronaut observes the surface of Mars with an average luminance of 2350 nit or of Venus with 50000 nit, the adaptation level must be somewhat below that of the observed surface to achieve maximal visual acuity, as follows from Fig. 1 after Foxell and Stevens. The astronaut should have a possibility to obtain the desired level of adaptation in order to recognize as much details as possible.

Another function of our eye supporting recognition of details is *color vision*. We observe yellow-red and green areas on Mars, a great red spot an other colored features on Jupiter, white and yellow belts on the golden ball of Saturn, etc. We will consider only a few of the factors affecting color vision, namely the luminance of the observed area, the adaptation state of the eye, the size of the object, and assume normal color vision of the observer. The threshold illuminance for correct recognition of colors is about 10 lux. The distance from the sun where correct color discrimination is not possible any more because the illuminance by the sun is not sufficient would be about 18 billion km from the sun or about three times the distance of the planet Pluto from the sun. The colorless world

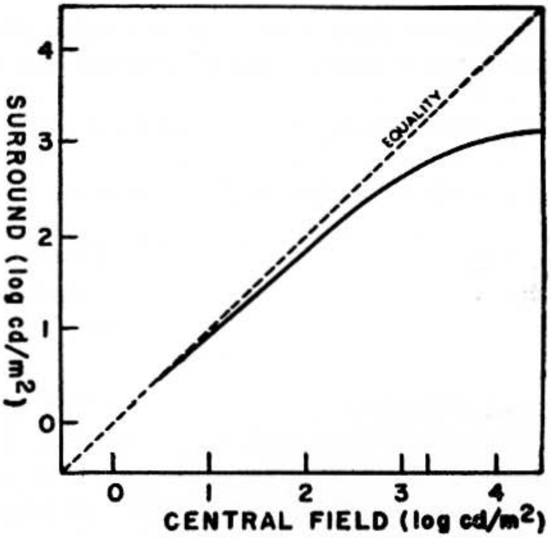


Fig. 1. Luminance of surround for maximum visual acuity (central field 0.5°, surround 120°) (redrawn after Foxell and Stevens).

of interstellar space with a black, star studded, sky can be called a *hypophotic zone* (Strughold) in comparison to the euphotic zone which in respect to solar illumination is favorable to space operations and to life on planets.

Not only the luminance, but also the size of the colored area is of importance for a correct recognition of colors. By compiling the data of the literautre Fransworth found a product of area times intensity below which color vision become tritanomalous and a somewhat lower product below which it is tritanopic. In the tritanomalous stage orange-red and bluegreen and violet are about colorless and hardly distinguishable from each other. Because of the tritanomaly of the fovea, Syrtis Major, a large dark area on the northern hemisphere of the planet Mars will be seen with unaided eyes in its real colors with certainty only wehen the astronaut approaches the planet to about 652000 km that is about 1½ times the distance of our moon from Earth.

In order to observe colors the eyes must be bright adapted. Dark adaptation, which the astronaut obtains when scanning the sky, is unfavorable insofar as it makes dim colors appear unsaturated and causes a shift in their luminosity, known as Purkinje phenomenon.

Even when luminance and size of the observed area are sufficient and the eyes are adapted to brightness, we cannot be certain that the colors perceived are real. For decades astronomers have argued the question of whether or not the dark green and bluishgreen areas of Mars are really green and bluegreen or merely a phenomenon of contrasts. By simulating the conditions of observation of Mars in the laboratory it has been shown that production of the Martian coloration by means of contrast phenomena is definitely a possibility (I. Schmidt). These findings cannot be used as evidence against the existence of vegetation of Mars, however, since, first the vegetation may have some dark color, different from green, and secondly, as we know from observations on earth, distant green areas do not appear green, but unsaturated bluegreen or even blue, due to the absorption by the atmosphere and to an additional coloration by scattered indirect sunlight, the bluish air light. Since the atmosphere on Mars is not very transparent for short wavelenghts, such phenomena can take place also on that planet. Moreover, dark areas in the vicinity of large sunlit areas, for instance snokfields, assume a bluish contrast color to the yellowish bright areas (for more details see Middleton). This may occur also on the surface of Mars, the atmosphere of which by attenuation my render the sunlight yellowish.

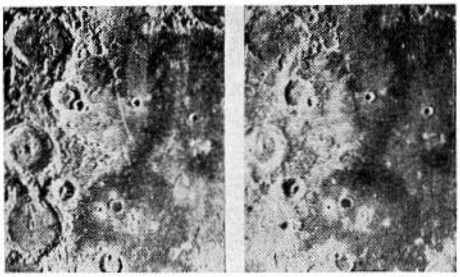
From a certain high luminance value on colors lose in greeness and redness and become increasingly yellowish and bluish. Color vision of a normal person becomes similar to that of a red-green blind. On further increasing luminance everything becomes achromatic, colorless. The lower limit, above which color vision is appreciably disturbed, is, according to Segal, beyond 6000 trolands. A troland is measure of retina illuminance, obtained by multiplying the luminance of the observed area in nits with the pupillary area in mm^2, e. g., a retinal illuminance of 6000 trolands is produced when an area having a luminance of 1,910 nits is observed through an artificial pupil of 2 mm. diameter. Thus, when observing Mars through the atmosphere (1880 nit) color vision would not be effected whereas when observing in outside the atmosphere (2350 nit) it probably would.

When the astronaut with unaided eyes takes a look into the bright sun, or at near distance from the planet Earth glances toward its surface (having an average reflectance of about .35, Earth reflects a great portion of the incident sunlight) a *dazzling glare* would result causing discomfort to the observer because of a blinding after-image and disabling him for any visual tasks. The astronaut will be particulary prone to such glare since his eyes, when scanning the sky will be dark adapted and the pupils will be wide. When there is a glare source in the field of view, e. g. the sun from a great distance, which would permit vision while it is present, it may produce a veiling effect through scattered light by the eye media and thus reduce contrasts, The effect of the veiling glare depends on the angle between the visual line and the direction of the glare source. In the presence of high intensity light sources subtending a small angle, the rest of the visual field is affected as if a veiling luminance L_1 were present over the visual field. If φ is the angle between the visual line and the direction of the glarse source, E the illuminance at the eye from the glare source, then $L_1 = \frac{E}{\varphi_2 \quad K_1}$. For L_1 in nits, E in lux equals 13.7 ∓ 1.6 (cited after a survey by Rose). Rose computed that the eyes of the astronaut would sitll suffer from glare up to a distance of 1.8×10^9 km from the sun that is beyond the orbit of Saturn. At that distance the illumination from the sun is about 1000 lux.

Special attention must be given to possible hazards to the eyes when observing the sun without appropriate protection. With sufficient energy a retinitis solaris or even a burn of the retina can occur, resulting in a *helioscotoma* in the visual fielde (Strughold). Such burns are known from observation of solar eclipses with an insufficiently smoked glass. Outside the atmosphere the danger is greater and increases of course in heliopetal direction, for instance on an expedition into the region of Venus. From data available about similar effects from atomic flashes (Byrnes, Brown et al.) it can be estimated that an exposure time of the order of 15 seconds or less of the eye to the solar rediation in space at earth's distance might be sufficient to cause retinal burns. On a flight in the direction of Venus the critical time of exposure would become shorter. (It may be of interest that in the optical blinking reflex, a time of 0.15" elapses from the onset of the stimulus until the lids are closed (Lawson) and that time required to contract the pupil equals 0.45 to 0.7 seconds (Petersen).

Depth perception is not of great value in space except during approach and hookup between two spacecrafts, because the distances arte too great. The binocular cue of stereopsis is useful only up to about 200 meters. The so-called empirical or secondary factors of depth perception will be helpful to some extent: for instance geometrical perspective: an apparent slight curvature of the obviously parallel belts of Jupiter support the impression of a globe, a partial overlay permits us to conclude that the blue clouds on Mars are higher than the yellow clouds, the size of known objects, e. g. satellites or spacecraft may be helpful to judge their distance. Motion parallax which is enhanced by high speed (Rose) may play a role. When observing the surfaces of celestial bodies, the transition between light and shade gives the surfaces a quality of shape in the third dimension. A gradual transition of shading yields an impression of a curved surface, an abrupt shading that of an angled surface. Fig. 2 shows two photographs of the same area on the moon. One must know the direction of the incident light, otherwise an optical illusion may take place. In the right picture the sunlight is incident from the left. We perceive craters with elevated edges. In the left picture the sunlight is incident from the right, but we have the impression that it is also incident from the left and the craters appear as mounds. By rotating the figure the illusion disappears.

The use of the human eye in the control of the spacecraft is limited by the distance the vehicle travels during the time necessary for *perception and reaction*.



(a) (b)

Fig. 2. (a) Moon last quarter. (b) Moon first quarter (after F. L. Whipple).

According to a survey by Strughold the latent period of a simple optical perception is 0.1 seconds at low luminances and in the periphery of the retina, in the fovea and in daylight 0.05 sec. The reaction time for a fixation movement is about 0.18 sec. Recognition takes 0.2 to several seconds. To permit evasive control action an object must have a visual range exceeding the distance travelled durig the chain of latencies. The spacecraft would have also mechanical latencies before a change in the flight path occurs. Since within a time of 1 seconds a spaceship travels 7 km, but a meteorite 40 km (its visual range may be shorter that 40 km), there is permanent danger of collision with meteorites.

Still the visual sense is the sole sense which serves the astronaut for orientation concerning his position and movement in space in this world of silence and weightlesness, where the mechanoreceptors, the pressoreceptors and the otolitic organ cannot provide any information.

SUMMARY

The visual observation of the sky by an astronaut differs from that by an astronomer insofar as it is not done through the light absorbing and light scattering medium which our atmosphere represents. The sky appears dark with the celestial bodies permanently visible, whiter and brighter than when observed through the atmosphere. A day-night cycle is lackink Brightly illuminated area bordering deep shadows. The functions of contrast sensitivity, visual acuity and color vision are discussed in view of recognition and observation of oncoming spacecraft, satellites, meteorites and of planets as prospective landing targets, including the planet Earth. Since the eyes of the observer are dark adapted when scanning the sky and the pupil is wide, a glance toward the sun and even toward Earth may cause a dazzling glare or at least a veiling glare disturbing vision. Special attention must be given to avoid retinal burns. Depth perception is not of great value because the distances are too great. Due to the high speeds on one side and sensorial and mechanical latencies on the other side there will be permanent danger of collision of a spacecraft with meteorites.

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